Angles of View

Collected Edition
1995 through 2000
Educational Series

DA-LITE®

Angles of View

Collected Edition – 1995 through 2000

Volume I – 1995
A series of technical notes on the aspects of visual displays.

Volume II – 1996
A series of interviews with acknowledged experts on various core technologies related to visual displays.

Volume III – 1997
A collection of "closer looks" at the attributes and properties of visual displays.

Volume IV – 1998
A series of articles examining the various issues related to the concept and nature of Information.

Volume V - 1999

A collection of articles presenting various display "Issues for the Millennium."

Volume VI - 2000

A series of articles which discuss "Special Venues" Applications for Display Technology

Volume VII - 2001

A series of articles examining the new and developing technologies that are constituting visual displays.

Angles of View VOLUME I – 1995

A series of technical notes on the aspects of visual displays.

Angles Of View

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For years people in the screen business were able to characterize the performance of a projection screen by mentioning just two measurements: the gain and the dispersion. The gain number indicated how much brightness was visible from the screen's center when the viewer was on axis to that center. The dispersion number was commonly specified as the number of degrees the viewer could move off axis before the measured gain decreased by 50 percent. Although it was understood that the two numbers were related to each other (as the gain went up, the viewing angle went down), they were mostly considered independently and screens were specified according to which of them was the more important for the particular job at hand. Today all of that is changed and several additional factors go into an informed screen specification. One of these new criteria is

Uniformity

Let's begin by observing that both traditional screen measurements are made by pointing the light metering device at screen center and only at screen center. Everybody's published gain charts (including ours) provide no direct information about how bright other parts of the screen are as seen from any viewing angle. All they tell us is how bright a screen's center will appear from viewing angles between 0 and something like 50 degrees.

Back in the days of multi-image slide projection it was a generally safe bet to assume that the "area of principal interest" in a typical image was going to be located at its center. Today, however, when our customers are looking at video projected spread sheets (for example), neither they nor we can be sure if the most important data won't be in the cell way out at one of the screen's corners. And that can be a problem.

Is it technically possible for a projection screen to have a perfectly uniform coating? Certainly. Does such uniformity guarantee an equally uniform display? Certainly not. The most uniform screen we make is our front projection Matte White. Theoretically a matte white surface is "a perfect diffuser." That is, the observed brightness of such a screen doesn't change with the viewing angle. Thus the eye perceives as much brightness at the center of the screen as it sees at the corners which in turn is the same amount of brightness visible from **any** angle of view.

Even though we come pretty close to this perfect uniformity (our gain is 1.1, for example, and not the theoretically required 1.0), the chance of finding one of our screens exhibiting completely even light distribution in the field is surprisingly small. Why?

Three-gun video projectors have a serious limitation in that the light emitted from each of their CRTs, one Red, one Green, and one Blue (RGB), is decidedly non-uniform. When we measure the brightness at the center of one of these lenses and then compare it with a reading from an edge, the ratio is not 1:1, but 10:3. The effect of this disparity is that the cone of light shining out of one of these projectors is 70% dimmer at its edge than at its center. The human eye is normally tolerant of brightness differentials which are less than 50%, but is sensitive to larger discrepancies. It is ironic that screens are often blamed for the resultant "hot-spot" when in fact even a matte white can't disguise brightness discontinuities as gross as 70%.

What happens when we use a screen that is not matte white and which has a gain greater than 1.1?

Gain, we must always remember, does not imply amplification. No screen can add power to the display. All available brightness is created by the projector and only the projector. So when a gain screen exhibits increased brightness at its center, it is certain that it has robbed that extra energy from somewhere else. With all diffusion screens, therefore, the higher the gain, the lower the uniformity. This is the principal reason to recommend low gain screens whenever possible.

If the diffusion is on a rear projection screen does it make any difference? Not really. Diffusion coatings always scatter light rays equally about their angle of incidence and this is true whether the coating is reflective (on a front screen) or transmissive (on a rear). Our Video Vision, for example, is an extremely efficient diffuser whose can be degraded only by projector limitations.

When the diffusion coating contains more than a diffuser, however, problems particular to rear screens begin to arise. When darkening pigments are added to our rear screens we are improving two important attributes. 1) The darker hue significantly increases image contrast. 2) The pigment serves to absorb (and, therefore, not reflect) ambient light incident to the screen's front surface. This second virtue is all very well except that the pigment also absorbs light emanating from the projector and thus the overall transmission of the screen is reduced.

Transmission should not be confused with gain. The latter is controlled by the diffusion and governs the degree to which light from the projector is scattered. The former is reduced by the quantity of darkening pigment and governs the total amount of light that gets through the screen.

Obviously the balance between diffusion and pigmentation is a delicate one. We are fortunate to offer an exceptionally wide selection of Polacoat® diffusion screens which range from Video Vision (which has no darkening pigment) to the

DA-100 HC (which has lots). Careful attention to our customers' needs is essential to ensure that they make the optimal screen selection.

In addition to diffusion coatings we also manufacture profiled screens which are comprised of lenticulations and/or Fresnels. What effect can they have on the of a display?

Lenticulations have no influence on uniformity. Although they are lenses, their only function is to scatter light about its angle of incidence. The difference, of course, is that lenticulations restrict their dispersion to the horizontal axis only. This results in excellent horizontal viewing angles but does not result in reducing brightness discrepancies between an image's center and its corners. There is only one screen element that **can** improve uniformity and that is a Fresnel lens.

Of the billions of light rays that come out of a projector at any instant, let's look at the paths of just three. First there is the centermost ray, the one that's going to pass exactly through the middle of a screen. Call this the On-axis ray. Then there's the outermost light ray on the right. Let's call that one the East ray. And finally there's the outermost ray to the left, which we'll call the West ray.

We remember from above that both the East & West rays start off life a lot less bright than the On-axis ray and now, when we consider the angular direction of their paths, we see that they are aimed far away from the direction of the On-axis ray. Therefore, as we viewers sit in front of this projection beam, it will be particularly difficult for us to detect much brightness at all from these East and West rays because they aren't aimed anywhere near our eyes. The angles through which those outer light rays would have to be bent in order to reach our eyes are called Bend Angles.

What a Fresnel lens does is reduce these bend angles so that each of the light rays emitted by the projector is bent back just enough so that its direction becomes parallel with the On-axis ray. We can see that at the center of the projection beam the Fresnel is not doing very much work. But by the time we move out to the edges of the beam the Fresnel is bending the rays through ever larger angles until we get right out to the East and West rays where the bend angle is maximal. Notice that our Fresnel has its greatest effect at the very places we need it most: at the extremities of the image.

Many of us used to assume that a Fresnel was primarily used to increase screen gain. Although it does do that, it's no longer very important (high brightness projectors are now routinely available). But by making the corners and edges of an image less dim, a Fresnel significantly reduces the brightness fall off from the center and thereby serves to increase overall uniformity.

The process by which divergent light rays from the projector are bent so that they are all parallel is called collimation. No other rear screen function is more important to the critical question of image.

Another recognition of the importance of in a display is the new way in which many of the projector manufacturers are quantifying the brightness output of their products.

When a projector manufacturer used to assert that his device was rated at 800 lumens "peak white," that meant that he could get a meter to read 800 lumens at a zero angle of view when he drove the projector flat out and in a way that was useless for displaying acceptable images. Furthermore, that specification said nothing whatsoever about how many lumens were available elsewhere across the field. We could be sure, however, that it was a lot less than 800; maybe 70% less.

Just like the screen manufacturers, the projector people took their maximum reading at the center and conveniently ignored everywhere else. That is, until they created ANSI lumens.

In 1992 the American National Standards Institute (ANSI) helped establish and promulgate a series of measurement specifications which were intended to evaluate "the actual viewable image which emanates from large screen display devices." At last people were judging the image, not just the projector or just the screen in isolation. It is the two in combination which make up the **display.**

Prominent among the standards which evolved from the ANSI effort is a new way of measuring brightness. The display is now divided into nine rectangles each of which measures ⅓ of screen Height by ⅓ of screen Width. A brightness reading is taken at the center of each rectangle and then **"the average of the nine readings in lux (lux = lumen/square meter) shall be multiplied by the number of square meters of the image at the plane of the meter reading. The result is the light output specification of the projector in lumens."**

The choice of units simply ensures international comprehension; the choice of method represents a momentous change in the way all of us in this industry think about displays. Internal to a brightness specification in what have come to be called ANSI lumens is a clear recognition of the vital importance of available from some candidate projector.

Particularly welcome to our industry are the newly refined light valve and liquid crystal light valve projectors. In addition to their exceptional brightness, these machines are able to provide across their fields which may vary from center to edge by as little as 20% - a vast improvement over previous display technologies. When one of these projectors is rated at 2500 ANSI lumens we can be confident that overall brightness will be high and that any discontinuities across the image will be minimal.

The emphasis on image in the display industry is certain to increase. Computer and video projector manufacturers will go on pushing as hard as they can to boost bandwidth and resolution. Our own on-going attention to the available from our screens and our understanding of the factors which create it remain essential components of our job as salespeople and as manufacturers.

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Vol. I, 2 ©Da-Lite Screen Company February 1995

As an index of their flexibility and power CRT video projectors are often described in terms of bandwidth. The LCD projectors provide a similar indication when they announce the number of pixels they can display. Understanding the significance of these specifications is useful to predict what projected images will look like on a screen. The attribute they measure and a critical feature of all visual displays is called

Resolution

At first glance the concept of resolution is simple enough. A dictionary (American Heritage) defines it as "the fineness of detail that can be distinguished in an image, as on a video display." What is not so simple is the number of places and the number of ways it can be limited or measured.

When we look at a video image on a screen we are actually at the end of a projection chain with six links in it: Software → Hardware → Projector → Screen → Eye → Brain. Whatever resolution we perceive has been created, modified, and limited by each of the five preceding links.

Software and hardware combine to produce the nature, content and shape of a video image. All of those data are then electronically divided up into an exact number of small pieces or bits which, when transduced by a projector into a beam of light, have come to be called pixels.

The pixel (the word is a contraction of the phrase "Picture Element") is the fundamental building block of all video images. When we are told that a projector has a resolution of 640 horizontal by 480 vertical, we can determine that any image cast by that projector will be divided up into precisely 307,200 pixels which are formed by the intersection of 640 columns with 480 rows. (The reason there are not 640 rows is the 3:4 aspect ratio of the video signal; 480 is of course ¾ of 640.)

Video images, then, are partitioned just like a piece of graph paper where each little box is a pixel and all lines, curves, and colors can only be drawn by filling in (or not filling in) every one of them. Because filling in half a box is not allowed, if the pixels are large enough aspects of the image like diagonal lines will look like stair steps. Horizontal or vertical lines, of course, will be continuous as either of those can be made by filling in contiguous boxes in a row or column.

Although this pixellation causes a video image to be broken up like a jigsaw puzzle into thousands of little pieces which are all the same size and shape, the overriding benefit of this digital signal is that it can be collapsed or copied an endless number of times with no loss to its original integrity. Because each pixel is mapped to a specific address inside the image (e.g. Column P, Row 423) the puzzle can always be electronically reconstructed within a tiny fraction of a second.

Even though they can provide vastly higher resolution (on the order of 10,000 lines for 35mm Kodachrome®), images made with film cannot be mapped in this way because their structure is chemical, not electromagnetic. If you enlarge a slide image far enough you'll detect the grain of the emulsion, but that in no way will resemble an orderly matrix of pixels.

As we have noted, CRT projectors state their resolving capacity in terms of bandwidth which is an index of how many bits of information the device can process every second. The units for bandwidth are expressed in kilo Hertz. Just as a six lane highway permits more vehicles to move along it in an hour than a two lane road could manage, a projector scanning at 80kHz (80,000 cycles/second) can display a lot more information than one scanning at 15kHz. Hence the broader the bandwidth, the greater the available resolution.

Once the projector has transmitted a video signal out through its lenses resolution is no longer specified as a function of time (cycles/sec) and becomes instead a function of space. Regardless of a signals' bandwidth, image resolution on a screen will depend principally on what we can perceive visually and, therefore, the appropriate measuring techniques will change.

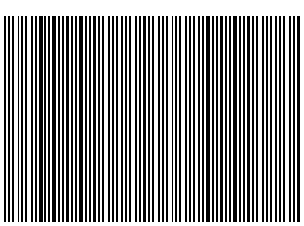

Figure 1

When you look closely at Figure 1 you should be able to count each of the black and white alternating lines. When you hold this page out at arm's length, however, you should not.

If the box were moved farther and farther away from your eyes the size of the space it occupies in your overall visual field would get smaller and smaller. Eventually you would not be able to detect that the box was different from the blur of dark type around it.

If the box were to become a projection screen, is there a way to determine how big it would have to be to ensure that everybody in the audience could count all the lines? Yes there is; even if we don't know the room size or how many viewers are in it.

We do know the number of lines in our display and we know that number will not change as the screen gets bigger (or smaller). And we also know what is the minimum space in anybody's visual field that any single line needs to occupy in order to be countable. That space is most usefully measured not in inches or millimeters, but in degrees.

When you look out across a room, your eyes are taking in about a 30^{o} horizontal field-of-view. Fields broader than 30^{o} tend to make us uncomfortable if we have to look at them for extended periods of time. This is why the minimum recommended viewing distance from a projection screen is two times the screen's width. From that distance the screen fills up about 28^{o}.

At the other end of the visual range is the smallest object the human eye can perceive. And that is generally specified as measuring 1/60th of a degree or, 1 arc minute. A fighter pilot with perfect eyesight is predicted to be able to detect that there is something in the sky before him when the object subtends 1 minute of arc. This feat is equivalent to being able to pick out this dot ☻ when it's printed somewhere on a blank piece of paper from a viewing distance of 28.6 feet.

For images displayed on projection screens, of course, the practical resolution standard is a lot less demanding because it needs to include legibility. How big must a character be in order for us to read it? The answer is that the height of lower case letters must subtend not less than 9 minutes of arc.

Because measurements made in degrees of arc automatically account for distance, it is important that we determine the size of our smallest character cell from the position of the least-favored-viewer. This is the person occupying the seat that is farthest away from the screen. Once his distance from the screen is known, the 9 arc minute height is readily calculated. (Convert the viewing distance to inches and multiply by .0026.)

We must remember that absolute character size is not the only criterion for legibility. Contrast, color and font selection are among the other factors which influence whether text in a projected image can comfortably be read.

Some screen manufacturers like to specify the resolution available from their diffusion screens with a statistic such as "70 lines/mm." Common sense should quickly expose such an assertion as questionable. No projector could get that number of lines/mm onto a screen and no human eye could delineate them if they were there.

What accurately can be said about all diffusion screens is that the structure of their coatings is sufficiently fine to ensure that they will not degrade the resolution available from any conventional projection source.

When the surface of a projection screen is lenticulated, however, the possibility of reducing the overall resolution of a display becomes conceivable. Lenticulations have a fixed pitch or frequency across the width of a screen. If the pitch equals 1 mm we know that there will be about 2400 of these vertical ribs in a screen which is eight feet wide.

If a projector is capable of putting characters onto the screen which measure less than 2 mm in width, then elements of that character (the vertical stroke of the letter L, for example) could get lost from view. This can happen because the function of lenticulations is to divide the light rays which strike them into two separate bundles one of which is sent to the left side of the audience and the other to the right. For reasons that will be explained in detail later in this series [Vol.III,2], if the ratio between the pixels and the number of lenticulations dividing them is too small, significant image degradation can occur.

To combat this challenge Da-Lite has been careful to include in its line of profiled screens, surfaces which have the finest possible lenticulations. One of these models, called the Da-View, has a pitch of .28mm. This means that this screen has 90 lenticulations in every inch of its width. This sort of frequency is increasingly important as it is certain that the resolution of all the electronic devices in the projection chain will be rapidly and continuously improved. Users of projection screens are already demanding that the video images they project be the equal of the images they see on their computer monitors. The largest gap which divides the two is not brightness, but resolution.

Thus in a very important sense the resolution of a display is a completely appropriate gauge of how much information it can convey. So the number of pixels is going to get larger and the bandwidths are going to get broader and more and more information is going to be cast up on our screens.

Is there a practical limit to these inexorable technological advances? Probably. The human eye, after all, is not likely to change much in the decades ahead. And so, when the resolution of a video display eventually surpasses even the fighter pilot's ability to distinguish it (and one day it will), the issue may finally be resolved.

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Everybody knows that projection screens come in a huge variety of sizes. We in the business understand, however, that screens don't come in an equally large number of shapes. That's because there are only a limited number of projection formats each of which is in part defined by a numerical relationship between the height and the width of the images it makes. And that relationship has nothing to do with size. The height of our television screen, for example, has always been ¾ of its width regardless of how big a set we own. And the short edge of a 35mm slide will always be of the long one whether we measure the slide itself or the biggest image we can imagine projecting from it. As we shall see, the variance of these proportions from one format to another can noticeably affect our appreciation of the projected imagery. Because this strict correlation between height and width can always be fully expressed by a single pair of numbers, the fraction appropriate to each format is called its

Aspect Ratio

It used to be that the only sensible way to size a projection screen was to give its measurements, its height and its width. Nowadays people are much more inclined to specify a screen by giving just a single number - its diagonal.

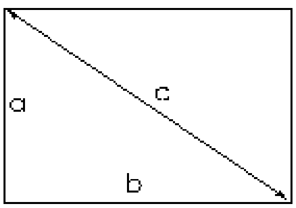

Figure 1

Since any rectangle can be defined as two identical right triangles sharing a common hypotenuse (the diagonal "c" in Figure 1), we could theoretically always figure out an actual screen size from just its diagonal as long as we know the aspect ratio. Harkening back to high school trigonometry, we recall that the square of the hypotenuse of any right triangle is equal to the sum of the squares of each of its sides: $a^2 + b^2 = c^2$. That's the Pythagorean theorem, remember?

Armed with that venerable formula, let's have a quick look at some typical aspect ratios. If it's a screen for slides, we know their aspect ratio is 2:3. Since those numbers seem friendly enough, what would the diagonal be? Well, the square of the diagonal is going to equal the square of one side plus the square of the other, hence 4 + 9 = 13. The diagonal then is going to be the square root of 13. But the square root of 13 is neither a warm nor a friendly number and no one should blame us for deciding not to use it when we talk about slide screens.

How about HDTV? That's the famous 9:16 aspect ratio (of which a good bit more will be said). What about its diagonal? 81 (9^2) + 256 (16^2) = 337($?^2$). The $\sqrt{337}$ exists, of course. To five decimal places it equals 18.35756 which isn't very helpful, either. So we'd better leave HDTV's diagonal alone, too.

Ignoring these disappointments, the world remains full of 67, 84, and 120-inch diagonal screens. How come? Because the aspect ratio for video and TV screens just happens to be 3:4. By a quite remarkable numeric coincidence, the diagonal produced from those numbers turns out to form a perfect integer relationship with them: 3 - 4 - 5. And 5 (with no decimal places, mind you) is a usable number.

For instance, how big is a 100-inch diagonal video screen? Dividing 100 by 5 we get 20. Multiply that by 3 and we get the height, 60". Multiply the same 20 by 4 and we get the width, 80".

Aside from its striking numerical convenience, were there other reasons behind the establishing of 3:4 as the aspect ratio for all original video images? As a matter of fact, there were.

When television was being developed at the beginning of the 1940s, the principal aspect ratio of the motion picture industry was 1.33:1. Where did that ratio come from? It's actually still our familiar 3:4 only in a Hollywood disguise. Film people, you see, like to state aspect ratios as the number by which you need to multiply the image height to get the image width. Hence 4 = 1.33 x 3.

The real origin of the 3:4 aspect ratio had to do with the size of the negative in 35mm movie film after you subtracted for the perforations needed to pull it through a projector.

If television, then, began its life with tubes of the same aspect ratio, movies could be broadcast without any significant reduction in the frame size.

It is also true that when the developers of commercial television decided that its bandwidth couldn't afford to be more than 6 MHz and that its vertical resolution had to be not less than 525 lines, something very close to a 1.33 maximum screen width popped out of the calculations as a mandated default.

Notice that no part of the 3:4 genesis had anything to do with how pleasing images in this aspect ratio actually are visually. And in fact there isn't anything intrinsically appealing about 3:4 pictures. This is why the movie industry, which at first regarded television as a major threat to its revenues, was quick to develop a whole series of wide, panoramic screen shapes which included

Cinerama® (2.76:1), CinemaScope® (2.35:1), 70mm (2.05:1), and the currently familiar Panavision® (1.85:1) - the prevalent "letterbox" ratio.

Any of these widescreen formats is a better approximation of the human visual field, than the boxy, nearly square shape of a TV screen. After all, our two eyes are set side-by-side and their field-of-view therefore has an aspect ratio a good bit wider than 3:4. Yet TV screens were everywhere and when video projectors appeared on the scene, to what aspect ratio were they obliged to conform? You guessed it, 3:4 again.

Are we doomed to watching video pictures shaped like 50-year old television screens forever? We can hope not. There is, thank goodness, the shape of things to come. Its name is High Definition Television and compared to the video pictures we're used to, HDTV's specifications are certainly impressive.

US television nominally has 525 lines of resolution (the overseas PAL system supports 625). To avoid seeing these raster lines we're supposed to sit 7 screen heights back from an NTSC display. That suggests the proper viewing distance for a 27" diagonal is about 9½" feet. Also from the "7 screen heights" number we can determine that the image we're watching will occupy only 10^{o} in our horizontal field-of-view.

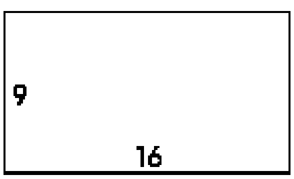

Figure 2

Now let's look at the HDTV picture (Figure 2). First of all it's aspect ratio has gotten much wider. 3:4 has jumped to 9:16 (or, in the film nomenclature 1.33:1 has become 1.78:1). In addition it has twice as many lines vertically (1050). This statistic is a little subtle because the overall resolution of HDTV is not two times better than NTSC, its more than five times better. Video resolution is established by the total available pixels inside a display. That number is calculated by multiplying the vertical lines times the horizontals. Hence there are just over 350,000 pixels on your screen today; there will be almost 2,000,000 on an HDTV screen.

At that resolution in that aspect ratio how far back should we sit? The answer is 3 screen heights. And at a viewing distance of 3 screen heights the screen fills fully 30^{o} of our horizontal field-of-view.

These numbers are extremely significant because the designers of HDTV appreciated that

a wider aspect ratio coupled with a vastly improved picture would provide the viewer far more involvement with the program. It was determined by exhaustive research and testing that a 30 degree field of vision would not only excite the central portion of the human visual system, but the peripheral vision as well. That gives a very heightened experience of reality to the viewer....[1]

Other, independently conducted research showed that *"the human visual system is clearly divided by two functions - the ability to see detail better in the central area and the ability to see motion in the peripheral."* [2] Thus if video was ever going to match the impact of the movies it needed, quite literally, to change its image. Anyone who has seen an HDTV, 9:16 display recognizes instantly its enormous visual superiority over the old 3:4 aspect ratio.

Even though real HDTV isn't generally available yet, advances in projector technology now permit owners of multi-scan projectors to broaden the aspect ratio of the image they're watching at the touch of a button. To enhance this convenience Da-Lite has developed an electric, twin aspect ratio screen series called the Dual Masking Electrol which enables the user to have a screen sized exactly for either letterbox (1.85:1) or HDTV (1.78:1) projection in one configuration and a viewing surface sized precisely for conventional, 3:4 video in the other.

To convert from whichever widescreen format to the standard TV aspect ratio, the Dual Masking Electrol drops a vertical black masking strip down each of its sides which then recedes tautly back against the underlying projection surface. The careful engineering necessary to bring the masking flush back against the face of the screen ensures that no shadowing will be present to distract the viewer.

Effectively, then, the Dual Masking screen works by reducing the screen's visible width. A 9:16 is converted to a 9:12 (3:4) when each descending black masking strip is 2 units wide.

Whether we identify them by their diagonals or by the lengths of their sides, whether for front projection or rear, at Da-Lite the correct aspect ratio for any format is always differentiated.

Whether most of our screens will ever be formatted for HDTV is a question only the networks and the set manufacturers can answer. Because the costs attendant to its installation are so enormous and because the international competition for its configuration remains ferocious, it is difficult to guess how long we may have to wait for this potentially splendid advance in the overall quality of our visual displays.

[1] Cripps, Dale, Widescreen Television - The HDTV STORY, *Wide-screen Review*, July/August 1993, Page 17.

[2] ibid., Page 20. The author is indebted to Mr. Cripps and to the editors of *Wide-screen Review* for their exceptionally informative coverage of this and related issues.

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Take a projector (any projector), turn it on, point it at a screen, focus it, and presto! We see an image. But how does a screen do this? How is it that a front screen can reflect a projected image, but a mirror cannot? How is it that a rear projection screen can display an image, but a pane of glass cannot? Do light rays know which is which? For that matter, what is the difference between

Front and Rear Projection?

The best way to see how a projection screen works is to take one away. Watch: First let's aim a slide projector at a screen and move it just far enough back that its beam fills our image area. When we put a slide into the gate and focus the projection lens we'll see a good, clear blowup of whatever image occupies that strip of 35mm film. Let's say it's a shot of the swing set in our backyard taken on a nice day last summer.

If we leave the projector on and undisturbed but we decide to whisk away the screen, what happens? The projector doesn't know the screen has vanished, the slide's still in place, and the lens is still focused. At the plane in space where our screen just was, can there still be an image?

Yes. Indeed there can.

In setting up our experiment we intentionally did not define whether our screen type was front or rear projection and thus far it hasn't mattered. Now, however, it will be helpful to label our screen as a rear projection device because then, when we remove it, we will be left squinting directly into the very bright beam of light coming out of the projector. (We could have the same uncomfortable experience after removing a front screen, of course; we'd just have to turn around.)

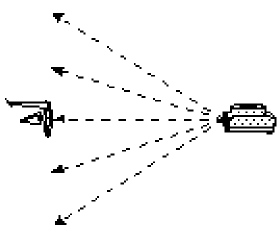

Figure 1

Next let us imagine that we can put on a pair of extremely dark sunglasses which enable us to look comfortably and without squinting into that bright, bright bulb. With these protective glasses firmly in place, what happens when we move forward just enough so that our eyes are positioned exactly at the plane of the missing screen? Can we see the image? No; but if we look very carefully straight into the projection lens we can see a tiny *part* of the image. How big a part? About as much as is covered by the iris of the eye we're using to look with [See Figure 1].

If the place on the image plane where we first put our eye is up at the top, we are going to be able to see a little section of blue sky. (Incidentally, the entire surface of the projection lens will look blue from this vantage point.) Now if we move to a lower point on the screen, we can see green (a small patch of lawn). At still another point we can find the red of one of the uprights on the swing set. And so forth.

Alternatively we could accomplish the same thing if we took a little circle of some rear projection screen material (about 5mm in diameter) and, holding it between thumb and forefinger, moved it around the image plane. Anywhere we stopped we would see just that little section of image which our "micro-screen" can capture. And of course we could never see the whole image, the big picture, because neither our eye nor the "micro-screen" is big enough.

So a question to ponder is, when we reintroduce the full size projection screen into the system and we look from virtually any position in front of it, how is that we can see the complete image, displayed clearly across the entire screen, without even having to move our heads?

Without the screen we can only make out one minute little area of the focus plane at a time and then only if we put our eye at exactly the right distance away. With the screen we can see the whole image clearly from a huge variety of viewing distances and angles. How does a screen do that?

The answer is that screens scatter light. Front projection or rear projection, it doesn't matter; all screens disperse projected light rays incident to their surfaces. Reflection or transmission isn't enough. Mirrors reflect; panes of glass transmit. But neither disperses.

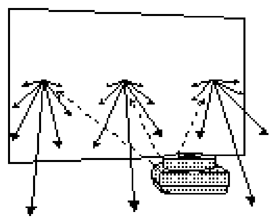

Figure 2

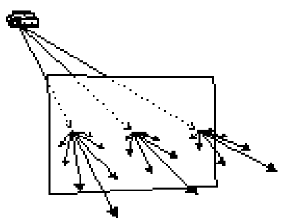

Figure 3

Figures 2 and 3 represent, respectively, a front and rear projection screen. The dotted arrows coming from the projector are to indicate idealized light rays. When one of these rays hits a screen it gets broken up into a bunch of smaller rays each of which splinters off in a different direction.

As you can see, some of the scattered little rays get redirected at angles which diverge considerably from the original incident angle. Hence you no longer have to be positioned exactly in front of an incoming light ray to see it. By breaking up each incident light ray into a smear of smaller, less intense rays the energy of the original ray is distributed across a much broader field-of-view. Without a screen our field-of-view was effectively 0° . That is, we could see nothing of an individual ray unless we positioned ourselves precisely in front of it.

With a screen the field-of-view can easily be enlarged to 60° or more. This is how, for instance, we can see information in the upper left hand corner of a screen when we are positioned in front of the lower right.

True, if a screen is permitted to have an on-axis gain that's too high, the scattering will be minimal and an opposing corner will appear murky and dim. When that happens, of course, we perceive the center of the screen as excessively bright and call it a hotspot.

Fundamentally, then, front and rear projection screens are operationally alike. They both disperse the projection beam directed at them so that some portion of each and every incoming light ray is scattered across the screen's total field-of-view.

With this underlying similarity established for both types of projection screens, what about differences? Is one better than the other? Should we prefer a screen which is reflective over a screen that transmits? Or vice versa?

The single greatest difference between front and rear projection screens is that when you use a rear projection screen it is easy to ensure that the only light aimed at the audience comes from the projector.

A front projection screen will indiscriminately reflect all light incident to its surface with equal efficiency. Thus light from the projector can be diluted by light from other sources (room lights or windows, for example).

All competing light sources in a rear projection system travel in directions essentially opposite to the projection beam. And since a rear screen is transmissive in both directions, only a small fraction of whatever light may strike its front surface is reflected; the major portion passes harmlessly through the screen to be absorbed by the booth behind it.

That same booth, of course, comprises the great drawback to rear projection. By definition rear projection has to have space behind the screen for the one or more projection devices which are to be aimed at it. And, needless to say, the bigger the screen, the bigger the booth area.

Improved projection lenses with shorter focal lengths and clever mirror systems now exist to decrease the amount of space necessary for a rear projection booth, but its existence remains unavoidable and its size non-trivial.

With front projection of course the architecture can remain unaltered. Since the audience and projector are on the same side of the screen, the room size will always accommodate both. This convenience by itself is enough to explain the statistical preponderance of front projection screens over rear.

That actuality aside, however, the very highest quality displays are invariably rear projected. Particularly when the projection source is some form of video, rear screen technology includes a range of optical coatings, tools, and lenses which singly or in combination can display outstandingly fine imagery often under extremely challenging conditions.

Front projection screens are also available in numerous configurations but all of them to a greater or lesser extent are constrained by their sensitivity to extraneous light sources and their utility, therefore, is generally confined to darkened interiors.

Despite these seemingly clear distinctions, picking out the right projection screen for a particular application can be a daunting task. Even after deciding whether you want front or rear, the choices don't immediately get easier. Da-Lite currently offers front projection screens in nine different models and provides rear projection screens in eleven. To make things even more complicated, some of the latter come on two different substrates, glass or acrylic.

To help navigate through this possibly bewildering array of screen alternatives, Da-Lite has published a pair of guidance manuals which both define and distinguish appropriate applications for each model.

A part of the company's *Presentation Media Application Series*, the first of these 24-page handbooks is entitled Selecting Front Projection Screens For Today's Presentation Applications. The second is dedicated to selecting rear projection screens.

Each of these publications begins with usefully concise descriptions of the principal applications in which, respectively, front or rear screens are most commonly used. Next the reader is presented with a short list of carefully crafted Selection Criteria which step through the basic application parameters such as projector type, ambient light conditions, and audience configuration.

Answers to the Criteria questions are then assembled into a prepared Checklist with which the user may turn to the final section of these manuals, the Da-Lite Decision Matrix. Here the reader will find a series of uncomplicated flowcharts, one for each projection method, which lead, question by question, to a series of screen recommendations appropriate to each set of conditions. Finally each manual closes with a short Glossary of useful terms.

Each of these texts is available at no charge and is part of Da-Lite's ongoing commitment to providing the very highest levels of quality, service and support to its customers.

Angles Of View

Vol. I, 5 ©Da-Lite Screen Company June 1995

Prominent among the attributes of a visual display are Uniformity, Resolution, relative size (Aspect Ratio), and orientation (Front or Rear projection). There is another variable to add to this list which can have such a profound effect on image quality that its importance arguably exceeds all of the other factors combined. This feature is called

Contrast

The quality everybody wants first from a projected image is brightness. And certainly some amount of projected light is always needed if we're to see the image. But how much brightness do we really require?

If we have lots and lots of brightness, because we've got a very powerful projector, aimed at a modestly sized screen, then we might suppose that we're going to enjoy quite a good picture. Let's find out if that's necessarily so.

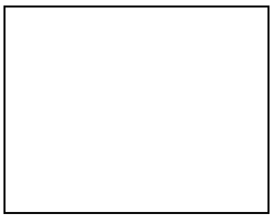

Figure 1

Figure 1 is an accurate representation of an illuminated projection screen flooded with light. Right across the center in big, bold, sharply resolved characters are the words HIGH GAIN. There are no other light sources impinging on the screen. How do we like this very bright, very uniform, high resolution picture? Would it be better if we made the screen a rear projection display? How about if we changed its aspect ratio? Neither alteration would help at all.

So whatever could be the problem? With all that light, how come we can't see anything?

Figure 2

Now look at Figure 2. It's the same screen, displaying the same message, but this time we can clearly make out the text. What's changed? Now we can read it not because we added more brightness, but because we took some away.

On the first screen the letters were exactly as bright as the surrounding area. On the second they are many times darker. Thus there is a large perceptible difference between the brightest portions of the second screen (the background) and its darkest elements (the characters). This differentiation between light and dark is the essence of contrast.

From Figures 1 and 2 we understand that the absolute value of the measured luminance of any display is no indication of its contrast. A screen reflecting 15 foot candles doesn't have to have better (or worse) contrast than one showing 200. Contrast depends exclusively on the ratio between the maximum and minimum light levels within any image.

We determine this ratio according to the formula

$$\frac{Max - Min}{Min}$$

where Max and Min are measured in some consistent units such as foot Lamberts or foot candles.

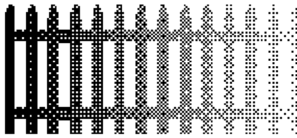

Figure 3

Let us suppose that we have a slide image of a picket fence (Figure 3) - really just a series of alternating black and white bars. If we use a photometer to read the amount of light reflected off a screen where there is a white bar, we could get a number like 1200. When we point it at a black bar we get a number like 3. Plugging those values into our formula we find this display to have a contrast ratio of 399:1. We can believe this extremely high ratio because when we take the slide out of the projector and hold it up to the light, we see that its white bar areas appear virtually transparent and its black bar stripes are nearly opaque. So the difference in this slide's transmission density can actually be four hundred to one.

Can video projection provide a contrast ratio of that magnitude? Regrettably not. CRT projectors generally produce contrast that is less than 100:1 (and often much less).

Why this is so has much more to do with these devices' capability to project black (the Min value) than their ability to project peak white. Blacks emanating from video projectors are really closer to shades of dark gray than true black. Thus if we take that same picket fence image and put it through a CRT projector we will observe the effects of light intended only for the white bars leaking over into the dark bars and thereby significantly reducing the contrast ratio.

The primary cause of this phenomenon is that the phosphors on the surface of the CRTs emit light in a pattern that is much broader than the tightly focused beam of electrons which excites them. Thus their action is similar to a diffuser and the light energy they transmit spreads in a pattern that is roughly Lambertian. This scattering makes it extremely difficult for CRTs to keep dark areas separated from light ones.

Notice that the challenge of maintaining a high contrast ratio occurs in the control of the Min value and not, as might otherwise be supposed, the Max. The CRT theoretically can be made to produce every bit as much luminance as a slide projector, so the Max need not decrease. It is the increase to the Min which debases the contrast. And, as is evident from the formula above, even a small increase in the Min term will have a dramatic effect on the ratio.

Another way of thinking about contrast is to observe that it's the only attribute of a display system that can suffer from too much light. As we have seen unwanted light from the projector is bad enough; unwanted light from other sources can be calamitous.

If the houselights were suddenly turned on while we are in a theater watching a movie, we would immediately notice that the screen which just a moment before had seemed so lustrous and bright has now become hopelessly "washed out."

Of course the screen itself hasn't changed. It continues to do an excellent job reflecting light incident to its surface. But our eyes have changed, quickly adapting to the suddenly increased average light level before them. Now when we look at the screen the light coming off it containing imagery (the movie) has to compete with the reflected room light. Both the screen and our eyes add the two kinds of illumination together because there is no way to distinguish between them. We are left looking at all light and no dark. And without that dark, there can be no contrast. And without contrast there can be no imagery.

Another way contrast can affect image quality concerns the placement of a display within its audience's field-of-view. Since a screen rarely fills up our entire visual field, the experience of watching it is going to include some peripheral awareness of the surrounding environment.

A screen placed before a dark wall will appear to be brighter than one in front of a white background. A screen with a black border will seem more attractive than one that's white all the way to its edges. We often confuse these impressions with questions of brightness. But they are actually perceptions of contrast.

In order to ensure a real impression of brightness the contrast between a screen and its surrounding field must be at least 5:1. If this minimum ratio is not achieved, human eyes will not judge the screen to be "bright", no matter how great its actual luminance.

Brightness, then, can properly be understood as a comparative term. An image will be perceived as "bright" only when it is seen to be brighter than something else. And if the "something else" is a totally dark room, very little actual luminance off the screen will be required to produce a strong sensation of "brightness."

Unfortunately total darkness is not practicable in the majority of applications which employ projection screens. Some amount of extraneous light is almost always present and the question becomes, what can be done to minimize its impact on the screen's contrast ratio?

If our screen is a front projection display, our options are limited to trying our best to keep energy from all the light sources other than the projector from striking the screen. Carefully recessed ceiling lighting, or properly shaded task lights, for example, will not excessively diminish an image's contrast except insofar as some portion of their illumination is directly incident to the screen's surface.

With rear projection screens the available options are less limited. Since all rear projection screens are designed to transmit light rather than reflect it, the majority of the light striking a rear screen's front surface is not reflected back at the audience. Thus it does not compete with the light *projected* at the audience.

Better yet, rear projection screens actually can improve the contrast of a display by the inclusion of darkening agents in their diffusion. Da-Lite has been a leader in the development of these High Contrast tints and now offers them throughout its Polacoat line of rear projection screens.

Here's why they help. If we determine that the Max from a conventional rear screen is, say, 100 units of brightness and the Min is measured at 5 of the same units, we know from our formula that the Contrast Ratio is 19:1. Now suppose we put a little bit of colorant into the diffusion; just enough to reduce the transmission by 2 brightness units.

Our new tinted screen has a Max that has been reduced to 98 and a Min that's been lowered to 3. It's true the new screen is a little bit (-2%) less bright, but the benefit of that cost is a contrast ratio that has jumped (72%) to nearly 33:1.

If we compared the two screens side by side, the brightness differential wouldn't even be noticeable while the improved contrast would be recognizable instantly.

Figure 3 shows the picket fence we discussed above. Scanning from left to right we can see the contrast degrade from the first picket to the last. The rightmost picket appears foggy and difficult to make out not because there isn't enough light illuminating it, but because there's too much. What is missing is something to bring its darkness (the Min) back to the level exhibited by the leftmost picket.

Across the entire range of visual displays, brightness is not the element which most influences image quality. It is contrast, the degree of separation and distinction between the light and the dark elements of an image, which most strongly affects our perception and ability for visual discrimination.

Angles Of View

Vol. I, 6 ©Da-Lite Screen Company July 1995

Diffusion screens take many forms. Some are flexible and roll up, others are rigid, with substrates of glass or plastic. Some can be tensioned while others cannot be stretched. But these are all mechanical properties; they are not optical. What unites diffusion screens optically is that they all have a surface which interacts with light falling on it. What are the properties of these

Screen Surfaces?

Surely the screen surface with which we are all most familiar is Da-Lite's Matte White. An industry standard, this surface is often thought of as the "plain vanilla" of screen choices. But is the Matte White screen really that pedestrian? Or could it be that Matte White is one of the most remarkable projection screens of them all? Let's see.

Imagine that we are seated directly in front of a Matte White screen and, because we are not prepared to trust our own eyes, further imagine that we have an extremely accurate photometer which reads brightness over a 1^{o} angle. (We don't want the spot meter to read too large an angle as that might obscure the brightness differences we're expecting to find.) When we point the photometer at the center of the screen, it measures, say, 10 units of light. When we pivot in our seat and point the meter out at a corner of the screen we see that it will read, once again, 10 units of light. Intrigued, we get up and move to some other position that is not normal to the screen and we repeat our measurements, pointing our meter back at screen center and then at numerous other points anywhere and everywhere on the screen. And no matter how often we do this we always get the same, exact reading: 10 units of light, anywhere we look.

We referred to this remarkable phenomenon in our discussion of Uniformity [Vol I, 1] but now it is time to try and understand it. First, however, let us perform a little experiment which will nicely demonstrate the case.

Take a piece of blank white copy paper and, grasping two of its opposite sides, hold it up before you. Notice its whiteness. Now slowly move one of your hands away from you until the paper is perpendicular to your eyes and you are sighting straight across the edge of the flat surface. Notice that the sheet is still white; and notice that it will remain white no matter how you orient it. At no time does it become dark, even when your viewing angle is 90^{o} .

Both common sense and our scientific intuition suggest that Matte White projection screens should not behave as they do. One would think that the center of the screen should be brighter than the corners when we are positioned directly in front of it. Lambert's Law (which governs the physical dynamics of light reflecting off a radiating surface, a screen) tells us that *the radiant intensity emitted in any direction from a unit radiating surface falls off as the cosine of the angle between the normal to the surface and the direction of the radiation*. Yet despite the certainty of this mathematically prescribed fall off, we still see the same amount of brightness wherever we look at a Matte White screen.

The explanation for this spectacular uniformity involves the geometry of our viewing angle and is easily illustrated.

If we turn off the projector and substitute a flashlight for our spot meter, we will notice that the shape of the beam as it strikes the screen directly in front of us is perfectly circular. As we pivot and sweep the beam out toward the edge of the screen we notice that the shape of the spot is no longer circular, it has become elliptical. The farther out we point the light, the more stretched out it becomes. In fact, if we get up and hold the flashlight right against one edge of the screen, the "spot" turns into a fanlike band which extends down the entire length of the surface.

Both the photometer and our eyes behave in the same fashion as the flashlight. The surface area of screen they include when they are aimed at a portion of the screen directly in front of them (the circle) is smaller than when they look to the side (the ellipse), which in turn has a smaller surface area than the band.

And it just so happens that this increase of surface area is exactly inverse to the intensity fall off dictated by Lambert's Law. This means that although the *amount* of light per unit area coming from the projector is indeed reduced as our viewing angle from that unit area is increased, the *number* of unit areas included by our enlarged viewing angle will in total exactly make up for the loss in intensity from each of them.

In practice, of course, finding a uniform projection source is extremely difficult. Almost all projection lenses transmit very much less light out of their edges than they emit from their centers. Additionally, the classical inverse square law dictates that since light reaching the edges of a screen has travelled farther than light falling on the center, the outer light rays will arrive with less intensity. Neither of these factors, however, involves the screen and thus the sheet of paper is always white and the Matte White screen is always uniform.

Matte White screens are not, however, made out of paper (which is, however, both matte and white). Their surfaces are actually created with a substance known as Magnesium Carbonate ($MgC0_3$) - or a variant thereof. Magnesium Carbonate looks like white chalk and technically may be called a "perfect white diffuser." That phrase implies that no light striking such a surface will be absorbed and that all light so impinging will be reflected in a pattern that is isotropic. Thus the energy from any light ray arriving normal to the screen will be scattered identically in all directions.

Given these splendid optical properties, why would anyone want any other surface than Matte White on a projection screen? And the answer is because frequently it is desirable for a projection screen to have gain. By definition Matte White is unity gain surface. It does not have a gain greater than 1.

Screen gain is achieved by using a diffusion material which does not behave as a perfect white diffuser and which does not, therefore, reflect projected light isotropically. Da-Lite's Pearlescent and Video Spectra™ screens have a gain of 1.5 and consequently will be brighter when viewed from a small viewing angle than from a large one. What is going on at the surface of these Video Spectra™ and Pearlescent screens which produces this gain is interesting.

Examined under magnification their surface looks like a large series of flat stepping stones regularly laid out across a white field. The stones are actually platelets of mica and the field beneath them is a Matte White diffuser. From the discussion above we already know what will happen to light rays incident to the diffuser. But what about light striking the platelets?

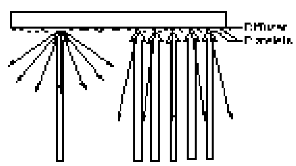

Figure 1

These crystals have had their flat sides coated with Titanium Dioxide ($Ti0_2$) which renders them highly reflective. Thus they can be thought of as forming an array of tiny mirrors. As Figure 1 illustrates these platelets reflect light quite differently than the diffuser beneath them. The Pearlescent and Video Spectra™ screens turn out actually to be clever hybrids of two surfaces: one highly reflective and the other extremely diffuse. The platelets (shown on the right) give these screens their on-axis gain and the diffuser (sketched on the left) provides their uniformity.

Now that we've had a look at front projection diffusers, what about rear screen surfaces? How different are they? The answer is that are hardly different at all.

In fact the only real distinction between the material constituting a rear screen diffuser and a front is chemical. Instead of choosing substances that efficiently reflect light, we now need to utilize coatings which proficiently transmit it. A suspension of finely ground silica ($Si0_2$) is a typical example of a good optical transmitter for rear projection screens.

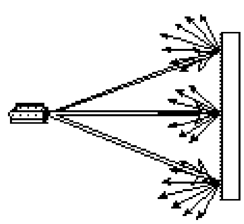

Figure 2

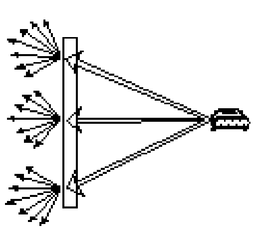

Figure 3

Although the projectors in Figures 2 and 3 point in different directions notice that for an audience seated to the left the two screens have identical distribution patterns. Varying the gain of either screen would obviously alter its pattern but otherwise, if we took the projector out of each Figure, we could not tell which screen was Front and which was Rear.

In rear screens gain is controlled by varying the density of the surface coatings. Lower density diffusions contain fewer particles to scatter the projected light rays so more of them pass through the screen at small exit angles which produces more on-axis brightness.

Higher density coatings will more thoroughly disperse the incoming light which will contract the on-axis gain but expand the size of the audience field.

Gain from a front projection screen is not governed by the density of the diffusion material but by the degree to which its reflectivity is allowed to be directional. The more specular or mirrorlike a front screen becomes, the more its gain will increase and its viewing angle will shrink.

Lastly it should be noted that screen surfaces do not have to be thick. Relative to the wavelengths included in the projected light surface depths of only a few microns are more than adequate. Microscopically, of course, these surfaces are not at all smooth and resemble instead a plain strewn with millions of irregularly shaped boulders through which the light waves must pass (if its a rear screen) or off of which they must bounce (if its front).

Mechanically, a projection screen, front or rear, is really just a wafer-thin surface which, if it could stand upright by itself, would need neither a backing nor a substrate.

Optically the function of a projection screen is quite independent of its substrate. It is the diffused *surface* and only the surface which does all the work.

Angles Of View

Vol. I, 7 ©Da-Lite Screen Company August 1995

Virtually all projection screens utilize some kind of diffusion to disperse the light impinging on them. There are some screens, however, which have surfaces comprised of more than a diffuser. These screens have a tangible structure or profile which significantly alters the way in which they reflect or transmit light. What are the properties of these

Other Screen Surfaces?

There are two principal distinctions between diffusion screens and surfaces with physical structure. One is obvious, the other subtle. The conspicuous difference is that profiled screens are not flat. Their surfaces are variously structured and periodic - the patterning on their surfaces repeats in some way. Usually the structure is coarse enough to be detected by running a fingertip across the surface. Diffusion screens have no such discernible profile; their only "structure" is molecular.

The second way that profiled screens are different is that their designs can permit them to disperse light asymmetrically. To see how this works, let's first consider a screen which Da-Lite makes called Super Wonder-Lite™. This is a soft, aluminized front projection screen which has a series of straight, parallel ribs embossed onto its surface.

The first thing the ribs do is render portions of the surface not flat. And if these raised ridges are oriented vertically, they will present to the projector a series of beveled slopes alternating with an intervening series of flat planes. Light rays which fall upon the plane portions of the surface will be reflected according to the law of specular reflection which states *that the angle of incidence equals the angle of reflection*. Thus light arriving at a 15^{o} angle from the left will bounce off the screen at "an equal and opposite" angle of 15^{o} to the right.

Rays falling onto the ridges will also obey the specular reflection law but, because their incidence angle to the screen is altered when the area they strike is sloped, their reflectance angle will be commensurately shifted. If the face of a rib rises from the surface of the screen at an angle of 20^{o} , then the same 15^{o} light ray we considered above will have an incidence angle of 35^{o} (15+20) and thus will bounce off the screen at a 35^{o} angle to its surface. Since the Super Wonder-Lite™ screen has a pitch of 42 ribs/inch, about half of its active surface area is sloped and the other half flat. In a sense, therefore, it is two screens in one: each has a high gain (due to its metallic coating which is much more mirror-like than the standard matte white diffuser) and a resultantly narrow viewing angle. But because one narrow viewing angle is aimed at the center of the audience field (this is all the flat parts of the screen) and the other narrow viewing angle is aimed at the edge of the audience field (all the sloped portions), the combination of the two produces a front projection screen with a gain of 2.5 and a horizontal half-angle of approximately 35^{o} .

Super Wonder-Lite™ screens are frequently chosen for their ability to display 3D images. This facility is not produced by the existence of the ribs but results from the fact that the screen's coating is aluminized.

Another front projection surface with high gain is Da-Lite's new glass beaded High Power™ material. Although glass beaded screens have been around for years, the High Power™ surface represents a substantial advance in technical excellence. The surface of High Power™ is comprised of a huge number of tiny glass beads distributed evenly across a white vinyl field. In constructing this surface Da-Lite has found a way to get the diameter of the average bead reduced to about 9 microns. This is better than a conventional glass beaded screen by a factor of 7 since their typical bead diameter is about 65µ. The consequent improvement in resolution is of course equally great.

High Power™ has an additional advantage in that its special manufacturing process causes each of the beads to be firmly sunk about a third of the way down into the vinyl beneath it. This means that when the finished material is attached to a roller no beads will rub off when the screen is raised or lowered. This mechanical stability coupled with its exceptional resolution and 2.8 on-axis gain make the High Power™ material the best glass beaded screen on the market.

But what is it about glass beads that makes them useful to a projection screen in the first place? The answer is that the screen behaves as though it were partially retro-reflective.

When a screen (or any other reflecting device) is made to be *retro*-reflective the angle of reflection is not paired with an equal and opposite angle of incidence. The angle of incidence is the angle of reflection. In other words, when light rays strike a retro-reflective surface they only bounce back along the exact path they came in on and therefore end up returned to the projection source from which they originally came.

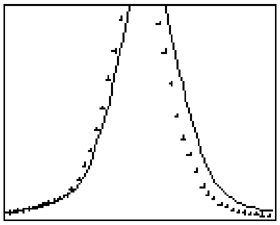

Figure 1

Figure 1 shows a series of brightness measurements (the Y-axis) made from just behind a projector (0^{o} on the X-axis) that was first positioned normally to a High Power™ screen (the solid line) compared with another series taken when the projector was moved 20^{o} off of the normal (the dashed line). Noticing the degree to which the two plots are unshifted and identical in slope, it is easy to see why glass beaded screens are assumed to be retro-reflective.

To understand how glass beads really work, however, we first need to recall a little bit about an optical phenomenon called refraction. This is the process which governs the change in direction which light rays undergo when they cease travelling through one medium (air, for example) and start to travel through another with a different density (glass or plastic, for example).

If the medium the light is leaving is less dense than the medium, the light is entering the refraction process will bend the light towards what is called the "normal" of the denser medium. When light exits a denser medium it is bent away from that same "normal." How much bending (in either direction) is proportional to the difference in densities between the two media.

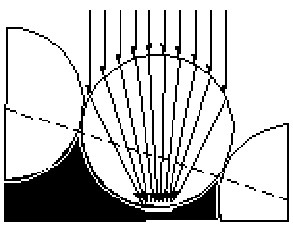

Figure 2

Figure 2 illustrates a bundle of projected light rays striking a single glass bead located somewhere out near the left-hand edge of a High Power™ screen surface. Because glass is denser than air, each ray is refracted through a specific number of degrees *towards* the "normal" - which in the case of a sphere is a radius, a line connecting the point on the surface where the incoming light ray strikes and the center of the sphere. Notice that the spherical shape of the refracting surface causes all of the light rays in the bundle to converge such that they will reach the bottom of the sphere very much more tightly clustered than when they entered it.

If, after passing through the back surface of the sphere, the light rays encountered air (a less dense medium) they would of course be refracted *away* from the normal (all those radii); but they don't. Instead of air they strike a matte white diffuser into which the sphere's underside has been tightly embedded. (For contrast purposes only this diffuser has been shaded black in Figures 2 and 3.)

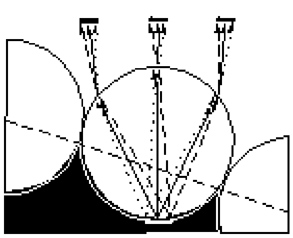

Figure 3

Because it's a perfect diffuser, the matte white reflects all of the light back up through the sphere which now can be thought of as a microscopic rear projection screen which *images* just that little area of illuminated diffusion beneath it [Figure 3]. Note that when the reflected light rays reach the top of the sphere and reemerge into the air, they are refracted *away* from the normal (those radii again) which conveniently happens to mean that they're bent back towards the projector.

Refraction is also the operative process controlling profiled rear projection surfaces. When one of these is ribbed it is said to be lenticulated which signifies that its shape is going to act as a refracting lens for light rays passing through it. When both surfaces of a rear screen are parallel to one another (as in the case of the flat sheets used as substrates for diffusion screens) all refractive effects can be ignored. Since the normal to both surfaces is the same, the incoming bend toward the normal is exactly cancelled by the outgoing bend away from it.

When the two sides of a sheet are intentionally rendered out of parallel interesting things happen. Suppose for example that a projected light beam first strikes the plano side of a lenticulated sheet of plastic. The angles of incidence within the beam will of course vary greatly between its central ray (0^{o}) and its outermost ray (which might be 25^{o}). The normal toward which all of these rays will proportionately be bent, however, does not vary: it is the perpendicular to the sheet's flat surface.

When these refracted rays get ready to come out through a back surface that is shaped like an undulating series of ridges and valleys they discover an infinite range of new normals only two of which (the point at the exact bottom of each valley and the one at the exact top of each ridge) are parallel with the entrance normal.

By varying the radii of these curves (the ridges and valleys), screen manufactures can control the degree to which exiting light rays are dispersed by the two surface system. It does not matter whether the light passes through the curved surface before the flat surface or after it. Da-Lite sells the Da-View™ screen whose lenticulations face the audience.

The reason that all of these screens provide such wide viewing angles perpendicular to the axis of their lenticulations can now be seen to be the result of the series of unequal normals between the flat surface and the curved. If the lenticulations were curved along both axes (if they were craters instead of ditches) then viewing angles parallel to their original axis would also be refractively controlled. As it is, the dispersion about that parallel axis (generally the vertical) is largely unaffected by the lensing and thus remains small by default.

We saw in earlier issues that pure diffusion screens scatter the light projected at them. We now see that alternative, structured surfaces can be used to reflect that light (Super Wonder-Lite™) or to refract that light (the glass beaded and lenticulated surfaces). These are the only things a projection screen can do: Reflect, Scatter, or Refract.

Angles Of View

Vol. I, 8 ©Da-Lite Screen Company September 1995

As the advantages of rear projection become more and more evident to users of video and data displays, the utility of rack and mirror systems is becoming more and more common. Yet there are still many people who shy away from mirrors because they worry that folding the projection optics will introduce unsightly distortions in the projected image. This article will seek to dispel that uneasiness by suggesting some guidelines for using mirrors so that they will always preserve a system's optimal

Projection Geometry

Before we discuss how to use mirrors, let's recall why we use them in the first place. Put simply, mirrors let you get a big image out of a small space.

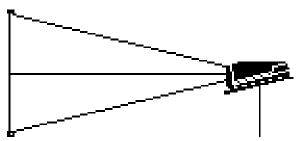

Figure 1

In Figure 1 we have a side view of a typical video projector shooting its beam straight through a rear projection screen. The top and bottom light rays form a triangle with the screen as its base. The apex of the triangle is inside the projector and the middle line coming out of the projection lens illustrates the projection axis, the path of the light ray which bisects the screen.

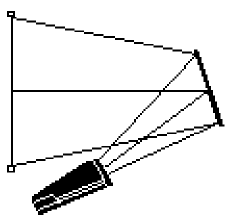

Figure 2

Figure 2 shows what happens when you take the above triangle and use one mirror to fold it one time. Notice how the size of the box containing both projector and screen can now be smaller.

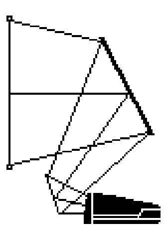

Figure 3

Figure 3 shows the same triangle folded twice, through two mirrors, and the surrounding box is smaller still. The sole purpose of mirrors is to reduce the required depth of the projection booth. When you use them, that's all you're doing and that's all you *should* be doing.

To see this clearly, if you unfold the projector from the little mirror in Figure 3, you'll get Figure 2; and if you unfold from the bigger mirror in Figure 2 you'll be back to Figure 1.

Another way of expressing this is to state that the angles at which all light rays pass through the screen will not be altered by the use of mirrors. No matter how many times or in how many ways you crease and fold that triangle, its base will always stay pinned to the back of the screen and its apex will always be attached somewhere inside the projector.

Do you have to fold any particular triangle in one and only one way? No; in Figure 2, for instance, we could make everything work from an even smaller booth by enlarging the size of the mirror and moving it closer to the screen. We would not have to change the angle of the mirror or the position of the projector, although we could alter both. (Can you see why if we change one we can't escape changing the other?)

The real trick with mirrors, then, is not figuring out how to fold the triangle but determining which is the best triangle to fold. And the very best way to make that decision is to forget about mirrors entirely and assume that instead of too little throw distance, you're suddenly given a mile of it.

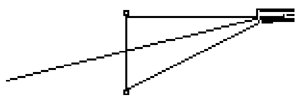

Figure 4

Now you're free to ascertain exactly what is the optimal projection axis which is going to connect your projector to your audience. Recall that the projection axis is the path travelled by the projected light ray which passes through the center of the screen. If the projector is ceiling mounted, as in Figure 4, the path of this "principal ray" is downward, which is quite different from the direction of the same ray in Figure 1.

Video projectors don't mind these shifts in orientation because they are electronically able to correct for whatever distortions may result from their being raised or lowered from a position perfectly perpendicular to screen center. (Nothing in this article refers to shifting the projection axis horizontally because it is seldom necessary and rarely recommended.)

To determine the ideal position for the projector, start from a point approximately in the middle of the audience and extend a line straight back through the center of the screen to a point far enough behind it to satisfy the throw distance requirement. You have now located the apex of the triangle you'll want to fold.

Only occasionally will the geometry thus formed by projector and screen be an isosceles triangle (as in Figure 1). More frequently the optimal triangle will be a right triangle (Figure 4) with the projector flipped so that its base is perpendicular to the screen at the top. This, of course, is because audiences are generally arrayed below the center of a rear projection screen (if they weren't, the heads in the front row would block the bottom of the screen from the eyes in the back row).

But whatever the shape of the optimal triangle, that's the *only* triangle that should be folded. Whether it's folded once or twice depends on the actual depth of the available projection booth. Which angles are chosen for the mirror or mirrors and whether the projector is upside down or right side up technically doesn't matter. As long as the optimal triangle is preserved, the projected image will exhibit exactly the same geometry as it had before its optics were folded. No distortions will occur.

Everything we have said so far about mirrors is true and is particularly true for CRT projectors because they are fixed focal length devices. When it comes to using mirrors in front of LCD projectors, however, there are a couple of additional variables to be considered which, if overlooked, *can* cause distortions.

Most LCD projectors come with a button on them marked Zoom and some have an additional button marked Shift. Pressing the Zoom telescopes the lens in or out so that the image size can be changed from a fixed throw distance. The Shift function enables the user to raise or lower the image without moving the projector.

Convenient as these flexibilities are for quick set ups in the front projection mode, either of them can be exasperating when undertaking a permanent installation with mirrors. In the latter case, it is generally much safer to establish the Zoom and/or Shift settings before combining the projector with the mirror system than to try to adjust them afterwards.

A straightforward way to do this is to begin by aiming the projector at the *front* side of the screen. Take it back the desired throw distance (the same length that you'll "fold" when you use the mirror system behind the screen) and adjust the zoom so that the image precisely fills the screen. If you also have a Shift button, you'll need to figure out what is the vertical position of the projection lens relative to the screen when your mirror system is unfolded (that triangle again) and duplicate it while you're still out front. (It is worth noting that many LCD projectors work best when their lenses are *not* located dead normal to screen center. The optimum position is often about 25% up from the bottom or down from the top.)

Once the Zoom and Shift functions have been established in the straight throw mode, treat the projector thereafter as if it were a fixed focal length device and the correct triangle will be preserved when the beam is subsequently folded.

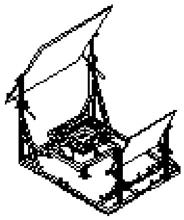

Figure 5

To help with all of this, Da-Lite has created a Commercial Mirror System which accommodates virtually any projector and can be easily set up to utilize either two mirrors (Figure 5) or one. The sled on which the projector sits pivots through 45^{o} and the surrounding racks are expandable to hold a mirror as large as six by eight feet.

Da-Lite will calculate for you the correct angles and sizes for your mirror or mirrors if you tell us the make and model of your projector, the size of your screen, the available depth of your projection booth and the height you wish screen bottom to be from the floor.

It will also be helpful if you tell us the angle you wish for your projection axis and, if you are using a projector with a zoom lens, what throw distance you have chosen. If you have a Shift setting as well, you'll need to specify how far from the top or bottom of the screen you want the projector's lens to be. With these data in hand, Da-Lite will quickly generate a drawing indicating all appropriate dimensions and angles.

In the end there really isn't much that's obscure about mirrors and how to use them. Upon reflection it should now be clear that a suitable projection geometry can always be displayed.

Angles Of View

Vol. I, 9 ©Da-Lite Screen Company October 1995

When we speak about screens and projectors we are always interested in gauging their brightness. But when we declare that some particular display is "bright," how do we know exactly how much light we're looking at? To find out we need to survey the ways in which light is quantified and to define its

Units of Measure

Surely the most effective light meter ever invented is the human eye. When it comes to registering brightness, this instrument will respond to light over a range of intensities which extends from 1 to 500 *million*. The dark adapted eye can detect the smallest packet of electromagnetic energy there is: a single photon. Yet that same instrument functions perfectly for us in the middle of an equatorial desert at high noon where the brightness level is exponentially larger.

Since all of us possess this extraordinary photosensitivity, how come we can't see if the edge of a projected image is not nearly as bright as its center? The answer is that the eye-brain interface doesn't permit any one portion of the visual field to outshine the remainder. Moreover it tends to ignore continuous portions of its field in favor of changes, discontinuities and motion. We don't perceive the projected center-to-edge fall off because it is smoothly continuous. Gradual brightness differentials of as much as 50% are thus rendered hardly noticeable.

To be sure, there are light levels so low that we can't really "see" anymore, when it really is "pitch dark." And of course there are circumstances when there is so much light flooding our retinas that the visual system goes into overload and we experience what we call glare. (It is interesting to note that common to the onset of both extremes is the impairment of our ability to distinguish detail...)

But in between there is this enormous range of light levels to which our eyes are able to adjust automatically. How, then, are we to decide what is and isn't bright?

When people first set out to quantify visible light they chose as their standard a source that was familiar and common to all of them: a candle. Yes, it had to be a specifically sized candle, made of a specific material and molded in a specific way, but an ordinary candle nonetheless. The amount of light emitted from such a candle became our first and most fundamental unit of brightness. It is called 1 **candlepower**.

If we visualize such a candle lighted at the center of an otherwise darkened room, we can see from walking around it that its energy is radiating equally in all directions. It is also apparent that the farther we retreat from its flame the less light it appears to be shedding. Although those two facts are straightforward enough, some powerful deductions can be made from them. Generalizing from the observations, we can state that light from a point source (the candle) radiates outward in all directions such that it uniformly illuminates the surface of an ever expanding sphere. As the radius of that sphere gets larger and larger, the surface area grows at an even faster rate and thus the energy from our candle is spread ever thinner.

Since the surface area of a sphere of radius r is given by $4pr^2$, we can see that a radius of 1 foot will give us a surface area of 12.56ft^2 (or $4pft^2$, since $r^2=1$). Increase the radius to 2 feet, however, and the surface area jumps to 50.27 ft^2. When r=3 feet, the surface area has ballooned to 113.10 ft^2; and so on. This is the Inverse Square Law and among the things it explains is how come a 6 x 8-foot screen (48 ft^2) isn't half as bright as a 3 x 4-foot display (12 ft^2), it is a *fourth* as bright, even though the throw distance (r) has merely doubled.

Now suppose that in addition to defining a unit of emitted light (the candlepower) we wish to establish some sort of standard for measuring light incident to a surface area. Let's place our candle at the center of a sphere with a convenient radius of 1 foot. And now let's calculate the amount of our candle's energy that is incident to just one square foot of the sphere's surface. And, because it makes perfect sense to, let's call that quantity 1 **foot-candle**.

Armed with this definition we can establish and communicate all sorts of useful standards by taking all sorts of repeatable measurements. The noonday sun can deliver 10,000 foot-candles onto the roof of your car, for instance; while the full moon will deposit only 0.02. Workspaces in our offices and operating rooms want to have 15 or more foot-candles; an auditorium may need only 5. For comfortably sustained reading it's nice to have 10 and for close machine work we'd better have more than 30. In a darkened theater, the bright parts of the movie will have about 15 foot-candles, the night scenes as little as 2.

The next step we want to take concerns deciding exactly what fraction of the energy in 1 candlepower is expended in the production of 1 foot-candle. We need this new unit because when we come to consider light sources other than candles we recognize that some of them, video projectors, for example, do not radiate spherically but beam all their output in just one specific direction. They illuminate, therefore, only a section of the sphere surrounding them and we want some way of accounting for that.

As the radius of the sphere is still 1, the total surface area is 12.56 ft^2 (*4p* again). Since we are only interested in 1 of those square feet, it follows that our new unit will equal 1 candlepower divided by 12.56. Let's call this unit 1 **lumen**.

Understanding the relationship between foot-candle and lumen enables us, for instance, to calculate precisely how much light will fall on a screen of any specified size from a projector of some specified lumen output. All we need to know is the requisite throw distance (the *r* of our formula). Or, given the foot-candles, we are equally adept at solving backwards for the lumens.

So now we know how to express numerically the brightness of a light source and we also know how to quantify the light emanating from that source as it illuminates a distant surface. What happens if that surface is a screen which is, therefore, reflective (or transmissive), how will we quantify the brightness it may re-radiate?

First, let's stick with the square foot concept and make our newest unit a measure of the light coming off 1 ft^2 of surface. And what energy unit would be appropriate to choose? Let's use the lumen again and declare that 1 square foot of surface radiating 1 lumen of light is producing 1 **foot-Lambert**.

To tie all this together neatly we need just a few more terms, the first of which is the word *flux*. Technical people like to say flux when they are referring to a flow of energy. (When they quantify such a flow onto a surface, incidentally, they'll say *flux density*.)

Another phrase popular with scientific types is *solid angle*. An ordinary angle of the kind we draw on a piece of paper has just two dimensions (and is often called a plane angle). The angle formed at the vertex of the cone of a projection beam, however, has three dimensions and is, therefore, deemed to be "solid." (Thought about in this light, we can generalize that a solid angle must always be formed by at least three intersecting planes, the intersection of two walls and a ceiling being a typical example.)

With this small vocabulary in mind we should be ready to decipher a full-blown, scientific definition:

A lumen is equal to the luminous flux through a unit solid angle from a uniform point source of one candle, or to the flux on a unit surface area all points of which are at a unit distance from a uniform point source of one candle.

We can also state with equal rigor (but a tad less pomp) that an intensity of *1 lumen/*ft^2 *equals 1 foot-candle.*

And we will concisely define the foot-Lambert as a *unit of luminance equal to 1 lumen/*ft^2.

In fairness we now have to acknowledge that all of the brightness units we've developed so far count on one foot. And although citizens of the United States and a few other enclaves remain comfortable with this 12-inch length, the rest of the planet may find it bewildering.

Can we convert our definitions to the metric system without stumbling? Of course. Notice that our expanded lumen definition has already freed us from reliance on any particular distance unit. *Any* consistent unit will serve.

Let's start with the same candle. When we light it in the metric system, however, we don't assign any specific number (like 1 meter) to the radius of its surrounding sphere. We pay attention instead to the solid angle (whose vertex is our candle) formed by the radius and a "square" section of the surface whose sides are equal to that radius. We call this solid angle a *steradian*. We should not be surprised to discover that there are *4p* (that number again!) steradians in every sphere.

Metric people use as their basic unit 1 lumen/steradian. They call this unit a **candela**.

If 1 lumen per square foot equals 1 foot-candle, 1 lumen per square meter equals 1 **lux**. If the surface area is reduced to 1 cm^2, the unit becomes a **phot**. And 1 candela/m^2 is known as a **nit**.

If you recall that there are 10.76 ft^2 in 1 m^2, you could extract foot-Lamberts from candelas by dividing the latter by *p* times the square feet (*ftL=cd/ð* ft^2), although you might not want to.

Now that we are conversant with these various units, something useful that we could do with them is discover why so many manufacturers of LCD projectors choose to express the brightness of their products in lux rather than in lumens.

If, say, the luminance of one of these machines is stated to be "600 lux (@ 40" screen size)" the first thing we do is elucidate the parenthetical phrase and convert a screen diagonal given in inches (a unit wholly inappropriate to start with) into a screen area measured in square meters. That calculation yields a convenient answer: .50m^2 exactly.

That established, we are ready to plug our values into the formula

Lumens = (Lux x Area) / (Screen Gain)

Since we may take ScreenGain to equal 1, we are left with 600 lux (a largish number) to multiply by .5 (the area) to get 300 lumens (a smaller number). To complete the analysis, suppose that we consider a screen size a good deal more typical than a 40-inch diagonal; suppose we take a 100-inch diagonal screen. Can you see why the number of lux from a 300 lumen projector will plummet from 600 to 97?

There is nothing wrong of course with wanting to see a product in the best possible light. A clear understanding of the units chosen to express brightness, however, can also be illuminating. Knowing how to interpret the illuminance of a projector or the luminance from a screen requires that we keep a sharp eye on the units used to express them. Brightness specifications are not meant to obfuscate or disguise. Surely they are meant to enlighten.

Angles Of View

Vol. I, 10 ©Da-Lite Screen Company November 1995

After we have learned how to select a screen surface and after we have decided to utilize rear or front projection, and after we have established the size and arrangement of our audience, we are left with one unanswered question: How big should the projection screen be? Identifying the type of projection device(s) will yield the aspect ratio of its dimensions, but to determine its absolute magnitude we shall have to explore some criteria for screen

Sizing

Until about five years ago the rule of thumb for figuring out the size of a projection screen went like this: Measure the distance from the screen to the Most Distant Viewer (the MDV in Figure 1) and divide by six to get screen width. Thus if the person seated in your contemplated last row was 38 feet back from the screen, you wanted to have the width of that display at least equal to 76 inches (which meant you rounded 76 up to 80 and ordered a 100-inch diagonal).

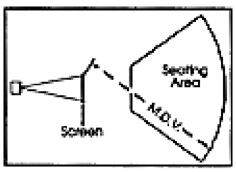

Figure 1

Today the experts prefer us to do it differently. They want us to begin by calculating for screen height, not width; which means that we divide the distance to the MDV by eight, not six. Since for all 3:4 aspect ratio displays either calculation yields the same result, is there any real significance to this change in emphasis?

There is; and the experts are right. The distinction arises from the advances in technology which have enabled yesterday's video projection to evolve into today's data display. The inexorable improvements in computer speed and software sophistication have impelled projector manufacturers to deliver ever broader bandwidth and continuously finer resolution. Once it was permissible to install a screen big enough for everyone to see; now it is essential that it be made large enough for everyone to read.

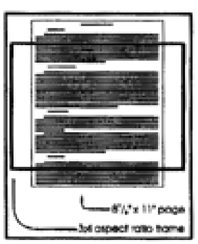

Figure 2

If we think about the process of reading for a moment, we will notice that the aspect ratio of a typical display is not 3:4. It is 8.5:11 and it's a page of text (this one, for instance).

If virtually any printed page is taller than it is wide, virtually any projection screen is wider than it is tall. Thus when we go to project a block of text we have to take special care that it's big enough for all the MDVs to read because the page's largest dimension is going to be the screen's smallest (see Figure 2).

When multiple projection sources (either of the same or differing kinds) are being used, figuring out screen height first is particularly useful. Once you've got enough height for all the images to be comfortably read, the screen's overall width can be calculated by plugging that height into the various aspect ratios, solving for their widths, and (more or less) adding them up. Thus two side-by-side video images have a screen aspect ratio of 2.67 (that is, its overall width will be 2.67 times greater than its height). Alternatively, two side-by-side horizontal slide images and a center video overlap require a screen with a width 3 times its height.

In the case of a single video image, combined with a single slide projector, the aspect ratio must be square if (but only if) both vertical and horizontal slides are to be shown. Because video produces much lower resolution than slides, the minimum height for its image must be calculated first. The actual width of the screen then becomes 1.33 times that video height. However, because of the vertical slide requirement, the actual screen height has to be equal to the actual screen width (making a kind of hybrid aspect ratio of 4:4). Note that none of the short dimensions of all three aspect ratios (3:4, 2:3, and 3:2) will ever fill such a screen, although all of the longer dimensions will.

Once we've figured out how big our screen's going to be, our next concern is to decide how far its bottom should be up from the floor. The rule here is plain: get the lower edge of the screen high enough so that the backs of the heads in the front row don't block the view of the heads seated behind them.

Since the nominal distance up from the floor to the eyepoint of a seated adult is 44 inches, we can add about another 4 or 5 nominal inches to get to the top of that person's head. If there are to be multiple rows of seats, we next need to inquire if they are arranged for single-row vision (a viewer can look over the person directly in front of her) or double-row vision (a viewer sees the screen between the heads in front of her). We also want to learn if the floor upon which the chairs are placed is flat or tiered. If the latter, how many risers are there and what is the height of each?

After assessing carefully whatever combination of these factors is relevant to our application, we'll typically end up placing the bottom of our screen somewhere between 36 and 48 inches off the floor.

So now that we know how tall the screen must be and where we need to position it on (or in) its wall, there remain two final sizing questions to consider. What should be the minimum distance from the screen to the front row? And, how wide can that row be?

The answer to both these questions is derived by ascertaining how much geometric distortion can be tolerated within a projected image. By geometric distortion we mean the apparent deformation that occurs when our viewing angle to some portion of a display is anything other than 0^{o} .

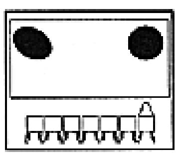

Figure 3

Figure 3 demonstrates that for a viewer positioned perpendicular to one edge of a screen a circle (or the letter "O") will appear less and less circular as the viewing angle from which it is perceived is enlarged. As the "O" becomes increasingly elliptical, the ease with which it may be recognized as a circle diminishes. It turns out that the maximum acceptable viewing angle is 45^{o} . Beyond that the character or other image element risks becoming undecipherable.

Since it is quite typical to see alphanumeric text displayed in 80 character lines, we now understand that we must be sure that a viewer positioned perpendicular to the first character in the line be able reliably to read the 80th. And if the angle formed between that viewer's eyepoint and the 80th character mustn't exceed 45^{o} , then some simple trigonometry discloses everything we want to know about the front row.

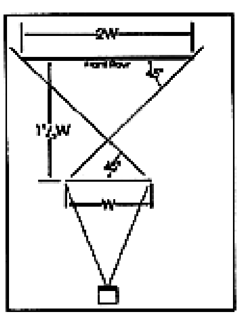

Figure 4

Figure 4 illustrates a screen of width W. Lines drawn at 45^{o} from each edge of the screen intersect at a distance from the screen which is one-half of W. By definition, then, no one can sit closer to the screen than half its width and accurately read text at both its edges.

Beyond the .5W distance the lines diverge and form an ever expanding cone which can, the further back we go, accommodate an ever widening first row. Some useful proportions to remember are that at a distance back from the display equal to 1.5 of its widths, you can have a front row that is twice as wide as the screen (See Figure 4). At 2W back, the first row can be 3W wide. And so on.

What happens when sizing for the back row conflicts with sizing for the front row? What happens when we can't get the screen high enough for the back row or we can't get the front row back enough for the screen? We have to compromise. And the most sensible way to do that is to identify which of all the viewing positions is occupied by what is called the Least Favored Viewer (the LFV).

The concept of the LFV really describes the proverbial "worst seat in the house." In a conference or boardroom we are likely to encounter the LFV seated much too close to the screen and way too far off to the side. In an auditorium he's probably to be found way out at the edge of the back row where, of course, he's not only the LFV but the MDV as well.

In either case, once identified, the compromise in screen size should be made to his advantage which would mean that the boardroom screen size might shrink a little or that the auditorium screen might get a little too wide for its front row.

Regrettably all of these guidelines are rendered ineffectual if proper attention has not been given to the proportions of the data points to be projected. If the chosen font size for the displayed material is too small and if the character or line count is too large, then all our efforts properly to size the screen will be to no avail. Fortunately there exist well established legibility standards which can keep us out of trouble.

Since we want everybody in our audience to read our display, clearly we must ensure that all of our projected symbols and characters are legible by the MDV. Whether he's also the LFV here doesn't matter; viewers seated close to the screen will always be able to decipher a single character (even if its bigger, for them, than it needs to be) but the fellow seated farthest away has to have the text be of a minimum size or he simply won't, even with 20-20 vision, be able to make it out.

How big is that minimum size? Research has shown that for any viewing distance the smallest symbol to be discriminated needs to subtend at least 9 minutes of arc. That limit, incidentally, describes the body height of a lower case character.

A quick and useful way to calculate this minimum font height is to take the distance to the MDV, convert it to inches, and multiply by .0026 (the tangent of $.15^{\circ}$). This will yield a symbol height that increases ¼-inch for every additional eight feet of viewing distance.

Since graphical information will often include lines or other non-alphanumeric elements of the sort generated by CAD programs, etc., the dimensions of the minimum "character cell" become dependent on the smallest element of the drawing you will expect an MDV to read. Common sense would encourage the diagonal (or diameter) of that minimum area to subtend at least 15 arc minutes. And that standard may be satisfactory only for high resolution displays (e.g. 1024 x 1280). Lower pixel counts will require larger "cells" if there is not to be information loss within them.

Summing up, it's easy to see that projectors and computers will inevitably go on improving their abilities to display information. What won't be so easy to see is the contents of that information because our eyes regrettably are not going to get better at reading it. When we look at screen sizing decisions for today, then, what we really must see is reading requirements for tomorrow.

Angles Of View

Vol. I, 11 ©Da-Lite Screen Company December 1995

Even though the elements of a complete visual display system are varied and complex, they can nevertheless be generalized as a series of progressive stages which begins with a light source and ends with recognition activity behind our eyes. Sometimes this sequential chain of events is called the

Optical Train

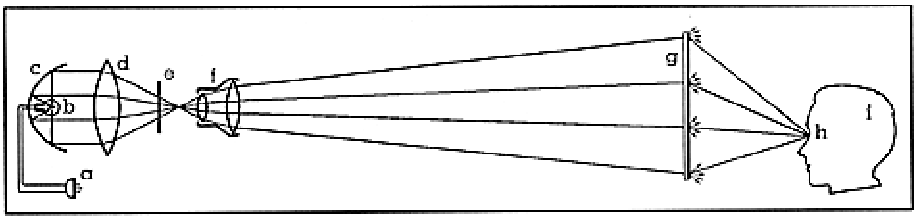

Figure 1

The figure above depicts an idealized display system which begins with a power source and ends at the brain of an observer. In between this engine (*a*) and its caboose (*i*) is a minimum number of cars which make up the rest of the train.

All projection systems need a light source which we'll loosely call a "lamp" and which is located at (*b*). This is the device which turns electricity (those electrons zipping through the power cord) into light (photons flying through the air). Now the thing about light emanating from a lamp is that its rays will scatter in every conceivable direction and we would much prefer that they travel more or less along the tracks of our train.

To accomplish this a reflector (*c*) is usually inserted behind the lamp so that light rays striking it will be reflected back toward their source. But even though we've got light from (*b*) and (*c*) now going in the right direction, the rays are still spread over quite a broad front.

In the projection system we're looking at, a simplified slide projector, this broad packet of light rays is passed through a condensing lens (*d*) which, through the refractive angles of its two surfaces, bends the rays such that they will pass through the plane (*e*) - in this case the aperture of a slide. The "contents" of the slide, that is, the information contained in its emulsion, is the first instance in the train where we can declare that there is an image.

It is important to stress, however, that this plane (*e*) need not be a slide at all. It could also, for instance, be the face of a CRT. To be sure, with a video projector we don't need a condensing lens and the "lamp" where electricity is turned into light is actually the surface of the tube itself.

The plane (*e*) could also be said to represent the surface of a LCD. Here too, the pixels within its face will be varyingly illuminated by a light source behind them and will combine to form an image.

If the final purpose of an optical system is to actualize a comprehensibly viewable display, then there must always be a point where pictorial information is added to the light path. Exactly which sort of tickets, analog or digital, the data present is not important - what is important is that they board the train.

Now, even though the packet of light rays moving down the tracks has acquired significant additional structure by virtue of its new information content, it is still not organized enough for us to decode it. To get the visual data coherently spread across an adequately large visual field, we need next to pass the bundle of light rays through a lensing system at (*f*).

Depending on the type of projector the number and kinds of lenses contained in (*f*) will vary greatly but all such systems are designed to capture as much light as possible from the elements in the train preceding them. Then, by a series of consecutive refractions, the lenses shape the light so that it exits out into the air in a conical shape which will diverge according to a particular aspect ratio.

Furthermore, the lensing system has to arrange that all of the light rays it manages are focused such that at some exact distance out from its frontmost element, a plane surface (*g*) set perpendicular to the projection axis can exhibit all of the information imparted at (*e*) in a correct and error free way.

As we learned previously (Vol I, No.4), the insertion of a projection screen (*g*) into the projection beam can only discover a focused image - it cannot create it. All of that work has been done within (*f*) and is quite independent of a screen.

What the projection screen does do, of course, is to scatter all of those incoming light rays so that they are dispersed over a large enough solid angle that each of us in its audience can comfortably detect the information arrayed across its surface from any vantage point within that included angle.

The device shown at (*g*) is depicted as a rear projection screen just to keep the diagram straightforward. It could as easily be a front projection display and everything drawn to the right of it would remain unchanged. But if it doesn't make much difference to the optical train whether (*g*) is front or rear, what about this other word that we use to distinguish one screen from another. What about the word Gain? Since gain implies an increase in brightness it will be interesting to look at the optical train strictly in terms of energy.

We begin at (*a*) with a theoretically boundless source of power which (ignoring impedance questions) flows through wiring until it reaches (*b*) where its electrical nature is transformed into electromagnetic radiation - light. And let us say that from out of our plug in the wall we have lots and lots of energy - let's assign it a unitless value of 1,000.

The moment that those 1,000 units of electricity begin to course through the filament of that lamp two products promptly emerge. One is the visible light that we're looking for but the other, distinctly less welcome, is heat. How much of our initial 1,000 energy units is lost to heat? At least 500. Fully 50% of our available energy is taken away from us and our train has barely left the station.

But wait. If we really would like to have 1,000 units of light, why don't we just increase the output through the plug to 2,0000 incoming units? Then, after we pay the 50% heat toll, we'd still be left with the 1,000 units of light we want. Considerations of the electrical bill aside, it seems like a good idea.

Except that in order for the lamp to produce 1,000 units of light (twice as much as before) it's got to be able to tolerate and dissipate twice as much heat as before and twice as much heat is certain to be more than enough to burn it out. If only projectors didn't have to worry about heat, they could theoretically be as bright as we wish. Since the laws of physics have decreed otherwise, however, we must proceed with just 500 initial units of light radiating out from our lamp.

What happens next depends on what kind of projector we're considering but this much is certain: each and every time our light rays are manipulated by any portion of an optical system they will inexorably and inescapably lose energy.

In the generalized figure above the ability of (*c*) to be a perfectly efficient reflector is of course limited. Some amount of light will be absorbed at (*c*), and not all of the light reflected by it will bounce off at an angle suitable to reach (*d*) where at least 4% of the incoming energy will be reflected off its back surface and another 4% will be lost to reflectivity off its front surface (with, one might as well add, an extra little bit lost to absorptive phenomena in between).

But let's be optimistic and say that all of that adds up to only 10% and so even if we're down to 450 units, we're now ready for our information pickup at (*e*). Does information cost energy? It certainly does.

If the page you are reading were blank, it could reflect more light than it presently does. All these squiggly marks of black ink add up to a fair amount of surface area which, because it is black, essentially doesn't reflect at all; it absorbs. Thus by the very process of adding information to a packet of white light we must reduce some portions of its energy if we are to have any contrast between its dark and light elements.

If the display is not monochromatic, if it is to include color, then all wavelengths other than, say, that of the required red (or green, or blue) will need to be discarded from the total wave packet with the result that its overall intensity (its amplitude) will be grossly reduced. Still, let's be generous; let's say adding information only costs 50%. We're down to 225 units and we're now ready to go through the lensing system.

It's hard to generalize how many different pieces of glass or plastic will go into the (*f*) stage of an optical train. But it's easy to state that each and every piece will extract a price similar to the ones paid at (*d*) above. So if there were, for example, four lenses within some (*f*), then losses at its eight surfaces would reduce our 225 brightness units down to something like 160.

Finally, our light beam has escaped out of the projector, and with its 160 units of brightness in tact is streaming toward the projection screen, the place where, at last, we get to see it. And, since our screen has a "Gain" of at least 1, we can assume there won't be any more losses, right?

Wrong. If the screen is a rear projection screen at least 50% of our 160 units will be thrown away to back scatter and reflectivity. But it is true that the other 50%, a mere 80 units and less than 10% of our original supply, will be left over for distribution into the screen's field-of-view. A front projection screen will conserve nearly all of the incoming 160 units, but it will scatter them over such a large area that only about the same 80 of them end up illuminating a usable field-of-view. (This is how a 1-gain rear projection screen can look exactly as bright as a 1-gain front projection screen.) Choosing a higher gain screen only decreases the size of that field; it will never, never add energy to the system.

At last some portion of the remaining 80 units reaches our eyes - how much each of us is allotted depends exclusively on our viewing position within the established field-of-view. Since our 80 units must be spread throughout that field each of us will be lucky to get as much as 1% of it into our eyes.

Yet our eyes, comprising only a tiny fraction of the overall field (much much less than, say, our shirtfronts), still manage at (*h*) efficiently to re-image light rays from all portions of the screen onto their retinas. And at (*i*) those light rays are converted back into electricity and the optical train pulls into its final destination.

Angles of View VOLUME II – 1996

A series of interviews with acknowledged experts on various core technologies related to visual displays.

Angles Of View

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***Craig Park** is Vice President, Integrated Solutions for Intellisys Group, engineered design/build systems integrators in Mountian View, CA which he joined in 1996, Prior to that he spent 10 years as Principal and the Director of Audiovisual Services for Paoletti Associates, Acoustical and Audiovisual Consultants in San Francisco, and 15 years designing audiovisual systems and facilities for the Hubert Wilke organization initially in New York and then as Manager of its Los Angeles office. A Fellow of the Society for Marketing Professional Services, Mr. Park has made numerous contributions to the education of our industry. He can be reached at cpark@intellisysgroup.com. He is interviewed here on the subject of*

Planning a Visual Display - Getting it Right the First Time

Da-Lite: One of the many paths along which you must guide your clients as they seek to acquire a presentation system is the one that leads to Screen Selection." What steps do you take to ensure that the very best available screen gets specified?

Park: First and foremost we insist that we talk specifically with the people who will actually be using the space for presentations. Very often in a designer's daily life we are faced with clients (architects or end users) who are not in fact the people who will use the space being commissioned. As such they are not the people responsible for building the media to show the information they want to get across.

But if you can talk specifically with the people in the client organization who are building the content about the nature of that content and about what their expectation is for what they're showing, you can create a successful facility. Because with that knowledge, you have the ammunition to go back to the architect or the facilities manager and say, OK, for this kind of data you need images of this size if they are to be readable by audiences that you have defined as the program for this project.

Da-Lite: Which formula do you use to size a screen?

Park: The formulas have been out there for years and years and you can argue whether or not 6w or 6h, 8w or 8h, 4h are the right formulas but I think ultimately it's going to vary with the very specifics of the kind of data being presented. An accountant is going to be more likely to want to push the envelope because he's going to want to show facts and figures at a scale much smaller than what one would normally want to design for. But if you want to accommodate him and if he and his staff constitute the group that's going principally to use the room then you have to make the argument to whoever's in charge that this room will not function to anyone's expectation if you don't accommodate its users. When the politics of the situation prevent you from talking with the real users of the system you're specifying, then there's a very high risk that expectations will not be met and that the clients will be unhappy.

Da-Lite: When you can speak with the actual users, what do you say?

Park: Easy. "Show me." You want to take a close look at the kinds of overhead transparencies they're producing, the kinds of slides they're producing and, if they're doing computer imaging, the kinds of graphical images they intend to show.

With the computer stuff you'll get lots of variety, from the person who is used to doing her presentations with a pre-formatted, good guideline, no more than 7 lines of text on what I'll call a slide but which may in fact be a direct computer-to-displayed image, to the guy who's interested in showing C++ code which, on his 17-inch monitor, is displayed 50 or 60 lines deep. And the audience, which may be a group of ten people or a group of 100 people, all need to be able to read that.

Now, to a certain extent, you have to educate your clients to the laws of visual acuity. Unless we make that character two inches tall when we show it, once you get past 50 feet you're not going to see it anyway. So, to make 50 lines of codes visible at that scale may require a screen size well beyond what the building will support.

You can see why you may have to compromise. But as long as everybody's educated about what that compromise is (and everybody *remembers* it when the project is done), then everybody wins. But in most cases I think you can say that in conventional building design for rooms of the kind we're talking about which, after all, generally seat about 25 people, that it's very easy to get appropriate screen size and appropriate room volume around it so that the image is up at a place where people can see it.

Da-Lite: Do you mean see or, do you really mean read?

Park: Absolutely I mean read. Over the past five years everyone has learned to be guided much more by the issues of reading than of seeing. We will always argue that to design for the former will satisfy the latter. In my experience there are very, very few facilities being designed these days which do not have readable alpha-numerics as the key criterion.

Da-Lite: How about when the image content is purely graphical, when, for instance, it's highly detailed CAD material?

Park: Well, here you start to push the issue of what a building can accommodate. In a conventional office building, it's virtually impractical to put in a screen that's more than six feet tall, given the norms of slab to slab construction. So when your client wants to display that high a level of resolution on an image large enough to take it, you have to rely on the computer's ability to zoom up on at least a portion of the image so that its readable. The good news is computers will do that. And conventional optical media, slides or overheads, won't. At least not on an ad hoc basis, when I need it, right now.

Da-Lite: Whre do you come out on the subject of front projection versus rear?

Park: My position is that in any facility where one of the imperatives is interaction between the participants, whether it be in a corporate boardroom, or a symposia-lecture setting, or if it's in training or in sales or marketing, rear projection is the preferred methodology to display imagery. If the point, conversely, is to establish what I call a theatrical" presentation, a show, a staged event, front screen is normally and perfectly acceptable.

Da-Lite: When doing rear screens, how averse are you to using mirrors?

Park: Not nearly as much as I used to be. Of course, if you have the opportunity to design a building envelope, you want to avoid mirrors because they cost you brightness. But most of the time you don't have that luxury and the extra 150 square feet of leased space is too expensive to your client not to warrant at least looking at a single mirror bounce to reduce that throw distance.

Da-Lite: When, for whatever reason, you're obliged to use front screens and the application isn't, as you put it, theatrical, what about the issue of lighting?

Park: I have been arguing recently that with advances in high gain front screen formulations (like your Silver Lenticular and the High Power material) that if you can do careful lighting control, that is, with as close to zero vertical foot candles incident to the screen's front surface as can be managed with zoning, switching, dimming, scene selection, etc., you actually can get close to 30 usable horizontal foot candles on what I call the desktop or the audience laptop.

I will say the perceived image quality will be better if it's a rear screen application, but the same rules apply. If you take a fully lighted room, turn off the lights in the front third and leave the back two thirds at half the original, fully lighted level (whatever that may have been), then, front or rear, you'll get perfectly acceptable imagery.

Da-Lite: What about the question of audience size versus audience configuration?

Park: This goes back to the issue of visual acuity. I generally work with a ratio between image height to audience depth of 6:1. That goes against the current published 8:1 guideline, but when the clients are relying on computers to generate imagery which is likely to be something like a Windows® 95 full screen display, you need the bigger size.

Eight to one is still OK as long as you can say that you're going to work within established standards of no more than 14 lines of text and preferably only seven lines of single-spaced text. But especially when the system includes what I'll call video foils or a graphics cameras taking the traditional overhead transparency and converting it into a 3:4 video image, the 6:1 ratio gives me the ability to make that page of text big enough.

Da-Lite: If 6:1, then, tells us how best to size a screen relative to the back row, what can you say about the front row?

Park: That's a tougher question, because it's much more forgiving. If you want to provide a comfort zone for the presenter at the front of the house, using 2H will give him sufficient space to work the stage. However, there are many other facilities where 1H is perfectly acceptable. And by that, I mean that I can sit 1H back from the screen and read the data without having them be compromised. Thinking about it in terms of screen width, I'd say at least 1W and maybe more, maybe 1½ W. Two times W is extravagant..

Da-Lite: Are there any width limitations for an audience array?

Park: Yes. I don't want anybody seated more than 60º off the transmitted (or reflected) angle by which I mean that I want no one positioned before the left side of the screen to be outside of a cone formed by the outermost light ray passing through the right side of the screen and line forming a 60º angle with that ray. In addition I think that ideally no row should be wider than 3W.

Da-Lite: Is another limiting factor of contemporary displays resolution?

Park: You bet. As we've seen video become the dominate display technology there has been a related convergence of traditional optical technologies into that same video field. And when you introduce clients , for example, to the various scanners, or to slide-to-video conversion devices, or to graphics cameras as replacements for overhead devices, they are sorely depressed when they see what 525 lines does to that old, zillion line slide that they had or that overhead transparency they spent so much time working on. Those once fine images now look pretty poor: soft, fuzzy, out-of-focus.

Of course the other side of the argument is that now that it's in video I can do with it whatever I please in terms of where it goes or to how many people it goes and all the other potentialities which the medium enables.

Da-Lite: And what about screen gain? Do you have preferences?

Park: I am a practitioner and I base my recommendations and my designs as much on experience as on theory. Hence over time I have become convinced that a flatter gain surface, with a more even resolution across the visual field-of-view is better in all cases than a higher gain surface which sacrifices a wide field-of-view. Uniformity is more important than gain.

In my office we stay with the low gain screens: Matte White fronts and the 1 to 1½ gain rear screens are our bread and butter. However, there are cases where screen brightness beyond SMPTE standards (18 foot candles for video and 24 foot candles for slides) is required and when that happens I pitch, as strongly as I can, Fresnel-Lenticular screens because of their uniformity. Selecting and sizing the right screen is important. It is, after all, the one thing the client is sure to look at.

Angles Of View

Vol. II, 2 ©Da-Lite Screen Company February 1996

***Steven T. Barlow** is Product Group Manager for Large Screen Display Products at BARCO, Inc. in Kennesaw, Georgia. He has spent the last thirteen years managing the development and sales of Barco projectors. He has written numerous articles explaining the technologies which enable various projection devices and is an acknowledged expert on large screen displays. Mr. Barlow is interviewed here on the subject of*

Projecting the Future - the Liquid Crystal Display

Da-Lite: Much of your history with your company has been involved with three-gun CRT projectors. Yet over the past several years Liquid Crystal Display technology has begun to compete vigorously against the traditional CRT devices. What qualities do LCDs have which make them special?

Barlow: Beginning in about 1987 I participated in many discussions about alternate projection technologies which were then just coming into the rumor mill. From all of the various approaches we looked at, my company felt that the Active Matrix Liquid Crystal Display (AMLCD) was the most viable because that's where the big investments were being made on development throughout the technical community. We concluded that AMLCDs were not only technically viable but commercially viable as well.

Da-Lite: Is it fair to say that the market which drove and continues to drive that development was screens for notebook computers?

Barlow: I think that's a big part of the driver but I also think that in a general way people look at the classical CRT and say, this is awkward, this is a vacuum tube; we don't use vacuum tubes anymore.' So they're looking for a better way to make a display. They want a lower cost, more reliable, higher resolution device that *isn't* based on vacuum tubes. Paradoxically, of course, CRTs have just gotten better and better. Whether we're talking about your TV set, your computer monitor, or a video projector, compare today's model with the best that could be done five years ago and you'll see just how spectacular the improvements have really been. CRT technology still has a lot of life left in it.

The LCD, however, is what people have found to be the most attractive alternative. There are others. Gas plasma or electroluminescent displays, to name two. But clearly the LCD technology is by far the most well researched and most actively developed.

Da-Lite: Why?

Barlow: I think that the primary reason why has to do with what you put in versus what you get out. The amount of money needed to manufacture an LCD panel, speaking in broad terms, versus the quality of the display that you can get is very attractive. The downside to that is that the initial cost, the entry cost of LCD manufacturing is *extremely* high which prohibits all but a select few companies from really participating. Those that have overcome the initial problems relating to yield are now very successful at producing high volumes. This results in a large number of panels which can create high quality displays which have theoretically zero maintenance over a very long useful life.

Da-Lite: So when you were looking to produce high brightness, large scale, projection systems that incorporate non-CRT technology, you choose LCDs, right?

Barlow: Yes. Really, we've taken special derivatives of those LCD panels which nevertheless are part of a very reliable core technology, and built around them all of the other components necessary to make a high performance LCD projector.

Da-Lite: How does it work?

Barlow: An LCD projector can be considered as an electronic slide projector. You have a light source, you have a slide', you have a lens, you have a picture on the wall. The question is, when we substitute an LCD panel for the slide, how does this new slide really work? We know that with a slide projector, we have light and it goes through the slide and it images that light onto the screen.

The LCD is a little bit more complicated than that because it deals with the polarization of light and with the liquid crystal's characteristic of rotating the polarization of light.

The light which emanates from the lamp is not polarized, so it must undergo processing to be useful. To start with, we very carefully position a metal-halide arc lamp at the exact focal point of a parabolic reflector. This serves as the first step in the light collection process and results in a directed beam.

A problem with this beam is that it's circular and we're using rectangular LCDs. Another problem is that the light that comes out of this lamp is wide spectrum: it contains ultra-violet and infrared as well as visible components. So we have to insert a filter in the beam's path which eliminates the UV and the IR. Thereafter we end up getting a bundle of cool light' which, however, is still circular.

The next thing that we do is to feed it through a very special optical integrator that's designed to change the shape of that bundle from circular to rectangular. The effect of this device is that we achieve a high degree of luminance uniformity.

Da-Lite: Is this different than CRT projectors?

Barlow: Yes. For example, if we measure 100 units of brightness at the center of a CRT image, we find only about 25 to 30 units in the corners. Whereas in our LCD projector typically what you'll see is 75-80% of the center brightness at the corners. This is a dramatic improvement and provides considerable presence' to LCD imagery which CRTs simply can't achieve.

The next optical element in our projector polarizes the beam so that the light coming out of it has only one orientation. Now it's ready to be passed through the LCD panel which is made up of a number of pixels each of which contains liquid crystal material. Depending on the electric charge given to that material, it will either rotate, partially rotate, or not rotate the polarization of the light passing through it.

The light then passes through a post polarizer, sometimes called the Analyzer which has an orientation exactly opposite to the first polarizer. Depending on how much rotation occurred in the LCD, the Analyzer fully transmits, partially transmits, or blocks the light from each pixel on the LCD panel. Finally the light is imaged on your screen with the projection lens.

Da-Lite: Actually the process you've just described occurs in triplicate. One each for red, green, and blue?

Barlow: That's right. After we extract the white light from the lamp and render its beam rectangular, we have to split it up into its spectral components. We do this by using dichroic filters which as their name implies act on two colors. Thus they will either pass or block certain spectra of visible light. It takes two dichroics to separate out the R, the G, and the B. And, after each spectrally pure beam is acted upon by its dedicated polarizers and LCD panel, we use another two dichroics to recombine them back into a single beam of white light.

Da-Lite: After all of these manipulations, how much brightness have you left versus the amount you started with?

Barlow: We use lamps which put out 50,000 lumens to get 1,000-2,000 lumens up on the screen. And our collection efficiency is the best in the industry.

Da-Lite: Other than increasing the lamp wattage, are there other things you can do to increase brightness?

Barlow: There are technical limits that are in the LCD panel. A particularly important quantity is what's called the Aperture Ratio. This is the ratio of the active area of the panel to the total area.

So if you looked at an LCD very closely you'll find that there are a series of pixels or little windows which are arranged in a series of rows and columns. When driving the LCD what the electronics typically do is to say, Hello, Column 1-Row 3, here's your data.' And then the liquid crystal inside the pixel gets a certain amount of charge that says, for example, OK, you're on 50 per cent.'

Since we can measure the height and width of a pixel we can know its area and since we know the total number of pixels in a display, let's say it's VGA: 640 by 480 or 307,200, we can figure out the total size of the display's active area. The total area, of course, is given by the size of the panel itself: 3-inch, 6-inch, 10-inch or whatever.

Da-Lite: What goes on in the areas of the panel which surround each pixel?

Barlow: They are filled with a series of electrical connections and contacts which make up a matrix of wires which don't have any value for the projected image. We don't want those areas to give us light because that light would be meaningless. So all those areas are typically painted black which also enhances the contrast of the display.

Now when people look at an LCD projector, sometimes they say, I don't like it; it's too pixellated; it looks like chicken wire.' What they're really saying, of course, is that they don't like their picture broken up into these pieces. Well, I don't like it either.

Da-Lite: Is there a way to get rid of that?

Barlow: Yes. If we take the same LCD panel, same size, same number of pixels, but this time make the pixels themselves much bigger, then, as you can imagine, the gaps between the pixels become much smaller. Very simply, it's like having a wall filled with windows. If it's got x number of small windows only a certain amount of total light will pass through them. If I keep the same number of windows, but I make them twice as big, I'll get twice as much light through. So aperture ratio has a lot to do with how much light a panel can transmit and it also has a lot to do with how much perceived space there is between pixels. If you look at two projectors, side-by-side, and one has an aspect ratio of 35% and the other of 50%, not only will the 50% machine be brighter, its image will look better because it's less pixellated. As the distance between pixels shrinks, ultimately approaching zero, then what we would have is a perfectly homogenous and continuous image.

Da-Lite: So is it fair to say that the higher the aspect ratio the closer a viewer can be to the screen without detecting the pixels?

Barlow: Yes. Advances in panel design, particularly in the panels made with polysilicon, have enabled manufacturers to come out with projectors which produce double and even triple the brightness of their predecessors but which are still the same size and the same price. How do they do that? By having made big breakthroughs in the aperture ratios.

Da-Lite: What other problems are being worked on?

Barlow: The biggest problem with LCD projectors is that they're not flexible. They're easy to set up, they're bright and they're convenient. But at 640 by 480 pixels the only input signals they can take is VGA, Mac, or Video. But typically if you want to display XGA (1024 by 768), for instance, it just doesn't work.

At BARCO we have developed an advanced Pixel Map Processor which, through processes we call pixel decimation or pixel interpolation, proportionately reduces or increases the pixel count of the signal from the outside world to fit the resolution of the panels inside the projector. With that sort of technology installed, LCD projectors can now be as flexible as CRTs while remaining more reliable, brighter and easier to set up. And that's the way they ought to be.

Angles Of View

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***Dr. James L. Davis** is the President of GRADIENT Inc., a firm specializing in the design and creation of visual display systems for the simulation, training, and entertainment industries. Subsequent to receiving his doctorate in Electrical Engineering from MIT, Dr. Davis spent fourteen years in the simulation industry, working for Rediffusion Simulation and IVEX. He is a frequent lecturer on business and technology issues relating to entertainment and training. His Internet address is 74673.3342@compuserve.com. Dr. Davis is interviewed here on the subject of*

Virtual Reality - How Real Is It?

Da-Lite: There's a great deal of talk about virtual reality these days, but it's not always easy to understand just what they're talking about. What is virtual reality, anyway?

Davis: It depends on whom you ask. There is an accepted definition that virtual reality is a simulation of experiences recognizable by the human perceptual system (touch, taste, sight, hearing, and smell) which do not originate in the real world. You can envision many applications for this sort of thing. Historically, one of the first was teleoperation.

Imagine a robotic manipulator of some sort that's far away, or maybe under the ocean, working on the base of an oil rig. But a human operator still needs to control it and there's no economically feasible way to get a human that far down. So the concept is that you put in a couple of TV cameras and enough lights to illuminate everything and gear it all to a servo operated manipulator. However, you have to give the human operator enough information so that he can perform the task. So what you do is you provide him with a virtual environment which, in the simplest case, is just a TV monitor which portrays what the remote manipulator is seeing. And then you give him a control with tactile feedback so that in principle he could move it forward, clamp down on something, twist it or turn it. This is a very simplistic form of virtual reality.

Da-Lite: It gets a good bit more elaborate, doesn't it?

Davis: Yes. With the help of science fiction novels and such people can get carried away. They want to do more than simple tasks. They want to amble around, they want to smell the flowers, they want to see the birds flying in the sky, feel the wind in their faces, and hear the brook gurgling in the background. Very quickly they find out how limiting and limited technology can be unless they have infinitely deep pockets.

I personally believe that flight simulators are the best examples of virtual reality you can encounter in the world today. Think about it. Here you have a flight simulator that contains a virtual environment using three million dollars worth of computer image generators and displays. You compliment that with this ten million dollar device that moves and tilts exactly like a real cockpit would and you've got a pretty good virtual experience. You've got tactile cuing, motion cuing; you've got twelve to eighteen speakers to provide aural cuing. And you've got visual cuing over some field-of-view that's commensurate with the vehicle, typically. You don't have taste, but taste isn't part of the experience being sought anyway.

Da-Lite: Presumably the pilot could take a real cup of coffee in with him, couldn't he?

Davis: Certainly. And I'm sure it would taste better than what they serve you on airlines. But the thing to notice is that a flight simulator is a device which costs about fifteen million dollars. The problem with virtual reality today is that people in the field are trying to be much *more* ambitious in terms of what they're trying to undertake for a whole lot *less* money.

Da-Lite: Why must it be so expensive?

Davis: Because it's very expensive to fool the human sensory apparatus. People train it from the day they're born. So when you get a hold of a person who's twenty years old , his visual sense is *sharp*. He knows what's right and what looks wrong. And if you screw up in terms of a simulation, he'll pick it up instantaneously.

And with flight simulators, even after spending millions of dollars, it's still not perfect. But it turns out that for training psycho-motor skills and such it doesn't have to be perfect. When you go to school, for instance, it isn't a perfect simulation of the real world, yet through certain techniques they can teach you a great deal about the real world. In terms of training and teaching virtual reality is just another tool. And it's better for some things than others.

Flight simulators work because their manufacturers don't try to do too much, they haven't been adamant about being perfectly virtual. They include actual aircraft parts so the touchy-feely stuff is very good. But notice: the other thing they've done is narrow the application so that they only bite off what they can chew.

The cockpit in which the pilot sits is really a buffer between him and reality. The application is not free motion through an infinite world. So you don't have to simulate everything, you only have to simulate the sorts of interactions that you get in an aircraft.

Da-Lite: That means you don't have to apply pressure to the pilot's feet or put sensors on his fingers, doesn't it?

Davis: Exactly. Your subject is enclosed in a rigid structure and all you have to do is buffet and tumble it in some aerodynamically correct way. Then, when the visual software displays an accurate rendition of, say, a runway at O'Hare airport you've got an overall setup that's really very successful.

One of the reasons this aspect of virtual reality has been such a success is that flight simulators have been able to build off technologies that have largely been subsidized and driven by consumer products. The reason the visual displays in simulators are as good as they are is that there's an entire world out there that needs 25-inch color CRTs for their TV sets. People need 9-inch projection tubes for their in-home theaters and the numerous corporate applications.

And you can now get screens from a company like Da-Lite that are really quite good; they have the right sort of gain profiles and such, and, best of all, they're available in large enough sizes.

Da-Lite: And the reason you need big screens?

Davis: An important project in the virtual reality field is called the Cave." This is a cubical chamber with a front projection screen for a floor and rear projection screens comprising three of its walls. In order to accommodate a human subject, those screens have obviously got to be big.

I think the key to success for virtual reality in the coming years will be to leverage technologies that are being developed for other, perhaps entirely unrelated applications. Because, finally, the challenge for virtual reality is not just technology; it's cost reduction as well.

Da-Lite: Thus far you've been talking exclusively about large scale virtual reality systems. Isn't there a whole other delivery system which we might describe as helmets?

Davis: Ah yes; the head mounted displays. There are two principle types: the see-through version and the totally immersive version. The former permits you to see through the imagery projected onto your display. Thus you can see the world around you. The immersive type is totally opaque to the outside world and thus is the configuration favored by the virtual reality purists.

At the upper end of this technology you find CRT driven head mounted displays which are either monochrome or are color via field sequential techniques. And at the lower end you find LCD driven head mounted displays. Now the trouble with these is that their resolution is limited. If you want color you're usually limited to only about 60,000 pixels per eye.

Da-Lite: How many pixels would be enough?

Davis: It depends on how ambitious you are for what's called instantaneous field-of-view.

Da-Lite: Does that mean that when you turn your head 30^{o} , your visual field shifts accordingly?

Davis: No; that's field-of-regard. If you can turn your head around and see behind you, you've got a 360^{o} field-of-regard. instantaneous field-of-view is: if you hold your head steady, how wide are the blinders?

There have been human factors studies done which demonstrate that your sense of immersion in a virtual environment is really helped by the presence of peripheral vision. Thus the larger the instantaneous field-of-view, the more realistic it is. Ideally, then, you'd like to create a virtual reality visual system which provides about 170^{o} horizontal field-of-view by about 110^{o} vertically.

Let's calculate how many pixels I would need to give to each eye if I want to have 20-20 vision over this large instantaneous field-of-view. To have 20-20 vision, you need 1 arc-minute resolution which means you need 60 pixels per degree (1 pixel/arc-minute). Multiply that out and you see that for each eye you need 67,000,000 pixels. Well, gee; that's very difficult to do.

High-end computer image generators are happiest when they are working with about 1.2 million pixels per channel - max. So you see, they're not even in the ballpark.

Da-Lite: What's the compromise?

Davis: The best I've ever seen restricted the instantaneous field-of-view to about 12 by 16 degrees. Yes, it was tunnel vision, but the resolution was adequate.

The conundrum for the people who make helmets, then, is that they need to give you large fields-of-view yet they can't afford to give the resolution necessary to make their virtual reality seem real. And it's well nigh impossible technically to apply that amount of resolution with a head mounted display. You just can't get that much equipment onto the head.

Da-Lite: And if you take the helmet off?

Davis: Then you're back to the flight simulator visual system or the Cave" concept. Either one creates a stationary projection system which is much more like the real world. If you want to see a different part of the image, you turn your head and, sure enough, you're seeing a different part of the visual field. Mind you, the available resolution in a the cave isn't all that good. You couldn't read a page of text, for example. But if your purpose is to interact with objects whose scale is sufficiently large, the outcome can be quite satisfactory.

Da-Lite: How, finally, can we measure the effectiveness of virtual reality?

Davis: I once saw a three axis graph which, depending how far out you were on each axis combined to measure the degree of achieved virtual reality. One of the axes was the feeling of immersion. Another was the degree of interactivity. And the third parameter was the level of realism.

Each scale goes from zero to one. To concoct just one example, you could put yourself into some sort of diorama which might rate a 1 on the realism scale but would get a 0 on the interactivity scale and likely only a very small number on the immersion scale. Most people would say that's not virtual reality. I would argue that all three values have to be non-zero if genuine virtual reality is to be achieved.

And, yes, there are a number of focused applications which, given certain types of chambers, under the right conditions virtual reality can be fully actualized and the results are swell. But for any reasonable amount of money, those conditions have to be carefully limited. Night scenes are easier than trying to simulate broad daylight. Narrow fields-of-view are easier than wide ones. And so forth.

Virtual reality has a long way to go before it can truly fool us. Because when it comes to actual reality, we are, all of us, experts.

Angles Of View

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Hubert Wilke *was the founder of The Wilke Organization, the first audiovisual consulting firm. For more than 30 years he has been directly involved with the design and creation of the world's most sophisticated audiovisual systems. Seven years ago Mr. Wilke came out of retirement to become Senior Principal at the firm of Shen, Milsom & Wilke, Inc., consultants in acoustics, audiovisual and telecommunications systems. Mr. Wilke can be reached at HWilke@SMWinc.com. He is interviewed here on the subject of*

Audiovisual - From Where He's Been to Where We're Going

Da-Lite: Given that you had no precursors in the audiovisual community, how did you come to found your consulting firm?

Wilke: Initially I was involved in broadcasting. I wanted to be a sports writer and was a sports editor on my high school paper. I was never much of a student and never went to college. But I had an orchestra in high school (Sid Caesar played saxophone) which got sponsored on the radio by Standard Vacuum (later to become Mobil Oil). That exposure to radio got me away from my interest in sportswriting to an interest in sports casting.

Then I won a contest picking football winners which paid me $100 (a fortune in those days) and which got me interviewed on WOR coast-to-coast by Stan Lomax, who was broadcasting games for the Giants. In that interview I ended up asking him more questions than he asked me and he subsequently invited me to sit in during his broadcasts, which I did, and that led to a job as a radio announcer.

Da-Lite: An auspicious beginning, to be sure; but weren't you still a long ways off from AV consulting?

Wilke: Well, the next sequence after broadcasting was about six years in the ad agency business where I was a radio and TV director. But the real lead-in to AV was when I left the advertizing industry and went with TelePrompTer.

Now, you may think that TelePrompTer just made prompting devices, but in the mid 50's Irving B. Kahn (then head of that company) moved strongly into what he called "Group Communication." And, as part of that vision, TelePrompTer designed and built what as far as I know was the first remotely controlled, multi-image, rear projection system in the world.

Da-Lite: Who was the client?

Wilke: The U.S. Government for the Army's facility in Huntsville, Alabama and it was in reaction to the Russians' successful launching of the Sputnik satellite.

TelePrompTer sold the system to the military who recognized that they needed a device to make persuasive presentations to visiting Congressmen so that they could get our missile effort off the ground.

Da-Lite: What was the system made up of?

Wilke: It had five images: one large, 3¼ by 4 slide or film image in the center flanked by two, smaller, over-and-under pairs of slides at each side. There was a tremendous amount of information to be conveyed but, (remember, this was a long time ago) there was no random access device available.

So my good friend and colleague, Ray Wadsworth, designed and built one for TelePrompTer which could search and select among five hundred slides. As I remember, it cost about $7,500 and was five drums high.

Da-Lite: Was Huntsville the only system of this type that you installed?

Wilke: No. We next did a room in the Pentagon which was an Air Force Command-and-Control center and it was never to be used unless we were attacked. It was several flights below ground and had all the slide and film technology that Huntsville used plus one of the earlier projection TVs with a direct line to the Sutland weather base in Maryland. Fortunately the room was never used.

Two subsequent rooms in Washington we did and which were used belonged to the General of the Army and to the Admiral of the Navy.

The challenge then became to take this technology developed for the military and see how it would fit in and be helpful to education and industry. As I remember, American Airlines was the first corporate customer and the University of Wisconsin was the site of the first classroom application. Believe it or not, the two departments first to embrace the system as an integral part of their teaching were English and Russian History!

Da-Lite: Ultimately, however, you left TelePrompTer. How did that happen?

Wilke: By the mid-1960's, TelePrompTer had made a significant commitment to producing closed-circuit TV events which resulted in the divestiture of the department for which I had been working. And at the first takeover meeting with the new owners I understood immediately that they were not interested in developing AV systems, they only wanted to sell pieces of equipment.

It was during the ride home from that meeting that I first had the germ of the idea to start an independent consulting function. So in 1965, in a one-room office facing an air shaft in New York City I began the Wilke Organization.

Da-Lite: Were you the only employee?

Wilke: Yes. My first client was the J. Walter Thompson ad agency and I think my fee was all of $250. My fourth client, however, was Lyndon Baines Johnson, the President of the United States.

Da-Lite: And how did that transpire?

Wilke: I got a call late one Friday afternoon from someone I had met in Washington when we'd been putting in the TelePrompTer systems. The President, I was told, has decided that he wishes to address the full 89th Congress and to thank its members for all the legislation that had been passed in service to the Great Society. In addition to the speech the Johnson team wanted to dramatize all these new acts with visuals. Would I come down to help?

So I went down for what was supposed to be just a Saturday morning meeting and didn't get home for two weeks. It was the most exhilarating, exciting, and frustrating time I ever spent.

Da-Lite: Was that the job which really put you on the map?

Wilke: Well, it certainly helped. Thereafter, I hired Ray Wadsworth and we went from there. Domestically, we did work for virtually every major ad agency . Exxon was our first Fortune 500 client and IBM was our entré into the international market. Our first project for them was a training center just outside of Brussels and this caused us to open an office in that city and other foreign offices followed.

I guess our biggest project was the Sears Tower. Because it was to be programmed back then (in 1970) for the year 2000, we fought for two things. The first was that a separate communications shaft be installed, a quarter mile high and throughout the entire building, dedicated exclusively to computer, electronic and television cables. The second battle was for a higher ceiling on one floor where we were going to have the TV studio, the recording studio, and a major meeting room.

Da-Lite: And did you win?

Wilke: Yes. We had a newsletter in those days and I was tempted to publish the headline Sears Gives Wilke the Shaft" but resisted. As for the higher ceiling, you can look today at the 27th floor and see for yourself.

Da-Lite: What sort of AV system were you able to design in those days?

Wilke: It was dual or three images. It was for boardrooms, for major, major conference rooms, and management information rooms which were always rear projected and auditoriums which were, by in large, front projected.

So we'd consider room dimensions and environment, support facilities, seating configurations, and sightlines, etc. Then we'd design for slides, 16mm film and TV, and, even when we specified a rear projection screen, we always called for a front screen as well.

Da-Lite: Why?

Wilke: Because we had to make provision for the overhead projector. Remember, our clients were people who depended on the flip chart and the overhead. Many of them had never even used slides. I used to fight to get major corporations to install at least the capability of two images in their boardrooms. That was back then," of course.

Da-Lite: Nevertheless, it's obvious that you prevailed and, along the way, the world caught up with you and random access slide projectors and dissolves became widely manufactured and the community began to take real advantage of your core concepts. Did these new technologies make it easier?

Wilke: The challenge is never the technology. The challenge is the people problem - getting clients fully to utilize and understand the technologies we give them. Changing peoples' habits is much tougher than changing technologies.

Da-Lite: Do you in fact judge presentation technologies to have changed much?

Wilke: Until about two years ago, no. Yes, video replaced 16mm film, but people still use slides and they still use overhead transparencies and they still look at dual image screens. The really big change that has occurred is that AV has gone from being an *optical* medium (something it's been since the lantern slide) to an *electronic* medium. You see, I think that the combination of computers, projection TV and telecommunications is going to skyrocket. It's going to move much more quickly than the transition from film to video and with a lot less resistance.

Da-Lite: Why less resistance?

Wilke: Because we now have clients that have been acclimated to computers. That's the key to it. There is a generation now assuming management responsibilities in educational and corporate America which is computer literate.

This is why the past has been difficult. The client was not familiar with the technology we brought him. And he was always caught by the time element, the need to preprogram everything way in advance. That time lag, that turnaround time held back using slides. Whereas the overhead was always accepted not, mind you, because it was wonderful to look at, but because you could change it right up to the very last minute.

Da-Lite: But you think those days are over, right?

Wilke: If they're not over already, they're about to be. The clients understand computers. They don't need to be trained how to use them; they already know. And if the computer is what is creating the software for the presentation, those data can be updated right up to the last second before the board meeting begins.

Da-Lite: Does having a client population considerably more sophisticated about the core technologies change the role of the AV consultant?

Wilke: No, not really. Other than having to be more technically proficient, there is still the need to guide the architect and client, make base building provisions to accommodate the new technology, and design and specify the most appropriate AV/telecom systems for the clients' intended use.

That is our objective today just as it was in 1965.

Angles Of View

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***Lenny Lipton** is the founder and Chairman of the Board of StereoGraphics Corporation in San Rafael, California. Mr. Lipton has been a pioneer in the development of 3D projection systems and is the inventor of the first practical electronic stereoscopic products for computer graphics and video applications. Also the author of numerous books and articles on film and film making, Mr. Lipton can be reached at Lenny@crystaleye.com . He is interviewed here on the subject of*

3D - Just Another Dimension?

Da-Lite: Three dimensional imaging is experiencing a noticeable resurgence. May we suppose that this renewed interest is driven by parallel developments in computer technology?

Lipton: Yes. The marriage of electronic displays and computers with binocular stereoscopic displays is a good one. It actually turns out to be easier to make a dependable 3D product using a computer graphics monitor and time sharing or time multiplexing techniques than it is to go into a neighborhood theater and turn it into a stereoscopic theater.

Nevertheless , a major change which has taken place in the projection of stereoscopic movies is that, in the last decade or so, you can find them being shown on a regular, continuing, and ongoing basis, particularly in theme parks.

Da-Lite: Are these movies well produced?

Lipton: Yes. They are well shot and well projected, in the sense that there are no technical screw ups such as the projectors getting out of synch or all kinds of other awful things. They have a dedicated projectionist who's in the booth all the time and not down at the candy counter or running about the other fourteen theaters in the multiplex. And you need that expert technician which the theme parks can provide but which just isn't practical for a neighborhood theater.

Da-Lite: Is this part of the reason 3D has enjoyed only a cyclical popularity?

Lipton: It is true to say that stereoscopic imaging has had an erratic history in terms of commercial acceptance. There have been a lot of problems, technical problems which have been difficult to overcome.

Da-Lite: What are some of these problems?

Lipton: Stereoscopic projection requires two images, one for each eye. Both of these images have to be of the same brightness. So the upper right hand corner of the right image has to be as bright as the upper right hand corner of the left image. And that's true on a point-by-point basis across the entire screen.

If, for example, the right image which is being projected has a lot of vignetting and the left image doesn't, it's going to feel very bad to look at.

Da-Lite: Is the ordinary viewer going to be able to tell why he feels that it's bad?

Lipton: No. Because these things are not seen in the visual world; these mistakes can only occur in a stereoscopic display. So if one image is out of focus, or one image is higher than the other or contains different color values, you'll feel uncomfortable looking at it, but you'd have to be an expert to diagnose the problem exactly.

Typically the discomfort a viewer feels is referred to some other part of the body. Occasionally people will say their eyes hurt but usually it's a headache or a feeling of nausea that's experienced. Sometimes instead of stereoscopic images, bad projection will produce pseudoscopic images.

Da-Lite: Whatever are they?

Lipton: Pseudoscopic is when the left eye is seeing the right image and vice versa. Now that's something you never see in the visual world and its very strange and confusing.

Da-Lite: So if you pump left-eye data through the right eye...?

Lipton: It doesn't add up to a stereo image. You get a conflict of cues; the stereoscopic cues will conflict with the monocular cues.

There are many ways you can perceive depth and see a three dimensional image in the real world. When you look around this office there are lots of depth cues. For example, geometric perspective. The edges of the ceiling tiles form receding lines. Then, because I'm in front of the wall behind me, you can't see it through me. That's a cue called interposition. If you look out the window there at those hills, there's a little bit of haze between us and the hills and that makes them look further away. That's called aerial perspective. All in all, there are about half a dozen such cues.

Da-Lite: And these cues obtain in a photographed image as well?

Lipton: Sure, but when you add a stereoscopic cue that's a *pseudo* stereoscopic cue, there's a massive conflict which may actually inhibit some viewers from being able to recognize what they're looking at!

Da-Lite: What are the ways to avoid this sort of mistake and how do you make good stereoscopic imagery?

Lipton: You'd think it would be easy, wouldn't you? After all, it's just a matter of the coordination of two images.

Well, you need somehow to generate or capture two images from two perspective viewpoints and those perspective viewpoints have to be related by a rule or series of rules.

Da-Lite: So, since you need to use two cameras, how far apart must they be?

Lipton: The answer that I like is, far enough apart to make a good looking picture but not so far apart that it hurts your eyes. For large scale, aerial photography you might have 20 feet between the cameras. At the other extreme, if you're doing computer generated images of molecules, then the interaxial separation of the perspective viewpoints is going to be extremely close together.

Da-Lite: If it's not the interaxial separation, what is the mechanism which creates the extension out of the screen?

Lipton: The principle entity in a stereoscopic image is called parallax. This refers back to your eyes. Your left and right eyes are seeing slightly different images of the visual world. Now, if you could freeze those images on your left and right retinas and, say they were on film, you removed them and then superimposed them one on top of the other, you would see that there's a horizontal displacement of corresponding image points. The superimposition would be good vertically, but there would be some points which would laterally be displaced. And it's that information which on the retinas is called retinal disparity.

The purpose of stereoscopic photography or computer generated imagery is to produce retinal disparity.

Da-Lite: But how does this disparity give that special depth sense?

Lipton: When you look at a display screen, your eyes are focused at the plane of the screen. And they're also converged at the plane of the screen. This is similar to when you hold out a finger in front of your face. When you look at that finger your eyes are focused on it and they are also converged which means that the axes of the left and right eye cross or intersect at the finger.

Now when you look at a stereoscopic image on a display screen your eyes may be focused at the plane of the screen but they're converged for differing distances, either in front or behind the plane of the screen. This is different from seeing in the real world and it uses different sets of eye muscles.

Da-Lite: Most people can remember seeing 3D movies. Are there other, more industrial applications for the technology?

Lipton: Definitely. The history of my company, for instance, has paralleled the development of the interactive computer display. The capacity of these devices to generate stereoscopic imagery enables the customer base to use workstations to do scientific visualization.

If, for instance, you're looking at a complicated molecule and there are therefore hundreds of atoms on the screen, the way that people have tried to visualize the structure is to rotate it. This adds another monocular depth cue which is called motion parallax, which gives you a continuous change between the portions of the image that are close and the portions of the image that are far. By rotation, then, people found they could visualize a complicated shape.

The only trouble was, if you stopped it, the three dimensional effect vanished. This is why if you want to stop a complicated object and study it carefully you need to have it displayed stereoscopically.

Da-Lite: What other sorts of research employs stereo graphics?

Lipton: People in astronomy and people in computational fluid dynamics use the technology. The latter use includes wind tunnels and aircraft design, for instance.

Another use is satellite earth mapping where the aerial photographs are digitized and, when projected stereoscopically, can then be analyzed in exquisite topograpic detail.

Da-Lite: That's a long way from throwing a spear out of a movie screen, isn't it?

Lipton: It certainly is. The rise of multi-media PCs and their monitors have enabled a whole new approach to stereoscopic display. For computer generated imagery you have only one projector" (the monitor) and the way you produce stereo graphics is to alternate left eye, right eye information about 80 or 90 times a second.

To "see" the stereo graphics, you put on wireless active eyeware which we call CrystalEyes®. These contain liquid crystal shutters which, through an infra red link with the projection source, open and close their left lens, right lens in a manner exactly synchronized with the monitor.

Da-Lite: Can this technology be employed using CRT video projectors?

Lipton: Absolutely. It is also possible with the video projectors to use passive polarizing eyeware. This requires a liquid crystal modulator which switches the characteristic of polarized light at the video field rate, so it switches between one type and the other type of polarized light 120 times a second, and when you look through the polarizing glasses at the right kind of screen, you see stereoscopic images.

Since the screen must preserve polarization in this type of display, you need something like your Super Wonder-Lite® for front projection or one of your high-gain, profiled screens for rear. The CrystalEyes® approach of course permits you to use any screen surface you wish as it is not dependent on polarization effects.

Da-Lite: How significant is it that you've developed ways to get away from double projectors to create 3D?

Lipton: Extremely. My design philosophy is that I'm interested in products, not experiments. We have to make the displays work with *one* computer, *one* tape recorder, *one* projector. Anything else is, these days, just an experiment.

So it's not only the rise of powerful computers and all kinds of improvements in display technology that have enabled us to make a product but also the development of these electro-optical shutters which can be opened and closed as much as 160 times per second.

Da-Lite: At such large field rates the viewer is certainly not going to see flicker, are there any other defects he might encounter?

Lipton: No. You should be able to create a perfect stereoscopic image if it's computer generated.

Da-Lite: So what's next?

Lipton: Next, of course, is to get rid of the glasses.

Angles Of View

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***Dr. Richard Burrows** is the Product Development Manager for Da-Lite's Polacoat Division, located in Blue Ash, Ohio. He was graduated from Muskingum College in 1988 and received his Ph.D. in Physical Chemistry from the University of Cincinnati in 1993. Dr. Burrows can be reached at rburrows@da-lite.com or through Da-Lite's website: http://www.da-lite.com. He is interviewed here on the subject of*

Screening the Future - Da-Lite at the Horizons

Da-Lite: What were some of your first impressions of the technologies used to create projection screens?

Burrows: When I interviewed for the position I was privately wondering, do they really need a chemist? But then, when I saw the processes and grew familiar with how screens are made, I wondered why we don't have a larger staff of chemists. The chemistry that's going on here is wonderful chemistry and it is a particularly wonderful application of polymer chemistry.

Da-Lite: What do you mean by "Polymer" chemistry?

Burrows: If you stop to think about it, all projection screens are made up of two parts, a substrate and a surface coating. The coating is the part that does the optical work. The substrate is the part that provides the coating with mechanical stability. The science is to get the coating to lie flat on the various substrates and to get it to adhere. Polymers are typically carbon based molecules which can be formed into long chains. The chain structure enables great flexibility within the coating while at the same time fostering its ability to stick to a substrate.

Da-Lite: Is all of this chemistry pretty well finished business? That is, have all the questions been answered?

Burrows: By no means. I am continually researching ways to make our products flatter, harder, stronger, more flexible, and/or more durable.

Da-Lite: Those of course are all mechanical properties descriptive of substrates. Are there instances where alterations of the substrates can have optical significance?

Burrows: Absolutely. When the material in question is part of a rigid rear projection screen, the substrate itself has to be optically active. It needs not only to be translucent but as transparent as possible.

Da-Lite: Doesn't any clear material, glass or acrylic, accomplish that?

Burrows: Yes; but not with equal efficiency. Acrylic has a measurably higher optical throughput than glass in the visible spectrum.

Da-Lite: Does that mean that acrylic substrates are to be preferred to glass ones?

Burrows: You might have been able to say that in the past, but I've been working just recently on ways to increase the transmission of our Da-Glas. The results, while still a bit premature, are very encouraging. Stay tuned.

At the moment, however, a higher percentage of the light emanating from a projector will get through a Da-Plex screen than will pass through Da-Glas - even when the two screens have identical gains.

Da-Lite: Please explain the difference between Gain and Transmission.

Burrows: Screen gain is the ratio of a measured amount of on-axis light reaching the back of the screen to a measured amount of light radiating from the front. The angle from which both measurements are made should be the same and is usually 0^{o}.

Transmission is a measurement of the total amount of light available from the projector compared with the total amount of light radiated by the screen. Transmission is generally given as a percentage and is reduced by phenomena such as back surface reflectivity, internal reflection, and absorption.

Da-Lite: Obviously you can vary the gain of a screen by altering the density of its diffusion. Can you also vary the transmission?

Burrows: Yes; the purpose of diffusion is to scatter light, not to absorb it. Often rear projection coatings contain colorants which serve to darken their overall hue. The "N" suffix in our Polacoat line, for example, stands for "Neutral Gray" which is a highly desirable color for a rear projection screen because the precise "Gray" we've developed significantly improves image contrast without altering the overall color balance between the Red, Green, and Blue portions of the image.

Da-Lite: But the gray colorant absorbs some light, doesn't it?

Burrows: Yes it does. And that's convenient if the light absorbed is from ambient sources, but less convenient if it is light from the projector. But, as it's not possible to have one without the other, transmission is reduced. The consequence of lowered transmission is that the screen's half-angle will be diminished, not its gain.

For example, our highest transmission screen is Video Vision which, in addition to containing no colorant, is a coating specially formulated to be highly non-absorptive to light rays. Therefore, since the resultant transmission is higher, there is more light available to be scattered over larger angles of view. This is what makes this screen so exceptionally uniform. Its molecular composition also enables nearly perfect chromatic fidelity - but details of that process are proprietary.

Da-Lite: What about front projection screens? Does your work include their consideration?

Burrows: Of course. Because front projection screens are not rigid, all sorts of chemical things need to be manipulated so that the mechanics of their substrates behave suitably. There are requirements that the screen not chip, fade, peel or crack, for instance.

Da-Lite: And what about the optical layer, the front projection screen's front surface?

Burrows: I'd like to answer that question this way: Of all the elements which make up a contemporary display system - computers, switchers, interfaces, projectors, lenses and screens - there is only one which performs anywhere near its theoretical efficiency. That one, of course, is the projection screen. The energy losses incurred at every other stage of the display are enormous. Yet here we have in this simple, unassuming flat surface coated with ordinary Matte White, or Pearlescent, or Video Spectra, an optical device which is capable of reradiating at least 98% of the energy it receives. I think that's quite remarkable. I also think finding ways to reduce that remaining 2% is very difficult. But we're trying.

Da-Lite: What else are you currently working on?

Burrows: We're making a screen for a laser system which needs a diffuser with an especially small particle size, in this case about 5*m* . That's way smaller than the human eye can resolve but it's not too small to be machine readable. In my opinion such specialty screens will become more and more prevalent as data capture technologies advance.

Another project which is particularly interesting is a rear projection domed screen which has to preserve polarization.

Da-Lite: Is this for some sort of 3-D application?

Burrows: Very probably. Polarization is relatively easy to preserve with a front projection screen: you just make sure the coating is metallized. To get a rear projection screen to be non-depolarizing is extremely difficult. As we're finding out, however, it is not impossible.

Da-Lite: Do you do a lot of work with curved screens?

Burrows: Yes; both simple (curved in just one direction) and compound (curved in two). Some of the screens we produce for customers in the aircraft simulation industry are quite large. They consist, for instance, of spherical sections which have radii greater than six feet and which extend horizontally for 220^{o}. (That's more than 23 feet of arc length, by the way.) We have become quite expert in getting single pieces of acrylic formed into that shape and then coating them to very exacting tolerances.

Da-Lite: Do you coat on the outside or the inside of the curve?

Burrows: Either one, although the convex side is more usual. Obviously the chemistry of the diffusion for a curved surface needs to be different from flat screen diffusers. Getting the coating to apply uniformly across curved surfaces requires very careful formulation and a custom delivery system.

Da-Lite: Does your group do a lot of custom work?

Burrows: Indeed we do. The laboratory that I work in is extremely well equipped to develop and prepare a wide variety of coatings for virtually any display application. Sometimes the specifications we're given call for thousands of small screens to be included in a customer's OEM product and at other times we'll work equally hard developing special formulations for customers who maybe want only one or two big screens. Inquiries like those are what makes my job so fascinating. And it's always intriguing to see how imaginative some customers can be with applications for projection screens. One of our cardinal goals at Polacoat is to try never to say no to a customer.

Da-Lite: Does the work you do for your custom customers help you improve the regular product line?

Burrows: Of course; but the distinction between regular and custom is getting increasingly blurred. All of the tolerances we work with around here are getting tighter and tighter. A scant five years ago customers were perfectly comfortable with a gain tolerance of ±25%. Recently we've had to perfect ways of holding tolerances given by the second decimal place. And that's for our regular customers!

Advances in the collateral technologies, the computers and especially the projection devices compel us to upgrade our formulations continuously.

Da-Lite: Can you provide an example?

Burrows: Sure. Not so very long ago the best resolution you could find coming from a CRT was NTSC video. Today resolution of 1024 by 1280 is commonplace. Our job is to make sure that our screens can display that sort of detail with no degradation. That means that all of our coatings have got to be extremely smooth and uniform.

We are fortunate in this regard because the chemistry that we use to fashion our diffusers enables them to form molecular bonds with their substrates so that they cannot be peeled off. The only way to remove them is chemically. This means, among other things, that we can keep the thickness of our diffusion coatings to an absolute minimum.

Da-Lite: Why is that important?

Burrows: Because the thicker a coating is, the more chance it will have of degrading image resolution. And when projected displays are expected to match the resolution of work stations, it doesn't take much extra thickness to make a noticeable difference.

Da-Lite: Speaking of work stations and such, do you think that devices of that kind will ever supplant the projection screen?

Burrows: I think the future of visual displays splits into two paths: displays for small audiences and displays for large audiences. Wonderful technology is nearly upon us for displays which have an audience of one. Although the helmets and the other devices under development will perforce contain screens, they won't be projection screens as we currently define them.

But for large audience venues (and as projectors get brighter and more versatile there will be more and more of those) projection screens will remain the best solution. As such their future is sure to be bright.

Angles Of View

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***Patrick Pluto** is Systems Operations Manager for the International Communications Industry Association in Fairfax, VA. Among his principle responsibilities at ICIA is the development and advancement of its industry's presence on the Internet. Graduated with a degree in Applied Computer Science from Plymouth State College in New Hampshire, Mr. Pluto has created HomePages for numerous ICIA members and is the author of the association's website http://www.icia.org He can be reached at icia@icia.org and is interviewed here on the subject of*

Industry on the Internet - Caught in the Web?

Da-Lite: Let's start with an easy question. What is the Internet, anyway?

Pluto: About twenty-five years ago the U.S. Defense Advanced Research Projects Agency (DARPA) determined that it would fund the creation of a network of computer networks that would link strategically important scientific and governmental sites together. Each of these sites was called a "node" and, by the early 70's, there were about 37 of them.

What made this network of networks remarkable was that it was designed specifically to survive interruption. DARPA was originally interested in ensuring that this "Internet" would go on running smoothly even if one or more of its nodes was knocked out (presumably by nuclear attack).

Da-Lite: How was that accomplished?

Pluto: The programming concept had to do with breaking up every message to be sent on the Internet into many small "packets" of information. Each packet has its destination address included within it as well as a code appropriate for reassembling it back into the original, larger message when it reaches that destination. The route by which each packet traveled, however, was neither pre-specified nor necessarily identical with the path taken by any other packet. Any path traveled by data moving across the Internet was as good as any other and there were no preferred connections. Thus if one of the nodes on the network crashed, the traffic on it was automatically re-routed through other nodes. This process is called "dynamic routing" and is actually operating all the time.

Da-Lite: Could you give an example?

Pluto: Sure. Suppose you're in Washington, D.C. and you want to send an e-mail to someone in San Francisco, California. When you press "Send" your message is broken up into packets and it is as likely that some of the packets will pass through Warsaw, Indiana as it is that others may pass through a computer in Warsaw, Poland. When all of the packets are received in San Francisco, your message will be reassembled back into its original form and its recipient will be able to read it.

Da-Lite: The Internet, then, has become a worldwide network?

Pluto: The Internet certainly exists on all seven continents and is growing at a nearly unbelievable rate. I've read that today there are at least 5,000 networks attached to the Internet which have something like 35 million users. That number, incidentally, is supposed to increase by half by the end of this calendar year.

Da-Lite: Is DARPA still involved?

Pluto: Oh no. DARPA disassociated itself with the net back in 1984. By 1989 the first public commercial Internets were created. And by 1995 the National Science Foundation, which had played an interim central role, also ceased to be involved and the Internet became essentially independent of governments. A good place to learn more about all this, incidentally, is on the Internet Society's HomePage: <http://www.isoc.org>.

Da-Lite: Are you able to decode that address?

Pluto: Sure. The "http" stands for HyperText Transfer Protocol. The "www" stands for World Wide Web. The colon, slashes, and periods are separators; and "isoc" is an acronym for Internet Society. The closing suffix, "org," stands, of course, for organization.

The suffixes are important and worth remembering. In addition to *.org* there's *.edu* for educational institutions (harvard.edu, for example), *.gov* for governmental addresses (irs.ustreas.gov), *.mil* for military (navy.mil), *.net* for network resources (usa.net), and *.com* for commercial organization. Your company's address, for instance, is da-lite.com.

Da-Lite: Why does everything seem to get written in lower case?

Pluto: The most common operating system shared by computers on the Internet is Unix and the language of Unix is case-sensitive. So FILE, file, and File are three different words in Unix.

Da-Lite: What about this HyperText business?

Pluto: When you go to the ICIA HomePage you'll see that various sections of the opening screen contain strings of text that are underlined. On your HomePage there are areas like buttons which turn your mouse pointer from an arrow into a hand. Any of these signals signify a HyperText or HyperMedia link. When you click on one, your screen changes to a new display which itself can certainly contain yet additional links. Often the links stay within the domain of the particular HomePage; but they don't have to. It's routine for a link in one HomePage to lead directly to a completely different HomePage. That's what HyperText means.

The World Wide Web was developed specifically to take advantage of the HyperText concept. In a sense, you use the "web" as a navigation device with which to explore the Internet. Remember, there are something like 35 *million* addresses you could conceivably go to, so you need some guidance in the connections between one address and another.

Da-Lite: As the trade organization for the audio visual industry, what is ICIA doing to exploit the Internet?

Pluto: Our primary goal is to get our membership on line in some form or another so that they may promote their goods and services in a way that will gain them greater exposure, electronically, to a world wide audience.

Our members need to look at the growth potential of the Internet, to look at its population explosion and at the commerce that's coming to be on it. To help them with that we have established our own presence on the net.

We started off with Who We Are, What We do, and our publications. We are now offering on-line trade show registration and we're now selling our publications through financially secure pages. A current project is to put our membership directory on-line. But that directory will be exclusively for our membership; these will be password-protected pages.

Da-Lite: Has your membership generally been receptive to these efforts?

Pluto: We've had such a fantastic response to all of this that we decided to offer our services to establish a presence on the Internet for our membership. This meant that when we created a HomePage for the ABC company it went up onto the World Wide Web right along side of and was just as accessable as, say, Microsoft Corporation, or the White House, or Purdue University. And they could accomplish this presence for less money than the cost of a full page ad in a local newspaper that might only run for a week.

On top of all that, the HomePage isn't static like a newspaper. Through multi-media a HomePage, literally, can sing and dance.

Da-Lite: And ICIA will create a HomePage for any of its members?

Pluto: Absolutely. I've put entire product catalogs on the web for some of our manufacturers and wholesalers and I've made smaller, less elaborate pages for some of our dealer members.

Da-Lite: How much does it cost to create a HomePage?

Pluto: We charge $99 for the initial setup and for up to 25 pages nested within your HomePage the fee is $225 per year. It costs an additional $25 per month to maintain the page but that includes unlimited updates.

Da-Lite: So any ICIA member company can have its own HomePage professionally created and maintained for less than $650?

Pluto: That's correct. Many people would argue that publishing and distributing information on the World Wide Web is the next era of marketing and promotion. And it is.

You're taking your traditional printed media (whether they be newsletters, press releases, or promotional materials) and putting them on-line where they can be accessed in a much more timely fashion and where they can be updated on the fly. Your data can be accessed by people who might not be on your mailing list. And so on.

Whether you're a huge manufacturer or just a little mom-and-pop dealer, if you put your information on the web the playing field is absolutely level. Because John Doe customer in Singapore can access your information just as easily as he can access General Motors.

Da-Lite: You chose to say Singapore because, on the Internet, that's no more remote from Virginia (where you are) than is Brazil or Austria?

Pluto: Yes. The Internet is a global phenomenon. It has no headquarters and any address is the complete equal of any other. It may be the single most democratic entity ever created.

Da-Lite: What are its drawbacks?

Pluto: Well, with more than 35 million addresses, there's a lot of junk and foolishness out there. You understand, since anybody can put up anything, some people, somewhere, will put up just that, anything. So you can come across stuff that's vulgar, stuff that's stupid, and stuff that's downright offensive. But once you learn how to browse you can find literally endless quantities of fascinating information on literally any subject you can imagine.

Da-Lite: Are there technical improvements that need to be made?

Pluto: Yes. Accessing and downloading need to be faster. Sometimes there's so much traffic at a particular site that response times get sluggish. But faster modems are helping and developments like Integrated Services Data Network (ISDN) telephone lines will enable much, much speedier transmissions.

Da-Lite: So what do you see in the future for the Internet?

Pluto: When you work on-line all day long as I do, when you're getting e-mail all day long, it's interesting to see, as time passes, that the skepticism about the Internet is slowly dissipating. Reluctance to engage in commercial transactions via the net is going away.

E-mail is so popular because it deserves to be. The ability to send a message to anybody in the world who has a computer and a modem and have that message be delivered at no cost within minutes of real time is really quite miraculous.

So I think all of the stuff we're seeing now are just stepping stones to the future. I think the Internet really will become the information super highway with all of the communications technologies we're separately familiar with today - newspapers, magazines, television, telephone, fax, etc. - seamlessly integrated into it.

Da-Lite: That suggests a whole new platform for communication. Will all businesses eventually have a website?

Pluto: I think so. Not taking advantage of the Web is a little bit like being a tightrope walker: you can get on-line alright, but it really is much safer to use the Net.

Angles Of View

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***Steven J. Orfield** is President of Orfield Associates, a consulting and multi-disciplinary research laboratory in Minneapolis, MN which specializes particularly in the evaluation of perception. A frequent contributor to trade and technical journals on subjects ranging from acoustics to visual presentation, Mr. Orfield is interviewed here on the subject of*

Visual Intelligibility - What Are We Looking At?

Da-Lite: How do you distinguish between perception and presentation?

Orfield: The classic little metaphor that works to describe all perception is

SourceÞ PathÞ Receiver.

Presentation emphasizes the first two, perception ivolves the third. A good portion of my business comes from perception. We do a lot of work characterizing not what can be measured from a product but how people respond to a product and what they associate with their response.

So, when people look at a visual display I want to know not just if they think it's bright, I want to know if they think it's high quality. If they do think it's high quality, then I'd like to be able to correlate that with how bright it is (or how even it is, or how good is its resolution). This is why we're not so interested in the absolute value of the measurement as we are in the associative characterizations of the viewer.

Da-Lite: From this perspective, what are some of things you've learned about quality in visual displays?

Orfield: We have done a study (with Da-Lite's help, I might add) on this question and the number one conclusion that it reached was that *the only way to evaluate the quality of a visual image is to evaluate the amount of information that one can gain from it in a given time*.

Da-Lite: And how do you go about measuring that?

Orfield: Well, with video the analysis is generally given by a set of statistics related to its transfer function: How well does a particular video display system accomplish the transfer from Source to Receiver? The answer has generally relied on the notion of accuracy. How closely does what I'm trying to do replicate an ideal solution?

Notice that the underlying assumption here is that if your projected video was exactly the same as the image it captured then you'd have perfection.

Da-Lite: -Is that unreasonable?

Orfield: Not at all. You just have to be careful about your measuring assumptions. An accurate transfer function in one circumstance may be wholly inadequate in another. Yet one of the big problems you see in video is the assumption that you either have a good system or you don't. And if you do have a good" system, no matter what you put on it, it's OK.

Da-Lite: Is your point that even the acquisition and assembly of top quality components may not produce an effective display?

Orfield: Exactly. If some members of the audience can't make out what they're supposed to from the screen, it may well be that upping the character size of the text could alter the perception of the screen and its quality more dramatically than changing the screen itself.

I believe one of the greatest services the video industry could do for its clients is to define in fact what constitutes appropriate displays. Developing a useful model for visibility of visual displays will have to include some sort of conclusion about what is the minimum amount of detail a person needs to see. And then that standard will have to be indexed against the age demographic of the viewer.

Da-Lite: The age question seems inarguable. Older viewers are statistically less likely to enjoy the same visual acuity as younger members of the audience. But a standard suggesting what constitutes minimum detail seems much more problematic. Isn't looking at slides of the Grand Canyon (for example) a visual task hugely different from analyzing a complicated spreadsheet?

Orfield: Of course; but what's the currency of the issue? In other words, some visual tasks have what's called "Failure" as a possible outcome. Other visual tasks don't. If you see less detail in a scenic image, it may well constitute less quality, but its generally not semantically considered failure.

So there are two types of visual tasks: those that embody the potential for failure and those which entail only quality issues.

Da-Lite: Could another way of labeling these two groups be Seeing vs. Reading?

Orfield: Sure. That's distinguishing between a screen full of visual information and a screen full of cognitive information. In the latter case things can often get a lot more complicated than just reading.

Da-Lite: What do you mean?

Orfield: Reading is linear information gathering. Confronted by a projected page of text, everybody knows to start in the upper left hand corner of the screen and scan along the rows of characters, picking up pieces of data.

Images like maps or schematics, however, are what I call complex visuals. The process of looking at them is not linear. It's generally not clear where you're supposed to start looking. It's a search task; it's a detection task; it's a sort task. Complex visuals are, therefore, much more demanding and unpredictable than pages of ordinary text.

Da-Lite: Given, then, this tremendous range of possible content, however is the A/V industry going to establish standards for reliably intelligible displays?

Orfield: I think that as you look at a dealer and a designer and their problems with video systems, there are two very important questions which sometimes don't get asked. What are you going to display? And, Who's going to view it?

These are the biggest issues that can cause a system to fail. It's useful, for instance, to tell a client that if his display falls below this sort of characterization, it's going to be too hard to see. Let's don't design this way. Don't display below this size for information.

Also of course it's very useful to consider who's viewing. The problem here is that a lot of data which would be pertinent simply isn't available. There's very good reason, for instance, to have a body of research done that would characterize what happens with people's viewing of different kinds of visual systems with age.

We do know that as we look at depreciation in vision and hearing that it's bad for women and it's worse for men. But if I want to consult a study of what an optimal display is and how it changes as you move from 20 to 70 years old, I won't find it. It's not in the literature. So these sorts of demographic issues simply have to be databased. But that work hasn't been done yet.

Da-Lite: Do you think there's been enough work done on the quality of the display itself?

Orfield: Probably not. I think we ought to find a way to throw out all the current evaluation procedures for visual displays and come back in with the viewer. I think we ought to apply standardized tasks to various viewing juries and determine what really happens, what really is the quality of a visual system.

It may well be, for instance, that quality has other, more important characterizations than luminance. There's a whole matrix of preference issues which needs defining and many of our intuitive assumptions regarding the value of, say, contrast or color saturation may not fit in that matrix in predictable ways. We just don't know; but we ought to find out.

Da-Lite: Do you think that changes in the projection screen can improve display quality?

Orfield: Of course. But I think that the information your company in particular is providing about the suitable use of your screens in terms of what is being displayed on them and who's viewing them is dramatically more important and useful than any incremental improvements you may make in the products themselves.

Da-Lite: Do you think that new developments in projector and computer technology will ensure more intelligible displays?

Orfield: No. If you have a good, objective standard for the perceptibility of displays, the display technology becomes unimportant. And I doubt that new technologies will change that communication. And so once we have some standard displays and once we have some standard methods, and once we have some standardized viewers and once we have some correlation between all of those and measurement, then we'll begin to understand what the question is. The screen and the projector will become part of a potential answer.

Da-Lite: Why do you think our industry hasn't created these standards already?

Orfield: Because once you can be benchmarked, you can fail. And if you can't be benchmarked, you don't fail. So I think there's an incentive not to have standards within the industry and within the design community too. Because if there are no standards, you don't make mistakes. You may produce better or worse things, but it can't be said that you simply screwed up.

Da-Lite: So if we did (somehow) have a display that fully met the standards of intelligibility, what would it look like?

Orfield: That's an easy question. If a display represents a visual task - the assimilation of some quantity of information over some period of time - the technology producing that display should in no way mask the task. The final standard would be that the viewer could concentrate on the information alone and ignore the process of its delivery. In this way the achievement of the intelligibility standard would be its invisibility.

Angles Of View

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***Keith Blackey** is Vice President of Marketing for Light Valve Projectors at the AmPro Corporation in Mountain View, California. He has been directly involved with the design and development of light valve projectors for the past 25 years. A co-founder of one of the technology's progenitors, Greyhawk Systems, Inc. Mr. Blackey can be reached at kblackey@lv.amprocorp.com. He is interviewed here on the subject of*

The Light Valve - Through a Glass, Brightly

Da-Lite: Let's start with an historical perspective. How long have people been working with light valves?

Blackey: There are actually two trunks to the light valve tree. In the early 70's work was started on reflective light valve projectors by Hughes Electronics and, more or less simultaneously, AT&T Bell Labs. I was a part of the latter group.

Da-Lite: And what is meant by the phrase reflective light valve"?

Blackey: The reflector was a mirror; and in front of the mirror was a film of liquid crystal that was blocking the mirror. So if you were to shine light at the mirror, there was no reflection because the liquid crystal film blocked it from reaching the mirror. The only way to get the light to pass through the liquid crystal was to open up the Venetian blinds (so to speak).

Da-Lite: How did you do that?

Blackey: The way we got the crystals to open or rotate in those days was to put a small electrical charge across the molecules of the crystals and, because their film was extremely viscous (almost like molasses), they wouldn't move until we drew on them with a hot laser beam. And whichever molecules were touched by this hot laser beam would warm up enough to be snapped open because of the electric charge and now light could at those points pass through and be reflected back out again by the mirror beneath them. So whatever design the laser beam wrote into the liquid crystal film was immediately reflected.

Da-Lite: Did the laser scan like the raster in a CRT or was it calligraphic, writing just in vectors?

Blackey: We worked with both kinds actually. In each case, however, the liquid crystals had some storage ability in the sense that as the beam moved on, the crystals it had warmed would re-freeze opened. Thus you'd never have to go back and refresh them.

So those early projectors were extremely high resolution because the laser had a very fine tip but they couldn't refresh.

Da-Lite: Given that limitation, what was the market for these devices like?

Blackey: It was larger than you might suppose. People used them for displaying things like satellite imagery or other, relatively permanent pictures. Incidentally, when I say you couldn't refresh them I really mean that you couldn't get them to rewrite in less than about 30 seconds.

But to give you some idea of the available resolution, we had projectors that could display 10,000 pixels by 10,000 pixels.

Da-Lite: Can light valves do that today?

Blackey: Conceivably, yes. The difference in today's projectors is that they no longer employ lasers. Instead they use CRTs to write the image.

Da-Lite: : And what brought about that change?

Blackey: Well, it was a change for my team only. Hughes, the other trunk of the tree that I mentioned, had always used CRTs. But when my group failed at getting the laser to write fast enough to get an acceptable refresh rate, we converted over to CRTs as well.

Da-Lite: So how does the modern light valve projector work?

Blackey: First off, I'd like to say that in my opinion light valve projectors are not a projection technique. There are only two projection techniques on the market. There's CRT. And there's LCD.

All light valves are really just turbo-chargers. We can put a light valve on the face of a CRT and take that image and make it ten to twenty times brighter. But the light valve is not a display technique in itself, it's a turbo-charger for CRTs.

Da-Lite: OK, but how exactly does it do this turbo-charging?

Blackey: The principle is still pretty much unchanged. There's a mirror with a film of non-structured liquid crystal spread across it like peanut butter on bread. Today, though, the liquid crystals are much less viscous than peanut butter; in fact they're watery. And now what twists them is solely an electronic charge.

You've got a CRT with an image on it and in front of that CRT you put a photoelectric film which maps the optical pattern of the image into an electronic pattern. This electronic pattern is then traced into the liquid crystal film.

Da-Lite: Where does the brightness come from?

Blackey: If I went up and shined a flashlight onto the face of that liquid crystal film, the image written into it by the photoconductor would reflect back onto to me.

If I put a brighter flashlight on the image, it would be brighter. And technically there is no limit to how bright the flashlight can be.

Da-Lite: So your "flashlight," your light source shines on the light valve from the front, correct?

Blackey: Exactly. This is the great virtue of light valve projectors. If I want a brighter picture, I simply exchange the flashlight for a more powerful one. If I want a better picture, I simply change the CRT. The result, of course, is that the light valve uncouples, for the first time in history, resolution from brightness.

Always before there has been some inescapable trade off between brightness and resolution. With the light valve no such price need be paid.

Da-Lite: Are there really no limits to either?

Blackey: There's a limit on LCD projectors and there's a limit on DMD projectors, but if somebody said to me that the current standard is no longer going to be 2500 ANSI lumens and a resolution of 1024 by 1280, it's instead going to be 5000 lumens and 2400 by 3200, I could have such a projector by Infocomm '97. It would depend entirely on market demand.

Da-Lite: If you have that much independent control over resolution and brightness, what about uniformity?

Blackey: The typical fall-off in a CRT projector can be as much as 70%, center to edge. Mine is 20% and sometimes only 10% to 15%. Part of that improvement comes from the back side - it's only a 3½" CRT, after all. And part comes from the front side because I can illuminate the light valve much more evenly by some simple collimation optics placed in front of the lamp.

Da-Lite: And now what about contrast?

Blackey: Good question. In order to control contrast some tricky things need to happen. The first is that the raw light from the lamp in a light valve projector needs to get polarized. Now, when this polarized light reaches the liquid crystal light valve one of two things will happen. Those portions of the incoming light which reach the mirror will be reflected back with their polarization unchanged. Those that fall onto the surface of the liquid crystal and not onto the mirror will have their polarity rotated.

Da-Lite: So this enables you to distinguish between image light (that which has reached the mirror) and non-image light (that which reaches just the surface of the film)?

Blackey: Yes. The only way for a light valve to exhibit good contrast is to project just the light that has reached the mirror. The other light, distinguishable by its rotated polarity, is not allowed to escape and is thrown away.

Da-Lite: Some light valves, it is said, can have a contrast ratio as high as 1000:1. Can that be true?

Blackey: Probably.

Da-Lite: What about color? How do you manage that?

Blackey: We take a single white light source, polarize it, and then, by using dichroic mirrors which pass light of certain wavelengths and reflect others, we split up the light into three bundles, red, green, and blue. Each of these is allowed to fall onto its own light valve (hence in our projectors there are actually three light valves) before being recombined by the optical system in such a way as it exits the projector through a single lens.

Da-Lite: That's pretty much how many of the LCD devices do it too, isn't it?

Blackey: Yes, just exactly like they do, except that we need to throw away less light.

Da-Lite: Are there any deficiencies, any limitations to the light valve projector?

Blackey: I really don't think so. Cost is an issue today, but it need not always be. A liquid crystal light valve is like any semiconductor device. You begin with a substrate onto which you lay down thin films and if you compared the AmPro facility in Mountain View with the Intel facility in Sunnyvale you wouldn't see a lot of difference in the way we build these things. Now when you are only building fifty a month, like any semiconductor, they're extremely expensive. But when you're building a million a month, the price goes way, way down.

Da-Lite: Aside from manufacturing costs, is there no other limitation?

Blackey: I'm biased of course, but I see that there's a place for a light valve projector in every living room in the world. After all, don't we want in our houses the same thing we see in somebody's boardroom? We want a very bright projector that doesn't take up much room, that's pretty quiet, and that's easy to operate. All that is very achievable with the light valve.

Angles Of View

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Arlie Conner *is Vice President, Technology at Lightware, a manufacturer of LCD projection devices in Beaverton, Oregon. Mr. Conner, who has been Research Director for In Focus Systems, has worked for the last ten years on the technical design and development of Liquid Crystal Display systems. He can be reached at arliec@lightware.com and is interviewed here on the subject of*

Monitoring the Future - the LCD

Da-Lite: Liquid Crystal Displays have become an extremely well established technology. But they weren't always so common. What originally prompted their wide acceptance?

Conner: Do you remember the earliest laptop computers? Initially many of them were using things like plasma or electroluminescent displays for their screens. And, until someone thought of LCDs, there was no simple solution to portable computer screens. However, principally because their power requirements are an order of magnitude lower than the alternative systems, LCDs rapidly became dominant.

Da-Lite: And how did they then migrate into projection display devices?

Conner: The really kind of fun breakthrough, the aha!, happened when someone first stuck a liquid crystal display onto an overhead projector. Once that had happened, it was suddenly group sharing of a big screen version of a computer monitor. And pretty instantaneously five or six companies sprang up to build these LCD panels or platens, as they were sometimes called.

Of course overhead projector manufacturers were delighted and it didn't take them very long to develop projectors with the significantly increased brightness which the LCDs demand. How bright, for instance, is your company's new overhead?

Da-Lite: Our Model 5000, as its name suggests, is conservatively rated at five-thousand lumens.

Conner: In addition to the panels for overhead projectors, those of us in the LCD world also recognized that there were certain benefits to be had if one could make an integrated system that wrapped the OHP and the LCD into one small package that could be fitted, as it were, into the overhead compartment on an airplane.

Da-Lite: Were the manufacturers of the LCDs cooperative?

Conner: They did take a little bit of convincing because they knew and still know today that the main market for their products is portable computers. But once aspects of that market began to call for smaller format LCDs (to go into screens for sub-notebooks, for instance), it wasn't so difficult to get smaller LCDs for inclusion in integrated projectors. A 10-inch LCD is what you may need for an OHP panel, but what you need for an all-in-one projector can be much, much smaller.

Da-Lite: OK; but regardless of its size, just how does a layer of liquid crystal become a functional projection device?

Conner: The LCD with which we are probably most familiar is called TN, for Twisted Nematic. That refers to the crystalline phase of the material. The term nematic means that the molecules of the crystal are long and rodlike and generally at room temperature are loosely organized such that, like a school of fish, they're all parallel and heading in the same direction.

Da-Lite: What about the "twisted" part?

Conner: If you sandwich a cell of TN liquid crystal material between cross polarizers, top and bottom, the alignment of the molecules at the bottom might be, say, North-South, but as you move up the column towards the top polarizer the intervening layers of molecules twist smoothly, layer by layer, so that, by the time you get to the top their alignment is East-West.

Da-Lite: So the twisting transition takes place in a plane perpendicular to the orientation of the molecules?

Conner: Think about it as a column of liquid crystal. At the top, everything points East-West. At the bottom everything points North-South. And in between there's a 90º gentle, spiral staircase. When polarized light is passed by the first polarizer, its orientation may be said to be North-South. And as it passes though the liquid crystal layers that polarization is rotated such that, like the molecules themselves, it has become East-West by the time it reaches the second polarizer which is more accurately termed the "analyzer."

Notice that even though twisting the molecules are still lying flat to the glass above and below them. But when you apply an electric field across the gap between the two glass polarizers, the molecules of the liquid crystal now want to tilt up which means that all of them are suddenly more or less perpendicular to where they had previously been pointing.

Da-Lite: What does that accomplish?

Conner: What it means is that the spiral staircase vanishes when the molecules tilt up and therefore you have a polarizing "valve" proportional to the applied electric field.

So if our model says that the first polarizer is going to pass light of only a North-South orientation and that light no longer encounters a spiral staircase to twist its polarization by 90º, when it reaches the analyzer (the second polarizer) which passes light of only an East-West orientation it can't get through. And you get black.

Da-Lite: If you vary the intensity of the electric field, then will the degree of tilt assumed by the molecules also vary?

Conner: Exactly. And that's how LCDs can produce grey scales of such surprisingly good gradation and uniformity. To produce grey scale requires good control of the cell gap (the spacing between the glass plates which normally is six to ten microns) and a proper understanding of the driver design.

Da-Lite: The drivers are what establish and control the pixels, aren't they?

Conner: Yes; and I'd like to point out that the fundamental benefit of an X/Y matrix like that which drives an LCD is that if you have 640 times 480 pixels, you have an awful lot of pixels. But we only have 640 *plus* 480 column and row drivers. So a flat panel LCD is really quite an economical design.

Da-Lite: Is that true whether or not the display is an active or a passive matrix?

Conner: Yes; although the performance characteristics of the active matrix are considerably better.

Da-Lite: In what way?

Conner: The contrast ratio of an active matrix is typically 100:1, whereas passive matrices might top out at 20:1.

Da-Lite: Why is that difference so large?

Conner: It results chiefly from the driving method. Passive matrices have a limitation on the voltage that you can have between an on and off pixel. Generally it's about six per cent. Active matrices are not similarly limited.

Da-Lite: Do most LCD projection devices now contain an active matrix display?

Conner: Yes; three of them in fact - one for each color, red, green, and blue. All high performance LCD projectors will use dichroic mirrors to separate the white light from the lamp into its constituent RGB wavelengths which are then passed through three identical black-and-white light valves before being recombined through the lensing system. The quality and saturation of the resultant colors are much superior to a single, filtered LCD.

Da-Lite: How efficient is an LCD projector? How much of their light source's initial brightness gets lost?

Conner: About 95%. Actually, it's worse than that. Almost none of the projectors is better than about 2% efficient.

Da-Lite: And what about resolution?

Conner: Well, perhaps I'm oversimplifying, but I think resolution depends on the state of the technology at any given time. Of course everyone would like more pixels but to get them you pay a cost in the complexity of their manufacture. Getting more dots onto the same size panel is always a challenge and never easy.

Da-Lite: Why can't you just use larger panels to increase your pixel count? That would increase their number without decreasing their size.

Conner: In fact that's what is going to be done. Although clever designers have been able to increase the number of dots from VGA to SVGA without enlarging the 1.3-inch diagonal panel size, to get to the larger number of dots implied by XGA or Workstation resolution they've had generally to go to the 1.8 or 2.4-inch diagonals.

However, because the manufacturing lines for these panels are set up to use 6-inch diagonal quartz substrates, the number of images you can get on a single substrate decreases sharply as their individual size is increased. Hence the unit cost goes up quickly and badly.

Da-Lite: And what do you see as the future for LCD projectors?

Conner: I'd say that LCDs are something whose time has not even fully come yet. Even as we speak the developmental improvements are staggering. Maybe it's not the same as the semi-conductor paradigm (where theoretically processing speed and memory capacity double while costs halve every six months), but LCDs have their own growth curve and their performance and cost have both been respectively improved and decreased radically over the past five years. It's hard to imagine where it's going next. But there's no clear end in sight.

Angles Of View

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Digital Micromirror Devices - Reflecting on the Future

Da-Lite: Currently the DMDs your company is manufacturing contain more than 50,000 movable mirrors arrayed over the top of a silicon chip that isn't any bigger than a postage stamp. That seems like an awful lot of angels to fit onto the head of pin. However do you do it?

Yoder: Basically we start with a standard silicon memory wafer which is very common in the semiconductor industry. What that layer gives us are digital memory cells from which we can control each mirror. After we build a mirror over each of these memory cells we can plug a 1 or a 0 into it which will cause the mirror above it to tilt ±10°.

With that in mind, all we really do is accomplish a series of photo lithographic layering on top of the memory cells. To get the mirror high enough above the memory cells so that its corners have enough room to tilt down by 10°, we'll deposit a spacing layer that's appropriately thick. Then we'll etch where we want the holes, or lines, or spacings to be. Once that's done we can layer on the aluminum which constitutes the mirror and when it has formed we dissolve or wash the spacer layers away.

Da-Lite: From the illustrations in your literature and on your website (www.ti.com) , each completed mirror looks rather like a little flat topped mushroom which is connected to the structure beneath it only at the base of its stem. Is that correct?

Yoder: Yes; and it is at the base of that stem where the hinging takes place. If a charge is put into one side of the memory cell it will electrostatically cause the edge of the mirror above it to pull down toward it. If the charge is put into the opposite side of the memory cell, the mirror will tilt the other way. At these opposing sides we've placed little stops which mechanically block the mirror from tilting more than 10° in either direction. When there is no voltage applied, the mirror has no reason to tilt and it sits at 0°, which is to say parallel to the bottom of the chip.

Da-Lite: How fast can you switch each mirror through those 20°?

Yoder: 50,000 times a second.

Da-Lite: Inside a projection device one or more of these DMDs gets placed in front of a light source (a lamp) and behind a lensing system. How does it create a picture?

Yoder: When a mirror is in the +10° position light falling on its surface from the lamp will be reflected out through the lensing system and onto the screen. When a mirror is in the -10°position light falling on it will be reflected away from the lensing system.

Since a typical chip will include 600 rows of 848 mirrors, this is the resolution limit of the display. 600 x 800 of the mirrors are used as the pixels of a 3:4 aspect ratio image and 480 x 848 are used to display the 9:16 aspect ratio NTSC video signal.

Da-Lite: And of course you produce gray scale by varying the number of times, between 0 and 50,000/sec, each mirror is in its On position, correct?

Yoder: That's correct. Because we're digital and because we can switch the mirrors from On to Off in only 16 microseconds, the gray scale produced by DMDs is extremely accurate.

Da-Lite: What are the other intrinsic advantages of this technology?

Yoder: The first is that DMDs are reflective. So if you do the math for them you'll find that in video operation 60% of the incident light will get off the DMD. Now for an LCD projector, you start with 100% light but, since you have to go to polarized light, you throw out 50% right away, and by the time it gets through the rest of the system you've got only 6-10% left. But because we're not transmissive, because we're reflective and therefore don't have to use polarized light, DMDs have an inherent brightness advantage that's really powerful.

The other advantage we have (although we see that the LCD people are moving fast to narrow this gap) is what I call Fill Factor.

Da-Lite: Is that what other people call Aperture Ratio?

Yoder: Yes; it translates into the amount of useful information on the screen. I like to talk to people in terms of blocks. Imagine that if your screen was divided up into ten square blocks. With DMD technology nine of those ten blocks are full of information (which is a 90% aperture ratio). With LCD technology, today, at best six or seven of those blocks are full of information. The rest are black.

What you really want to see is 100% information but of course technology can't do that right now. So we're limited by that Fill Factor/Aperture Ratio. Although once you get that up to 90 or 95 per cent, you can't really resolve the unfilled 10% - at least from any reasonable viewing distance.

Da-Lite: What makes up that 10% on a DMD?

Yoder: Well, first there's the spacing around the mirrors. That gap equals one micron. Then, there's a very tiny hole right in the center of each mirror which we call the "via."

Da-Lite: That's the part leading down to the hollow stem of the mushroom?

Yoder: Yes. It is because of the gaps and the vias our Fill Factor ends up at "only" 90%.

Da-Lite: Is there some reason the size of the individual mirrors, at only 16 microns square, has to be so small? Doesn't that make them terribly hard to make?

Yoder: Not really, no. If you follow semiconductor technology, you see an endless push for more and more transistors per square inch and faster and faster switching speeds. A few years ago the standard was .8 microns, which meant that .8 microns was the smallest dimension you were permitted. Now they're down to .3 microns....

Now think about these mirrors. Including the gap, they're 17 microns. They're a no brainer! It's not at all difficult to create objects of this size if you're using .8 micron technology. So creating our chips is well within the bounds of the old semiconductor limits and even more so within the new.

Da-Lite: Will the dimensions of the mirrors need to change when you go to make a chip of higher resolution than 600 x 848, or will you simply enlarge the chip to accommodate, say, 1024 x 1280 mirrors.

Yoder: We could go either way. The new .3 semiconductor standards would permit us to make smaller mirrors or, as you suggest, we could keep the current size and make the chip bigger.

Da-Lite: Given what must be the great difficulty of concentrating large amounts of light onto a surface the size of a postage stamp, wouldn't a larger chip give a greater collection efficiency?

Yoder: Yes, but larger chips mean a smaller number of them can be created from a standard wafer. But that cost question aside, there may well be high brightness and professional applications where we will want bigger chips because we want to collect more light.

As you've seen, it's possible to achieve over 3,000 lumens on the current size chip, 848 by 600. So, if you do the math, you discover that chip to be about .67 inches in diagonal. Now when we go to a 1280 by 1024 array of the same sized mirrors, we jump to a chip with a 1.1 inch diagonal - which is close to four times the surface area. Obviously that will enable us to collect far more light.

Da-Lite: How bright do you think projectors using three of those chips could get?

Yoder: We're anticipating 10,000 lumens and higher.

Da-Lite: And what principal applications do you see for a projector that bright?

Yoder: Certainly the most prominent is large screen video projection in movie theaters.

Da-Lite: You mean as a replacement to film?

Yoder: Indeed I do. Here at TI we are doing a lot of work to quantify what does film give you today and to what extent can an audience tell the difference between film and electronic cinema.

Da-Lite: A DMD prototype projector was demonstrated adjacent to Infocomm this year and the quality of its video images was extremely impressive. But was it really as good as film?

Yoder: We know there's still a way to go and what was shown in Philadelphia in some critics' opinion wasn't quite there. But we're still moving forward and I believe we will get there.

Da-Lite: You believe that you can achieve the resolution, the brightness, and the color saturation of a fresh print shown in a first run movie movie house?

Yoder: Yes. Think about the phrase "fresh print."

Go to a movie after six weeks and see how fresh the print is. Whereas electronic projection is constant; constant beautiful performance. No hairline scratches, no dust, nothing. What happens when you take away all of those film artifacts while at the same time you don't introduce any digital artifacts? You have a better picture. You talk about getting to where film is?

We just might *surpass* where film is.

Angles Of View

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***Joe Kane** is the founder and President of Joe Kane Productions, Inc. headquartered in North Hollywood, CA. Mr. Kane consults, lectures, and writes widely on defining, building, and maintaining high quality display devices. He can be reached at joekane@worldnet.att.net and is interviewed here on the subject of*

Display Screens - Revealing the Standards

Da-Lite: In a general way, what do we mean when we speak about a "display device"?

Kane: A display device is something that converts electronic signals carrying picture information into something that is intelligible to us as human beings. From a communications systems point of view, a display device has to be a fixed, well known pallet. Otherwise it's a useless piece of arbitrary hardware.

The purpose of a display device is to present visual information. In order to convey the intended information to a large audience, the medium has to be well defined. That fact was clearly recognized when our color television was first defined in 1953, but up until recently, the rules set out at that time have been difficult to implement. The computer industry is scattered enough so that there is not yet a recognition for display standards. Yet if they really want to move into the information age, there must be standards for displaying information. I've found myself in a position of demonstrating the need for such standards.

Da-Lite: If the purpose of the devices you're talking about is to project the display, may we say that the function of a screen is to display the display?

Kane: Sure.

Da-Lite: And would you agree that the principal purpose of a screen is to deliver as much as possible of the energy from the projector into the eyes of the audience?

Kane: Well, yes. But the mention of energy makes me nervous. I have been fighting how much is made of that particular parameter above all others. Concentrating on light output over everything else is why most display devices produce such poor picture quality.

Da-Lite: So you believe that brightness should not be the foremost attribute of a display device?

Kane: I do. The first job of a display device is the accurate reproduction of the incoming signal.

Da-Lite: And the first job of a screen?

Kane: The screen should maintain the standards of the signal.

Da-Lite: If we're looking at an image displayed on a screen, what are the essential attributes of a good looking picture?

Kane: The ideal contribution of the screen to the display of information should be neutrality and uniformity.

Da-Lite: By uniformity do you mean that from any given position a viewer could not easily detect brightness differentials between one area of the image and another?

Kane: Uniformity of performance encompasses more parameters than just light output. There is, for instance, the ability of the display to handle color as well as light falloff.

Da-Lite: What sorts of properties should a screen have to enable it to handle color uniformly?

Kane: Any surface will somehow alter the characteristics of light hitting it. That's the nature of a surface; it's going to absorb some of the light and it's going to reflect or cast off part of it. It's important that a screen be able to reflect light off its surface equally across the entire light spectrum, at every point in the screen.

Another parameter of the screen surface is that it needs to be fine enough not to get in the way of light variations in the source signal. In other words, the screen shouldn't interfere with the detail in the picture.

Da-Lite: Are there other levels of uniformity?

Kane: Yes. There are actually three. First there's white field uniformity, or light output across the entire screen. This has a physical component, such as not having any waves.

Second its color characteristics have to be equal. That means that it has to provide the viewer with a flat spectral response.

And third there can't be anything, either fixed or variable, that would get in the way of light variations from the source which would degrade detail.

Da-Lite: What other characteristics should we think about? And, do they apply equally to front and rear projection screens?

Kane: Rear screens are slightly more complicated than front screens. A big issue is the thickness of the diffusing material. The light goes into a different medium (air to plastic or air to glass) and is bent. If the diffuser is too thick, this bending will defocus the information. Although they aren't Da-Lite's, there are some rear screen coatings being used today where a small dot of white on a black background will become an unrecognizable blur when it finally exits the screen. That's why it's so important for the diffuser to be as thin as possible.

Da-Lite: We absolutely agree with you.

Kane: Then, in rear screen in particular, there arises the necessity to help out the projector a little bit. This is so because the typical CRT projector is usually way too close to the screen and the rays of light coming from its three lenses are by no means parallel as they travel towards the screen. So we want to add a helper behind the screen called a Fresnel which helps bring the light straight out of the screen.

Da-Lite: Do you believe that a Fresnel lens would be a useful addition to any rear screen?

Kane: Actually there's a practical limit to a Fresnel's utility. If the focal length of projection lenses is greater than 1.5, the value of a Fresnel become questionable.

Da-Lite: But if the throw distance for a particular projector is, say, 1.2 times the screen's diagonal...?

Kane: Then you should include a Fresnel behind the diffuser screen.

Da-Lite: A display attribute you have yet to mention is contrast.

Kane: That brings us back to the discussion of diffusion thickness, which of course can destroy the contrast ratio.

Da-Lite: Why would it do that?

Kane: The real contrast of a picture is determined by looking at adjacent areas of an image. It is not determined from one corner of the picture to another or from a totally black picture to a 100% white picture. If you measure anything other than the adjacent area contrast it will have little or no meaning to the eye. What a thick diffuser does is kill adjacent area contrast by scattering the light from a bright area to an adjacent dark area. This will dump the contrast ratio something fierce and the picture will look washed out.

Da-Lite: At Da-Lite we believe that adding gray colorant to some of our Polacoat diffusers measurably improves screen contrast, particularly in the presence of ambient light. What is your opinion of that practice?

Kane: Unfortunately what I've found is that putting a colorant in the screen to absorb ambient light alters the spectral response of the screen. You see, when you put any kind of a coating on the screen the light passing through it will become attenuated. And once you start attenuating light, it's important to attenuate it equally clear across the spectrum. You can't favor one part of the spectrum versus another. However, that's what the majority of the screen darkening materials do.

This is why your Video Vision screen is a milky white color. That's what it takes to get a flat spectral response with a fairly high degree of efficiency in being able to pass the light from the source to the audience.

Da-Lite: Thus far you've been describing display devices which are 3-gun, CRT projectors. What happens if there is only a single exit pupil?

Kane: With three tube projectors the light sources are spatially separated and there will be differential gains to contend with. When all of the light comes from a single source spectral response is not as critical. Yet even here, white field uniformity remains important. The whole motion picture industry has begun to realize this, for example, in its attitude towards front screens. They're realizing that their movies look better on your Cinema Vision material than they do on the material they've always been using. They notice an improvement on Cinema Vision, because it's got such a flat spectral response, the blues and the reds are noticeably richer.

Da-Lite: Although much of your work focuses on kinetic imagery, how different do you think the standards are for static displays?

Kane: I think there are two important differences. In a static image we are able to produce more apparent resolution at the source and, when the image is not moving, we tend to study it more.

Da-Lite: In this context what then do you think about including lenticulations in the surface of a screen that, as you put it, has to be studied? Many people conclude that if you have twice as many lenticulations as the upper limit of the display device's horizontal resolution, you're OK. What do you conclude?

Kane: I think it was Nyquist who first theorized that all you need is two samples per element to tell what's there. I am much more conservative than that. I believe that screen resolution should be at least ten times greater than the source resolution.

Da-Lite: So you're saying you want as high a sampling rate as you can find?

Kane: Yes; that's what diffusers are all about. Some people in the industry have specified a good, thin diffuser as having a sampling rate of about 1400 lines per inch. There's not a display device in the world that could even approach resolution that fine.

Angles of View VOLUME III – 1997

A collection of "closer looks" at the attributes and properties of visual displays.

Angles Of View

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In Volume I of this series we set out to establish a series of preliminary definitions for most of the attributes and properties of visual displays. In order to make those discussions as clear as possible, however, certain simplifications were introduced which now, in Volume III, will be amplified. Various practical elements attendant to the specification of optimal display systems will be emphasized with particular concentration on the interrelationships between their components. This third collection of articles then will take a series of in depth and Closer Looks at much of the material covered in the first volume. We begin with a re-examination of

Screen Gain - Whose Loss?

When we come to contemplate a projection device in conjunction with a projection screen, there is considerable irony in the fact that the term "gain" is routinely applied to the screen and hardly ever to the projector. Yet it is the projector, not the surface, which is powered by electricity and it is the projector, not the surface, which comes with a twistable dial marked "Brightness."

Nevertheless screen gain does exist. Although still a misleading misnomer, gain is not purely some shibboleth of the A/V industry. A screen with a gain of 3 is certainly and observably different from a screen with a gain of 1.5. *How* it is different merits analysis.

As was noted in the very first article of this series, screen gain is measured by pointing the light meter at the center of the screen from a position that is essentially perpendicular and on-axis to that center. Let's be iconoclastic for a moment and examine the assumptions underlying this procedure.

Does it mean that there's anything unique about the particular square foot of fabric which happens to comprise screen center? Of course not. No strip, area, or square foot of screen material is manufactured to be different from any other. Optically they are all fungible; as well they should be.

If indeed there's nothing special about the screen's center, what about the other variable, the viewing angle? Is 0º somehow preferential to all other angles of view? To start with it is quite rare these days to see a projector vertically positioned exactly opposite to screen center. Much, much more frequently the projector is mounted parallel to the top or to the bottom of the screen. And when it is somewhere else, it's still not at 0º but is instead something like 25% down (or up) from the screen's top (or bottom.).

Since it is so unlikely for light reaching the center of the screen to be itself "on-axis", it's a little hard to see what could be the advantage of measuring light from an on-axis position.

The final observation we want to make about Gain is that the number we deduce from our measurements is not a number intrinsic to the screen itself but one which is relative to a fixed, non-screen reference standard - generally a block of magnesium carbonate.

To all intents and purposes a flat expanse of $MgC0_3$ will absorb none and re-radiate all of the light incident to its surface. Furthermore, that re-radiated light will be distributed with perfect uniformity throughout all possible viewing angles. This point is subtle and deserves emphasis. Another way of expressing it is to say that light rays incident to such a surface will be re-radiated in such a way that all traces of their incident angles will be lost.

Thus the number displayed by a photometer aimed at an illuminated block of $MgC0_3$ will not vary as the instrument is moved through any number of random "viewing" angles. And, to make the experiment really interesting, our number will also remain invariant if we move our light source through an equally large and equally arbitrary range of projection angles.

There is, then, no combination of positions for the projection and measuring device which will yield a greater or lesser amount of "brightness" from this, the common reference standard against which we calculate screen gain.

What is confusing about all this is that the reference standard is itself said to have gain when in fact that's the very thing it most importantly *doesn't* have. A projection screen has gain when in one way or another it can be measured as being brighter than the reference standard. This is really what screen gain signifies, an increase by some amount over not the low gain, but the no gain $MgC0_3$.

There is of course one (but only one) screen surface which also has no gain and which also behaves identically to the reference standard. This is the ubiquitous and extraordinarily useful Matte White. Array an audience before a matte white surface and you can be sure that all of its members, regardless of the projection angle or of their viewing angles, will be assured of a picture that is consistently and equally uniform throughout.

If we could trace a bundle of projected light rays striking a piece of Matte White screen, what we would see is that the rays will bounce off the surface in a pattern that forms a perfect hemisphere. The equator of this hemisphere is flush with the plane of the screen and no matter where on its circumference we choose to look through, we'll always see that it's filled with the same amount of light.

Now let's ask what happens if we vary the intensity of the incoming bundle of light rays. We could do this by fiddling with the brightness knob on our projector or by switching out the projector itself for one with greater or lesser lumen output. Would anything change about our hemisphere?

Yes, one (but only one) thing will change. The radius of the hemisphere will get bigger as we increase the amount of light filling it. So there is a directly proportional relationship between the *volume* of light (commonly referred to as total luminous flux) available from the projector and the *volume* of the resultant hemisphere. Varying the amount of flux, however, has no effect whatsoever on the *shape* of the hemisphere. That, if we are using a matte white screen, remains constant always.

And if the screen is not Matte White, if it has been manufactured to have a gain of 2, for example, what happens to the luminous flux reaching its surface?

As reflective materials are added to the matte white, to increase screen gain, the base of the hemisphere contracts and, as the distance to its "north pole" expands, it starts to adopt the shape of an extending tear drop whose outer surface is still curved but whose diameter grows smaller and smaller as the screen is given higher and higher gain.

Furthermore, the axis of the tear drop (the line from its base which extends through its "north pole") points in a direction that is increasingly dependent on the incident angle of the light rays filling it and will therefore be less and less perpendicular to the surface of the screen. Despite these transformations, however, the volume of the ever lengthening tear drop will always be the same as that of the original hemisphere.

Interestingly, the shape of the lobe of light leaving a rear projection screen is not hemispheric - even when the screen has a gain of 1. And while the volume of the screen's transmitted light remains directly proportional to the amount of luminous flux from the projector, the two are never equal. This is so because all rear projection screens fail to transmit all of the light incident to their back surfaces. Quite a significant percentage of the flux in fact will be reflected by those back surfaces and some additional (but smaller) percentage will be absorbed by whatever medium is comprising the rear projection screens' substrates (typically acrylic or glass).

The gain of a rear projection screen is increased by arranging for the diffusion layer (the scattering medium) to be less and less dense. This results in more and more of the projected light rays being permitted to pass through the screen with their incident angles undisturbed.

The essential behavior, then, of both rear and front projection screens is not created by any direct manipulation of their displayed "brightness." Screens cannot create energy. That's what projectors are for. Screens can (and do!) control the angular distribution of that energy and by that process and that process alone they create what is called their gain.

This mechanism is especially useful to keep in mind when we come to match a screen surface with a specific projector type. Unfortunately not all types of projectors produce luminance (flux) that is uniform across the beam. CRTs, for instance, are notorious for emitting only about 30% of their on-axis luminance at their corners. Alternatively, some LCD projectors can now deliver imagery whose corners are fully 80% as bright as their centers.

To match a CRT projector with a high gain screen is therefore precarious. If from any given viewing angle we are comfortably to discern all four corners of an image, we'll need to scatter the light reaching them as widely as necessary. If the volume of the flux illuminating those corners is low and the angular distribution from the screen narrow, we inescapably will perceive them to be dim. Sometimes we reverse that observation and say that the center is too bright and that we are looking at a "hotspot," but that is not, strictly speaking, a correct conclusion.

Projectors with greater center-to-edge uniformity of course fare less badly with higher gain screens. But even they will do better still with low gain surfaces.

Does this mean that we should never utilize a high gain screen? Of course not. But we must be careful and even cautious in its selection. Otherwise we may not gain nearly as much as we hoped.

Angles Of View

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The ability our industry enjoys to provide our customers with an ever burgeoning variety of visual displays is enabled by two, consecutive technologies. The first is the computer which, with its ever faster chips and graphics boards, is continually reinventing what's possible in digital image formation. The second is the projector which is continually improving the quality of the images it can deliver to a screen. The connector which binds the two together is their maximum pixel counts. Anyone interested in contemporary displays must, therefore, think carefully about

Resolution - How Much Should We Count On?

To begin with the obvious, all electronic displays are comprised of pixels, a term whose etymology is a contraction of the phrase "picture element." A pixel is the smallest unit used to create a digital image. Thus the specification of a display's resolution is given by the maximum number of pixels it may contain. This quantity is generally expressed as a pair of numbers describing a matrix of the pixels' horizontal and vertical distribution.

When we see "640 by 480 (VGA)" labeling some device, we know that the maximum number of pixels available for writing images is 307, 200. We also know that the larger of the two numbers specifies the number of columns of pixels running horizontally across the display, while the smaller number tells us the maximum number of rows running down it.

If we use these pixels to draw a line across some image area, we are able to specify the precise number and locations of the "points" which make it up. In contradistinction, the number of "points" making up a line within an analog image is theoretically infinite and cannot be specified. The analog line can be diced up into as few or as many sections as we wish. The number of pieces comprising the digitized line cannot be either increased or decreased. It has a fixed and immutable count.

Extending this line analogy a little longer, we can go on to see that if we want the pixellated version of a line to be a convincing imitation of its analog version, we need to put together a large enough number of points that we can place close enough together so that from any reasonable viewing distance, we cannot tell them apart. In this way the illusion of the perfectly continuous analog line can be created.

For the illusion to be successful three major thresholds must be crossed. The horizontal resolution must be high enough, the viewing distance large enough, and the image size must be small enough that we can see only what we want to see: the picture, not the pixels.

We are able to perceive the line as continuous because the resolving power of our eyes fortunately is not infinite. If it were, our line would always be made up of unconnected dots and we could never see a forest for the trees.

When we come to look at projection screens in connection with resolution, we can establish promptly that the role played by diffusion screens is always small. This is so because the largest units used to make up a diffusion layer are particles whose absolute size is measured in microns. Pixels, on the other hand, get measured in millimeters and are resultantly three orders of magnitude larger.

The picture changes radically, however, when we look at screens which have large scale structure. The best example here are lenticulated rear projection screens. All of these have surfaces which contain a series of tangible grooves which can be expressed as a frequency. Thus a lenticulated screen which has a "pitch" of 1 millimeter (meaning that there is 1 lenticulation for every 1mm of screen width) has a frequency lower than one which has a pitch of .6mm (meaning that there are 5 lenticulations in every 3mm of screen width).

After noting that we are looking here at frequencies which are spatial and not temporal, let's return to our digital projection devices for a moment and notice that, come to think of it, they too can be described as having spatial frequencies.

If the horizontal resolution of some projector is 800 (SVGA), we know that when that row of pixels is projected across some screen its spatial frequency will obviously be 800. Varying the size of the screen which displays that row will change the size of the individual pixels, but it will not alter their frequency. Equally, varying the size of a lenticulated screen displaying the 800-pixel row will *not* change the size of the individual lenticulation, but it *will* alter their total number.

We have, then, the beginnings of an interesting mathematical relationship. Our projection device is dicing up our image into an exact number of horizontal pieces and our lenticulated screen is interestingly able to do the very same thing. What happens when we bring the two devices together depends largely on the relationship between their frequencies.

Another way to define a series of pixels and a series of lenticulations is to state that they are both wave forms. (The lenticulations actually look like waves and the projected pixels actually behave like waves.) Since we know that all types of waves are capable of interfering with one another, will we not be surprised to discover that the two we are presently considering are no exception.

The magnitude of their interference is visually detectable through a phenomenon called Moir fringing. It is mathematically calculable according to the expression

$$\frac{1}{(\Omega-\Omega_0)}*\cos(\Omega-\Omega_0)$$

where W is the frequency of the lenticulations and W_0 the pixel frequency." If we make W_0 always equal to 1 and crank a long list of incrementally increasing values for W through this formula and then graph the results, we get figure 1.

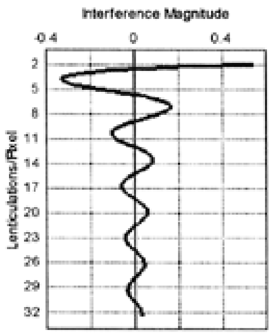

Figure 1

$$\frac{1}{(\Omega-\Omega_0)}*\cos(\Omega-\Omega_0)$$

As the number of lenticulations per pixel is increased, the extent to which the interference line moves away from the Y axis decreases. Thus the amplitude of the effect diminishes as the frequency of the lenticulations is increased.

When we look at a screen which is exhibiting Moir¨¦ interference patterns, the text or data we are trying to read or discern will appear indistinct and blurry. Often the severity of the effect will vary according to our viewing angle - the greater the angle, the greater the illegibility. Although we might at first suppose the projection lens is not focused properly, a closer look makes clear that the information content in the pixels themselves is somehow being scrambled.

But wait. We have established above that a pixel by definition is the smallest building bock with which we can create a display. If that is really so, then its content must be homogeneous and, therefore, impossible to scramble. Have we somehow misrepresented?

No, not exactly. Let us imagine a single pixel chosen at random from within some display. At the time we examine it, its assigned content is some particular shade of some particular color. And, as soon as we utter the word color, we begin to glimpse the origin of this sort of Moir¨¦.

Almost all digital projection devices create color by blending light from three distinct sources, each of a primary color. What is essential to see here is not that the sources, the Red, the Green, and the Blue are chromatically separated but that they are *spatially* separated. Thus with a CRT projector, for instance, a colored pixel is actually a stack of three pixels, one overlaying the other, which in combination create the desired color. In most LCD, light valve, and DLP projectors there are also three, spatially separated color sources. Thus the chromatic information inside a given pixel is not always homogenous and, therefore, *is* capable of being scrambled.

Interestingly, a projection device which utilizes only a single light source and which creates its color by spinning a tripartite translucent wheel before that light source will not be susceptible to resolution loss when combined with a lenticulated screen. (Neither, of course, would a solely monochromatic projector.)

But when "red" light rays contributing to a single pixel are different in their source from the "blue" which are in turn different from the "green," the intended mix of their combination can be significantly altered by the lenticulations which sample them on a screen. If the number of lenticulations per pixel available to do that sampling is small, the resultant effect will be proportionately coarse and noticeable.

Today, when projectors are becoming ever brighter, and images ever more detailed, the decision to use a lenticulated screen must be accounted for carefully. If our customers are counting on us to provide them with top quality displays, we may just be well advised to offer them a diffusion screen on which we ourselves don't have to count but on which they most surely can.

Angles Of View

Vol. III, 3 ©Da-Lite Screen Company March 1997

Common to all visual displays are three principal elements: projector, screen, and audience. Ideally the configuration and arrangement of the first two should function so that the maximum number of light rays emitted from the first will be relayed by the second directly into the eyes of the third. All other distributions of the light are superfluous. With this basic precept in mind, let's take a closer look at

Some Reflections on Front Projection Screens

Although there are many different types of projection devices, there are not so many types of screens. In fact there are only three. There are screens that reflect light, screens that scatter light, and screens that refract light. Understanding a little about how each of them works can help improve our ability constructively to choose between them.

Let us consider first screens which are reflective. These are the surfaces which are governed principally by the Law of Reflection which states that the *Angle of Incidence = the Angle of Reflectance*. When light falls on such a surface, it bounces off in a direction which is largely determined by the direction it originally came from. This is comparable to the behavior of a ball on a billiard table. If we propel it toward a cushion at an angle of, say, 30^{o}, it will rebound at an angle of -30^{o}.

The second kind of screen is the type that scatters. Light bounces off this surface in a remarkably uniform way that is completely independent of its incident angle. To extend the billiard ball analogy, whatever direction we chose to aim at the cushion will have no effect whatsoever on the way the ball will bounce off it. In fact, the "ball" doesn't bounce at all. Instead it spontaneously breaks up into millions and millions of tiny little balls which flow outward from the cushion, spreading evenly across the entire table. This, of course, is the Matte White screen surface and for a detailed discussion of its properties see Vol I, No. 6 of this series.

The third kind of screen is refractive. Since refraction is a phenomenon which occurs when light ceases traveling through one medium and enters another, we don't normally think of it in connection with front projection screens. Nevertheless, the optics which underlies all glass beaded screens is definitely refractive. Light projected from some angle at this type of screen neither bounces off at an opposite angle nor scatters uniformly. Light directed at a glass beaded screen is returned along the very same path it arrived on. It is because of this peculiar attribute that glass beaded screens have come to be called retro-reflective. If a billiard table were retro-reflective, a ball aimed at one of its cushions from whatever angle would rebound only along a path leading directly back to the tip of the cue stick.

Among these three basic types of front projection screens, glass beaded surfaces have been the most maligned and the least understood. That is unfortunate because, as we shall see, they can be exceptionally useful devices which no longer deserve the reputation they once had.

Historically, there were two drawbacks to glass beaded screens as they were initially manufactured. One was mechanical, the other optical. To create a surface that's glass beaded, a screen manufacturer has to find a way to apply a very large number of very small glass balls onto a substrate (a backing) which is thereafter going to get rolled up and down possibly thousands of times. If it was hard enough getting the beads glued to the substrate in an acceptably uniform way, getting all of them to stay stuck to that substrate as it went through all those ups and downs was pretty well impossible. What often occurs with typical glass beaded screens is that some of the beads do get rubbed off as the surface supporting them gets repetitively furled and unfurled. Worse than the litter they create when they fall onto the floor are the bare spots they leave behind on the screen.

The optical problem has had to do with the size of the beads themselves. Most conventional glass beads used on projection screens have diameters which, by optical standards at least, are quite large. This deficiency is most apparent under data or graphics projection when the otherwise highly resolved images can exhibit a kind of granular, sparkly appearance, which is often distracting.

Recent breakthroughs in screen manufacturing techniques have overcome both of these defects in extremely successful ways. Da-Lite Screen Company has introduced a fabric called High Power™. To ensure complete mechanical stability, all of the beads in the High Power™ fabric are covered by a thin, protective top layer which stretches over their upper contours like a tight elastic skin, holding them permanently in place. Not only is the resultant surface washable, it is completely smooth to the touch and the adhesion is so perfect that it requires a powerful magnifier to confirm that the surface really is beaded at all.

Da-Lite has surmounted the resolution problem by finding a way to use beads that are only 9 microns in diameter. This is a sevenfold improvement over the best of the traditional beaded surfaces and it completely eliminates all traces of granularity and scintillation. (To put that 9μ diameter in perspective, 10μ is the typical width of a single human hair.)

Because the development of the High Power™ fabric has eradicated so convincingly the defects associated with earlier glass beaded surfaces, designers need no longer hesitate in specifying retro-reflective screens. Now all three screen types can be considered equally with the choice between them dependant only on their optical merits. To select efficiently among those merits, it's best to begin by examining the spatial relationship between the projector and the audience.

Front projection systems are rarely set up with the projector dead normal to the screen. When a projector is placed exactly perpendicular to screen center, it tends to be right in the middle of the audience, too close to the tops of the heads of the people seated beneath it and too obstructive to those seated behind it. To escape these difficulties, projectors are often hiked up above the normal and configured so that they shoot downwards at the screen. Since we always want a screen surface to redirect the light from the projector into the eyes of the audience, we want in this case to choose a screen which obeys the Law of Reflection. In fact the rule could be:

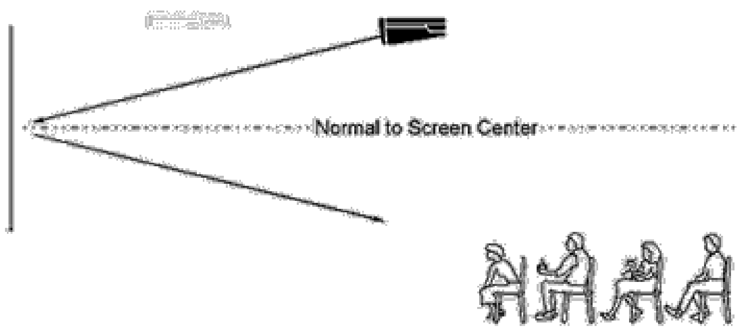

Figure 1

Whenever the projector and the audience are on opposite sides of the normal, use a screen that is reflective. [See Figure 1]

Next we want to ask what happens when the projector isn't top mounted, when its most convenient placement is on a tabletop, below screen center? Using a reflective screen in this configuration would be a mistake because the upwardly directed projection beam will only get bounced yet higher still. Unless our audience happens to be seated "up there" (as might be the case in an amphitheater, for example) the majority of the projector's brightness will never reach their eyes. This, then, is a good opportunity to take advantage of a glass beaded screen. Thus the second rule could be:

Whenever the projector and the audience are on the same side of the normal, use a screen that is retro-reflective. [See Figure 2]

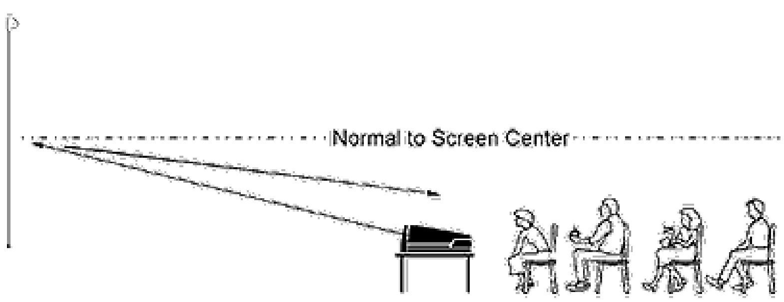

Figure 2

Notice that both of these configurations differentiate only between the vertical projection geometries. Although projectors rarely, if ever, are positioned off-axis horizontally, viewers often are. Whenever, therefore, the horizontal half-angles get larger than 20-30 degrees, the screen specification should probably revert to a Matte White surface. When, however, the requisite horizontal viewing angles are more modest, reflective or retro-reflective surfaces can significantly improve image brightness. Da-Lite's Pearlescent or Video Spectra™ 1.5 are both reflective surfaces which offer on-axis gains of +1.5. The new Cinema Vision surface delivers a slightly reduced on-axis gain of +1.3. If a retro-reflective surface is appropriate, the High Power fabric has an extremely bright on-axis gain of +2.8 which is produced by the optical action of the glass beads. Interestingly, outside of their viewing cone, the High Power™ material behaves nearly identically to a Matte White scatterer.

When selecting a front projection screen with gain, this article wishes to propose that choosing the magnitude of the gain is less important than choosing the type of reflectivity producing it. The goal of any display system must be to deliver the maximum number of information bearing light rays from the projector into the eyes of the audience. Ensuring by our surface choice that the fewest number of those rays end up anywhere else is sure to reflect well on all of us.

Angles Of View

Vol. III, 4 ©Da-Lite Screen Company April 1997

In expounding on aspects of visual displays systems, this series has thus far paid attention to various projection devices and numerous projection screens. But there is the third element in the classic model of communication, Source Þ Path Þ Receiver, which is, of course, the viewer. Since the whole point of any visual presentation is to deliver comprehensible information to the persons composing its audience, some fundamental data about the nature of human perception may be worth contemplating. With t hat thought in mind, then, let's take a closer look at

You and Eye - The Human Visual System

Let's start by thinking about computers. These days they are most frequently the devices which are used to generate the map of the images we're going to see projected on a screen. In preparing such an image, a computer issues a series of sequential electronic instructions which are going to characterize each and every pixel in its "display." The number of pixels to be instructed, even if the computer is a very high resolution device, will not be enormous (1024 x 1280 = 1,310,720, for example) but, assuming 24-bit color, the data stream will nevertheless be lengthy, about 10 megabytes.

The job of the projection device receiving this list of instructions is to convert or transduce its contents from electricity to light in such a way that some sort of optical system can emit the original information inside a bundle of light rays which, when converged onto the plane of a projection screen, can be assimilated by a human audience arrayed before it.

The job of the screen is to radiate (or re-radiate) at least some of the projected light rays incident to every single area of its surface into every single pair of eyes in the audience.

These jobs are the first two steps (the Source Þ Path) in our communications paradigm. They have been described in this somewhat abstract way because the third step, the reception of the data by the eye:brain interface constituting the Human Visual System, is a neat inversion of the first two.

In order to "receive" optical information, the visual system must incorporate this large collection of light rays, project them onto its own screen, and then, finally, reconvert them back into electrical energy so that they may be computed effectually.

The optical part of the visual system is, of course, the eye. Restricting our contemplation of this extraordinary organ only to its function as an imaging device, let's take a brief look at how it works.

Figure 1 is a sketch of an eye in vertical cross section.

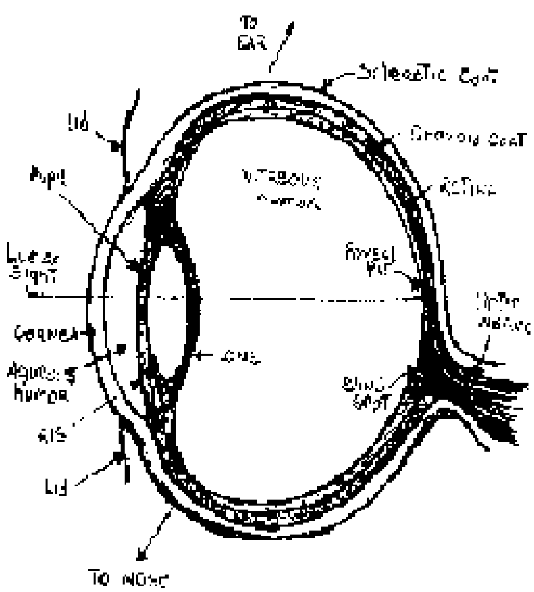

Figure 1

When light impinges upon an open eye, it first passes through the Cornea which is the frontmost extension of the Sclerotic coat. This is the white part of the eye that we can see.

Behind the cornea is the Lens and between the two is a space filled with a fluid called Aqueous Humor. At the top and bottom front portions of the lens is the Iris - that part of the eye which may be colored brown, blue, green, or black.

At the center of the iris is the Pupil which is "the hole" through which the incident light passes. The diameter of the pupil is variable and will become larger as the intensity of the light impinging on it decreases. Thus the pupil will be many times l arger when we're trying to see in the dark than when it is fully "stopped down" in bright sunlight.

The shape and thickness of the lens itself vary and are variable by the muscles attached to it so that it's focal length may, within limits, be altered.

The "screen" at which the lens is focused is at the back of the eye and is called the Retina. Separating the projection lens form the retinal screen is another body of fluid, called the Vitreous humor.

In the context of this article the retina may be thought of as a highly specialized rear projection screen whose surface is covered by a mosaic of two types of photoreceptors. Shaped either like a rod or a cone, each of these cells has one of its narrow ends pointed toward the Choroid coat and the other toward the light source.

The rods are extremely sensitive to low levels of ambient light. Thus they are the receptors which help us to see at dusk and at night. (This dark-adapted vision is called Scotopia.) The placement of the majority of rods within the eye is well away from the Foveal pit at which the refractive combination of cornea and lens will be converging most incoming light rays. This central area, measuring about 1mm2 is reserved for cones and contains something like 50,000 of them.

Cones are the receptors we use to see under bright conditions. (This daylight vision is called Photopia.) The cones, by virtue of their density at the center, additionally provide us with the ability to resolve fine detail in whatever we are looking at . They are bunched so closely together that they can sample extremely high spatial frequencies.

Conversely, the rods, less numerous overall, have their greatest density toward the perimeter of the retina and it is thus that our peripheral vision tends to be blurry and unsharp.

Once this retinal "screen" is illuminated, however, both the rods and the cones work to transduce the luminous data reaching them into electrical excitations of the nerve fibers behind them so that the resultant impulses may be transmitted through the op tic nerve to the Command and Control Center which, of course, is the brain itself. Before discussing that CPU, however, we need to observe a few more things about seeing.

Since the retinal "screen" has to have a hole in it through which the optic nerve may exit, there is a Blind spot in each of our eyes and any light falling on it won't be perceived at all. We fail to notice these ever present lacunae, however, precisely because we have two of them. Light impinging on the blind spot in the left eye will not have the same origin as light falling on the right blind spot. Since our eyes are about 6mm apart, information lost to one of them will be acquired through the other .

The size of each eye's visual field is impressive: 135º High by 160º Wide. Taken together, the horizontal field-of-view increases to 200º, which, you will see, is indeed more than 180º.

Now let's take a look at just how much information can regularly be produced from a field that large. Setting aside the enormous range of perceptible colors within the visible spectrum (that and related matters is the subject of another article), the capacity of our visual system to interpret the space before it at high resolution is, relative to other display systems, truly extraordinary.

Raise your eyes from this text and scan them across the room. Look out the window. Near, far, broad and narrow, wherever you direct your attention you are able to focus and assemble enormous quantities of visual data. Mind you, in directing that attent ion, your eyes are not actually traversing a panorama before them in a continuous, analog fashion. Instead they move in discrete jumps or jerks called Saccades. (As you read a line of this text, your eyes will not scan smoothly over each word, but will instead assimilate it in two or three distinct visual "gulps.")

Let us consider how much visual information might reasonably be contained in each of them. Recognizing that the "resolution" level of the real world is immensely larger than the computer generated graphics file with which we began this article, it is rea sonable to presume that each saccade will contain at least 40 megabytes of data. Since the visual system makes about four saccades/second, that means that our brains can sort, parse, process and interpret 160 megabytes of visual data during every second that we're merely just "looking around."

Should something within the field catch our particular attention and cause us to "fixate" on it, we'll now be using the on-axis cones in the Foveal pit and, in computer terms, as our attention zooms in, our available resolution will jump to something like three million pixels per square inch. It may be some time before advances in display technology cross that threshold.

Of course the utility and functions of our Human Visual System are vastly more varied and complex than the simple projection of an image onto a projection screen. The nature, quality, and quantity of information produced by the latter are exponentially smaller than that which are routinely processed by the former. But even if the display that we create is never likely to match the display that we can see, it may still fairly be said that for both the end is insight.

Angles Of View

Vol. III, 5 ©Da-Lite Screen Company May 1997

When we look at imagery projected onto a display screen, the pattern recognition activity undertaken by our eyes and our brain is multifarious and complex. In addition to discerning between lines and contours, darks and light, our visual system relies heavily on its ability to distinguish between what our brains call colors. Because these days every projector is certain to be a color projector, let's see what it takes to display an image in color and let's see what we see when we see

Hue and Eye - The Perception of Color

Before undertaking a closer look at color, let's take a sideways glance at black-and-white. If that classic pair is restricted to just those two extremes, we are contemplating a display that is just like this text. Even though the content and context of the words presented may be as complicated as we wish to imagine, the resources necessary to display them are not extensive. To "write" either all of this page or all of this screen, it is only necessary to instruct each of the pixels beneath to be either ON or OFF.

Next let's suppose that the "page" is actually a "frame" snipped out of a black-and-white movie. To "write" this one, the pixels are going to need more elaborate instructions which are no longer binary . What a moment ago was black or white has now become black, white, or some admixture of the two which we call gray. The number of gradations our display permits between its two extremes is what is called its grayscale.

Obviously a large grayscale permits greater subtlety of shading and texture than a small one. And whereas, we may not need much grayscale comfortably to read this text, we will appreciate it greatly if we are, for example, contemplating a photograph of Abraham Lincoln or a drawing by Rembrandt.

Grayscale, or the perception of the degrees of lightness and darkness of an object or a scene, is the first of three concepts we'll need thoroughly to examine color. The second two are called Saturation and Hue.

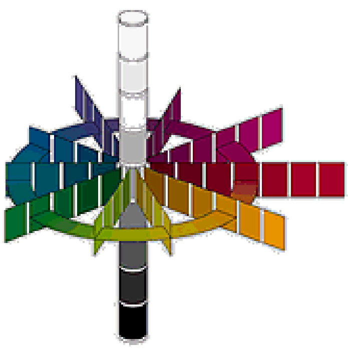

Figure 1

Figure 1 is an abstract diagram which plots the three "properties" of color in something called Munsell color space.

The axle around which the color wheel spins is the grayscale (sometimes called "value"). Each spoke represents a different color with a shift in hue progressing clockwise from red (the longest arm at the "3 o'clock" position) through orange to green to blue to purple and back to red. The Saturation (sometimes called "chroma") of each hue increases along each radial spoke as it extends away from the central axle.

It is important to note that it is neither accidental nor arbitrary that color space is defined as possessing three dimensions: Lightness, Hue, and Saturation. It is our eyes themselves which impose this expectation and unless we have all three we are in some sense "color blind."

At the center of the human retina is a dense cluster of photoreceptors called cones. Unlike the rods which govern the peripheries of our vision and which can only "see" in black-and-white, the mosaic of cones is divided into three separate types, each of which is sensitive to a different (but overlapping) range of colors. It can be no surprise that the central or primary color in each range is Red, Green, and Blue.

Theoretically any color we chose can be matched by some mixture of three primary colors. (Interestingly, the converse is *not* true.) Many colors can be matched using just two primaries, but not all. An especially interesting attribute of color which transcends its three dimensions, is whether it belongs to an object in the real world or to a representation of that object which we call its image.

When we watch a fire engine blaring down a road, our brains decipher that the object is red because the paint coating the sides of the vehicle has been constituted so that it absorbs the blue and green parts of the sunlight illuminating it. Thus only the light with the proper "red" wavelength is left to be reflected back for interpretation by our eyes and brains. If none of the light were to be absorbed, the fire engine would appear white. If all of the light were to be absorbed it would appear black. If we try to see it at night, it will appear gray because our night vision (the rods) is sensitive to grayscale much more than it is to either Saturation or Hue.

Now what about an image of that fire-engine, projected by a video projector and displayed upon a screen? Clearly we are no longer viewing in sunlight but have turned to look at Da-Lite. The fire engine, of course, is no longer there, but its image is and the image is red. It's most probably not the same exact red (spectrally) as the one we saw in the street, but it's a pretty close red nonetheless.

This kind of "object" is what is called self-luminous. The red color is projected at our eyes and if we want to change it to orange we don't *subtract* color (via absorption) we *add* it.

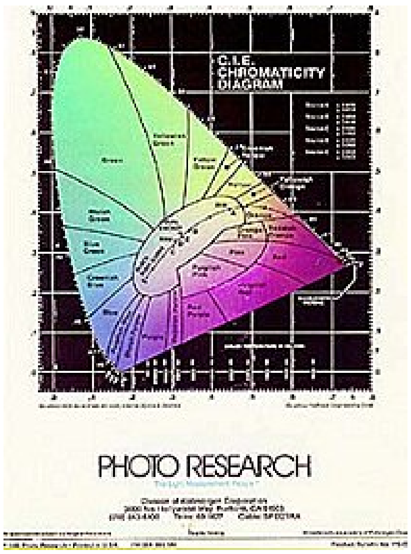

Figure 2

Looking at this phenomenon in a little greater detail, we can now see why all of our electronic projectors have, one way or another, three separate color sources, R, G, and B. These are the additive primaries. How they can be mixed together is demonstrated by another diagram (Figure 2) which was first constructed in 1931 by an organization known as Commission Internationale de L'Eclairage (International Commission for Illumination) or CIE.

Since it was already assumed that the human eye required three color stimuli for the perception of any color, the CIE decided to create a two dimensional representation of "color space" by creating a roughly triangular "chromaticity" diagram whose vertices were plotted according to the wavelengths of the three primaries.

At the curved top of the "triangle" is Green, at the bottom right is Red and at the lower left is Blue. At the center of the diagram is white. There is no black because in a self-luminous display black is created by the absence of light (and therefore color).

Note that any point within the diagram can be precisely specified by its X,Y coordinates which can then be used to inform a pixel what color it's supposed to be.

As a practical matter, when it comes to establishing the values of the primary R, G, and B light sources a smaller triangle is delineated within the CIE diagram so that adequate brightness can be achieved, even at the price of somewhat limiting the available colors. Figure 3 illustrates this and shows that only colors having coordinates within the inner triangle formed by connecting C_1, C_2, and C_3 can be projected. (This circumscribed color space is called the system's "gamut.") Brown, for instance, is color you don't often see in an A/V image.

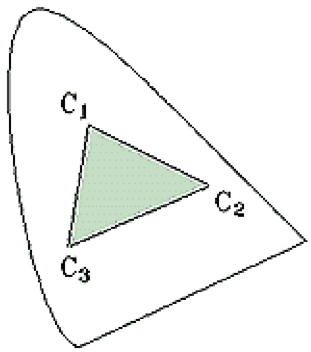

Figure 3

These limitations aside, how many colors can we expect to get out of our three sources and into an image?

The answer requires just a little arithmetic and begins with the black-and-white image that began this article. If the "color space" of an image is only black or white, it is said to be a 1-bit display. This means that each pixel only requires 1 bit of information to get its black or white color instruction.

If it's a black-and-white photograph, the color depth (grayscale) increases to 8 bits. This expansion is not linear, however, and the number of realizable shades jumps from 2 (expressed as 2^1) to 256 which is the product of 2 raised to the eighth power ($2^8 = 256$). What happens when we have three, 8-bit color sources, each with 256 available shades bracketing its primary color? The answer is 256 x 256 x 256 = 16,777,216 (2^{24}) which generally gets rounded in conversation to sixteen million.

Since the range of specific wavelengths to which the human eye is sensitive is actually quite limited (400 to 750 nanometers), it is truly remarkable that our visual systems can effortlessly process a spectrum of 2^{24} (or more!) colors. And when we recognize that the information received by our brains and telling us that a fire engine is red is not in fact *optical* information, but *electrochemical* information, we are looking at an intriguing paradox. Since light of no wavelength reaches the brain, color, as we know it, is only an abstraction.

"Color is a sensation that light produces in the mind."

The principal sources used in the research of this article are: Judd, Deane B. and Wyszecki, Gunter, *Color in Business, Science and Industry*, John Wiley & Sons, New York, 1975.
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Angles Of View

Vol. III, 6 ©Da-Lite Screen Company June 1997

In several previous articles in this series we have used the communications paradigm SourceÞPathÞReceiver to model various aspects of visual displays. And while we have resultantly paid ample attention to each of the three A/V equivalents, Projector, Screen, and Audience, we have yet to consider the significance and nature of those symbolic arrows between them. In other models the Þ can represent perceptibly diverse phenomena. In visual systems, however, we are always

Seeing the Light - The Visible Spectrum

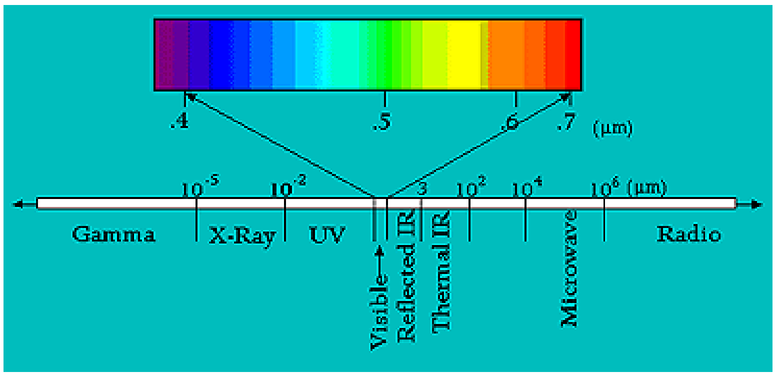

Figure 1

One of the most noticeable things about light is how very little of it we can actually see. Even though our world is continuously flooded with unending amounts of radiation of all kinds, only one narrow band of it is detectable by the human eye.

Figure 1 illustrates the entire range of the electromagnetic spectrum, with "light" as we know it occupying less than 3% of the full continuum but falling nearly at its center. An attribute which principally distinguishes one type of light from another is its wavelength. At the left edge of the spectrum are gamma rays which have the shortest wavelengths of 10^{-6} nanometers and at the right edge are TV and radio signals with characteristic long wavelengths of 10^{8} nanometers. In between are Red, Green, and Blue and thus all the colors which shade between them.

The most persuasive explanation of why human beings see light in only this region of the spectrum is that wavelengths of 400 to 750 nanometers are the primary constituents of sunlight (think, for instance, of a rainbow) which are transmitted through our atmosphere. And sunlight, of course, has been the principal source of illumination throughout the evolution of our species.

In addition to wavelength, light possesses two other properties which must be mentioned. The first is frequency and the second is speed.

If wavelength describes the distance between any two consecutive crests or troughs of a wave form, frequency identifies how many of those waves will flow by within a given time. All of the units which describe the measurement of light get counted with very large numbers even if they indicate very small distances. A nanometer, for instance, is equal to one billionth of a meter (10^{-9}m).

A unit for frequency is the Hertz, or one cycle per second. Gamma rays have a frequency of 10^{18} Hz, while radio waves have a frequency of only 10^{4} Hz. Visible light has a frequency of about 10^{14} Hz which means, for example, that when we see something as red our eyes are receiving just more than four hundred *trillion* light waves every second.

To manage all of these enormous numbers, light's third property, its speed, must also be very, very large. And it most assuredly is, clocking in at 186,282 miles per second. Expressed in different units, this number is scientifically symbolized as *c* (standing for the Latin *celeritas*, meaning velocity) which, of course, is the term that gets squared by our century's most famous equation, $E=mc^2$. When it is so squared, it becomes the correlative between energy and matter.

Among the other profound insights and discoveries made by that equation's creator, Albert Einstein, is the fact that the speed of light is always the same (regardless of how or from where we measure it) and that nothing whatsoever can under any circumstances travel faster. The constant *c*, then, may correctly be thought of as the cosmic speed limit.

Now the relationship between light's wavelength, its frequency, and its speed is close and mathematically formal. Fortunately, it is not mathematically complex. It simply states that the wavelength of light is equal to its speed divided by it frequency or, symbolically,

l= c/n

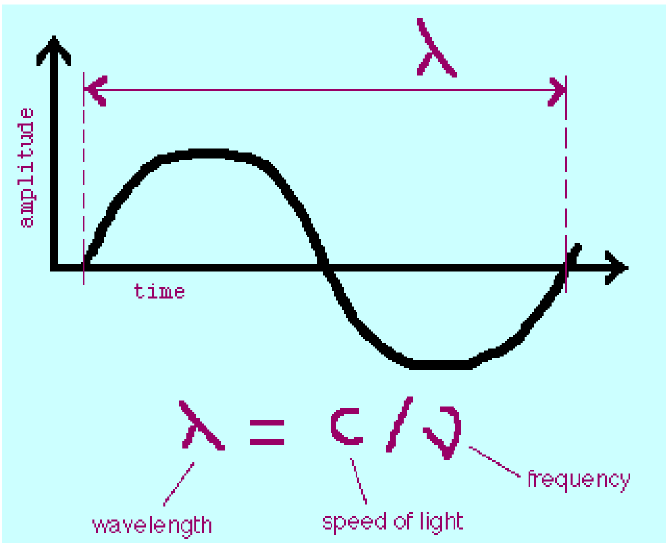

Figure 2

Figure 2 illustrates this relationship graphically and adds one additional dimension to a light wave, its amplitude. Frequency (or wavelength) is plotted along the X-axis and specifies precisely the color (or temperature) of a beam of light. Amplitude (the Y-axis) indicates how intense (or what we experience as bright) the light will be. In this sense, lumens, foot-candles, and foot-Lamberts are all measurements of amplitude.

So now that we have reviewed the basic vocabulary of light, let's see what interesting things can be said with it in the context of viewing, projection, and screens.

Firstly, it's worth noting that whatever we're looking at, light is all that we're seeing. When we wake up in the morning we do not, in fact we cannot see the ceiling of our bedroom. We see whatever portion of the daylight or lamplight that has not been absorbed by that ceiling reflecting back into our eyes. Thus in a very real way we can never see objects, we can only see light.

Light from a projector is physically indistinguishable from daylight or lamplight. That is, it will have closely similar wavelengths and frequencies. Although its amplitude may vary, its speed will be absolutely identical. Conceptually, however, projected light is not at all the same as its naturally occuring equivalents because, other than their spectral data, sunlight and lamplight don't contain information. Projected light does.

To load a beam of light emanating from a projector with information (which is to say with an image) we have to modulate it spatially. And what we mean by spatial modulation is that we will arrange that the light in one area of the beam can have a differentiable frequency (or wavelength) from the light in every other area. Theoretically we can divide the beam up into as many areas as we wish. If the light rays filling each little area are all aimed to converge at similar distances from their source, we will be able to discern the image they aggregately make up whenever we insert a projection screen before them.

The maximum number of available modulations within any given image defines, of course, its resolution. Thus, the familiar pixel is the smallest portion of an image which can be modulated and the total number of available pixels can be viewed as an index of information content.

Continuing these correspondences, the degree to which the amplitude of any modulation can be varied defines contrast, the largest amplitude limiting the maximum brightness, the smallest establishing what is called the black level. The breadth of distinguishable wavelengths produces gray scale and hence color.

What a screen surface does is get the message out of the medium at a place and on a plane where an audience can intelligibly receive it. Screens do this by arranging that the modulated light rays comprising every pixel are spread out over a wide enough area that some number from each is delivered to every viewing position.

Whenever we turn on a projector, electrical energy courses through its wires and is then transduced into light which can be shined in some direction and by which we can see. If that weren't remarkable enough, the same light which gives us illumination can also contain information by which we can learn.

Angles Of View

Vol. III, 7 ©Da-Lite Screen Company July 1997

In a previous article we noted that the speed of light, "c," is the maximum velocity anything can achieve. Lying just beyond that observation is the fact that even light itself can only reach that fantastic speed if it is traveling in a vacuum. In other, denser media (like our atmosphere) light travels at slightly slower speeds and in media still denser, such as glass or plastic, it will travel slower still. The importance of this fact cannot be over emphasized. Without it, we could not see. With it, we can make and use lenses. It is with lenses that we image everything. It is through them that we are

Getting the Picture - the function of Lenses

To see how a lens works there is just one more fundamental property of light that must be mentioned. Unlike the reasonable notion that light will slow down when it enters a medium denser than outer space, this other attribute is a little less intuitive.

When light travels between any two points it will always take the path that requires the least time. What this means is that light will not always follow the path representing the shortest distance. Most of the time the two paths are identical. But not always.

Let us turn on a light source, say a projector, and point it at the wall (or screen) across the room. The light rays making up the beam will reach the wall in the fastest time if they each travel in a straight line that we correctly define as the shortest distance between two points.

Now let's intersect the beam with a pane of glass so that all the light rays have to pass in and out of it before continuing their journey toward the wall. Once inside the new medium, the glass sheet, the light will have to slow down. But, remember, its task is nevertheless to get to that wall in the fastest possible time. So, in order to fulfill that assignment, each light ray will change its direction as it enters the glass such that it will move more closely to a line that is perpendicular to the surface of the pane. This line is called the normal and light will always be bent toward the normal when it enters a denser medium.

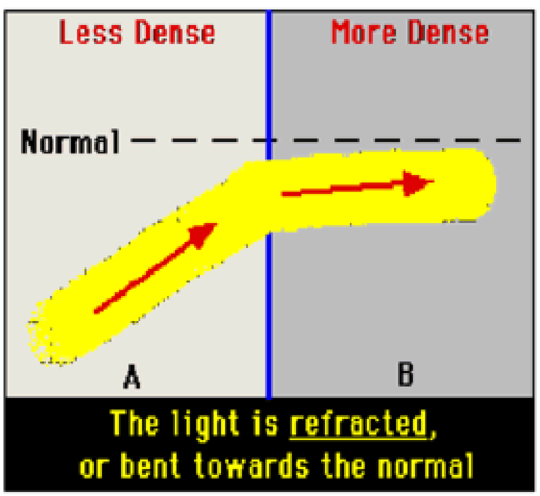

Figure 1

Conversely, when the light exits our pane of glass its direction will be bent away from the normal [Figure 2]. This is fortunate because, if the two surfaces of the glass sheet are parallel to one another, the consequence of the first bending is effectively canceled by the second. (This is why we can see through windows and windshields, etc. without perceptible distortion.) This process of bending or unbending the direction of light rays is called Refraction.

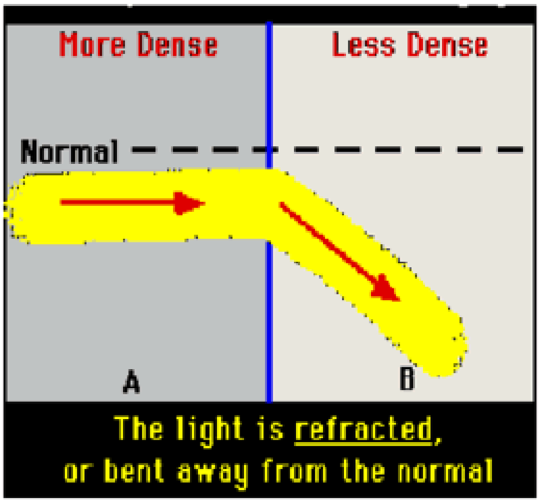

Figure 2

But what would happen if we arranged that the two surfaces of our pane of glass were not parallel to each other, if in fact the edge of the pane no longer looked like this ¡ and instead looked like £?

When that occurs, the normal to the first surface is not parallel to the normal to the second surface and very interesting things can be seen to happen when a beam of light is shined through it. Instead of being bent just once in one direction (and then being bent back), light rays passing though these two surfaces will be bent *twice* in the same direction. Rays subjected to this double bending will always exit the triangle in a direction *away* from the apex.

If we take the £ and add another one ¥ below the edge view of our glass will look like a diamond N. Light rays striking the bottom (and inverted) triangle will also be double bent and will, therefore, exit traveling away from *their* triangle's apex. This means that even if light rays arrive at the top and bottom of the first surface of the diamond-shaped glass in straight, parallel lines, they will exit the far sides of the diamond no longer parallel and will, at some point beyond it, intersect.

Once we recognize that simply by changing the angular relationship between two surfaces of a piece of glass or plastic we can alter and control the behavior of light rays passing through it, we have grasped the essential function of a lens.

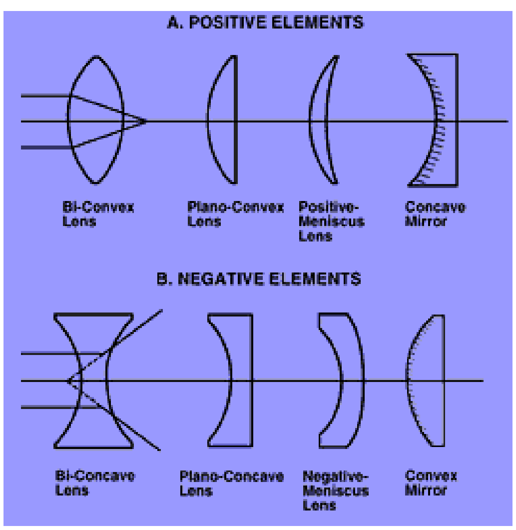

Figure 3

Smoothing the edges of the diamond into a large variety of curves, making some convex, others concave, still others combinations of both [See Figure 3], will empower us to redirect light rays in a great many ways so that they may be made to converge (a *positive lens*), diverge (a *negative lens*). Note that all of the former are thicker in the middle than at their extremities and the latter are thinner at their centers.

The extent to which the direction of light rays can be modified by a single lens is dependent on three variables: the incident angle of the rays, the curvatures of the lens, and the material out of which the lens has been made. A material capable of transmitting light has what is called an index of refraction ("n") which is simply the quotient of the speed of light in a vacuum ("c") divided by whatever is the slower speed within the chosen material. Since "n" for a vacuum obviously equals 1, then the index of refraction for all other materials will be greater than 1. Since the index for air is only 1.00029, it is generally permissible to round it down to 1 in most calculations. Water has an index of 1.33 and glass is about 1.5. Interestingly enough, acrylic has a lower index than glass, about 1.4.

The significance of these indices is that the higher they become, the higher will be the optical density of the materials they describe. The precise relationship between any two materials with different indices was first established by the Dutch mathematician Willebrord Snell in 1621. Snell found that $n_1 \sin q_1 = n_2 \sin q_2$, where n_1 and n_2 are the two indices on either side of the surface and q_1 is the angle of incidence to it and q_2 the angle of refraction from it. Obviously, knowing any three of these variables permits the calculation of the fourth.

Now that we know how lenses work, let's take a closer look at how they image. We'll start by setting a vase full of cut flowers in front of a projection screen. After stipulating that there is plenty of illumination in the room, we will nevertheless notice that there is no "image" of a vase and flowers visible on the screen. The reason that this is so is that light rays reflected from all parts of our object (the vase of flowers) fall upon all parts of the screen equally. Thus, on the screen at least, there is no spatial distinction between one part of the object and another and, therefore, there cannot be any discernable image.

We *see* the vase of flowers because the aperture through which the light rays pass in our eyes is small enough that only a tiny subset of the rays emanating from our vase can be transmitted through it. Furthermore, of course, the curvature of the eye at that aperture causes light rays incident to it to be refracted such that they converge onto the screen of the retina behind.

To get a good image of the vase onto a full size projection screen, we want light rays from the vase (or a representation thereof) to be passed through a lens that will refract them so that they will subsequently all converge with no overlapping exactly at the plane of the screen. The more light rays we can get the lens to converge onto the screen (always with no overlapping), the brighter our image will be.

A line drawn through the two centers of curvature of a lens [see Figure 3] is called its *principal axis*. The point at which a beam of parallel light rays, traveling parallel to that axis will be made to converge is called the *focal point*. The distance from the center of a lens to its focal point is its *focal length*.

If we take a converging lens and place it before our vase so that the distance between them is less than the distance to the focal point, the image that we will see of the vase will be magnified and will appear right side up. This is called a *virtual image*.

When the distance between lens and object is greater than the focal point, the image will not be magnified and will be upside down. This is called a *real image*. Since our eyes continually look at objects well beyond their focal point, all the images reaching our retinas are inverted. Our brains, of course, cause this function of lenses to be continuously reverted. We close, therefore, by asking whether an image you see projected though lenses onto and from a screen is virtual or real, upside down or right side up?

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Angles Of View

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When we look at data displayed for us on a projection screen, it is only in the rarest case that all we see is just the information. Unfortunately, projected imagery contains the potential for numerous visual artifacts unrelated to content that can compete for our attention. And, although the eye:brain interface is extremely good at filtering out extraneous input, it is even better at detecting aberrations and discontinuities. In order to minimize the effect of these distractions, it is important that we understand the differences between them. This article will take a closer look at some attributes of visual displays whose causes, by virtue of being often confused, sometimes make it difficult to distinguish between

Medium and Message - the Screen and the Image

All of us are well trained in the smooth assimilation of visual data if their source is the conventional printed page. The eyes skim along in practiced skips, line after line, neither disturbed nor even interrupted should some character be, for whatever reason, misprint ed. Yet, if we take a sample word and, instead of misprinting it, misspekl it, the eye suddenly stumbles and our attention must return to reexamine and verify the error. Such a defect, of course, is a blemish in the data. It is not a fault in the delivery system. What is more important, telling the two apart is not difficult.

The overall appearance, for instance, of nearly all printed pages is wonderfully uniform. The printing press impresses the letters and words at the corners of our book with exactly as much ink, sharpness, and density as it imparts to the characters in the center. In addition, the white of the paper itself is just as white at its edges as it is in its middle. These are consistencies we are accustomed to taking for granted in our reading materials. Not one of them, however, can be counted on if the text is to be projected.

A projector is not a printing press. A screen is not a blank piece of paper. The misapprehension of these two points regularly gives rise to bafflement and confusion. Each seems perfectly obvious. Both are actually subtle.

Let us first consider the projector and ask just what it is that it projects. The correct answer is the page, not the text. The text is a part of the page, but only a part. The whole page, pixel by pixel, is what the projector is obliged to display. That some pixels are instructed to be dark while most are told to be white is arbitrary and, in this sense, irrelevant.

Now let us consider the screen and ask what it displays. The answer again is the page, not the text. To see this, we need merely imagine that our projector is jostled or in some other fashion perturbed such that an edge of the image slides off the screen and onto, let us say, the adjacent wall. Obviously it will not only be the text that has moved but the "page" beneath it as well.

As emissive devices, projectors *don't* deposit jet black letters onto a snow white screen. In fact, while they try hard to project a snow white page, they simultaneously try very hard *not* to project any light into the text areas which, by virtue of their being *projected*, can never be jet black.

Seen in this light, we may rightly ask, well, if a screen is not the page beneath the text, just what is it? The answer is that a screen is not the page as long as what we mean by page is the background. But if what we mean by page is the surface on which is displayed, for example, a replica of a favorite painting, then, yes, that ' s exactly what a screen is: the high quality paper on which that detailed reproduction has been printed. Thus, although screens are indeed the paper, we need strongly to emphasize that they are *not* the page.

With these distinctions in mind, we can now turn our attention to the single greatest defect commonly attributed to projection screens: the Hot Spot. This unpleasantry barely needs defining. It's that nasty and distracting bright blob that seems spitefully to follow us no matter where we position ourselves in front of any display unfortunate enough to exhibit it. Confronted by such an eyesore, who in this industry has not heard a colleague point out, "Golly, that screen is hotspotting terribly, isn't it?"

And what really will they be looking at that causes this complaint? Clearly, they will be seeing an image which appears excessively brighter at its center than it is at its corners. Unmistakably, there *is* a hot spot.

Furthermore, if we leave everything else exactly in place and change out only the surface of the screen we are looking at, the hot spot can be diminished greatly. This, of course, convincingly demonstrates that hot spots are in fact a regrettable property of projection screens. Or does it?

Let us agree not to change anything about projector or image and let us agree to leave in place the very screen surface which produces the most fearsome and unpleasant hot spot we can find. But let us imagine only that the screen has magically been doubled in its width. This suddenly greater latitude will enable us to drag the screen to its left or to its right with no risk that the projected image will slip off its surface. Naturally we will expect to see the hot spot move right along with the screen. Or won't we?

Of *course* the hot spot doesn't move; it is a property of the image, not of the screen. No front projection screen is manufactured such that its center is intentionally differentiable from its edges. Most screen manufacturers make front projection surfaces with original dimensions that are something like 8 by 3,000 feet; certainly Da-Lite does. Then, from this very long roll, are cut hundreds of screens with hundreds of centers, in dozens of sizes, in numbers of aspect ratios, but without even one, single, solitary hot spot. At least that's the way it's done at Da-Lite.

" But wait! " you may say; "What about those screen surfaces we were changing out just a moment ago? Didn't one of those hotspot more than another? Exactly what's going on here?"

Good question. To answer it, let's put a projector behind a screen surface which is initially completely transparent and clear. (For simplicity, this example assumes a rear projection set up.) When we look at such a screen, all we will see through it is the blinding, white light made by the projector's lamp and directed by its lens. This, surely, is the mother of all hot spots.

When we start to add screen diffusion material to this substrate and as, therefore, we render it less and less transparent, the shape of the hot spot begins to enlarge and its core brightness begins to diminish. As we add yet more diffuser, vague outlines of the image contained within the beam begin to appear, although we can still see the light source beneath them.

Add still more diffuser, however, and it is the content of the image that will become more prominent to our eyes. When we reach the end of our diffusion process, the image will be fully resolvable and the hot spot (the light source) will no longer be resolvable at all. That, at least, would be ideal.

If we stop just short of putting on this optimal amount of diffuser, we'll still be able to see traces of the light source even though we can fully discern the contents of the image it's projecting. When we do that, we produce a diffusion screen that has gain. If we put on even less diffusion, we will produce a screen that's got even more gain. In this way, by allowing more of the light from the light source to be undisturbed by the diffusion at its surface, screens can be made varyingly to reveal or disguise a hot spot. But there is no way they can create one.

The really interesting question, then, is not why some screens sometimes hotspot. It's why most screens most times *don't*. To discover the answer, let's randomly choose a half dozen screens of the same size and of the same gain and place them before any six disparate projectors.

If the intensity of the light emanating from these projectors' lenses is carefully measured across the diameter of their lenses, it is extremely unlikely that the reading we take at the center of each lens will equal the readings we take from its edges. Some projector types will do a lot better in this regard than others, but all will fail to be perfectly uniform.

When we come, then, to point each of these projectors at our six screens (all of which, by definition, *are* uniform), it should in no way surprise us that the displays which exhibit the most egregious hot spots are the ones illuminated by the least uniform light sources. It is important to notice that we have said nothing whatever in this discussion about brightness. That's because, paradoxical as it may seem, varying the luminance of each (or any) of these projectors will neither erase nor exacerbate its hot spot.

The hot spot phenomenon, then, is correctly understood as being a function of uniformity and of uniformity alone. Moreover, when we see a hot spot, our eyes are actually disturbed more by the dimness at the corners of the display (the areas outside the hot spot) then they are by the brightness at the center. If there were some way to brighten those corners up such that they would become equal in illuminance to the center, the perceived hot spot would instantly vanish, even though that area's brightness would in no way be changed.

If we now leave all six projectors in place and swap out all six screens for new ones with a higher gain, the corners of all six will appear even dimmer relative to their centers and those that exhibited hot spots initially will now appear even worse. If we introduce lower gain screens, of course, the tendency reverses.

Projected displays are tricky. They include many more components than printed ones. Certainly their appeal is overwhelming and their power undeniable. Yet understanding them is important because otherwise, looking at them, it's sometimes hard to know precisely what we're seeing.

Angles Of View

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As manufacturers, designers, and end users have become increasingly sophisticated about the performance characteristics of their display systems, the correct interpretation of Gain and the quantification of Resolution now enjoy wide acceptance and consensus. There is, however, a third principal attribute whose standard has not, regrettably, been widely promulgated. The discussion which follows seeks to take a closer look at what might be revealed if we were to bring

Contrast - From Dark to Light

Defining what we mean by contrast is easy, perhaps too easy. Contrast is the disparity between the dark and the bright portions of an image.

Calculating a contrast ratio is also perfectly straightforward. As we have noted elsewhere (Vol I,No.5), the formula has been

Max - Min
Min

where Max and Min are the values we obtain for the brightest bright and the darkest dark.

Measuring those values or, more precisely, deciding where and how to measure them is not so easy and their definitions resultantly are sometimes ambiguous. Yet it is certain that a large contrast ratio is unambiguously better than a small one. As viewers, we can often detect changes in contrast that are as small as two or three percent. Perceptible changes in brightness, on the other hand, often entail variances greater than fifty percent.

To make all of this a little more concrete, let's enumerate some specimen contrast ratios. If you're reading these words, the contrast ratio of the page before you is about 80:1. If you're looking at them on your monitor, the ratio is closer to 50:1. If you go to the movies and watch a good, clean print, the ratio (given the right scene) might be 500:1.

Since each of these examples puts a value to what you will *see*, let's call this type of contrast Perceived Contrast. Another type might be what we measure directly on the surface of the projection screen. Let's call this Screen Contrast.

Now let's take the next step and look at our projection device. Is it possible that it may in turn exhibit a different ratio from our other two pairs of measurements? Very likely it will. Hence, Projector Contrast should be distinguished from the first two.

Finally, we are entitled to examine the contrast ratio of the image itself. We'll call this Image Contrast. If it is jet black print on a pure white page, surely its contrast ratio will be different from light gray characters written, shall we say, across a pale blue screen. Whatever this beginning ratio may be, it will be extremely difficult (but not, as we shall see, impossible) to enlarge through subsequent transitions.

Thus far we have kept things simple because our example has been text based. In terms of contrast, if there are only two candidate values to measure, it can't be too hard to decide which is which. (Furthermore, we can safely assume that the darkness of any character we measure is equivalent to the darkness of any other and equally that the field behind the letter **W** is no whiter than the field behind the letter **M**.)

Few of the projected images we routinely view are ever characterized by this monochromatic simplicity. Their grayscale gradations, the number of available colors they contain, instead of being a mere 2, will jump to something between 16 and 16 *million*. Still, in terms of brightness at least, that enormous palette must, nevertheless, contain just one blackest black and one whitest white. All we have to do is find them and we will have our Max and our Min.

So let's conceive a picture with lots of image contrast scattered through lots of image colors and send it along to a projection device for displaying. What happens to it next depends greatly on what sort of projector it is.

Looking at the descriptive literature which accompanies projectors these days, one is certain to find a luminous output spec (ANSI lumens only, please), one or more Resolution specs (VGA, SVGA, etc.) which are easy enough to interpret, and sometimes, but not always, an additional spec for Contrast. Here are some quoted examples: "100:1," "Greater than 100:1,""200:1," "250:1," "600:1," and "2000:1." It is as hard to find a projector admitting to a contrast ratio less than 100:1 as it is dumbfounding to find one professing 2000:1.

Because there is such a wide range of stated contrast ratios, we are entitled to wonder where, exactly, the various Max and Mins come from. Although we cannot answer that question with much surety here, we can state how a contrast ratio *should* be measured.

In 1992 a panel of experts convened under the auspices of the American National Standards Association to develop a document that is called Data Projection Equipment and Large Screen Data Displays -- Test Methods and Performance Characteristics (ANSI IT7.215-1992). Among the results of this effort was the establishment of the ANSI lumen standard for brightness. Less well known is the standard established for determining contrast ratios:

The contrast ratio shall be determined from illuminance values obtained from a black-and-white "chessboard" pattern consisting of sixteen equal rectangles.... The white rectangles shall be at full specified light output, as previously measured, with all controls at the same settings. Illuminance measurements in lux...shall be made at the center of each of the bright (white) rectangles and the dark (black) rectangles. The average illuminance value of the bright rectangles shall be divided by the average illuminance value of the dark rectangles. The contrast ratio is then expressed as (ratio):1 (e.g., 15 lux bright rectangles and 0.10 lux dark rectangles equal a 150:1 contrast ratio).

Notice that the projector is obliged by this procedure to project its brightest white and its darkest black *simultaneously*. Displaying one and then the other *sequentially* undoubtedly produces a more widely divergent pair of numbers, but their ratio is not descriptive of what a viewer actually would see.

Now that we know how to quantify projector contrast, let's turn our attention to screen surfaces and see how their design and selection can affect contrast.

Because front projection screens are obliged to reflect all sources of light incident to their surfaces, their perceived contrast is highly dependent on the presence of ambient light. The difficulty with non-projected light sources reaching a screen, of course, is not their effect on the Max portion of the image but the often disastrous effect on the Min. Generally speaking, front projection screens with higher gains will do the best job of preserving image contrast.

While it is true that front projection screens cannot increase the contrast of a display, rear projection screens can. They do this by a variety of techniques which exploit the opposite directions from which projected light and ambient light pass through them. Light from the former is transmitted toward the audience; light from the latter is transmitted into the projection booth.

Some rear projection screens, such as Da-Lite's Polacoat line, include spectrally corrective colorants which, by darkening the appearance of their front surfaces, render them less reflective of incident ambient light sources. (Again, see Vol I, No.5.)

For the maximal enhancement of Contrast, however, no screen is more effective than Da-Lite's new Black Stripe Screen from DNP. The design of this screen is elaborate and its structure intricate.

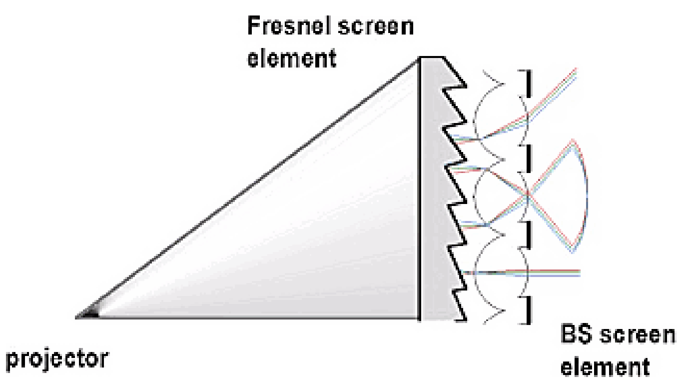


Figure 1

The drawing above well illustrates this complexity. Notice that the frontmost surface of the screen is comprised of a matrix of thin, opaque black stripes. Light incident to these stripes from ambient sources is not reflected (it is absorbed). Since the surface area of the stripes is nearly 40% of the total face of the screen, this resistence to ambient light is pronounced. Even in the presence of no ambient light, the black levels visible from this screen will be much darker than those obtainable from alternate surfaces.

The most intriguing aspect of the screen, of course, is what happens to the projected light which the projector aims at the back of the stripes. Because all of the projected rays are collimated by the rear element Fresnel, they all enter the back, lenticulated surface of the front element at effectively the same, 0º, angle. This enables the curvature of the lenticulations to refract the incident rays so that they are neatly redirected out of the screen *between* the black stripes.

Complex as this arrangement is, its effect on image contrast is extremely beneficial. Even though this screen has an on-axis gain of 4 (an indication of its Max), its real achievement is the reduction of its Min. In fact, manipulating contrast is always an art of darkness.

Angles Of View

Vol. III, 10 ©Da-Lite Screen Company October 1997

Not so very long ago, gain was the only specification anybody wanted to know about a diffusion screen. As the display world has become more sophisticated and quite properly more demanding, however, other criteria informing projection screens have come to be appreciated. And, outward appearances perhaps to the contrary, some diffusion screens have been significantly both improved and upgraded. To see how, we ' ll need to give

Diffusion Screens - A Closer Look

First off, it might be worth reviewing exactly how a diffusion screen works. That is, just how does a diffusion screen form an image and just how does it thereby enable us to see a picture?

From any given viewing position we are only going to be able to see an entire projected image if (and only if) at least some light from every single portion of the screen reaches our eyes. Thus, we may think of the screen (the "Big Picture") as actually being made up of many, many little screens each of which is dutifully spreading its mini portion of the projected light throughout the entire viewing area.

If light from any one of these "micro-screens" failed to reach our eyes, then, of course, what we would "see" is a dark spot from which no information could be derived [perceived].

But now let's turn the magnification up a notch or two farther and look to see what's actually making up the "micro-screens." Because, sooner or later, we've got to get down to some lowest common denominator which is the level at which something is actually being done optically with light rays. When we examine a screen microscopically, we do indeed see that its surface is made up of an array of tiny particles which, one way or the other, must be the entities which make the whole thing work.

If the screen is a front projection surface, its particles will principally be made of miniature chunks of a white, non-absorptive, chalk-like material, generally magnesium carbonate ($MgC0_3$). Like a huge expanse of irregularly shaped pebbles on a beach, these particles scatter light rays falling in them in every conceivable direction. If there are no other sorts of pebbles on the beach, the screen will have a Matte White surface.

If, here and there among the pebbles, however, we litter the beach with shards of small mirrors, some of the light rays falling on the beach will not be scattered by the pebbles and will instead be reflected back by the mirrors in specific directions. When this happens, the screen begins to have gain. And the more bits of mirror we strew among the pebbles, the more gain (directionality) the screen will have.

Rear projection diffusion screens also rely on particles for their optical action, but not, of course, reflective ones. On the microscopic rear projection beach the pebbles have to be transmissive. That is, light rays have to be able to pass through them and thus each acts as a refracting lens, bending light rays incident to its back surfaces so that they exit from its front at a large variety of new and near random angles.

In both types of diffusion screens, then, it is the jumble of particles deposited on one surface which disperses the projected light throughout the viewing area. Now, a possibly interesting question might be, what would happen were we to vary the size of those particles making them either significantly larger or smaller?

As the average diameter of the particles in enlarged, the image they are collectively displaying will begin to exhibit an additional characteristic which, quite properly, will be called graininess. As the coarseness of this grain is increased, the diameter of its constituent particles will start to become some meaningful percentage of the magnitude of a pixel and, when that happens, the resolution of the overall image quickly collapses.

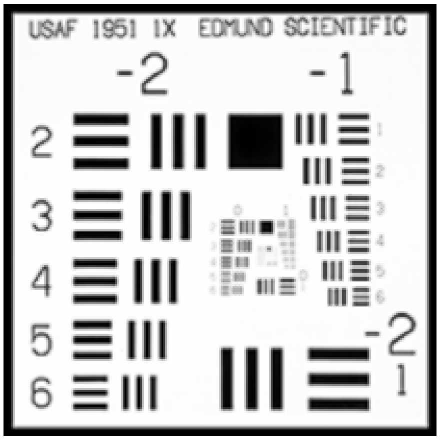


Figure 1

To see how this is so, we need to remember that each particle is redistributing light in some direction that is random compared to a neighboring particle but is quite specific relative to itself. If the particle has become too large to have lots and lots of closely packed neighbors, light rays reaching its part of the screen will be processed only by a few particles and not by many.

When that event, in fact, happens, the continuity of the diffusing effect is (literally) coarsened and the dissemination of the information contained by the light rays becomes similarly non-continuous. Note that as the average particle size is increased, the spaces between the particles must also become larger. These spaces, of course, can =t refract light with anything like the same efficiency as the particles and thus they can become (literally) holes in the data.

Now let's ask what happens when we make the particles smaller? Obviously the graininess we observed through large particles will diminish as the "fineness" of our diffusion is increased.

But, since we're thinking about particles which get measured in microns (1μ = .00003973"), even the large ones can't be all that big. So when we make them smaller, can we tell the difference between a 4μ screen and a 10μ screen? Let's see.

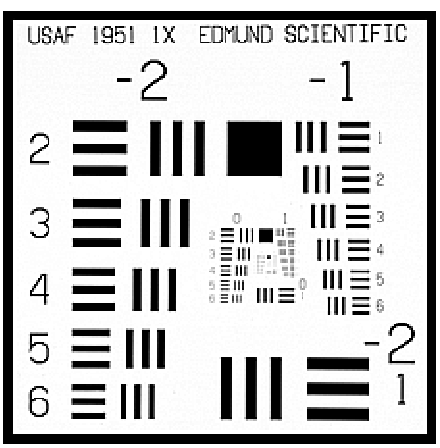


Figure 2

Figures 1 and 2 are representations of two carefully made images. Figures 1 and 2 are not, however, the images themselves. They are printed illustrations of a single, United States Air Force target slide which was placed directly against the diffusion surface of two different diffusion screens and photographed. The position of the camera and the projector were identical and fixed for each shot. The only light source in the laboratory was the projector.

After the high contrast copy film was developed, its negatives were scanned into a computer at a resolution of 300 dots per inch. Those images were then copied by the computer used to write this article and printed by an ordinary laser printer. The size of the two reproductions is nearly, but not exactly, identical to the original target slide which is precisely three inches square.

It is essential, therefore, that the reader appreciate that much of the differences clearly apparent to observers in the laboratory have been obscured by the numerous iterations the data have endured prior to appearing here. That disclaimer aside, however, there are, even here, some clearly discernable differences between the two figures.

The diffusion surface used to make Figure 1 is a commonly available rear projection screen made by a prominent manufacturer in our industry which has a specified gain of 1.8.

Figure 2 was made with Da-Lite's new, DA-180 high resolution coating which also has an on-axis gain of 1.8. The average particle size of the Da-Lite screen is very much smaller and thus, for instance, the characters "Edmund Scientific" are very much more defined in the second figure than they are in the first.

Unfortunately the resolution available to this document is not adequate to display the series of increasingly fine line pairs located at the center of each slide. Here is where, of course, the high resolution standard is properly to be tested. On actual screens the differences between the two surfaces are instantly apparent. Here they can only been simulated. (And, if you are reading from the web, the resolution you get from the Internet is even worse, maybe only 72dpi.)

In a world increasingly dedicated to the display of high resolution data and graphics, the impact that screen surfaces can have upon the perceptibility of the projected information can no longer be safely ignored.

One diffusion is in fact no longer equal to another.

Angles Of View

Vol. III, 11 ©Da-Lite Screen Company November 1997

Much of this series has been devoted to explicating various and particular aspects of visual displays. Among the conclusions not yet presented, however, is a recommendation as to which of the many display criteria should receive priority over others. The present article seeks to offer in this regard

Some Summary Judgements

Before declaring what are the most important attributes of an optimum visual display, it is useful to disclose a pair of fundamental assumptions. These are postulates regarding exactly what it is that a display is supposed to do and under what circumstances it generally will do it. Premise number one is: **the primary goal of any display system is to deliver the maximum number of light rays from the projector into the eyes of the audience**.

Premise number two characterizes the viewing environment and asserts: **except for entertainment, the venues for all contemporary displays systems include ambient light**. If these two presumptions are accepted, we can derive the conclusion: **whenever the geometry permits it, rear projection is generally preferable to front projection**. This is reasonable because only in rear projection can the projector be pointed directly into the eyes of the audience (premise one) and because only in rear projection can most ambient light be segregated from the projected light (premise two).

There is another set of observations to be professed which has to do with the way displays historically have been used. Ten years ago the only thing audiences had to do with video generated displays was to **look** at them. "Looking" was, as it were, the full extent of the visual task. Today, with the advent of data projection, the visual task has become very much more demanding and what audiences are now routinely required to do with displays is to **read** them.

Tomorrow, as the software creating the displayable content becomes ever more graphical, the visual task assigned to audiences will transcend reading and the requirement will be to **inspect** the displayed information.

When we look at something, the principle visual activity has to do mostly with recognition. If the "signal" is video, we find that we can tolerate quite a lot of "noise" within it and still have no difficulty recognizing the scene, identifying the actress, or following the action. We are, in effect, easily able to see "the picture" or, if you will, to watch "the movie."

If, however, we are required to read something, then suddenly our tolerance of seeing it in broad outline vanishes and being able to recognize that the image is, in fact, a page of text doesn't help us at all if we're not able to make out the individual words. Moreover, it definitely won't do if we can only discern some of the words, those that, for instance, happen to be printed in the middle of the page (and thus will be projected at the middle of the screen).

The strings of words which stretch along the outside edges of each line (or the numbers appearing within the peripheral cells of the spreadsheet) are just as important as their counterparts at screen center. And there are four times as many of them! (There are, after all, four corners to every screen; but there's only one center.)

And when we come to think about the *inspection* of graphical information, the visual task becomes harder still. When we see a screen that we're expected to read, we at least know to direct our attention to the upper left corner and to begin scanning right. If the content before us, however, is graphical - the schematic of our company's newest widget or even the plan for its new boardroom - we are bereft all such convenient visual cues and there is no special portion of the display which by virtue of its position alone deserves our attention. We know, therefore, neither where first to look nor what first to read.

Inspection, then, is a task which compels us to examine all areas of the display with equal acuity because there is no way to predict just where or in what manner our attention must be focused. That being said, one thing we do know is that we must be able to distinguish with equal facility every portion of the display.

And, while purely graphical displays, may today be an exception, they are certain soon to become the rule if only because the computer industry (of which, of course, the A/V business is a prominent, but decidedly collateral beneficiary) will never cease in its development of increasingly elaborate content. As the software encompassing that content and the hardware manipulating it both increase in power, capacity, and speed, the extent and kind of information which will be "presented" through projectors and onto screens is prospectively limitless.

Despite the vistas thus sketched by the prospects of Virtual Reality, 3D, and even, one day, holograms, there remains the stubborn reality that if the content being presented is informational, its audience is going to have to *view* it. (Conversely, if the purpose of the content is entertainment, the audience need only be able to *see* it.)

Here, then, are Da-Lite's five most important criteria for the viewing of visual displays:

1. Uniformity
2. Resolution
3. Contrast
4. Size
5. Gain

Presumably, the case for **uniformity** has been adequately made above and can, therefore, be rested. It may serve only to add that no matter the absolute luminance emanating from any portion of a display, if some other portion of that display is more than two times brighter than the first, the human eye will perceive the first portion as being dim. Thus, if an image isn't adequately uniform, we shall not adequately be able to "read" it.

Resolution is second in importance because the drive to create more of it from the computer industry is inexorable. And, as the pixels become more numerous, they become smaller. And, as they become smaller, finer detail can be drawn with them. And, as the parts of an image become ever more detailed, the technology displaying the image has to become ever less obtrusive. Thus a screen must ideally be a surface that will always fail to degrade the resolution of the imagery cast upon it. (This is one of the reasons why diffusion screens are being returned to such a well deserved popularity.)

The third most important display attribute is **contrast** which is particularly vital to projected imagery as what is called its "black level" can never actually be black. This, of course, is because black (by definition "the absence of light") cannot (again by definition) be projected.

No matter how bright, nor how finely resolved, nor even how uniform a display may be if its content has too little contrast, if its darkest elements aren't a *lot* darker than its brightest, the human eye will have an extremely difficult time distinguishing among the data. As contrast is one display attribute which may not be limited exclusively by the projection source, careful screen selection can importantly enhance it.

The fourth attribute is **size**. How large we must make the display is directly proportional to the visual task expected by it. It's easy enough to recognize the general nature of an image that's too small. But if we are to read that image, we have to have it bigger. And if we are to inspect it, it will have to be bigger still.

Since reading and inspecting don't oblige visual interaction with the whole screen at once (but rather with only small portions of it at a time), sizing calculations should be made with reference to the back row and once useful formulae regarding front row geometry can usually be discarded.

And finally, but only finally, we come to **gain**. This series has always done its best to give gain a bad name, even when that slander has not always been fully deserved. But screen gain is all too often still assumed to be a panacea for any number of display problems. And it shouldn't be. Gain is just one of the criteria; it is not all five. This is why it should get considered last on the list, so that the other four can receive their fair and proper due.

Still, are there applications in which a high gain screen is clearly more effective than a low gain surface? Of course. And they are numerous. This is among the reasons why Da-Lite is committed to offering the widest and most diverse range of screens and surfaces in the industry.

There are data being displayed on screens today which are enormously complex and whose discernment is enormously demanding on their audiences. End users have come to expect that the quality of the image they see on their large screen display is at least the equal of what they see on their computer monitors. While that standard may not presently be entirely fair, it is unlikely to vanish. Almost certainly, in fact, it will be met.

Recommending the right standards for creating the best displays is Da-Lite's responsibility. Consistently providing our customers with products of only the very highest quality is our duty. Continuously striving to perfect and upgrade those products is our obligation. And ensuring that each and every customer find exactly the best screen and surface for each and every application will remain our mission

series of articles examining the various issues related to the concept and nature of Information.

Angles of View VOLUME IV – 1998

A series of articles examining the various issues related to the concept and nature of Information.

Angles Of View

Vol. IV, 1 ©Da-Lite Screen Company January 1998

The fourth volume of this series will undertake to examine various issues related to the concept and nature of Information - any display system's best product. Anyone can see, of course, that light is the medium by which information is borne in a visual display. Yet, some of the exact ways this is accomplished are not always obvious. One particularly interesting property of light is the orientation of its waves as they propagate through space. The manipulation of this orientation attribute can be extremely useful in creating visual information and thus this first article will consider

Polarization - Learning to Ride the Waves

Let's begin, as always, with a simple light source. Since it's a projector, the light from its lamp is transmitted through a lens. If we measure the brightest light we can get from this projector, we will discover that it will be the "white" light from the lamp that will the most intense.

If, however, we cause the projection beam to contain some information, we'll immediately discover that we have lost energy. Some of that admixture of wavelengths we call white light has been taken away in order to make room for the information. Just as the text on this page (or screen) takes away from the overall whiteness (or brightness) of its background, so whatever content we choose to transmit through our projector must similarly reduce its available lumen output.

To elaborate this concept just a little farther, recall that each color that we are able to see is distinguishable from every other color solely by virtue of its unique wavelength. White light has no specific wavelength but is a superposition of many wavelengths. To make any portion of an illuminated image other than white requires the suppression of some number of its constituent wavelengths. And when we pay this energy cost in some sort of organized way, the benefit is that the resultant collection of wavelengths becomes suddenly interesting because it now has something to tell us (or show us) which, of course, is really what we mean by information.

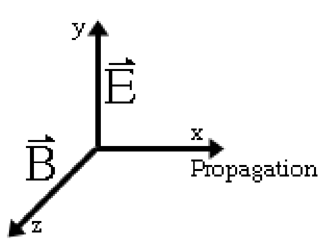
Another facet of projected images and of the information they contain is that the organization of the light rays filling them up is spatial. Each little packet of light rays must be modulated exactly to fulfill the instructions for the pixel it will illuminate. And the position of that pixel within the image must be maintained rigorously. The techniques for accomplishing this are numerous and varied, but they always require a lens to preserve this organization throughout the image area. And even when we look at kinetic imagery, movies, for instance, we really are not looking at content that's continuously changing in time, but instead are given the illusion of movement by a series of quite static, spatially well organized, frames.

It's perfectly possible, of course, to make light contain information that is actually organized temporally - semaphores come to mind, but those devices are not what our industry would comfortably call a projector and displaying their content upon a screen in no way enhances its comprehension. Conversely, when we project light that has been spatially organized and converged onto a screen, we suddenly have an extremely efficient surface from which we may assimilate the displayed information.

Thus far the optical vocabulary we have for getting information into light rays has been limited to two terms: wavelength and amplitude. Powerful as we know the combinations of those two can certainly be, there is a third property of light which, when added to the optical tool kit, makes the transmission of visual information even more effective. This, of course, is polarization.

To understand what polarization is and, at least coarsely, how it works, we have to shift the discussion from what projected information *is* to a description of how the light containing it *moves*.

Light travels in waves. More particularly, it travels in waves which oscillate side to side and perpendicular to the direction of the wave's propagation. Because they are at right angles to the axis of propagation, waves of this type are called *transverse*.



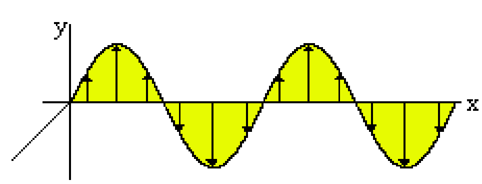


Figure 1

Figure 1 diagrams the three, orthogonal components of an electromagnetic wave. The drawing assumes that the light wave is traveling left to right across the page and hence (in Cartesian terms) along the x-axis. The y-axis extends up and down the page and the z-axis pierces the page perpendicularly. The oscillation (the wiggles) of the wave can rotate in any and all orientations about the x-axis. Its undulations move back and forth between being parallel with the y-axis and parallel with the z-axis and everywhere in between. We have seen already that the distance between each of the waves peaks (or valleys) is its wavelength. And the height (or depth) of each wave from the x-axis defines its amplitude. To these two variables let us now add a third, which is going to be the orientation of the light ray as it fluctuates around that x-axis. That orientation at any given infinitesimal moment of time is the wave's polarization. We take advantage of this attribute by forcing the light to adopt only one of those infinite possible orientations and then we make it stay that way .

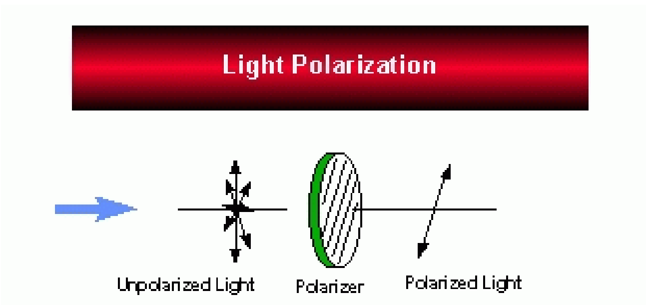


Figure 1:
http://abalone.phys.cwru.edu/tutorial/enhanced/files/lc/light/GRAPHICS/Xyz.gif

Figure 2

Figure 2 schematically illustrates how this works. The light is again traveling from left to right and we see that its orientations are always perpendicular to the direction of its propagation but are otherwise random and numerous. But when we insert into its path an object called a polarizer only the light which matches the orientation of that device gets through.

As the human eye is largely insensitive to polarization, changing its orientation doesn't change what we see. That's the good news. The bad news is that every time we polarize a beam of light we throw away 50% of its energy. (The reasons that this is so are complex, but suffice it to say here that they are imposed by the laws of physics and not by any human failure to be ingenious.) Now, we are often willing to pay that very high cost because the benefits we can derive are also considerable. One of them is the ability to employ liquid crystal displays.

LCDs require light from their lamps to be polarized so that molecules of the liquid crystal making up their panels can be made to rotate in ways which modulate the amount of light they will transmit. The utility of this technology to almost everybody in the projector world has become unassailable. The intriguing thing about this technology to some of us in the screen world has been that the light emanating from an LCD projector is polarized. Always.

In principle, therefore, it is possible to create a screen surface which could have a polarizer built right in to its surface. If that polarizer were to have the same orientation as the polarizers in the projectors pointing at it, then all projected light would be returned from the screen undisturbed and undiminished.

The fate of light from all other sources falling on the screen, however, wouldn't be nearly as benign. Returning to Figure 2, we can see that when *unpolarized* light is passed through a polarizer, only one of its orientations emerges and we now know that this output light can at *best* be only 50% as bright as the original input was.

Therefore, and again in principle, a screen sensitive to polarization could exhibit 100% of the projected light while simultaneously absorbing (and thus not exhibit) fully 50% of the competing ambient light.

Attractive as this idea is theoretically, it tends to be impracticable because there is no compulsion for the manufacturers of LCD projectors to all orient their polarization schemes in the same, identical way. That being so, a screen designed to have a vertical polarizer would work fine in front of an North/South projector, but wouldn't mate at all well with one that was East/West. And since a lot of projectors *are* East/West and still others are even oriented diagonally (e.g. Northeast/Southwest), such a screen just isn't statistically useful enough. But it is a bright idea, isn't it?

Angles Of View

Vol. IV, 2 ©Da-Lite Screen Company February 1998

One of the most interesting things about Information is that its transmission is essentially organized in two, and only two ways. Despite the enormous variety of available languages, despite the huge selection of available media, when it comes time to send a message, the content will be either analog or digital. And even though these two labels are bandied about in a large number of contexts, it may still be productive to ask

Analog and Digital - Signal or Code?

The world that we perceive is analog. Direct one of our senses we have at any portion of the world and the data available will be unlimited. If we add an instrument whose sensitivity to these data is greater than our own (a microscope or a telescope are two examples), we will still not be disappointed by reality's ability to present itself in ever greater detail. In fact, except at the level of the subatomic, all of our perceptions are limited only by the sensitivity of the instruments we use to make them. The external world really *is* continuous at all but the very smallest of scales.

This property of being continuous applies not only to the spatial resolution of the world but also to its temporal dimension. Although we divide a day into 24 equal parts and then divide each of those by 60 and then by 60 again, these units are convenient only to the diurnal rotation of our planet. They say nothing about the actual divisibility of time itself. From millennia to picoseconds, the duration of the world can also be measured at any scale and, theoretically, to any degree of accuracy.

When we wake up in the morning and look out our bedroom window to see what kind of day its going to be, we are making an observation. If we happen to glance at the thermometer tacked to the jamb, we are making a measurement. In either (or both) cases, what we have acquired is *information* about the weather. This example, intentionally mundane, seeks only to illustrate what information basically *is*.

Information means some kind of intelligence, some kind of data that has been put into a form that is suitable for communicating. That is, information may be thought of as the content of some signal or message which one person might wish to send to another.

In the analog world all signals are continuous and are continuously variable. If we monitor our conversations with a microphone attached to an oscilloscope we would see that our speech is carried by sound waves which have a distinct, undulating shape. If we modulate our voice, raising or lowering it, speaking faster or slower, these sine waves will exhibit continuously varying wavelengths and amplitudes each dependent, as it were, on our every word.

In the visual world, the most obvious analog signal is the classic photograph. The 3 x 5 snapshot exhibits a certain of amount of information. If we wish to see more, we take the negative from which it was made and create a bigger print, say an 8 x10, which will enable us to discern considerably more detail.

Since the detail within light rays which entered our camera and which exposed our film is infinite, in principle we could enlarge the analog image until its resolution matched the real world original. (In practice, of course, this turns out not to be possible because at a certain magnification the structure or grain of the emulsion [our "instrument"] intrudes and instead of seeing more useful information we see less.)

Whether, then, the recording we're making of some part of the world is audial, visual, or both, the apparatus we use, if they are analog, will copy their subject in a continuous, dynamic, and highly faithful way.

So. If all of that's true about analog, why do we need even to talk about digital, the other "way" to communicate information? What possible advantages could digital have and how are they different from analog's? In answer to both of these questions, consider the following little paradigm.

Two people walking in opposite directions are transmitting information to one another by using walkie talkies. Initially, as the experiment begins, they are separated by only a hundred yards or so and thus are able to hear one another's words with complete clarity. As they move farther apart, however, the sensitivity and power of the walkie talkies begins to be challenged and, as the signals issuing back and forth become weaker, their clarity is increasingly disturbed by extraneous noise and static.

At first only a word or two in any transmitted sentence may be garbled by the static and hence the receiver can do a pretty good job of filling in what she didn't in fact hear. But as the distance between the two instruments is increased still further, the static becomes so bad that maybe only one word in ten gets through and thus no dependable extrapolation is possible. The signal to noise ratio has been destructively inverted and neither person can make out the other's messages. Both are at a loss for words.

But what if instead of words which, after all, are strings of analog sound, they struck upon the notion of signaling one another by flicking the "transmit" button on their instruments on and off? Although each instrument can no longer reproduce words sent by the other, they both can still detect on/off signals.

Now it is extremely important to notice that when communication resorts to a binary vocabulary of on/off much more has changed than merely the "language" of the transmission. The strings of words sent back and forth through the two walkie talkies *were* the signal - other than their transduction, they required no further translation. But when a signal is digitized something quite new and very important happens to the communication process - the signal is encoded into a series of electrical pulses which, after being transmitted, must be decoded if they are to be understood. What this really means is that the signal is no longer being sent at all and instead of a string of actual words being sent we now utilize a string of zeros and ones which, by their unambiguous simplicity, can stand for the signal while they quite robustly withstand the noise.

A signal which we wish to send from point A to point B doesn't need itself to be sent if we digitize it. Instead what point B gets is a long series of on/offs which, if the recipients at point B know the right rule can be decoded in such a way that a new copy of the signal may be assembled from it.

As a few more illustrations may illustrate, the power of this approach is enormous. If we do not have to record (either audially or visually) the actual content of a possibly very complex signal, we merely have to create a series of small, literal instructions for its exact assembly someplace else. Think of the Pathfinder mission to the Martian landscape and the stunning pictures it returned of the surface of a planet some 170 million miles away....

Digital is so easy because it's so tedious; it exploits time as its medium of differentiation and spatial as well as temporal information is coded accordingly. Let us suppose that this page is a digitized message and that it's going to be projected onto a screen which uses a projector which has 480 pixels by 640 pixels (the redoubtable VGA). All the computer beneath it has to do is follow in rigid sequence a series of 307,200 very simple instructions. Starting at the upper left hand corner of the screen the display device gets the very first of the 307,200 sections into which the screen has been evenly divided and does one of only two things: it turns the pixel on (making it white) or it leaves it off (black). And that's it. (Yes, if it's a color display, there's one more part to the instruction: On or Off + what color; but this a quantitative, not qualitative, addition.)

Because a computer can carry out a very large number of instructions as simple as this in a very short period of time, a screen like this one can be written and rewritten more than 30 times every second. And if the image, instead of being a simple page of monochromatic text, were instead to be a fabulously intricate photograph of, the computer would never know the difference because what is being displayed is not the picture - it's just the pixels, one by one.

And since that is so, this page or that picture could be distributed to thousands of computers feeding thousands of projectors and each and every one of them would be able to produce (but not *re*produce) the same image each and every time.

The analog image is a copy (in the true sense) of some original. It has recorded the actual, cursive shapes of the letters on this page and the white spaces beside and beneath them. But the trouble with a copy is that all you can do with it is copy it again and again. And, as each successive copy is made some qualitative aspect of the original is degraded or lost.

A digital image, in contrast, can be edited. Since the "ON" signal from one of our walkie talkies has only a single frequency, all other frequencies can be filtered out, thereby liberating the coded signal from its enshrouding and extraneous noise.

Finally, the two methodologies are distinct not only as a code is distinct from a signal but also as to their resolution. *In the analog world this resolution is always continuous and infinite*. **The digital world never is.**

Angles Of View

Vol. IV, 3 ©Da-Lite Screen Company March 1998

This series has remarked previously on the increased expectation being placed upon audiences interacting with visual displays. Looking, it has further suggested, is no longer adequate to describe the generic visual task whereas Reading is. Everybody knows that the act of reading is one of the primary ways in which each of us assimilates formally prepared information. However, it still may be worthwhile to explore whether "reading" a projected presentation is the same as"reading" a book. Let's see, then, what may be said about

Reading Displays - Behind the Lines

Let's look analytically at what's happening when we sit comfortably at our desk or in our favorite armchair and open a book. If the pages that enjoy our regard are hardbound, their dimensions are something like 8 or 9 inches tall and usually about 6 inches wide.

A random (and not at all scientific) selection of 30 hardback volumes yielded an average print density of 42, 70-character lines for a typical page. The smallest font height in the sample was 1/8". All of the pages in the sample were white and all of the ink used in the printing was black. Since the resolution of this printed display is essentially analog, it's difficult to quantify. But because some number will be useful to the discussion which follows, let's set its value conservatively at 600 dots per inch (dpi).

Next let's consider the brightness of the light sources which may illuminate our book. A not very systematic series of photometric measurements taken in several offices and in several armchairs indicates that 30 foot-candles of light may typically illuminate the texts we read. It should be added that even under that much light, the contrast ratio of the monochromatic page is observably excellent.

Lastly, we consider viewing distance and viewing angle. Since reading a book is a solitary activity, the least favored viewer is also the only viewer. Further, that person (that pair of eyes) is essentially on-axis to the page and is only about two page heights away (15 to 20 inches). From that vantage point, the worst viewing angle is only about 10^{o} and would be measured to the corner of the block of printed text.

Those, then, are among the metrics of reading printed information. How different or how similar are the measured standards for reading projected information? Let's have a look.

But first a stipulation. Whatever else that's about to be said, we need to remember that the whole purpose of projecting information is so that it may simultaneously be delivered to an audience numbering greater than one. Furthermore, not only does a visual presentation get presented to a group, it gets presented to a group in a time limited way. This is significant because each "reader" of a projected display, therefore, tacitly relinquishes control of the time she will take to assimilate the data. That authority is transferred either to the presenter or, in the case of command-and-control applications, to events and circumstance.

For the comparison, let's use a 100-inch diagonal matte white screen and an LCD projector rated at 500 ANSI lumens and endowed with a native resolution of 768 x 1024. From guidelines well established elsewhere within our industry, we know that the audience field for such a display should not be deeper than 30 feet (six screen heights) and that, maximally, no viewer should be positioned at a larger angle to the screen than 45^{o}.

A little trig discloses that the width of the permissible back row could be as large as 30 feet. A little more trig reveals that the Least Favored Viewer could, therefore, be as much as 42 diagonal feet away from one of the screen's corners.

With all that in view, let's turn to the page of our projected "book." Optically, the whiteness of the screen and the whiteness of the paper are effectively identical. The amount of light constructively illuminating it, however, is significantly reduced. Fifteen foot-candles is all our 500-lumen projector can deliver to a 60 by 80-inch screen. Destructively, of course, there's ambient light to worry about which, even if we control it carefully, will inescapably degrade image contrast by some amount.

What we mean by contrast here, of course, is the achievable black level of the system. And the bad news for the projected page is that there isn't one. The black level of a printed document is, obviously, just exactly as black as is dictated by the opacity, saturation, and gloss of the ink that makes it up. Once that ink has been, let us say, "deposited" onto that white page, it soaks its way right into the fibers of the paper and renders them permanently and indelibly **black**.

Printed black, therefore, *absorbs* light and fails, to all intents and purposes, to reflect it. Projected black, on the other hand, is an oxymoron. When we look at monochomatic text projected onto a white screen, the sad fact is that we can never see black.

The responsibility for this deficiency, incidentally, is only partially the projector's. That device usually is the component which establishes the system's maximum black level and which no front projected display can ever manage to maintain.

If our 500-lumen projector has a rated contrast of 100:1, this might reasonably suggest that when it dumps 15 foot-candles of light onto one of our screen's square feet, the black characters within that square foot will have a total luminosity of only .15 foot-candles. If true, that would be a most satisfactory black level.

The trouble is, even if that .15 foot-candle is the minimum amount of light which the projector can project, it's unfortunately a lot less than any matte white screen can re-radiate. If we think about that last sentence for a moment, we will see that the problem lies not so much in the projected lines of text but in the screen behind them. Fabulously efficient surface that it is, the one thing it can't (and shouldn't!) ever be is black.

The fibers of this "page" are not ever going to be dyed black. Not one of them will ever absorb light. Every one of them will scatter light from any and all sources with egalitarian abandon. So now if we consider just a single "black" character projected onto our screen, what we'll see is the paper beneath the type doing a very good job of radiating light across, into, and out from the very area the projector would like to convince us is black.

True, we can diminish this particular effect by choosing a screen surface which has gain. Since higher gain screens have narrower dispersion patterns than lower gain surfaces, the higher the gain, the better the contrast. However, as this series has been at pains to point out elsewhere, the qualitative price to be paid for high gain often far outweighs any benefit in contrast.

The point in going into such detail about black level here is that trying to read text that doesn't possess much is hard, often very hard.

Another attribute which makes reading projected text so much more demanding than a printed version is resolution. We said earlier that a page of well-printed text has a resolution of at least 600 dpi. Let's see how that compares to a good projected display.

The smallest "dot" an electronic projection device can work with is a pixel. If our projector is an XGA device, it has 786,432 "dots" with which to write not only the text characters on its page, but every square inch of the page itself. *And*, it's got to distribute those "dots" symmetrically, no extra concentration for the black zones allowed.

On the 100-inch diagonal screen we've been using as an example, there are 4800 square inches. In each of the those inches, the pixel density will be just less than 164. To raise that number to 360,000 (600 dpi) would require a projector with a native resolution exponentially higher than anything we can contemplate today. And, even if we did have one with resolution that high, we remain OK only as long as we don't increase the screen size.

Resolution is an extremely useful index of information content. Established as a limit, the resolution of a display defines, quite precisely, the maximum amount of information it can contain. It isn't that the words comprising this line of text increase in number or simplicity as their resolution is increased, it is that, as more and more pixels can be devoted to the tracing of each stroke and curve of each character, they all become unmistakably easier to read.

In a way, the very reason this issue is problematical is because our industry's presentation technology and the computers which drive it have just recently begun to approach the capacity of the printed page to display information. Exciting as this breakthrough is, it remains beset by a host of difficulties and challenges only some of which are being identified here.

Most of us in the A/V industry tend to think of visual displays according to engineering standards. Convergence, bandwidth, color temperature, screen size, half-angle, viewing angle, etc., etc. Although all of these are vital criteria, none accounts directly for what are called the human factors. These are the ergonomics of how efficiently human beings may be helped in their assimilation of projected data by the parameters of the display system itself.

These are questions about which most in our industry arguably know little and demonstrably not enough. As our customers' demand for information increases, however, they are questions which not only must rigorously be asked, they must scientifically be answered.

Angles Of View

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After we have come to understand that deciphering information when it is projected is very much more difficult than comprehending its printed version, we want next to discover whether there are techniques and guidelines which, if carefully observed, can combine to minimize the substantial difficulties inherent in

Reading Displays - the Joy of Looking

Consider the following scenario:

The operators of an offshore oil drilling rig somewhere in the North Sea rely heavily on data delivered to them through an elaborate command-and-control room which consists principally of 12 rear projection screens set into a single wall and arrayed in a 2-over-6 configuration.

Monitoring systems throughout the structure feed to this room where corrective measures may be taken when or if any malfunction occurs. Data projected through the screens are, therefore, being updated continuously and in real time. Changes in those data must be recognized by the systems' operators who are also obliged to assess those changes in real time.

Although the room is certainly manned by well more than a single operator, each operator will nevertheless be assigned to oversee some subset of screens as his specific area of responsibility. Watching and watching over this multi-image display will be the operator's principle visual task and detecting and correctly interpreting fluctuations in the projected data will be his primary responsibility.

If we quite reasonably suppose that any single operator will not be expected to monitor a screen matrix that is greater than 2-over-2, we can still quickly see that his ability to assimilate data from any one of the four screens under his purview may not be at all equal to his capacity accurately to read the other three.

How far, for instance, should he be positioned away from the bottom two screens? At what vertical angle should he be positioned to the pair of top screens? For that matter, how big should each screen itself be? And how bright should be its imagery?

To continue with just a few obvious questions about the content of the display(s), how will we establish character size, color palette, and font? What can or what should our line frequency be? And if some of the "characters" aren't characters but are instead symbols, how then should we proceed? And, lastly, a question we *can* probably answer: What happens if we choose wrong answers to some of these design questions and then, in operation, something goes wrong?

While, indeed, this may be a plausible premise for a Hollywood techno-thriller, it is also an absolutely credible real world possibility whose outcome might not actually be a fully cinematic disaster but which could definitely be both expensive and regrettable. Even for single screen displays where the intention is neither to command nor to control, these are issues and parameters about which far too little is known. Yet both the integrators and users of all such systems rarely take the time to design or analyze them according to the metrics of intelligibility.

What are those metrics and where are they to be found are not at all easy questions to answer. In preparing this article, its author spent weeks searching the literature both on-line and off and with one notable exception was unable to unearth any definitive syllabus. It appears that no body of substantive research on these subjects is accessibly available.

There is, however, one major exception to that conclusion and her name is Dr. Joy M. Ebben. Describing herself as a "Human Factors/Ergonomics Specialist," Dr. Ebben has for the past 11 years quietly been researching the very questions that are being raised here. Her credentials for the undertaking include an MS in Education, an MA in Human Factors and Applied Experimental Psychology, and a Ph.D. in Applied Cognitive Psychology.

There are a few people in our industry who know about her and about her work. But only a few. That ought to change. Dr. Ebben, who lives and works in Alta Loma, CA can be reached by voice at 909-941-4539 or electronically at PhDJoy@aol.com.

When analyzing a potential display system, Dr. Ebben believes that the first criterion centers on the question of size and may be summed up as asking (lots of times), "Is it big enough?"

When confronted by our industry's current supposition that an adequate screen height can be determined by dividing the distance to the least favored viewer by the number 6, she was frankly skeptical. And, although this series has been enthusiastic in the promulgation of that standard, Dr. Ebben's mistrust of its reliability may, on second thought, be justified.

While wholeheartedly agreeing that screens displaying data that must be read by their audiences need to be bigger than screens presenting images that need merely to be recognized, she doubts that establishing the size of the "page" can by itself authenticate the intelligibility of the data to be "written" on it.

Here is a brief initial summary of her Human Factor Goals:

· **To help ensure that users can:**

-See the information
-Detect changes in the information
-Discriminate bits of information
-Understand the information

· **As required to perform their functions or tasks.**

The reason, Dr. Ebben points out, that display systems are provided in the first place is "to provide information to people. If those people cannot see, read, discriminate, and understand what is being presented, the system has failed."

Eight of the system specification criteria which Dr. Ebben contends must be considered are:

1) Perceived Character Size
2) Alphanumeric and Graphic Designs
3) Vertical Viewing Fields
4) Horizontal Viewing Fields
5) Vertical Screen Dispersion
6) Horizontal Screen Dispersion
7) Unobstructed Viewing
8) Room Layout

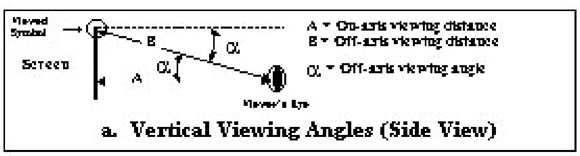

Figure 1

From analyzing the interrelationships between these metrics, Dr. Ebben produces recommendations for five intelligibility parameters:

I. Screen size, location, height, and configuration
II. Screen and Projector tilt
III. Closest seating
IV. Prioritized seating areas
V. Character size relative to design criteria

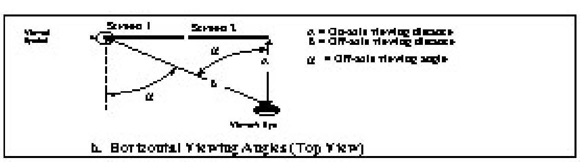

Figure 2

Figures 1 and 2 illustrate how viewing angles to projected symbols get measured. Dr. Ebben is convincing when she asserts that the only reliable way to ensure that the symbols are big enough for an audience to read is to calculate the character size on the retina of each viewer’s eyes. To do this, she solves for what is called the "subtended angle" (Figure 3) which is best expressed in minutes of arc. (An arc minute is defined as *a unit of angular measurement equal to one sixtieth of a degree, or 60 arc seconds*.)

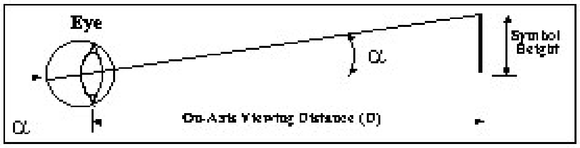

Figure 3

As may be seen from Figure 4, it turns out that the minimum height for the smallest symbol should subtend not less than 10 arc minutes. What the table also reveals, however, is that 10' is only reliable for viewers positioned nearly normal to the display.

Required Character Height

[illegible] (D)	Subtended Angle (in mins. of arc) (α) 10*	16**	20***
10 ft	0.35"	0.55"	0.70"
20 ft	0.70"	1.12"	1.40"
30 ft	1.05"	1.67"	2.09"
40 ft	1.40"	2.23"	2.79"

*Acceptable for non time-critical tasks

** Minimum standard when legibility is important

*** 20-22 preferred for reading and colored symbols

Figure 4

Because all other viewers are obliged to look at the display, as it were, askance, their visual task is incrementally more demanding and the size of the symbols must for them be proportionately increased.

To see what else may be necessary to the creation of intelligible displays, however, will require examining them from yet additional angles of view.

Angles Of View

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If you are reading these words on a printed page, you are seeing them in 11 point Times New Roman Italic. If you are using your browser to read them at www.da-lite.com, it's hard to say exactly what typeface you're seeing. And if by chance you're projecting the contents of your computer screen up onto (or through) a projection screen, then what will you see? And, more importantly, how well can you see it? This series has devoted many, many words to the visual display of information. Now it is time to consider the shape of those words which means looking at

Fonts - A Case in Point

Fonts, of course, have been around for more than 500 years - ever since Herr Gutenberg invented movable type in 1437. And, as anyone who owns a computer knows, there are lots and lots of them to choose from.

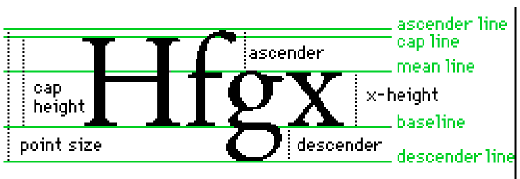

Figure 1

All fonts have faces and all faces belong to a family. Thus this font appears here in its standard face, but there is also *Italic* and **Bold** as additional faces. To see the elements which distinguish one font from another, consider Figure 1.

These are the principal parts of the characters and symbols which make up any font family. Additionally, ever since fonts became scalable, we can describe their printed size by specifying the number of **points** a letter is to take up. There are approximately 72 points to the inch and 12 of these points comprise a **pica**. Precise as those measurements are, however, they regrettably are of little or no use when the font is not to be printed but projected. Approximately one seventh of an inch high letters are fine for this page but, obviously, would be hopeless on a 100-inch diagonal projection screen.

Some interesting things may be observed about the legibility of fonts in general. One of them is that mixed case text is easier to read than TEXT WHICH IS PRINTED ALL IN CAPITAL LETTERS or even Text Which Has Just The First Letter Of Every Word Capitalized.

Another is that legibility depends on the tops of words.

Now see how much more difficult it is to decipher the lower half of the same sentence:

Figures 2&3

An enormously important attribute of fonts is whether any particular face is **serif** or **sans serif**. Serifs are small, usually horizontal cross strokes that are added to the ends of a letter's main strokes. **This typeface has serifs.** This typeface does not have serifs. Because of their ability to coax the eye along the line of type, fonts with serifs are generally acknowledged to be more readable than fonts that are sans serif.

Becoming sensitive to these observations is helpful, of course, but it still doesn't really answer the question, how can we think about fonts for projected displays and what guidelines can we follow for their manipulation? Fortunately there are some valuable answers and once again they emerge from research undertaken by Dr. Joy Ebben of JME International in Alta Loma, CA.

Dr. Ebben breaks the design of projected characters into five principal categories: *Shape, Height-to-Width Ratio, Pixel Matrix, Stroke Width, and Character, Word and Line Spacing*.

With respect to the shape of the possibly ambiguous characters, she offers the following case sensitive criteria:

A needs clearly delineated space above its horizontal stroke.
B needs approximately equal loops.
C & **G** are easily confused with each other and with **O** if the C break is not clearly discernable or if the horizontal stroke of the G is not long enough.
D & **O** can be confused if the O appears to square.
E requires clearly delineated spaces.
M & **W** need sufficiently long center sections.
P requires a large enough loop.
S & **5** are easily confused if the S is too square and/or the horizontal top of 5 is not long enough.
1 & **I** [sic] *must* be made to look different.
U & **V** will be confused unless the uprightness of vertical strokes of the U is maintained.
Y needs a long tail to differentiate it from **V** and it needs a distinctly v-shaped top to differentiate it from a **T**.
6 & **9** need apparent (but not too large) loops and fairly straight tails.

Other likely confusions are that **X** can be called **K** (and vice versa), **H** can be thought to be **M** or **N**, **J** or **T** can be called **I**, and **K** can look like **R**. Additionally, **B** can look like **R**, **S**, or **8**; **0** (zero) can seem to be **O** or both can look like **Q**; and, to get to the end of the alphabet, a **Z** can often look like a **2**.

Based on the typical width of a set of capital letters, the Height-to-Width ratio should be not less than 70% and not more than 90%.

The pixel matrix available for any character or symbol is absolutely critical to adequate legibility. Ironically, however, here is a case where the increased and increasing resolution from better and better visual displays does *not* help. When you upgrade either your computer or projector from the 600 x 800 device you had last year to the fancy new 1024 x 768 you've been promising yourself for this year, the first thing you'll notice is how much *harder* it is to read.

Why is that so? Because, although your new machine will display 306,432 more pixels than your old, not one of those extra pixels is devoted to the improvement of your font. Thus, if your SVGA machine reserved, say, a 7 x 5 pixel array to write each of its lowercase characters, then your new machine also will allocate only the same 35 pixels to the same task, even though each of those pixels is only 3/5 the size of its predecessor. That's (roughly) the difference between reading this phrase and trying from the same viewing distance to decipher this one.

Dr. Ebben's rule of thumb for visual tasks that require the continuous reading of projected text is that the minium matrix be 9 pixels high by 7 wide. Clearly, however, even more pixels will always result in even better character definition.

Next we come to stroke width for which the historical ANSI (American National Standards Institute) standard has been that it be greater than 1/12 of character height. Dr. Ebben and others believe, however, a stroke width of 1/4 to 1/8 of character height is preferable for projected text. Furthermore, Dr. Ebben has discovered that there is marked discrepancy between what she calls forward video – light characters on a dark background – and its inverse.

The rule, then, is to use at least a double pixel wide stroke for large screen displays which are forward video. Interestingly, this is true because double stroke width in reversed video (dark on light) appears to be narrower than single stroke width in forward video.

The ANSI standard for mixed case horizontal character spacing has historically been given as being not less than 10% of character height. Because of even moderate off-axis viewing angles, however, Dr. Ebben believes that the minimum space should be increased to 25%. In terms of a 9 x 7 pixel matrix, this corresponds to two dot elements. However, this spacing should be increased to 50% whenever viewing angles become large.

With regard to the appropriate spacing between words, Dr. Ebben reports that the distance between one word and another should not ever be less than the width of one character. Spacing between lines – leading (rhymes with bedding) – has been established by ANSI to be a minimum of 2 stroke widths or 15% of character height, whichever shall be greater. Dr. Ebben believes that there is good reason to increase this minimum to 50% of character height for projected text.

Are all of these typography criteria really worth attending? Yes. Because we must never lose sight of the enormous difficulties inherent to the task of reading information that has been projected.

In addition to Dr. Ebben's original research, other sources used in the preparation of this article are:

Shurtleff, Donald A., *How to Make Displays Legible*, Human Interface Design, 1980.
Cavanaugh, Sean, *Digital Type Design Guide*, Hayden Books, 1995
Carter, Rob, *Working With Computer Type*, Rotovision, 1997

Angles Of View

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If projected displays aren't hard to see, they sure are hard to read sometimes. Why this should be so isn't at all hard to understand once we see how hard it is to display lots of letters and numbers on a screen in ways in which people from all sorts of viewing angles and distances can still accurately make them out. Figuring out how to account for all of those viewing angles and distances is so complicated that the only way to simplify it is to resort to mathematics, the preeminent language of science and the tool by which so much of our comprehension of phenomena can be generalized. Since some attributes of visual displays can also be expressed in mathematical ways, this article, howsoever reluctantly, will be

Looking at Trig - Can I See You a Minute?

All of us in the Audio/Visual industry who continue to work hard and to work together to create better and better visual displays are discovering the task to contain more and more science and less and less instinct. If we all were pilot s, we'd be flying less and less by sight and more and more by instruments.

This development shouldn't surprise us all that much because most of us have seen it coming for a long, long time. Always remembering that ours is a business driven primarily by another, much larger industry ñ the computer industry ñ, we can easily see how very much more complex is the information that a computer can output to its screen today compared with what it could do only a few years ago.

Desktop publishing, web sites, presentation software, and multimedia in general have all become very, very sophisticated. "System Requirements" are routinely calling for 100MHz processors and 32 MB Ram as *minimums* just to get the programs to run. What is all that speed and memory (to say nothing of the huge amounts of space required from the hard disk) in aid of?

The answer, of course, is us. We're the ones who want to be able to pack more and more information onto our screens and we're the ones who want to be able to have those high density data communicated to lots of other people, in lots of other venues.

This series of articles has been stressing recently the critical significance of this data concentration in terms particularly of the visual task necessary to its assimilation. To put it simply (just one more time), it all boils down to this: We aren't looking at projection screens anymore. We're reading them. And reading something, as anyone who gives it a moment's thought can recognize, is much harder than looking at it.

When the material we are expected to read is projected and then reflected or transmitted by some screen, comprehension becomes downright demanding. Because the degree of this difficulty cannot be overestimated, efforts needed to manage it must be considerable.

Here's the problem: if you want to ensure that everybody looking at a display can discern and decipher all of the data projected upon it, you must absolutely guarantee that every single character and symbol is large enough to be reliably and accurately identified. This is not a question of font choice (although that is certainly important). Nor is it a question of the contrast or color pallette that is available (although these also can be vital). It is a question of size, pure and simple. If the characters and numbers aren't big enough to be read by the person positioned at the back of the room, she won't be able to figure them out (even if she squints). Period.

So, how do we ensure that all letters and symbols generated by all computers projected by all projectors onto all screens in all rooms before all audiences are big enough? We define the minimum size in a way that can be reliably generalized over all of those cases in all of their variations. What we actually say is:

The height of no lowercase character shall subtend less than 10 minutes of arc on the retina of any viewer.

That's the mathematically expressed rule and, once we understand it, we can use it in any and all cases always.

To see exactly why the concept of minutes of arc is so useful, consider Figure 1 (for which, once again, we are indebted to Joy Ebben, Ph.D.).

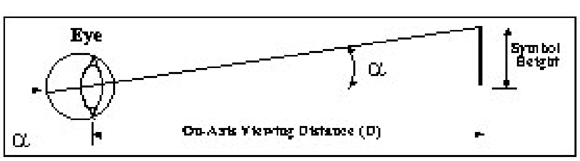

Figure 1

First let's dispense with the symbol a (the Greek letter *alpha*). That's the angle we're interested in and, for the moment, it is an unknown. (Mathematicians like to use Greek letters for unknowns. It makes them harder for the rest of us to understand.)

Now notice that there's a second a, the little one, pointing into the intersection of the two lines at the back of the eye. And *that's* the alpha we're really interested in. Fortunately, there's a provable theorem in Geometry which states that *all vertical angles are equal* and vertical angles are the two opposing pairs of angles which are created wherever two straight lines intersect. Thus, if we can find a way to measure or calculate the big alpha (a) we will automatically know the value of the little one way down there, inside our eyes and nearly impossible to measure.

Next we have to think about angles and how we see. If you get up out of your chair and, with your eyes open, slowly turn completely around, your eyes will have swept over everything in your horizontal field-of-view. Since that field is a complete circle we can define at as divisible into 360 equal slices, which we call degrees. But, since you don't have eyes in the back of your head, the only way you can "see" in all 360 directions is to turn completely around. Otherwise you can "see" only what's in front of you, which is only a part of 360°. How large is that part? Amazingly enough, it's a whopping 200° (for more on this, see Vol. III, No. 4 of this series).

But because 200° is not equal to the complete, 360° circle, we'll have to recognize that it's only a section of that circle and any section of a circle is called an arc.

When we look to see how much of that available 200° gets used by our eyes when read something, however, we discover that it's only the central part of our visual attention that gets used. It is encompassed by something less than 30°.

If we're reading a page of text, it ought, therefore, to be simple enough to divide each line by 30 and discover how many degrees are taken up by each character. Unfortunately, when we do that, we soon see that there are many more characters to a typical line than 30. Projected displays, for instance, often include lines that are 80 characters in length.

To deal with this sort of problem, mathematicians came up with a way to subdivide each degree into 60 smaller slices which, for numerically obvious reasons, they call *minutes* (and each minute may be subdivided into 60 arc *seconds*). This enables us to divide a 30° field-of-view not into just 30, but into eighteen hundred equal parts.

The final two things we have to think about there are easy; they're just vocabulary. The verb *subtend* is simply a mathematical word meaning *to be opposite to and delimit*. All it means here is that if we can measure the height of a symbol on a screen, we know that the angle (the big a) "subtends" on the screen will be the same angle that is subtended on the tiny screen inside our eye which is called the *retina* (and there's the other piece of vocabulary).

Having now done with the math, we can return to our rule and notice that its terrifically useful virtue is that it will and does hold true for all viewing distances and for all screens. (This is so because the size of the little screen, the retina, *doesn't* change even as all the other variables may.)

The way that the number of requisite arc minutes was proved to be 10 had and has nothing whatsoever to do with calculation. It was established by long and arduous empirical research which entailed asking lots of audience volunteers, "Can you read this from there or do I need to make it bigger?" When people positioned on-axis to the projected characters stopped saying that the symbols were hard to make out, they were measured to be subtended by at least 10 minutes of arc.

For *off-axis* viewing 10 has to be increased because trying to read something from an oblique viewing angle is much harder than looking at it straight on. Try reading a book you're holding way out to your side and you'll see for yourself.

But as a benchmark for on-axis viewing, 10 minutes of arc is a solidly reliable minimum. If you take the trouble, incidentally, to calculate it out, you'll discover that 10 arc minutes translate to just over ¼ inch for every 7 feet of viewing distance. Hence a lowercase letter should be not less than .86 inches high if people seated 24 feet back are to be able to read it

Now that wasn't so hard, was it?

Angles Of View

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If the dominant topic discussed in this fourth series of articles has been Information, the essential lemma of their argument remains the importance of distinguishing between visual tasks. Projected displays which are intended, variously, to be looked at, read, or inspected are no longer interchangeable. The geometries, specification, and design are now defined not just by their source, but by their function. From, then, the vantage of a screen manufacturer, what can be done to enable and enhance

Reading by Da-Lite — Ne Plus Ultra

At the recent INFOCOMM show more than 20,000 visitors flocked to Dallas and spent three very full days looking at our industry's myriad new wares. Many were kind enough to stop by the Da-Lite booth and cheerfully inquire, "What's new?"

Answers to that most welcome question entailed a round-the-booth tour, with many stops along the way. Most (but not all) of those stops involved an opportunity to look at some new (or newly configurable) projection screen. One observer to these proceedings was struck by the number of people who, while examining a screen, would position themselves at truly enormous angles to the projection axis and then, and only then proceed with their appraisal.

Is it really reasonable, we want now to ask, that a screen and its image, should be judged by a viewer down on her knees, with her cheek pressed against the wall supporting it? Even if a screen could produce such extreme viewing angles (and some actually can, ask your Da-Lite Sales Consultant), why ever would anybody *want* to look at it from such an uncomfortably oblique angle?

Yet, time after time, seasoned A/V professionals thought themselves diligent by checking out each and every screen under their purview from viewing angles exactly as unreasonable as have been described. Why? What could be going on here that makes these intelligent and highly educated people insist on putting humble screen products to such a torture test?

The most articulate retort is likely to be founded on necessity. The designer asserts that she has no choice in the configuration of her audience. She can specify the kind of projector and (within limits) its potency. She can specify the kind of screen and (within limits) its size. But she cannot specify the configuration and size of the audience. Those, she will tell us, are established by the end user who, although sometimes susceptible to her advice, rarely requires her consent.

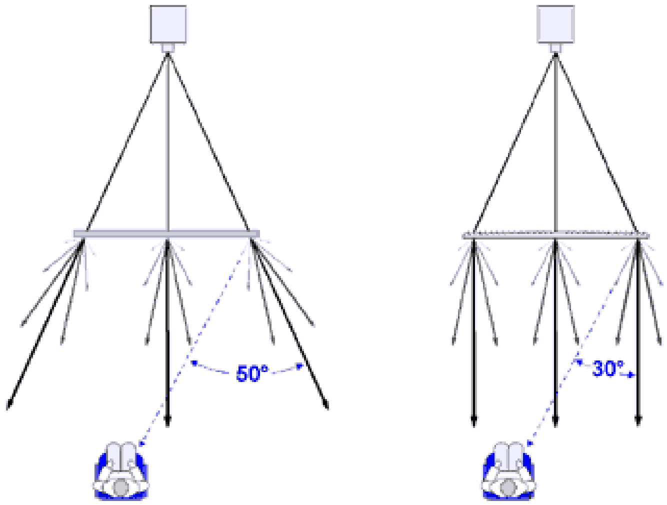
Thus, the reasoning continues, screens which enable extremely wide viewing angles are to be admired above screens which do not. Moreover, we happily repeat, there's the convenient fact that some screens these days really do have half-angles of 60º or more. So, since such surfaces are now ubiquitously available, what's the problem? Where, we might even ask, is the beef?

The suggestion we would like to make here is that everybody in the dialogue so far is forgetting (overlooking?) the change in the visual task. We're no longer allowing that audience of end users to be able just to see the screen from some arbitrarily large viewing angle. We're asking them to read it.

Can you recognize or see imagery on a screen from a 70º viewing angle? Yep; often even if the screen isn't some high-tech rear projection lensing array. (Test a matte white front screen this way, for instance). Can you read alphanumeric data or discern high resolution graphics from a 70º viewing angle? Nope; can't reliably be done.

Literature and research on maximum viewing angles for legibility abound. The consensus is overwhelming and unmistakable: 45º is the maximum viewing angle that can be tolerated by audiences required to read a display. Maximum.

Joy Ebben, Ph.D. and lots and lots of other experts all agree. Beyond 45º the eye is simply not a reliable data acquisition device and all kinds of characters and symbols will assuredly be mistaken for others.



Figures 1&2

In entertainment venues this distinction is largely meaningless. In commercial settings it is absolutely critical. Regardless of some screen's ability to distribute light over large angles, any screen person who advocates reading from larger dispersion angles than 45º is either irresponsible or sadistic. *Viewing angles are not reading angles*.

After belaboring that point, what else might be said about screens whose manufacturers now understand that their surfaces will need more and more to be read rather than looked at? Does that single, enormous paradigm shift have impact on the design of screens themselves? Da-Lite Screen Company, Inc. has determined that the answer is an emphatic yes.

If we know that a screen needs to be read, there are a couple of immediate conclusions to be drawn. They are that, first, the screen should be a rear projection device and, second, that it should be as uniform as is optically possible.

The advantages of rear projection over front for non-entertainment displays have been throughly detailed in numerous prior articles in this series. They include more efficient projection geometry, greater tolerance of ambient light, and higher image contrast, to name just three.

The advantage of maximum uniformity, of course, results from the necessity of being able to read the whole "page" of each screenful of data. That "page" has four corners which will need to be as acutely discerned as its center. From any given reading angle, however, if one or more of those corners is perceived to be less than half as bright as any other portion of the text to be read, its data is likely to be literally illegible.

Keeping the edges and corners of an image from being less than 50% of the brightness visible from its center is no mean feat. Even if the output of the projector itself is extremely uniform, there remains a geometry problem that will never go away.

This, of course, is the necessity that all projectors must emit light rays through their lensing system which must diverge. It is this divergence which allows for the size of a projector's image to get larger as its throw distance is increased. If the shape of a projector's beam were, say, rectangular instead of conical all of the light rays comprising it would be parallel, but the image would never be larger than the surface of the lens transmitting it. Although such a projector might be interesting, it would doubtfully be popular.

The drawings above illustrate the paths of three principal light rays projected through a rear projection screen. To reach the figure in Figure 1, light from the right-hand ray must be bent through an angle of 50º. Conversely, light from the centermost ray might need to be bent only five or six degrees to reach his eyes. Because the second job is so much easier than the first, any viewer will always receive more light from the screen in front of him than from the opposite side. People who notice this phenomenon call it a hot spot. People who have to read through it call it a pain.

One constructive approach to minimizing this problem is to utilize Fresnel/Lenticular screens. Classically, this solution has been extremely effective. However, remembering what it takes to *read* a display, the periodic structure which all lenticulated arrays impose into the image plane is no longer an attribute which can safely be ignored. *Anything* which can degrade resolution should always be avoided if reading is the visual task.

Thinking hard about all this, Da-Lite engineers asked themselves the following question, "What would happen if we decoupled a Fresnel from its lenticulations and diffused just that?" The result is Da-Lite's reading screen: the Polacoat®

Ultra.

Put a Fresnel behind the screen in Figure 1 and you get Figure 2. Because a Fresnel lens will collimate light rays from the projector such that they all travel parallel to the centermost light ray, all bend angles become significantly smaller. By reducing 50º to 30º, Figure 2 puts a whopping 40% more light from the corners into the viewer's eyes than can Figure 1. This huge improvement in overall uniformity cannot be overemphasized. And, since the grooves of the Fresnel (like lenticulations, also a periodic structure, after all) are behind the image plane rather than in it, the effect on resolution is imperceptible.

Thus, if you want to make data you wish to project maximally legible, there is no rear projection screen superior to the Ultra. It is, word-for-word, ne plus.

Angles Of View

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You're designing a display system. You've understood the client's needs and you've figured out which projector to recommend. You've picked out the right screen and you've made sure its surface won't be too small. Now all you've got t o calculate is how big the projected characters and symbols need to be. Since many members of the audience will not be seated normal to screen center, you know you'll have to consider some additional design factors if all of your client's texts are going to be reliably legible. In an effort to help with this process, here's:

How to Cosine a Document

We have said in earlier articles that ensuring a minimum character size is essential to the creation of readable displays. We have also worried that too many people don't worry about what happens when they fill a projection screen with data from a computer screen.

When you sit in front of your computer, the distance separating your eyes from its monitor is typically between 20 and 24 inches. When you measure the diagonal of your display, you'll find that it is at least 50% of your viewing distance. When you notice that you're positioned effectively dead on axis to your screen, you'll understand why you not only like what you're looking at, but why you also have no trouble reading it.

It's not clear that the manufacturers of your computer and its software had your visual comfort exclusively in mind when they combined their products in just this convenient way. But it is clear that, to date at least, the resulting geometry is fortuitous and forgiving. All of us in the large screen display business have been for years wishing we could match it.

Imagine the luxury: no seat in the house is further back than two screen diagonals and no viewing angle is greater than 20º. Within those parameters, can we make a customer's large screen display look as good as her monitor? You bet we can.

The problem comes when she wants us to do as well when there are people seated three, four, and five diagonals away from the screen and at viewing angles which are 30º, 40º, and 50º off-axis. Can we still make it look like her monitor? For she herself maybe, seated at the head of the table or in the center of the second row. But for most of her people the display isn't going to look at all like *their* monitors do even though they're the people who've got to assimilate the presentation. And it's our job to help them.

If the material being presented were old style stuff, title slides and simple graphs (but not graphics), worrying about reading it would be no big deal. But think about what you can display on your computer screen today versus what was available only a few operating systems ago. Multitasking and multimedia are the watchwords of the day and who among us can resist them?

We have established previously that if an audience member is expected to read the information displayed on a screen, the height of all lowercase characters must subtend *at least* 10 minutes of arc on that viewer's retina. A less rigorous way of saying that is to state that there must be ¼ inch of lowercase character height for every seven feet on-axis viewing distance.

If that's correct for on-axis reading, what about off-axis angles of view? How do you know what it takes to read from those? The answer is found in the following equations:

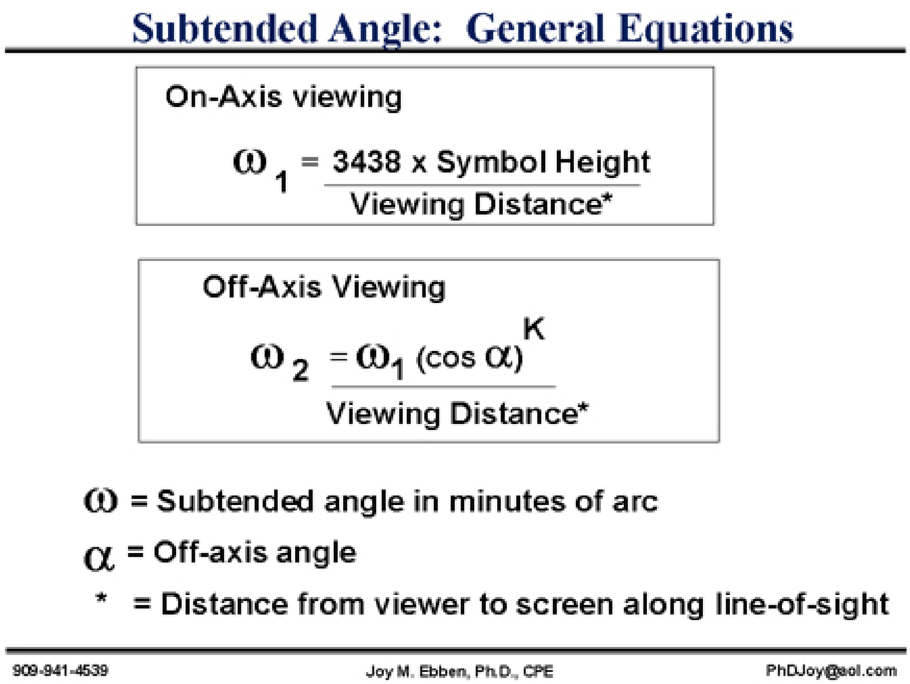

Figure 1

The first formula solves for minutes of arc for on-axis reading in still another way — it divides the product of 3438 and the character height (in inches) by the viewing distance (in inches). Hence, if the height of a symbol is, say, .65 inches and the viewing distance is 25 feet, then .65 x 3438 = 2234.7 / (25 x 12) = it subtends only 7.45 minutes of arc and is, therefore, *not* big enough. Working the numbers backward, we see that 300 x 10 = 3000 / 3438 = .88 inches of symbol height, which *is* big enough.

Figuring out how big to make symbols for off-axis viewing is a little more complicated. Notice that the viewing distance in both equations is along the line-of-sight. So it gets measured the same way but will always be longer for a view er positioned at the edge of a row of seats than it will be for a viewer at the center. Unlike w_1, however, w_2 depends for its size on two additional variables, a and the superscript K. As indicated, a equals the off-axis angle from which the character will be perceived. (You'll have to wait to hear about **K** but, for the moment, we'll neutralize it by assuming it to equal 1.)

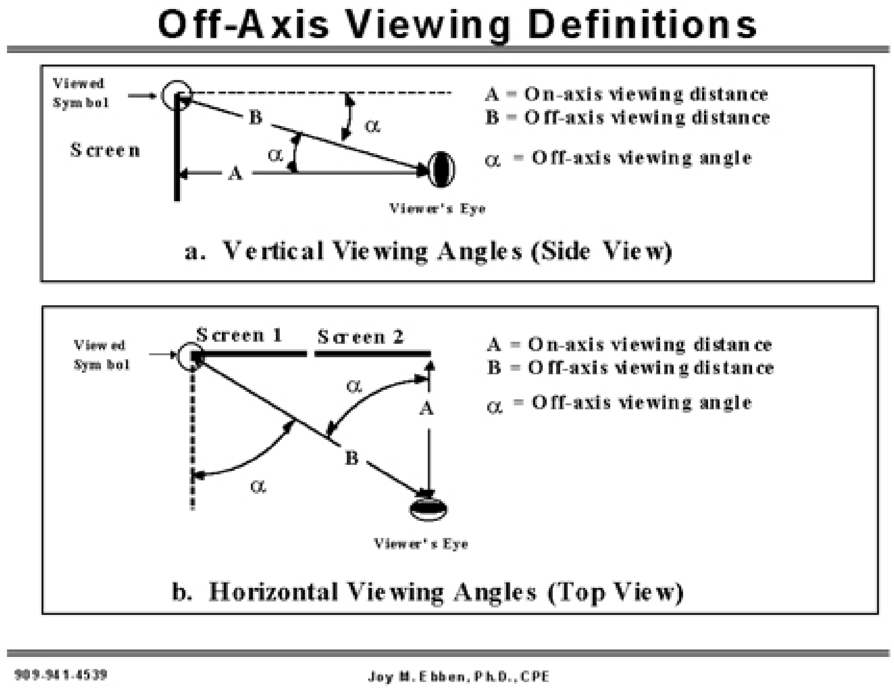

Figure 2

Recalling that all of these computations are based on pretty straightforward triangles like the ones illustrated, once again, in Figure 2, we can understand that the angle a is also an internal angle of a triangle and thus will have a cosine.

If we want to, we can recall that *a cosine of an acute angle in any right triangle is the ratio of the length of the adjacent leg to the hypotenuse*. But we really don't have to know that to solve the equation. Instead we can simply activate the "scientific" calculator that lurks in our computer's Accessories directory and ask it to tell us what the cosines are of whatever angles we wish.

Thus, when we iterate through the off-axis viewing equation for the example we used above (a row of seats 25 feet back from a screen), we discover that the requisite height of a character increases as is plotted in Figure 3.

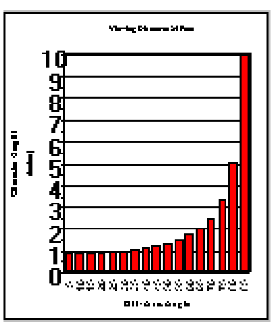

Figure 3

Slight increases are necessary when the angle is small, but by about 30º, the .88 inch symbol height has surpassed 1 inch and by 45º, the growth accelerates even faster, exceeding 2 inches by 60º. Even though this is fairly intuitive, it is extremely helpful to see exactly how the relationships between the variables may be controlled.

That leaves us to discuss that mysterious exponent,**K**, in the second equation. Interestingly enough, it turns out that the human eye doesn't respond to the demands of off-axis viewing exactly according to the cosine law. Instead , it does just a little better than that. Thus **K**, which we'll call the human compensation factor, is actually equal not to 1, but to about .9.

On the other hand, Dr. Joy Ebben, who was one of the first to work all of this out (and to whom we are indebted for Figures 1 and 2), is cautious about letting the **K** factor influence her design calculations. It's true, she says, that the eye performs a little better than you think it will at large angles; but relying on that fact removes even a modest fudge factor from both the computations and their outcome. Thus, she counsels, let K = 1. (It certainly makes the calculation easier.)

Large viewing distances and large viewing angles combine to make small characters unreadable. That much we've always known. But, if we are to keep our display systems from failing their purchasers, we now have to know more. Arduous though it may be, the results of a careful and mathematical analysis are now always worthwhile. Indeed, without them, display systems can fail and there could be no end in sight.

Angles Of View

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We have been discoursing over the past several issues about the selection and sizing of fonts. Once we have chosen what appears to be a good face, we then perform some calculations which provide some absolute numbers describing the smallest size one of our projected symbols is allowed to be. Since the variables attending this process are numerous and even a little complex, this article will return one last time to review

The Casting of Characters

If we imagine ourselves positioned in front of a display screen and if that screen becomes filled with projected text, it is easy enough to see that our viewing angles from one portion of the image will differ greatly from another. The word or symbol appearing directly before our eyes may appear quite differently to the woman seated at the other end of our row. And, actually, if we stop to think about it, the area that all of us will have the most difficulty making out is either or both of the display's upper corners. In virtually all audience configurations, no viewer will be positioned on-axis and normal to each end of a screen's top edge. Any information which is projected onto those areas, therefore, will perforce be off-axis to its entire audience.

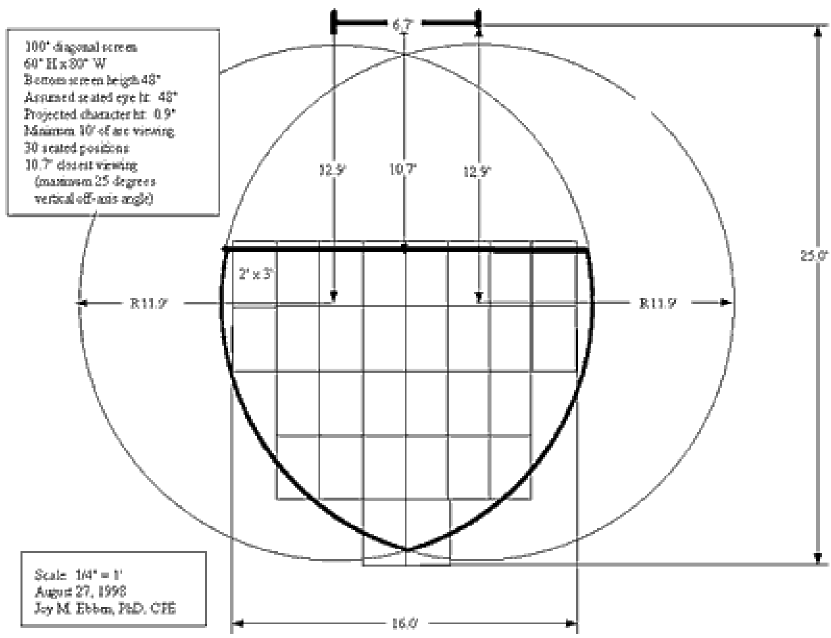

Figure 1

While this seems obvious enough, the thing to notice is that data appearing at those corners is off-axis to viewers in the horizontal *and* vertical planes. To read it, every one of us has not only to look to the side but has also to look up. And while we have learned to figure out how to accommodate for off-axis viewing in one dimension, what are we going to do about two?

Whatever we do, it's certain that we must ensure that each corner's data is projected large enough so that it can reliably be read from every seat in the house. And, of course, our answer for the upper corners will resultantly become the default for the entire display.

Our earlier efforts have taught us the value of requiring a subtended angle of at least 10 minutes of arc for the height of any lowercase character. That has translated, roughly, to mean ¼ inch of symbol height for every seven feet of viewing distance. When the viewing angle is larger than 0º, that ¼ inch or those 10 minutes of arc must consequentially be increased.

To see how these multiple parameters can be blended, let's create the following example: The job we'll concoct requires that we position an audience of thirty people before a 100-inch diagonal screen. We will further assume that the bottom of that screen is 48 inches off the floor and that the eye height of the average seated viewer is also 48 inches. Lastly, we will insist that the height of all lowercase characters subtends at least 10 minutes of arc on the retina of every viewer.

The two questions we want to answer are 1) How big should the characters on the screen be? And 2) If we assume an area of 6 ft² for every chair, how can we best configure the audience? The solution to this problem pops neatly out of some algorithms used by Dr. Joy Ebben (phdjoy@aol.com) and is graphically displayed in Figure 1.

To see what's happening here, notice first that the center of each of the two circles is exactly perpendicular to an outer edge of the screen. Each circle demarcates the floor area from which one upper corner of the screen can reliably be read. The area comprising the intersection of the two circles (outlined in *bold*), of course, works for both circles and is where we want to fit our seats.

Eye and Head Rotation

• Eye Rotation Only
— Optimum: 15° left - to - right
— Maximum: 35° left - to - right
— Optimum: Parallel and down 30°
— Maximum: 25° above parallel; 35° below parallel

• Head Rotation Only
— Optimum: Straight ahead
— Maximum: 60° left - to - right
— Maximum: 50° above and below parallel

• Eye and Head Rotation
— Optimum: 15° left - to - right
— Maximum: 95° left - to - right
— Optimum: Parallel and down 30°
— Maximum: 75° above parallel

Source: MIL-STD-1472D
909-941-4539
Joy M. Ebben, Ph.D.,CPE

It is interesting and perhaps a little counterintuitive to note that the front row is very much wider than the last but the discrepancy becomes immediately explicable when we consider both the viewing angle and the viewing distance to the edge of each row. The distance to the front row is calculated to keep the largest vertical viewing angle to not more than 25º. Dr. Ebben tries always to keep eye and head rotation within the limits presented in Figure 2.

Next we come to the character height of 0.9". If you play around with the math, you'll discover that this height is actually larger than necessary (by which we mean larger than 10 minutes of arc) for most areas of the display and for most seats. But it is *not* too large for the upper corners of the screen and, as we said earlier, it is those "worst case" areas which must govern.

Finally, it may be useful to indicate just how we can ensure that our projected characters will in fact stand at least 0.9" tall. As we sit before our computers, fine tuning the presentation we are about to make, is there a way to adjust our settings such that when our materials get put through a projector and up onto the screen they will meet our own standards? Fortunately, there is.

If we know that the height of the lowercase letter "x" must (in our example) be 0.9" high when displayed on a screen which is 60 total inches high, then we know that each "x" must be 60 / 0.9 or 1/67th of that screen height. Now we look at our computer monitor and recall that our projector will put up exactly a screenful of its contents at any one time.

Therefore, all we have to do is adjust our computer's point size setting until the "x" we see on its monitor is also 1/67th of *that* screen's height. The monitor on which this article is being written, for instance, has a viewing area height of exactly 9 inches. Dividing that number by 67, we get an "x" height of .134 inches which means that a lowercase "x" ought to be set at 14 points (in Times New Roman) and hence this high: x.

Please note that these proportions may not look right on your monitor and they certainly won't be right on a printed page because the latter contains more text than a monitor's screenful. Still, if you get a plastic word processing ruler, with scales on it that go down to at least 1/10th of an inch, you should have no difficulty measuring either your own computer screen or your client's.

The case for font and character control now rests. Its summation stresses the importance of its details. We have looked (in some depth) at many of the criteria which distinguish one font from another and we have examined (at some length) the sizing of projected symbols and the positioning of viewers expected to read them.

We do this work because we care about the quality of the display systems our industry delivers. Since the product of those systems is information, surely we, their creators, are obliged to be similarly informed.

Angles Of View

Vol. IV, 10 ©Da-Lite Screen Company October 1998

A cause for certain satisfaction in our industry is the increasing appreciation among our customers of the advantages and benefits of rear projection. This bright outlook has its dark side, however, because of the misconceptions and uncertainties regarding the techniques and equipment available for compressing rear projection systems into areas of the smallest possible depth. Perhaps no other issue risks so much misunderstanding and ill will between manufacturer and dealer. Let us, then, once more go into the projection booth and look into

Mirror, Mirror - Behind the Wall

Times are good; your business is booming. Your favorite projector manufacturer has just shipped you his latest and greatest machine and, sure enough, it actually is lighter and brighter than the other guy's. Better yet, you've got a client not only anxious to install it, but to install it in a Commercial Mirror System behind a rear projection screen both of which you'll also get to sell her. Does it get better than that?

Wind the clock forward a couple of weeks. The gear has all shown up right on time and your installer's over at the job site, finishing the set up. Then your phone rings and you're told the image through the screen doesn't look right. Maybe it's not square, or maybe a part of it doesn't seem to be in focus, or maybe it's not exactly filling the screen, or maybe a long list of other things; none of which is good news.

Then the client calls, reminding you of that meeting she has scheduled for first thing tomorrow morning and recalling for you just how much you're making her pay for all this high tech stuff and, "What do you *mean*, there's something wrong with my image?"

Not a pretty picture, is it? But the better question is, how do we fix it? Still better one is, how do we avoid it in the first place?

Let's take a typical application and go through it together, step by step. Let's assume that the screen size we need is six by eight feet and that the projector we're going to use is a single lens LCD device.

As we have stressed elsewhere, the very first thing we should do is determine where we want to place our screen in its wall. Second, we position our projector behind it as though there were no space constraints of any kind. These two decisions should in no way be influenced by our knowledge that we'll need eventually to use mirrors.

How high the screen should be off the floor depends only on its spatial relationship to its audience. The positioning of the projector relative to the screen on the vertical axis is dependent on two (but only two) factors.

The first and dominant of these is whatever off- axis limits are imposed by its manufacturer. How much flexibility does this particular projector permit us in moving it up or down from a direct, on-axis orientation to the screen while still maintaining a rectangular image that has four 90º corners?

Some projectors can't (or won't) make such a square image if their orientation is dead normal (0º) to the screen. They expect instead to be positioned off- axis such that they point either downwards (with their feet pointing toward the ceiling) at screen center or upwards at it (with their feet toward the floor). Whatever the case, it is essential to understand that whatever may be the positional constraints for each projector, they must categorically be observed and respected. Mirrors cannot *ever* be used to override these limits.

The second factor, however, determines where the projector should be placed within the limits imposed by its manufacturer. Even single position projectors can be mounted either with feet to the floor or, inverted, with their feet to the ceiling. Here, the decision should be made such that the center most light ray emanating from the device is aimed (as nearly as possible, anyway) through the center of the screen directly into the audience's eyes. Once that optimal position has been identified and established then, but only then, are we ready to look at mirrors.

Let's examine first Figures 1 and 2. They outline the orientation issue discussed above. The first figure shows a projector positioned normal to a screen. The second is placed such that it is shooting downwards with its feet toward the ceiling.

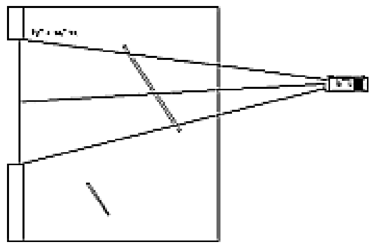

Figure 1

The triangle which has as its base the screen and as its apex the projector is different in each case. In Figure 1 it is an isosceles triangle with the lengths of the top most and bottom most light rays being equal and the center most light ray bisecting the screen at 0 (or, if you prefer, 90) degrees.

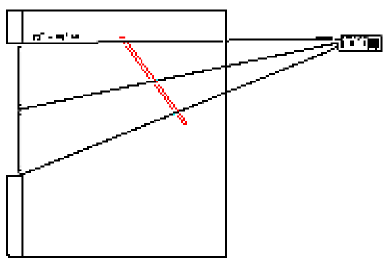

Figure 2

Note that the second (and more typical) triangle is a right triangle and it is the top most light ray which intersects the plane of the screen at 90 (or 0) degrees. The center most ray passes through the screen at one downwards inclination and the bottom most at yet another.

Both of these triangles have been drawn as though the rear wall of the projection booth didn't exist. This is as it should be. Always.

Note that either of these triangles can be transected inside the wall by an enormous variety of lines at a huge variety of angles. Theoretically, any one is as good as another, although some will be longer and some shorter than others. Whatever line we choose, of course, becomes the crease of our first fold and scales to the vertical dimension of the real life mirror.

Thus, Figure 2 becomes Figure 3 and if this first fold finishes with all or even part of the projector outside the box, we'll either have to start over with an alternative fold or we'll have to make a second fold in order to fit everything neatly in.

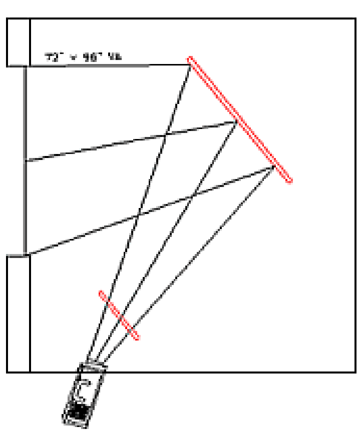

Figure 3

The difficulty with many of the first fold lines that we could draw is that in real life these lines are mirrors which have to be supported by racks. And racks are not nearly so variable. Therefore, we need to understand that an underlying but major constraint of any mirror system is the limited flexibility of its racking configuration.

The uprights of self-supporting rack systems, for instance, need generally to be parallel to and equidistant from the screen. This structural fact severely limits the number of possible mirror sizes and angles. Yes, technically, a rack could be built to accommodate any and every mirror orientation, but such a product line would be wholly impractical and prohibitively expensive.

In the case we have chosen, the final fold looks like this:

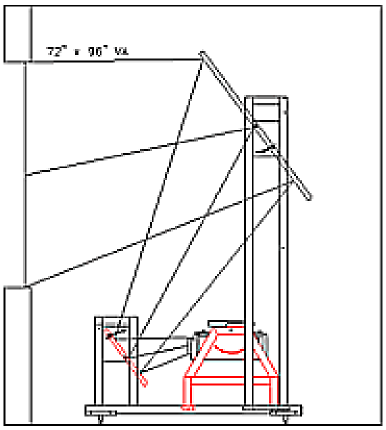

Figure 4

Please look carefully at this drawing. While it's obvious to note that the three lines extending to the screen from the large mirror are *exactly* the same as the comparable three line segments in Figure 2, it may not be so clear that the mirrors have to be set in their racks at angles *exactly* equal to what are shown in the drawing. A moment's further reflection will reveal that the projector must be inverted in its rack and set *exactly* at its specified angle or, inescapably, the image will somehow be skewed.

Anyone who believes that she can correct for a departure from one of these parameters by fiddling in the field with the others is in for serious trouble. No, if the cad drawing you're provided decrees that the angle for the large mirror must be 27°, you can't make it 25° and then "fix" the resultant distortion by fiddling the other mirror and/or the projector. It won't work. Please don't do it. If you do, you'll only blame us, your screen and mirror company. And we're sensitive.

If, on the other hand, you make sure that the entire mirror and rack assemblage is aligned symmetrically with the screen then, yes, your mirror system should indeed be the squarest of them all.

Angles Of View

Vol. IV, 11 ©Da-Lite Screen Company November 1998

The theme which loosely connects the articles presented by this series in 1998 is Information. That subject, of course, is enormous and encompasses many disciplines and fields of study. The purpose here is considerably more modest and seeks only to nibble off a small corner of the larger issue by presenting data relating to the effective display of information as it is likely to appear on a projection screen. Since the basic metrics for assessing the qualities of such images depend greatly on familiarity with their quantitative underpinnings, it may be useful to look anew at

Light Reading - Suggestions and Observations

The amount of human ingenuity expended by our industry in the continuous improvement of what we have come to call Large Screen Displays is phenomenal. Just recall, if you will, how recently it was that a 1,000 lumen projector was beyond the reach of all but the most lavish budgets. And remember when SVGA was a really big deal?

This year a modest budget can acquire a projector with XGA resolution and an output of 2,000 lumens. And next year? Can 1024 x 768 become 1280 x 1024? Absolutely. Can 2,000 lumens become 3,000 lumens? Inevitably.

Because of these shining achievements, there is a question being posed in our industry today which many of us who have been around for a while thought we'd never hear. It goes like this: "I have the Hi-Lite projector model 15C (1,500 ANSI lumens) and I'm pointing it at a Da-Lite 100-inch diagonal screen which has a gain of *x*, and **Is that going to be too bright?**"

For the first ten of the last fifteen years people in the display business worried almost exclusively about doing everything they could to maximize brightness. For the last five of those years, we've come to try to optimize brightness. And now, suddenly, should we concern ourselves with *reducing* it? Amazingly enough, the answer may actually be yes.

The thing to remember about "brightness," of course, is that it is an entirely subjective term. And while that doesn't make the word by any means meaningless, it does emphasize that it has no objective, scientific validity. Even then though, we'll go on including the word in our question, we'll need to revert to other terms if we're to identify a way to calculate whether any particular projector and screen combination can (will) be *too bright*.

Let's start with the projector and recall that, while its ANSI lumen rating may help compare it with other projectors, it isn't by itself enough to answer our question. Obviously, we'll also have to know over how large an area this collection of lumens is going to be distributed. That brings us to consider the size of our screen which in turn brings us to contemplate its surface properties which are dependent on the distribution of the audience. On top of all that is the nature, quantity, and effect of whatever ambient light that will be competing with the image.

Breaking all that down into measurable units requires serially thinking in terms of lumens, foot candles, and foot Lamberts. Since, one way or another, these are all interdependent, let's briefly review their construction.

The most important thing to remember about lumens is that they quantify the amount of power useful to the human eye emanating from a projection device. If we use a photometer to measure that power, we will easily satisfy ourselves that an 800 lumen projector is twice as bright as a 400 lumen device. Now if we take two 800 lumen projectors and "double stack" them so that they are each filling the same screen, what will our photometer read? 1,600 lumens every time.

A misconception prevalent in our industry and erroneously promulgated by the author of these articles has been that double stacking projectors produces *less* than twice as much light. This assumption, we are now pleased to understand, is not true. 1 + 1 does = 2; every time.

In an important sense, however, this lineally additive quality of lumens is true only if the device measuring them is other than the human eye. Our eyes, you see, do not respond to changes in brightness in a straight, linear fashion. Instead, they react logarithmically to changes in their input and thus, for instance, we are able to find our way out of a darkened movie theater, yet continue to see when we emerge onto the brightly lit street outside it.

If we array a human audience before some screen and first illuminate it with a 1,000 lumen projector and then turn on a second 1,000 lumen projector, will the audience see twice as bright an image? No, it will not. The perceived brightness will increase only by about 50%. It will not double.

All this being true, it's awfully hard to predict whether some large number of lumens will (or will not) be too bright or bright enough. To find that answer reliably, we'll need to factor in some other units.

Foot candles are a unit of illuminance. They measure the luminous flux (lumens) per square foot at any point on a surface exposed to incident light. Lux are exactly the same, but per square meter (10.7639 ft^2).

Foot Lamberts, conversely, are a unit not of illuminance but of luminance. As such, they measure the intensity of light per unit area leaving the screen. Foot candles are dependent only on the total amount of screen area and projector output. Calculating foot Lamberts requires both of those variables *and* screen gain.

A projector which outputs 1,000 lumens will cause 30 foot candles to fall on a 100-inch diagonal screen. But if that screen has a gain of, say, 1.8, 30 foot candles in will become 54 foot Lamberts out. (Please recall that, as these articles have been at pains to point out, this is only true because convention calls for the photometric measurements to be made always on-axis to both the projector and screen.)

Even though we now know how to determine luminance, we have still to be careful not to confuse it with brightness. In screen terms, luminance is the measurement of light from a surface while brightness is the subjective appearance of that surface. To drive home this point just one more time, 60 foot Lamberts of luminance will be twice as *great* as 30, but it won't be twice as *bright*.

Finally, we need to look at the last of these ponderables, ambient light. The difficulty here might at first be thought to depend on brightness issues. Actually, the real damage caused by ambient light occurs first in loss of contrast. Since the purpose of regarding information projected at a display screen is the assimilation of its content, we will need absolutely to distinguish the dark portions of the image from the light ones. Much as on this page, what we read is not the white paper, but the black lines of text strung across it.

Still, for reasons which are both reasonable and sound, only entertainment venues should have the luxury of zero ambient light. All commercial display systems have to be able to function under at least some of it. And the difference between the two viewing environments is about to become clear.

Years ago organizations like the Society of Motion Picture and Television Engineers (SMPTE) determined that a reliable luminance standard for showing motion pictures in a dark theater and onto a unity gain matte white screen is about 16 foot Lamberts. As a practical matter, the bright scenes we look at are often as much as 40% less than that but, for our purposes here, let's stick with 16 as an upper brightness threshold.

Now let's go to the TV part of SMPTE's work and see what has been determined as the acceptable upper limit of that technology's luminance. Since we don't typically watch television in a completely darkened room, it turns out that the new number is much larger than 16. It is, in fact, 50 foot Lamberts.

If that number is reliable for your TV, could it not be transferred usefully to demarcate when a projected display may become too bright? This article asserts that the answer is yes. Are there and will there be exceptions? Of course, but they will depend on ambient light levels that are unusual. Otherwise 50 foot Lamberts should be thought of as being, at last, *enough*.

Having so declaimed, let's see what consequences follow for choosing projection screens. In these articles and elsewhere Da-Lite Screen Company has for some years now been promoting the virtues of low gain screens versus the previously fashionable high gain ones. Although that thesis need not be repeated here, a new argument in its favor can now be introduced.

If we take 50 foot Lamberts to be our brightness benchmark and then choose (arbitrarily) a 100" diagonal screen with gains ranging from 1 to 3 and four projectors with outputs ranging from 750 up to 2,000 ANSI lumens, we get Figure 1.

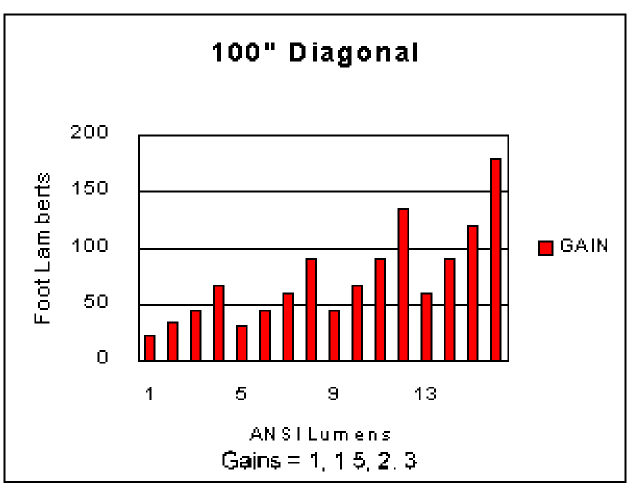

Figure 1

As you can see, 3-gain screens are too bright in every case and 2-gain screens fare only a little better. Yet there are screens for sale out there still boasting gains as high as *five*. Go figure.

Angles Of View

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At Da-Lite Screen Company we try very hard to make screens for almost every purpose, in nearly every configuration, and in almost any size. We do that because we appreciate the enormous number of ways our customers and friends, rely on our products to help create displays of the highest possible quality. One thing we'd like you to help us consider, however, is how the definition of "quality" as it applies to visual displays is changing. With that in mind, let's look carefully, then, at

Presenting Technology - It's Harder than it Looks

When we sit down before a projection screen and await the beginning of the "presentation," what are we looking at? The answer, of course, is a rectangular surface which is from our perspective fairly large but is otherwise, well, blank.

When we prepare ourselves to receive most other sorts of formal visual information, this empty "blankness" is generally not in evidence. We do not, for instance, open a book to wait for the print to swim up out of the page before we can begin reading. The information we seek is already there, passively awaiting our regard.

Projection screens are just the opposite. The information to be written on them is not illuminated by light falling on their pages. It is contained in the light itself. Thus, although there is often text, there is never print. Although there is certainly white space,
there is never paper.

All of us who make up the display industry are right to be sensitive to these differences. They are one way of describing the core question we must be adept at answering: How do you make projected information maximally comprehensible to its audience?

The problem, of course, is that the "V" part of the A/V industry is continually evolving. This is in sharp contradistinction to the "A" part whose essential "content," at least, hasn't materially changed in decades. Technically, the properties and attributes of the human voice (and ear) are extremely well understood and there are wonderfully sophisticated computer programs to aid designers in laying out sound systems for virtually any venue. The same, regrettably, cannot be said for large screen display systems.

If we think for a moment about why that would be so, we soon come to see that the imitative quality of the two representations is really quite different. Sound coming out of a loudspeaker is an analog signal consisting of pressure waves and discernable by our ears. The nature of the signal is identical to the nature of the signal emitted by our vocal cords whenever we speak. The audio trick, if you will, is to deliver the same collection of wavelengths (the speech) to the ear at the same amplitude and with a minimum of extraneous noise (non-speech). Given typical ingenuity and skill, it is certainly possible to create an "artificial" audio signal that is really hard to distinguish from the original.

With visual information, the delivery of the signal is much more complicated because the signal itself is *not* an analog representation of the original. No one, for instance, ever mistakes figures cavorting on a movie screen for real people. But everyone accepts that the speeches the actors are uttering are real sound.

Technically speaking, this difference in signal can be quantitatively
expressed in terms of the bandwidth required to produce it. Audio, at least in terms of the human voice and ear, needs only modest bandwidth, about 20 kHz, to deliver a really convincing signal.

Another way of expressing why this is true is to note that an audio signal need be transmitted in only one dimension: time. The resolution of visual images, conversely, requires at least two dimensions (the horizontal and vertical) and often a third, time. An image displayed by any of the chip driven or CRT projectors will not only be cast at some, precise resolution, it will, even if its content is static, have to be refreshed a minimum number of times each second or, its audience will see it flicker. Just to make sure that an audience won't be distracted by flicker requires a minimum refresh rate of 60Hz (and 72Hz is a lot safer). The total time bandwidth, of course, for a visual signal is hugely greater and is found by multiplying the refresh rate by the number of pixels in the display. Thus an SVGA image needs a bandwidth of something like 50 MHz, or more than 2,000 times larger than its audio component.

With respect to the spatial dimensions of a visual image, resolution is, of course, defined by the pixel density of the device projecting it. If that matrix is 1024 x 768, it's very clear that every single image you put up is going to be divided exactly into 786,432 symmetric and identical pieces. The absolute size of those picture elements will vary according to screen size, of course, but their absolute number will not.

Intuitively, more than three quarters of a million pixels seems like a lot, doesn't it? But let's see if it really is. If the image size is taken, typically, to be 120 inches in diagonal, then the absolute size of each pixel turns out to be .09375 inches square. More usefully we can say that there are about 114 of them for every square inch of our screen.

Now let's contrast this with what we've all been trained to read, a printed page. Its average resolution will be 600dpi (dots per inch) which translate to 360,000 dots per square inch. Even when we scale from a viewing distance of about 24 inches (two diagonals) from a printed page to 20 feet (two diagonals) from a 6 x 8 foot screen, the resolution of the printed information remains 300 times better than the projected data. *Three hundred.*

As an indication of just how enormous this difference is, let's choose as a random example the word *Visibility*. First, we'll allow our word processor to write it Large (36 points) and our laser printer to print it at 600dpi:

is what we get and few would quibble over its quality, much less its legibility. Now let's have a look at how it might appear were it to be projected onto a screen:

It seems almost superfluous and certainly rhetorical to pose the question, which would you rather *read*?

All of these remarks have been intended to illustrate and to emphasize the inherent difficulties in producing a high quality visual display. If the definition of quality is to include functionality (and it certainly must), then we, the display producers, must acknowledge and accept that the technology available to us currently is not nearly good enough to get the job done perfectly. Not yet, anyway.

Computers, of course, are sure to become more powerful. So will projectors. Both will deliver information at ever increasing resolution and density. Eventually the combination will become good enough that the differential between printed and projected media will shrink to less than one order of magnitude. That will be an important day.

Screens, interestingly enough, will not undergo nearly as many transformations. That isn't because people in the screen business aren't innovative (we like to think we are), but it is because many of our products are already completely developed and entirely suitable for the display of the future. It is extremely hard to imagine, for instance, any way in which a Matte White screen can or could be improved. It already really is "the perfect white diffuser."

On the other hand, making sure that your screen is the right shape and size, seeing that it gets positioned properly relative to its audience, and controlling the amount of ambient light affecting it are all of paramount importance to the creation of effective displays.

This series has been at pains to present other issues relating to the control and creation of the best possible visual displays. Not so very long ago, some of those would have been considered arcane and superfluous. Fonts? Character size? Cosines and arc minutes? Should we really have to worry about those sorts of things? Yes; we should. And, as the resolution of the information we're projecting continues ineffably to climb, we must.

One day these issues may in fact vanish. One day the imagery we'll all look at projected onto Da-Lite screens will look just perfect. There will be no more artifacts or anomalies to distract us. We will not be able to tell, looking at the image, what sort of projector is creating it. Nor will we be able to tell the difference between one portion of the picture and another. All that we will see is the only thing we're supposed to see: the information and only the information. Just as when we pick up a book, we do not need to look at either paper or ink, so should the goal of display technology also be:

Angles of View VOLUME V – 1999

A collection of articles presenting various display "Issues for the Millennium."

Angles Of View

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As the final year of this decade, century, and millennium begins, the future of the A/V industry has never looked brighter. That our customers, their markets and their institutions will continue to require information display systems from us is comfortingly certain. Although it will be the computer industry that will create that information, it will be our industry that will be presenting it. The techniques and the equipment available to assist us in that task are evolving at breathtaking rates which are unlikely to decelerate. Many of these new technologies will compel us to ask new questions; few will substantiate old answers. Exploring the more intriguing of these developments is the subject of this series' fifth volume. Among the first of these ***Issues for the Millennium****, we discuss*

New Years' Resolution

In the context of visual displays, here are some of the questions that all of us at Da-Lite Screen Company have been asking ourselves lately.

How bright are projectors going to get?

How much resolution will people be expecting (and expected) to look at?

What aspect ratio (or ratios) will projection screens have to accommodate?

What formula (or formulae) should be used to calculate the size and position of those screens?

What will be the new projection geometries and how will they affect viewing angles?

What screen surface (or surfaces) should be recommended?

At Da-Lite, we believe the answer to each of these questions is not only important, but new. This article will begin to suggest why.

Let's look first at projector output. Industry watcher and astute technology analyst, Gary Kayye (gkayye@kayye.com) has written recently that by the end of 1999 he expects to see "3000 to 5000 ANSI lumens projectors all over the place." We agree; and it won't be too long into the 21st century when double those amounts will become equally ubiquitous.

Now, let's be clear: 10,000 ANSI lumens is a lot of light; more than enough, in fact, to illuminate adequately all but the very largest of screens in the very toughest of venues. Once upon a time (and for a very long time thereafter) brightness was the first and paramount consideration when it came to designing and specifying a visual display. Many, many other variables were subordinated to the brightness issue and properly so. But those days are finally over and, therefore, the first thing we should recognize is that brightness will *not* be an issue for the new millennium.

Conversely, resolution, barely a factor when projectors were in their dim, dark infancy, has grown into an issue whose importance has become inversely proportional to brightness and will soon completely supplant it.

As an issue, VGA (a meager 640 x 480 pixels) meant almost nothing. That modest beginning has been overturned several times and, although XGA (1024x768) is typical today, 1024 x 1368 isn't far off. What will the turn of the century reveal? 2000 x 1600. Count on it.

Now 3,200,000 pixels is a *lot* of pixels; more than enough, in fact, to fill even the very largest of screens. Of course, the overwhelming number of screens that it will fill won't be in large venues, they'll be in conference and training rooms, just like they are now. And for those more modest screens resolution of that density must be managed with the utmost care or the vast new number of trees may completely obscure the forest. Whether, you see, we need the resolution or not to effect our presentations, we're going to have it. Learning to control and manage resolution may possibly be the single largest issue affecting the visual displays of the future. Certainly it is from the vantage point of screens.

Next there's the question of aspect ratios. Scaling through the past, 4:3 has prevailed steadily until recently when "work station" (1280 x 1024) displays became projectable and projection screens with its 5:4 aspect ratio began to crop up here and there. To be sure, the effect of that addition has not been seismic but there is another aspect ratio lurking in the wings which will, all by itself, revolutionize everything. We refer, of course, to 16:9 which not only will stretch all of our projection geometries out of their current shape, but is likely to impose on us its own quite extraordinary resolution of 1920 x 1080 (a prodigious total of 2,138, 400 pixels).

Few, if any, current projectors can actually display that resolution in that aspect ratio today. But they will; and when they do the repercussions on commercial displays will be so profound that all of their consequences aren't yet predictable. But here are at least some of them.

To manage that aspect ratio today most projectors simply "mask off" the top and bottom of their native 4:3 aspect ratio causing, effectively, the "3" part to be reduced to 2.25. Although that change makes the size of the image smaller, it has no effect on the throw distance required to cast that image size nor, really, on the bend or viewing angles that its light rays have to travel to reach the eyes of the audience.

When, however, the 16:9 aspect ratio is native to a projector, then what was once 4:3 will become 5.33:3 which will (must) produce images that are significantly wider (and hence larger). What lenses, with what focal lengths will be chosen is not altogether clear at the moment, but the consequent projection geometry, whatever its details, will definitely be a new issue for the next millennium.

To belabor this point just one step further, consider a screen that is 72 inches high. Its width today is almost certain to be 96. If it's a work station, that width is reduced to 90. If it becomes 16:9, however, the width increases 33%, to 128 inches and its area equally increases from 48 to 64 ft^2.

Brighter projectors, of course, will take care of the larger area. But notice that the bend angle issue nevertheless remains. Viewing angles to the edges of a 16:9 screen will inescapably be greater than they were for the original, 4:3 surface it replaces. How shall we size this new screen? Should we begin with its height and ensure that it be some fraction (¼?) of the distance to a Least Favored Viewer? Probably we should, though we will do well to keep in mind that taller ceiling heights are not likely to be prominent among the virtues of the next century's office architecture. Thus, audience layout and viewing geometries are also issues which will deserve our most careful and new attentions.

Lastly, we come to the issue of what screen surfaces are to be preferred for the displaying of all these forthcoming and wondrous developments. And on this subject, Da-Lite Screen Company is as clear as we are certain. Our overarching precept is that low gain screens are to be preferred to high gain screens whenever possible. There is nothing cryptic about this conclusion and its validity can be established in a few simple sentences. Projectors can create light. New Projectors can create a lot of light. Screens, even new ones, cannot create any light.

In front projection, this is simply yet another way of reenforcing the suitability of Matte White. (True, there are some subtleties here, but they are the subject of another article.) In rear projection, however, the news may be somewhat more startling.
It is our conviction that the first and best rear projection screen surface available today and completely suitable for the future is a Da-Lite Diffuser with a "gain" of only 1. To put it even more baldly, yes, we believe that diffused surface to be superior to all of the lenticulated, profiled screens which we sell.

Now our point here is not to announce that we're excising profiled screens from our product lines. We aren't, we shouldn't, and we won't. There will continue to be applications encountered by all of us wherein a profiled screen will represent the only viable solution. But, looking to the future, we think the number of those installations will diminish.

Once, the great advantage to profiled screens was their gain. Gains of 2, 3, 4 and even 5 were producible from profiled screens without having to pay a hideously expensive price in overall uniformity and viewing angle. But with the sort of lumens increasingly available to us, who needs all that gain anymore? As we have remarked elsewhere, excessive screen gains can actually make a display become too bright for comfort.

That's the negative reason why a 1-gain diffusion screen (DA-100 in Da-Lite's nomenclature) is a better idea. The positive reason is that it possesses unlimited resolution. No profiled screen can say that. All profiled screens, by definition, have a resolution limit that is directly dependent on the frequency of their lenticulations. As the resolution of displays increases, the periodic structure of even very fine pitch lenticulations will become a troublesome and possibly even destructive issue. In contrast, the diffuser poses no such risk.

Another way of thinking about this is to suggest that the life expectancy of any installed rear projection is quite likely to be two projectors and maybe three computers. What we know about two of those devices is that each will be brighter than its predecessor. What we guarantee about all five is that their resolutions will be higher. What we know about the screen is that it must compromise none. And, thus, for the moment, we hope the issue can be resolved.

Angles Of View

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Now that brightness control can reside once and for all where it belongs, in the projector, screens, particularly the rear projection ones, are at last left alone to the job that they do best. But what is that job? And, just how do they do it? Ignoring profiled screens for a moment, what should you look for in a diffused rear projection screen and how can you make sure you get it? The answers to those questions are a little intricate, but they can be seen easily when we come to look at

Da-Lite Diffusion - Making Light Work

Everybody who thinks about it has a pretty good intuitive grasp of how front projection screens work. Basically, you point a light source towards their surface and, one way or another, the light bounces back in a way that lets you see an image. Maybe some of us in the screen business might want to complicate that definition a little (just a little), but even we couldn't argue with it vigorously.

When we turn around and look at rear projection screens, however, our intuition suddenly becomes a good deal less reliable. This is so because we're a bit less sure about what is being done to the light from our source which turns it into the same recognizable image we were just looking at on the front projection screen.

We do know that the process can't involve reflection — there is, after all, no bounce. So maybe it's that other word, refraction; could that be it? Well, no, actually that isn't it, either. Profiled screens rely on refraction, but diffusion screens typically do not. So let's see now, if it's not reflection and if it's not refraction, the only thing left is what we call scatter. But the only trouble with scatter is that we thought it was a process reserved exclusively to matte white front projection screens. And if we just delete the word "front" from that sentence, we have it exactly right.

What is Matte White? It is, well, a diffuser. And what is a diffuser? It's a collection of tiny particles of a white, chalk-like material which has the property of *not* absorbing light. Considered singly each of these little particles has a three dimensional shape which is microscopically irregular and chunky. Furthermore, the orientation of each particle (for example, whether its longest dimension is pointing up or down) is generally random.

The way we make a diffuser out of a whole collection of them is to cause them to become distributed more or less evenly out over the surface of a piece of substrate. Now, lets train a microscope at some arbitrarily small area of the surface and see what it reveals. What we'll discover is a coarse distribution of our particles which will appear as though they were unceremoniously dumped out of a wheelbarrow. They will be strewn irregularly over each other and whatever area we're looking at and no one will have raked them out flat.

Since none of them absorb light, all incoming rays will be bounced off them in directions which often will careen them into other surfaces of other particles from which they will again bounce in any and every direction whatsoever. When this process is integrated over a very large collection of particles being struck by a very large collection of light rays which are bounced around through a very large collection of successive angles, you end up with a surface that scatters.

To recall what we mean by scatter, we can restate that all light emanating from the surface of such a screen (luminance) will be distributed in a pattern which is completely independent of the incident angle(s) of that light (illuminance). Thus, it doesn't matter what your viewing angle is to a Matte White screen, you'll always see exactly as much light as every other viewer, from every other viewing angle. Pretty neat, eh?

Here's a test question: If the preceding paragraph is true (and it is), can you see why a Matte White screen *must* have a gain of 1 and only 1?

Here's another interesting question: Will a rear projection screen with a gain of 1 also exhibit full field symmetric scattering? We'll tell you the answer to this one. No.

To see why, we have only to recognize that a diffuser intended to display a rear projected image must be thin enough that, somehow, light can get through it. Should the light not get through, we'd be back to a front projection screen but since it does get through, we're able to see the front projected image from the back.

Looking back to our microscope for a moment, we see that the particles of a rear projection diffuser are also strewn about on the surface in a random jumble but that the density of this jumble is noticeably less. Projected light rays here also do a fair amount of ricocheting around as they carom off one diffusion particle into another and each incoming light ray is resultantly broken up into a large collection of little light rays (raylets?) which flow onwards in a pattern more or less equally distributed about the direction of their original parent ray.

Some of them, of course, do bounce backwards. That's how come someone in a rear projection booth can easily discern the projected image from the screen's back side. We wish that weren't so, of course. It's inefficient and wastes energy. But, so far, we just haven't been able to come up with particles that are only forward thinking….

It would also be nice if we could find particles with enough integrity to be independently upstanding. Then we could dispense altogether with the transparent substrates whose only purpose, by the way, is to hold the diffusion layer up in space. In every other way substrates are unwelcome and unwanted. Their compositions absorb light (bad) and their back surfaces reflect it (worse). Incidentally, having said that, it is definitely worth mentioning that users should always prefer acrylic substrates to glass ones because their transmission (the percentage of light that does get through) is measurably higher.

Ok; now that we've coarsely established how a rear projection screen works, let's refine our view a bit and determine what makes one diffuser better than another.

The criteria one should always use in appraising any particular screen is the accuracy with which it displays the projected image and the absence of any detectible artifacts of its own. For better or for worse, the attributes which will be most prominently affected by diffusion are Uniformity and Resolution. You don't want to buy a screen whose coating has, one way or another, been put on unevenly. If you do, gain levels throughout the screen will vary unacceptably and the top will be too bright, the center ok, and the bottom too dim, for instance.

You also don't want to buy a screen where the materials making up the diffuser can be peeled away from the substrate. If you do, you'll have bought a diffuser that is optically too thick and your resolution will suffer.

Da-Lite has gone to considerable effort to avoid these manufacturing pitfalls by having completely reconstituted its diffusion chemistry. Ten years ago, for instance, the average diameter of our diffusion particles was equal to those of our competitors' today — 10 or more microns. Since a micron is only one-millionth of a meter, 10 microns may not seem to be many until, of course, they are compared with 5 — the size of our current diffusion particle.

Put simply, this reduction means that the thickness of the Da-Lite diffusion layer need be only half as great as the best of its alternatives. That thinness means that the image plane can be thinner which means that the focus of the image can be sharper.

Any image is "in focus" when all of the light rays emanating from its lens or lenses intersect and converge at some exact distance from their source. This may be thought of as a series of XXXXXXX's where the strokes converge from the bottom of the line and intersect and then diverge and separate for ever after toward the top. If the optical system is intended for projection, the line formed by the intersection of the X's should be straight and, generally, perpendicular to the center most light ray. Thus, if we insert a projection screen along that line, we get XXXXXXX and a sharply focused image will be revealed.

If the screen plane bisecting our light rays is allowed to be too thick, however, its depth will extend beyond the exact point of intersection and it will, therefore, include and scatter light rays which are *not* in focus because they have either not yet reached the intersection point or they have already passed it. The trick, then, is to make a diffuser that's dense enough to scatter a visible image without it being thick enough to be ever so slightly out of focus.

Can you tell the difference if you were critically to compare a Da-Lite diffusion screen with one of our competitors'? From the back row, of course not. But from the front row or from any other vantage point where the system's highest resolution is important? You certainly can. We believe you should. We hope you will.

Rear projection diffusion screens have been relegated to inferior status over the past decade or so. They have had to take, as it were, a backseat to their more illustrious cousins, the Fresnel/Lenticulars. But they need not any longer remain so overshadowed. Projectors, you see, have finally become powerful enough that the brightness advantage and resolution available from profiled screens are just not any longer so clear.

Angles Of View

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If 1998 marked the achievement in our industry of numerous projectors that at last have become bright enough, 1999 will see the commencement of a new trend which will even more profoundly change the way we look at visual displays. After nearly twenty years, the Video Age is about to become the age of High Definition and the new millennium will usher in a world of wide screen, nine by sixteen displays. The implications of this impending format are numerous and non-trivial. As a start at identifying some of them, let's try

Sizing Up 9:16 - The Shape of Things to Come?

We'll want to make clear from the outset that we're not talking about Oprah. Yes, we understand that the force driving this HD business is TV, not A/V, but we still don't think corporate America is going to reformulate itself just so it can get wide screen soaps into its boardrooms.

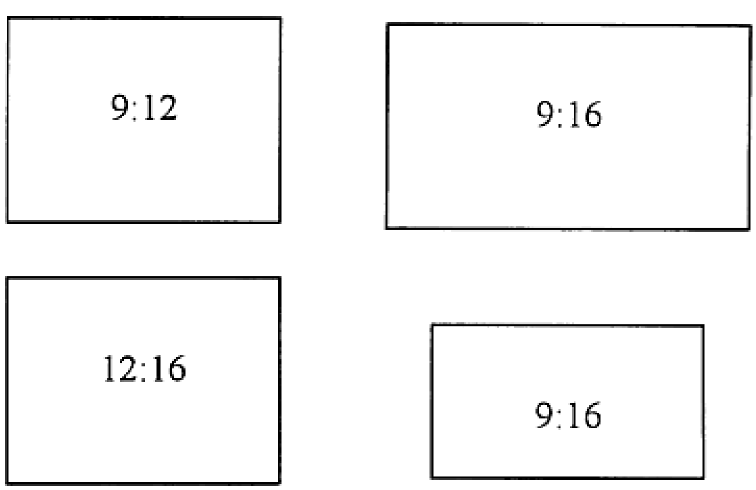
But soon enough the executives leaving those boardrooms are going to go home at night and watch whatever it is they watch on HDTV and that by itself is going to be enough to get them hooked on the wide screen format. They really will be seeing a better picture.

Then, there's the computer industry for which, surely, the shift from the currently crowded 3:4 desktop to a hugely more generous 9:16 should be an irresistible excuse to reinvent itself. Can we imagine Windows 2001 ("A Space Odyssey"?) as the new, 9:16 operating system? Of course we can and, probably, we will. So it's coming, this paradigm shift, and it's coming soon.

Right now, however, it may be worth remembering that all of the research that went into the establishment of the 9:16 format was directed toward the entertainment value of such a larger and wider TV screen. Its very purpose has always been to escape the limitations of the NTSC and PAL resolutions with their inescapable dependance on close-ups and the visually static talking heads. HDTV was invented to liberate television as a medium, enabling it to become epic, panoramic and, finally, as cinematic as cinema itself.

Whether HDTV was invented to display a spreadsheet, a computer graphic, or even a PowerPoint presentation is quite another question. All of those media have been developed to be shown inside a 3 x 4 rectangle and, perhaps, they should have been. Let's have a look.

The four rectangles which follow illustrate the spatial conversions between the two aspect ratios. In the upper pair the height remains the same and in the lower pair it is the width that remains unchanged.



As may be plainly seen, the choice between which dimension to keep constant has a significant effect on the consequent image area. Compared to the area of the original 3:4 aspect ratio rectangles on the left, the upper 9:16 is 33% bigger than its partner, while the lower is 25% smaller.

The first conclusion, then, that we should draw is that all of the new screens we'll have to size and specify had better be wider rather than shorter than our clients' present displays. Whatever our customers are writing up onto their current screens can't possibly be more legible when projected onto a new surface that is *smaller*.

Then there's the question of resolution. The pixel density of an HD image is expected to be 1080 x 1920. Let's give that resolution to both the right rectangles pictured above. Then, let's imbue the two left rectangles with XGA resolutions of 768 x 1024. Now let's load all four screens with an imaginary spreadsheet. On the two XGA screens the cell matrix should be about 10 columns by 30 rows. At the much higher resolution of the two right screens, however, the matrix is likely to become 18 columns by about 40 rows — which are a whole lot of additional data packed into the 9:16 displays and which are *not* dependent on absolute screen size.

That last point is crucial. Because both right-hand screens have the same aspect ratio and resolution, they will each contain the same data, even if one is a lot smaller in overall area than the other. And while in other contexts that observation is perfectly obvious, it is emphasized here so that we can explore how best we might establish rules for trying to ensure that the 9:16 screens we'll all be specifying are, in fact, *big enough*.

If a good rule of thumb for commercial, 3:4 screens is that their height should be at least one-sixth of the distance to their Least Favored Viewers, the guideline for sizing 9:16 screens is easy enough to suggest. Instead of one-sixth, make the screen's height equal to one-fourth of the distance to the LFV. This has the effect of reducing the audience's viewing distance which is perfectly appropriate given the enormously higher available resolution. Makes sense, doesn't it?

Unfortunately, there are two serious problems with this dictum and neither can safely be ignored. The first is ceiling height. If the old screen was 6 feet high by 8 feet wide and the edge of the back row was 36 feet back, then we're only barely fine in a room with a nine-foot ceiling. Our screen bottom is only a barely acceptable three feet off the floor (44 inches is much better).

But now when we upgrade to a 9:16 display and we go to our new, ¼ rule we see the new screen's supposed to be nine feet tall. Tilt. Ironically enough, the resultant enlarged width (16 feet) generally won't be a problem. We will have space for it, but all to often we won't have space for the optimum height.

The second problem has to do with what we call bend angles. To illustrate it, let's suppose that you're seated opposite the right hand lower corner of a 6 x 8 screen and you're looking at data being displayed on the upper left hand corner. If your chair is eight feet back from the screen, the angle through which the light containing that upper left data has to be bent to get into your eyes is, roughly, 120º.

Now let's swap out the 72 x 96-inch screen and put in one that measures 72 x 128. To reposition yourself such that you're opposite *its* right hand lower corner, please note that you have got to get up and move 16 inches to your right. And, the data in the upper left hand corner will also move a corresponding 16 inches to your left. Now, for simplicity's sake, let's assume that the throw distance requirements of your new projector are unchanged from your old and that, therefore, all incident angles to the screen can remain unchanged. The new bend angle still increases to 125º.

You could correct for that shift, of course, by moving farther back from the screen but, if you did that, you would effectively nullify all that extra resolution which your new projector is providing. The point here, then, is that higher resolution and closer viewing distances are inextricably linked. And, thus, if you cannot increase screen height because of too low a ceiling, what you can (should?) do is move your audience closer to your not taller but definitely wider screen.

How do you calculate how much closer? Well, here's one idea. Harkening back to the rectangles above, we now see that it is the upper pair which interests us. At XGA resolution, the number of pixels available per unit area on the 3:4 screen will be 7,282 (768 x 1024 = 786,432 ÷ [9 x 12 = 108] = 7,282). On the 9:16 screen, however, that number is 14,400 or, effectively, doubled. If the unit area was 1 ft², that would mean that each square foot of the right hand screen would contain twice as many pixels as are contained in each square foot of the screen on the left.

If, as viewers, we're going to take advantage of that major increase, obviously we've got to be able to see it. But does that really mean that we should move ourselves twice as close to the new screen as we were to the old? In the example given above, would we really want to end up seated only four feet back? (Incidentally, if we did, guess what *that* bend angle would be. 140º!)

The problem with all of these speculations is that we are obliged to make them because we are not using the 9:16 aspect ratio and its resolution for what it was designed for. We are not looking to be entertained. We are trying to read information. With that thought firmly in mind, we might ask when's the last time anybody tried to read something from a viewing angle greater than 60º? And who, in fact, would want to?

What we've been taught our whole lives to read generally has an aspect ratio that's a whole lot closer to 8½ by 11 than it is to 9 by 16. Yet there is an inevitability to the new format which is going to prevail. At Da-Lite Screen Company, we have always welcomed change and the impending arrival of this revolutionary aspect ratio will be no exception. But we think that some of its implications are tricky and we invite you to join us in puzzling through them.

Angles Of View

Vol. V, 4 ©Da-Lite Screen Company April 1999

The television and video worlds have been talking about HDTV and its 9:16 aspect ratio for so many years now that the rest of us may be forgiven a little skepticism and a lot of impatience. Yet, finally, it appears that HDTV really is on the horizon and 9:16 displays really are about to become widely known. But, what is it about 9:16 that makes it so special? Why, for instance, aren't the screens for the future going to some other aspect ratio, say 9:17 or 8:16? The truth is that a great deal of very careful work went into figuring out this aspect ratio and its properties. It may well, therefore, be useful to continue

Looking at 9:16 - In the Background

Although the concept of HDTV first acquired currency more than 30 years ago, the path followed by the development of its technology has been anything but straight. Nevertheless, although quarrels over precise definitions and standards abounded in both the national and international communities, the overarching conceptual goal was always clear. Television was to be made over so that it could look like the movies.

Three decades later and at the end of the millennium, display and presentation technologies parallel to television have become so powerful and sophisticated that there is little question that realized HDTV will have applications far wider than solely the broadcast industry. Obviously, the most prominent of these collateral businesses is the computer business which not only has lots of ideas of its own about High Definition but almost certainly has designs to subsume television itself.

Having said that, it is worth noting that the original thinking that went into both conceiving and defining HDTV paid no attention whatsoever to such extraneous and, at the time, superfluous concepts as data display. Instead a group in Japan called Nippon Hoso Kyokai (NHK) set out in the late 1960's to figure out just what it would take to deliver an entirely "new viewing experience" to television watchers. In pursuit of that goal, NHK arranged that a large number of technically untrained viewers were shown a broad variety of electronic images whose parameters were made to differ greatly, one from another.

Much of this work was repeated in the United States and Canada during the mid-90's. Even if the methodologies were disparate, the conclusions of both data sets were convincingly similar.

In the United States, for instance, a lot of research was undertaken to establish that Americans tend to watch their television sets from a distance of about ten feet. Nowadays, with larger, direct view CRTs readily available, that number may be reexpressed as equivalent to 7 screen heights, but the idea is unchanged. The point to see here is that at such a distance most of the limitations and artifacts implicit in the standard NTSC signal can't easily be noticed.

On the other hand, the "window" through which we look at a televised world is only about 10º wide. Lurking within this constriction is one of its primary determinants: resolution. With only 525 lines to work with, NTSC (625 for PAL and SCAM) doesn't do a very good job of furnishing much detail in shots which we would describe as being wide-angle. It needs instead to rely on its ubiquitous close-ups.

Thus, when it comes time to establish what a better, less limited picture would be, we can recognize that the new format's size and shape will be inextricably dependent on its resolution and vice versa. Let's unbundle the two for a moment and see how the HDTV standard emerges from both.

From the point of view of viewing angle, the worst thing about 10º is that it fails almost entirely to include peripheral vision. In contrast, even a modestly sized movie screen subtends closer to 30º of our visual field and is thus very much more a compelling and involving visual experience. When we come to transfer that angular relationship out of the cinema and into the living room, we discover that, at a ten-foot viewing distance, the screen has grown in height from something like 17 inches to more than 36 inches.

When we take those 36 inches and multiply by the HDTV aspect ratio of 1.777, we get a width of just more than 64 inches. And, to bring the analysis full circle, an image 64 inches wide at a viewing distance of 10 feet subtends almost exactly 30º. What is consistent between the two televisions is importantly neither their size nor their shape; it instead is their expected viewing distance — the same living room friendly 10 feet.

Of course, the new screen is a whole lot bigger (to say nothing of wider) than the one in our old TV and so our ten feet is no longer 7 picture heights back, it's a mere 3.3 picture heights. And, at only 3.3 heights back, we're going to have no difficulty at all detecting the evident coarseness of the old, NTSC resolution.

Quite a number of previous articles in this series have discussed the resolution of visual displays extensively. Except for occasional cavils, the position advanced in those pieces was that more resolution is generally preferable to less. The developers of HDTV, however, approached the resolution question somewhat differently. Once again, they started with viewing distance and concluded, perfectly reasonably, that the sensible limit for the resolution of their display was at the point where the eye is able just to make out the finest details in its picture. More resolution than that, they saw, would just be profligate.

The optimal viewing ratio, then, is formed by relating viewing distance to picture height. Why height and not width? Well, it turns out that "the discernable detail [of a television picture] is limited by the number of scanning lines presented to the eye and by the ability of these lines to present details separately."[1] Obviously, not all the smallest details (by which we mean one pixel's worth) in a TV picture are going to fall within a single scan line. Some are going to overlap into two scan lines and when this happens, of course, some vertical resolution is inevitably lost.

To see why this effect is important, we need to review briefly that there are two distinct ways in which those scan lines are written, interlaced and progressive. If the vertical resolution of a system is, say, 1080p (for progressive) it means that the raster starts at the top of the screen and, like a typewriter typing single spaced, scans across line 1, then 2, 3, 4 … all the way down to line 1080 before zipping back to the top of the screen to start again. If, however, the vertical resolution is given as 1080i (for interlaced), it means that the raster starts at the top of the screen and, like a typewriter typing double spaced, scans across lines 1, 3, 5 … down to line 1079 before zipping back up to the top of the screen to start typing the even numbered lines 2, 4, 6 … 1080.

For reasons having to do with bandwidth conservation, conventional (NTSC) television is interlaced. For reasons having to do with maximizing resolution, computer displays are generally progressive. Although both scanning schemes result in some loss of vertical resolution (typically about 30%), interlacing is worse (about 50%).[2] It had been an early goal of the HDTV developers to do away with interlacing, but, at some scan rates, it remains, for technical reasons, within the finalized standards.

After studying lots and lots of alternatives (both interlaced and progressive), the Japanese NHK group concluded "the preferred distance for viewing … their system has a median value of 3.3 times the picture height, equivalent to a vertical viewing angle of 17º."[3] For that ratio, it was found that just more than 1,000 scan lines were optimal.

The rationalization of the width of the HDTV aspect ratio emerged from somewhat different considerations. The movie industry had more or less invented the widescreen concept as a way of fending off what it initially viewed as television's threatening encroachment of its central position in the entertainment industry. Film, of course, is an analog medium and, therefore, has symmetric vertical and horizontal resolution. When you stretch it horizontally, however, its resolution in that dimension is proportionately diminished. The widest of popular film formats, CinemaScope, reached the limit of this stretch and was 2.35 times wider than its height.

Again, for reasons of bandwidth considerations, the developers of HDTV chose not to go that far and settled instead on a width that was 1.777 times the height. This translated to a 30º horizontal viewing angle at a viewing distance of 3.3 picture heights. Although 30º is only about 20% of our horizontal visual field, it happens conveniently to cover the area of the field "within which most visual information is conveyed."[4] Thus, the 9:16 format came to be.

Throughout the genesis of HDTV and 9:16, one thing has remained admirably clear: this technology has been designed around the programming and not, as has so often been the case in the past, the other way around.[5] As we prepare to welcome this new format into our A/V world, however, is not the exact reverse the case?

[1] Whitaker, Jerry, DTV: *The Revolution in Electronic Imaging*, McGraw-Hill, 1998. p. 71.
[2] ibid.
[3] ibid. p. 72
[4] ibid. p. 73
[5] ibid. p. 43

Angles Of View

Vol. V, 5 ©Da-Lite Screen Company May 1999

The two preceding articles in this series have discussed the importance and some of the history which inform the forthcoming change in display appearance from 3:4 to 9:16. Although it is surely not possible to predict all (or even most) of the consequences of this transformation, there do remain a few other observations which may usefully be made. Certainly all of the industries currently involved in the creation of every sort of visual display are anxious that we join them in

Approaching the Superhighway - Bit by Bit

After several months of thinking about the extent to which HDTV is likely to influence the A/V industry, only two things are perfectly clear. One is the aspect ratio itself. It does appear certain that the next millennium's first generation of screens will indeed be 9 by 16. The only other fact that seems incontrovertible is that the content to be projected on those bigger screens is going to be digital.

At first glance, that second observation may not seem like much of a big deal. All of us involved with data display have been looking at digital content for years. Digital, after all, is really all that computers do. But there's also an awful lot of video being projected throughout our industry and it hasn't so far been digital, it's been analog.

High Definition, the HD of the HDTV acronym, was a properly descriptive phrase for an aspiration whose foundations lie in the imitation of film. Thirty years after the laying of those foundations, however, the aspiration has been importantly refined and the new, more descriptive acronym has become DTV—standing, of course, for Digital Television. The distinction between the two concepts is important and bears some elaboration.

In the beginning, what was wanted was some way to transmit over the airwaves a signal that would contain a lot more information than was possible with the broadcast bandwidths assigned to conventional TV. Doubling up channels, for instance, might well have worked technically, but was considered highly unpalatable by the stations and their finance departments. Two programs with two sets of time slots for two sets of commercials were always superior to one with one. And so HDTV foundered and stalled and never really got off the ground until more than 20 years after people first began to think about it seriously.

But when adjacent industries began to demonstrate the enormous advantages of digitizing their media, the way to making HDTV real finally become apparent. This article is neither competent nor interested in establishing definitively whether digital was the egg or, just as plausibly, the chicken that will finally hatch HDTV. But we are interested in emphasizing the profound consequences of the connection between them.

Just consider, for instance, that the Advanced Television Standards Committee has authorized something like nine (9!) scanning frequencies ranging between 34 and 64 kHz some of which are progressive while others are interlaced. While dealing with each may be an electronic challenge, the fact is that the digital television set will have to deal with them all. "Every DTV appliance must decode multiple formats and figure out how to scale the results properly for optimal presentation on the local display."[1]

In the training or boardroom, this multi-scan flexibility is much less daunting for the display device because there is much less sensitivity to its cost than there will be in the living room. Furthermore, the A/V world is already familiar (if not always content) with multiple sources and multiple resolutions. Still, there is much ballyhoo being made about the imminent confluence of multiple technologies within a single device. Computer, Internet Browser, and TV are all supposed to meld together into a common interface which can be exploited both in the workplace and at home. If this actually transpires (and it may, it just may), the lingua franca of all the disparate media will, most assuredly, be digital.

When information of any kind, audio or video, is converted into nothing more complicated then a long series of 0's and 1's, or Ons and Offs, the degree to which it may be shared, duplicated, or transmitted is virtually limitless. A zero from your computer contains the same exact bit of information as a zero from your DTV.

Digital television, then, "is nothing more than a transmission standard that modulates an analog signal in a manner that allows digital bits to be transported, and a transport protocol to identify the syntax of these bits and the content they carry."[2]

Thinking about this in terms of A/V, it will mean that all of the media our customers wish to manipulate and from which they wish to glean information can (will) be converged into a purely digital format which, most interestingly, can (will) be quite independent of its resolution. Having said that, it must be acknowledged that a device's or a system's highest, uncompressed resolution will always be limited by the hardware making it up. If the chips in your projector have a horizontal pixel count of 1280, for instance, you're not ever going really to see imagery whose horizontal resolution is 1920. But that doesn't mean you can't read information that arrives in that much denser form.

If you believe all this and if you accept that our customers in only a few short years will be demanding that their systems be 9:16 capable, what, if anything, should you be doing differently now?

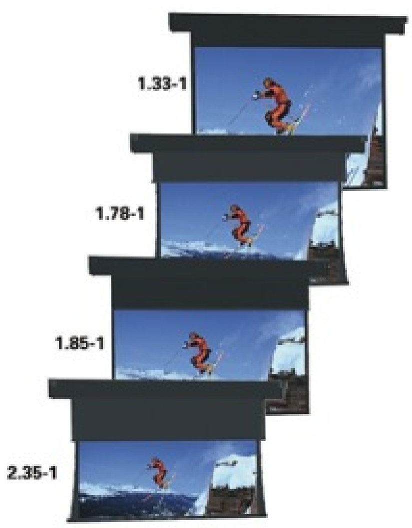
Robert J. Haroutunian, of PPI Consulting in Washington, D.C. (rharoutunian@worldnet.att.net), is someone who has given a lot of thought to this question and he believes that, at least in terms of screen selection, the issue depends on the length of his clients' leases. "If they're going to occupy the space for at least five more years and particularly if their system is rear projected, I am insisting that they put in a screen that is 9:16," he says.

"Since we know that the shift to 9:16 is federally mandated to occur by 2008, I am absolutely certain that the format will be required in the corporate boardroom well before that. To specify 3:4 screens today, therefore, only exposes the client to needless expense and inconvenience tomorrow, when the widescreen format will have become the standard," he continues.

Scott Walker, of Waveguide Consulting, Incorporated, in Decatur, GA. (Scott@waveguideinc.com) agrees. "We are specifying most of our screens as 9:16 these days," he says, "even though few current video projectors are truly 9:16 output devices. But, within the next few years, I expect they'll be plenty to choose from. In the meantime, it is critical that room geometry, sight lines and, consequently, projection screen specifications be considered with this evolution to 9:16 in mind. The *change* is happening and it's happening very quickly."

"It is remarkable to me how many executives who only a few years ago were afraid to touch a touchscreen have now bought themselves elaborate home theater systems and are resultantly telling us they expect their new presentations spaces to be fully widescreen compliant," he went on. "Once they see it [9:16], it's very difficult for them to imagine not designing their new space with this capability."

Still, both consultants and numerous of their colleagues acknowledge that today there are limitations with respect to what can be projected onto a 9:16 screen. In an effort to bridge the gap between a present and future aspect ratio, Da-Lite has developed a front projection screen system which we call the Horizon Electrol®.



This product, which may be ordered with any surface and can be tensioned, comes with a built-in electric masking system which, at the touch of a button, causes the viewing area of one format to convert exactly to the viewing area of any of three others. As shown in Figure 1, the preset aspect ratios are 1.33: 1, 1.78:1, 1.85:1, and 2.35:1. Currently, the largest screen width available in this model is 160 inches.

By default, Da- Lite ships each Horizon so that the four aspect ratios maintain spatially identical centers. This means that the projector creating all four images need not be physically adjusted as it electronically shifts between one aspect ratio and another.

Should, either presently or in the future, a projector be chosen which does not maintain symmetric centers but, for instance, instead maintains the bottom edge of each image at the same height off the floor, the Horizon can be reprogrammed in a few easy steps.

As a close, then, to the present discussion of 9:16, we can predict that with the imminent inception of all- digital displays, our customers really will be able, finally, to byte off more than they can view.

[1] Birkmaiier, Craig, *The Future of Digital Television, Part 1: September1998 - Are You DTV Ready?*
http://www.digitaltelevision.com/future1p.shtml
[2] ibid.

Angles Of View

Vol. V, 7 ©Da-Lite Screen Company July 1999

One particularly welcome consequence of the advent of readily available high-brightness projectors is that designers are now able to choose just how much "brightness" they want for any particular system. Of course, the very existence of this flexibility requires that the specifier have a clear understanding of just what factors she should consider in order to make her selection the best one. As an effort to help with that process, this article examines some of the parameters we can look at

By Different Lights - Contrasting among Brightness Levels

Let us begin by considering the most ubiquitous light source of all: the light which everyone in our industry reflexively calls "ambient." All of us have seen it (in fact, you're reading by it right now), but fewer of us have ever looked at it carefully. In a way, the most common things that can be said about it have to do with what it isn't rather than what it is.

The first of those negative definitions is that ambient light is *light that doesn't come from the projector*. The second is that ambient light is *not direct light*. Thus, we would not call a floodlight pointed at a projection screen an "ambient" light any more that we would describe as "ambient" the light of the morning or afternoon sun shining straight through our window.

While those two exclusions from the definition are helpful in refining our sense of the phrase, the collection of light and lights which is left remains large and amorphous. To name just a few obvious ones, there are flourescents recessed in our ceilings, incandescents on tables next to our chairs, or mercury vapor lights glaring above our trade shows. Fortunately, the exact nature of these light sources, their wavelengths, etc., is not nearly as important as are their location and their intensity (amplitude).

Lastly, we come to name the most dominant attribute of ambient light and this is its presence. To all intents and purposes there is one and only one venue in which ambient light need play no part and that, of course, is the entertainment venue. When we go to the movies or settle down in our home theater, the only thing we want to see is what's on the screen and so we watch it with all the other lights *off*.

In all commercial venues, however, at least some of those ambient lights must, should, and will be left on. None of our commercial customers should either be asked or ever be willing to interact with their visual displays in zero ambient light. If we recall that the business of those displays is the presentation of important information to groups of viewers arrayed before them, then it's not at all difficult to see that the process is most effectively accomplished with the lights on. Reasons supporting this truth are so well established that they are hardly worth repeating. Ambient light enables taking notes, facilitates watching presenters, and discourages falling asleep, to name just three.

The value, then, of ambient light to users of professional presentation systems is easy to establish *qualitatively*. The problem comes when systems designers attempt to establish the same value *quantitatively*. The specified light source, the projector, comes with its quantity of light output measured in convenient units and clearly marked. These days 1000 ANSI lumens can reliably be assumed to be exactly that.

But what about the ambient light sources? How can we know or how can we learn what their values are? Actually, this question is a little more simple than it might at first appear. The good news is that we really don't care how much ambient light is permeating through a room. We only care about how much of it is falling upon the surface of the screen upon which we will want to project our information.

It really doesn't matter how much light is falling upon our desktop, for instance, because when we lift our heads and direct our gaze toward the screen which is in or against the wall across the room, the desktop is no longer within our field-of-view. Fortunately, it is not physically possible to look at both simultaneously.

Yet some amount of the ambient light filling our chamber *will* inescapably reach our screen where it *will* have a negative effect on image quality. And, as we shall see below, it doesn't take much.

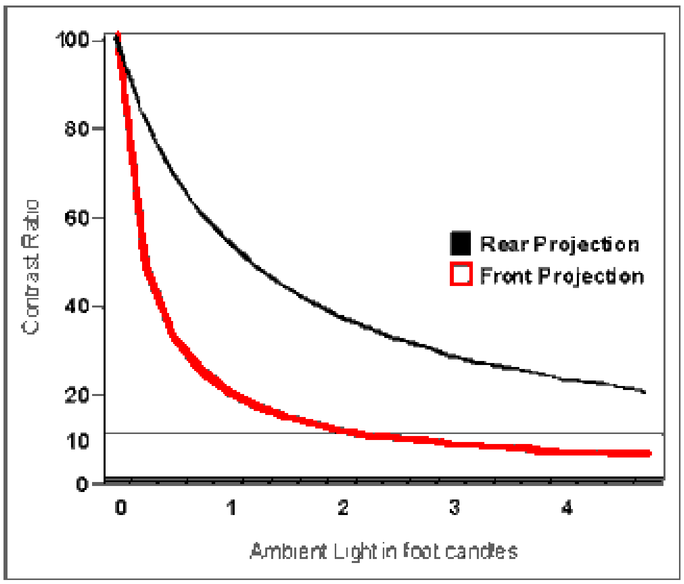
Now, since ambient light is a fact, and since even if we design the lighting in our room very, very carefully there will still always be some amount of it incident to our screen. The only other light source available to our manipulation is the projector. How do we choose, now that we can choose, among the excellent variety of lumen outputs currently available to us?

In an earlier article [Vol. IV, No. 11], we observed that 50 was a kind of upper threshold number for brightness and that if a screen were, in fact, to exhibit a luminance level of 50 foot Lamberts, it might actually be too bright for all but unusual environments. While that guideline remains useful, it turns out that there is a considerably more refined methodology for balancing among competing light sources in a system design.

One of the very best seminars offered at Infocomm '99 was given by Dick Blaha (blaha@mitre.org) and was entitled *Effective Application of Display Technology*. During that part of his presentation which dealt with Contrast, Mr. Blaha maintained that the design goal for a display system's Contrast Ratio should be "at least 10 to 1, white/black in the operating ambient light conditions."

He then went on to enumerate the determinants that combine to create the observed ratio. They are:

1. Ambient Light at the display surface.
2. Display black level
3. Display light output (Lumens)
4. Display surface (gain and reflectivity)
5. Image design



The graph above illustrates the extreme sensitivity that Contrast has to incident ambient light. A contrast ratio that starts out in a darkened room at 100:1 will drop precipitously under the influence of as little as a single foot candle of ambient light incident to the screen's surface. And only a scant 2 foot candles can depress the ratio of a front projected display to below the minimum recommended ratio of 10:1. The equation which produces these curves is

$$CR = \frac{L_A + (\rho \ x \ L_{amb})}{L_B + (\rho \ x \ L_{amb})}$$

where L_A is the Lumen output of the projector divided by the surface area of the screen multiplied by the screen gain (if any). p is the term which accounts for whether the display is front or rear projected. If front, let $p = 1.0$. If rear, let $p = 0.2$. L_B is the display black level and L_{amb} is the ambient light incident to the screen's surface, measured in foot candles.

Other extremely useful equations involving Contrast Ratio (*CR*) which Mr. Blaha presented are these:

$$\text{Light Output(Lumens)} = \frac{(\text{Image Area } x \text{ CR } x \, L_B) + (\text{Image Area } x \, (\text{CR} - 1) \, x \, L_{amb} \, x \, \rho)}{\text{Screen Gain}}$$

where Image Area is expressed in ft² and L_{amb} in incident foot candles. Here p is a coefficient for expressing the reflectivity of the screen surface and generally may be set to equal 1.0 for front projection and between 0.15 and 0.2 for rear.

If you do not know the precise black level, L_B, of your system, you can get a good approximation for it by solving

$$L_B = \frac{\text{Light Output}}{\text{Image Area}} x0.02$$

which assumes, of course, that CR_{dark} = 50.

Lastly, if you want to ensure that your system has a contrast ratio of at least 10:1, solve

$$\text{Minimum Light Output (Lumens)} = \frac{9x\text{Image Area } x\rho \ \ x\,L_{amb}}{(\text{Screen Gain} - 0.2)}$$

In setting forth these equations (for which, again, Mr. Blaha must be thanked), we at Da-Lite Screen Company hope that we are providing to our customers, the dealers and designers of the A/V industry, some specifically useful new tools. If they are incorporated regularly into the processes of system design and specification then, we believe, visual displays of ever higher quality will inevitably result.

Angles Of View

Vol. V, 8 ©Da-Lite Screen Company August 1999

Despite the extraordinary profusion of very high quality equipment and hardware being continually produced for the improvement of audio/visual systems, a significant portion of a display's visual quality can often be greatly affected simply by the manipulation of the angular relationship between its parts. This article discusses two of those relationships in ways which we hope may encourage

Different Perspectives - From Other Angles

The most effective way to improve any single- image display which is being rear projected is to include in it a Fresnel lens. Why this is so barely requires reiteration. Only a Fresnel can minimize the angles through which light rays diverging from the projector must be bent in order to reach the eyes of the audience.

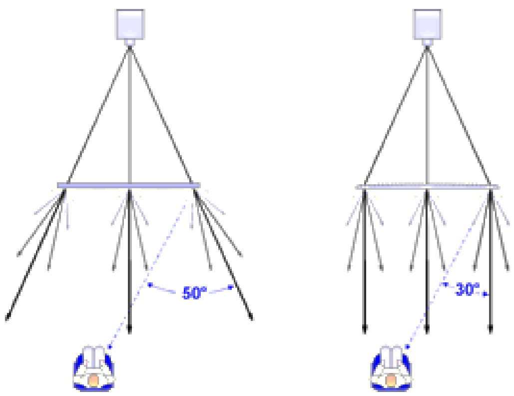


Figure 1

The two sketches above easily illustrate this advantage. In the left-hand drawing, light rays flowing from the projector through the right edge of the screen need to be bent through an angle of 50º if the seated figure is to see what they contain. In the right-hand drawing, that bend angle has been reduced to only 30º. This 40% improvement is accomplished by the Fresnel on the back of the right-hand screen which has collimated the incident light rays such that they all become parallel to the on-axis ray.

Although the only numbers which appear in Figure 1 are the two bend angles themselves, there are actually other numeric assumptions implicit in their deduction. One of these is that the screen has an aspect ratio of 3:4. The other is that the projector has a required throw of 1.2 times the screen's diagonal. These are absolutely standard numbers and apply exactly to an enormous number of existing screen installations throughout our markets.

Recently, however, there has appeared an inventive and interesting exception to these proportions and it deserves some attention. Because of the advent of numerous projection technologies which no longer require three, separate exit pupils (the R, G, and B guns of the classical CRT projector), it is now often possible to get a special optional lens for your new projector which permits a throw distance significantly shorter than the standard version's.

In rear projection setups particularly this development is often being viewed as welcome. Since everybody knows that "real estate" is the biggest single drawback to rear projection installs, it has to be acknowledged that the "wide angle" projection lens option is certainly attractive as a way to reduce minimum booth depth. And, no doubt about it, the availability of these short focal length lenses has helped projector manufacturers make sales which otherwise might have been lost to them.

From the point of view of a screen manufacturer, however, these new short lenses can cause as many problems as they solve. The issue, once again, is total bend angle. The graph in Figure 2 shows how the maximum incident angle onto a 3:4 aspect ratio screen varies inversely with the throw distance. Note that the slope of the resulting curve is not linear and instead becomes steeper as the throw distance is decreased. Thus, if at a throw of 1.2 times the diagonal the largest incident angle is something like 23º, by the time the throw has been reduced to .7, it has increased to more than 35º. For workstation screens with aspect ratios of 4:5, this angular progression is worse and for 9:16 aspect ratios, it's *much* worse.

What this means is that the use of wide angle lenses can't help but degrade the perceived uniformity of any image. Now, it is extremely important to state here that the observation just made has nothing whatsoever to do with either the quality or the design of the wide angle lens itself. We at Da-Lite have no doubt that optically these new devices are first rate technical achievements and, resultantly, are only to be admired.

The graph, you see, says absolutely nothing about the optics of the projection lens. It simply presents the geometric consequences of reduced throw distances which have the result of greatly increasing either angle labeled in Figure 1.

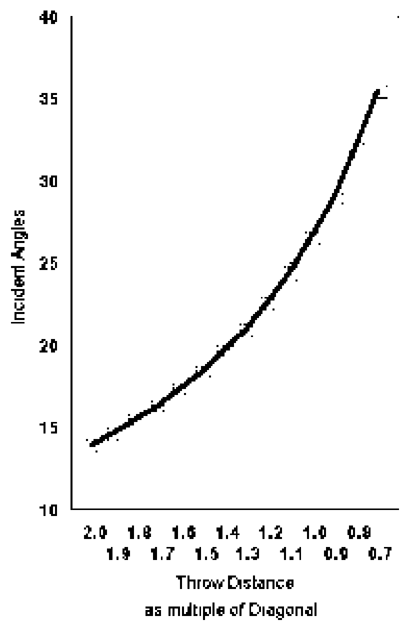


Figure 2

Thus, we at Da-Lite wonder whether the bend angle price is worth paying, especially if an acceptable alternative would be to use a mirror system to fold the light path and, thereby, enable the retention of a longer focal length lens. Yes, certainly the introduction of one or two mirrors into the light path will reduce by some measurable amount the overall brightness of the displayed image but that, in these days of ever more powerful projectors, may well be the less expensive of the two alternative optical tariffs.

Any screen, even one with a Fresnel on its entrance surface, cannot process very large bend angles with the same efficiency that it can manage moderate ones. Yet when a projection lens is designed such that it will completely fill a screen from a throw distance that may be as little as 2/3 of its diagonal, it is certain that the projected image will be seriously non-uniform. To be sure, a Fresnel backed screen like Da-Lite's Ultra will make this problem less bad, but even that device cannot render such wide angled geometry harmless.

There is a second matter having to do with Fresnel backed screens which also merits attention. This one has to do with the alignment of projectors and Fresnels on a display's vertical axis.

It is commonly supposed that the only proper position for a projector expected to fire through a Fresnel is exactly on-axis to the screen's center. The logic to this conclusion seems convincing and should be looked at. It generally goes something like this:

If the purpose of Fresnel is to collimate incident light rays such that all bend angles are reduced to a minimum, then, obviously, it is as important to have the projector centered vertically on the Fresnel as it is to have it centered horizontally.

On the face of it, that's perfectly true. The reason that this column disputes that conclusion stems from our long-standing conviction that the goal of any well designed display system is to deliver as many light rays from the projector as possible into the eyes of the audience.

Now, everybody knows that you don't want the bottom of a screen closer to the floor than, say, three to four feet. That being so, we also know that the center of our screen will (depending on its height), therefore, be five, six, or even seven feet above that floor. If we now recall that the average height of a seated audience's eye point is only 44 inches off that floor, then it's easy to see that the majority of the light emanating from a projector vertically centered on a screen will pass clean over the heads of everybody expected to look at it.

Alternatively, if we position the projector in such a way that its centermost light ray passes through the center of the Fresnel at whatever downward angle is permitted by the projector's optics and which as nearly as possible bisects the audience's vertical field, a significantly greater amount of the image light will be aimed *directly* at the audience.

Now, to be technical for a moment, let's look at whether pulling the projector off-axis to the Fresnel costs us anything optical which we might not wish to pay. We will find that it does not.

Since a Fresnel also is a lens, it too has a focal length which may be thought of as the distance back from its center that a projector needs to be placed in order to have all of its light rays collimated. If we put the projector at some distance which does not equal the Fresnel's focal length, one of two things will happen. If the source is outside its focal length, the Fresnel will converge the incident light rays to some extent. If inside the focal length, it will cause them to diverge to some extent.

Knowing this, we can now describe what happens when we position a projector off center vertically to a Fresnel. Because the incident angles of light rays passing through the Fresnel below its equator will now be steeper, they will converge. Because the incident angles of light rays reaching the Fresnel above its equator will now be smaller, they will diverge. Note, however, that both the divergence and the convergence of the rays is measured relative to the new, *downwards* (and, thus, no longer perpendicular) direction of the centermost ray. The overall effect, then, is precisely what we should desire and our audience is certain to be more enlightened.

Angles Of View

Vol. V, 9 ©Da-Lite Screen Company September 1999

As we have observed previously, there are many different perspectives from which one may contemplate and analyze display systems. Some of these concentrate on projector considerations, lumen output or requisite throw distance, for example. Others focus on screen considerations, aspect ratio or gain, for instance. Still others pay attention to audience parameters, widths of the front and back rows, and so forth. One concept connected to all of these is the idea of half-angle. This article seeks to present some ways of thinking about and

Figuring Half-Angles - An Idea Worth Illustrating

Just as all manufacturers of projection devices want to show us their lumen outputs, so, too, are we screen manufacturers similarly eager to expose our various surfaces' gains. Although both specifications intend to reveal something useful about their devices' "brightness", they each in fact are greatly improved by elaboration.

In the case of projection output lumens, the emendation has been the conversion to the concept of ANSI Lumens and its requisite averaging of nine multiple readings taken throughout a projector's full field. (As an aside, it is perhaps worth noting that "ANSI Lumens" is rather a misnomer. None of the ANSI IT7 standards refers to "ANSI Lumens". To be technically correct, the unit should actually be called "ANSI flux." But don't hold your breath.)

For its part, the concept of screen gain has undergone no such evolution and remains the consequence of only a single pair of on-axis measurements. While that may have been of some practical use back in the dark, dim days of early video projection, today it is by itself inadequate as a basis for skilled screen surface selection. What is missing (at least overtly) from the specification of a screen's gain, you see, is any description of its dispersion. This is how come all responsible screen manufacturers publish, in addition to gain specs, gain curves.

Figure 1 is a representative example of such a curve and describes a screen whose gain happens to be 1.5. By looking at the graph, we can discover all of this screen's additional dispersion properties and clearly see that its 1.5 gain is measurably reduced for all viewers positioned anywhere off its central projection axis. Even more usefully, for any given viewing position we can gauge what exactly that new, lower gain will be.

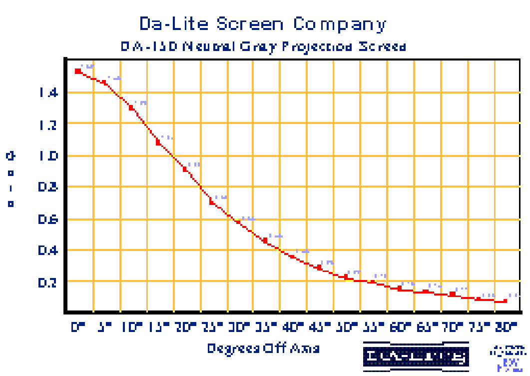


Figure 1

In this particular case, we can determine that viewers looking at the center of the screen from an angle of about 25º will see that center as being just half as bright as will other viewers seated exactly perpendicular to it. 25º, then, is the established half-angle for this 1.5 gain, neutral gray, rear projection screen.

Why we care about determining a screen's half-angle rather than, say, its quarter-angle or its two-thirds angle, results from the physiology of our own visual systems. It turns out that as long as a diminution in perceived brightness across a display screen is fairly smooth and not discontinuous, our eye:brain interfaces will not really take notice. Past the threshold where the perceived brightness is reduced by more than 50% , however, we can (and will) see those portions of the image as being dimmer. The calculation of each screen surface's half-angle, then, is what underlies the issuance of manufacturers' recommended viewing angle or viewing cone specifications.

Although all of this may seem straightforward enough, there are a few consequences of these facts which merit further scrutiny. In all of the diagrams which follow, the screen surfaces are arbitrarily assumed to have half-angles of 30º. The choice to make them rear projection displays is equally arbitrary and has been made only so that projector and viewer can graphically be kept spatially distinct. The principles here illustrated would be equally valid for any front screen with gain.

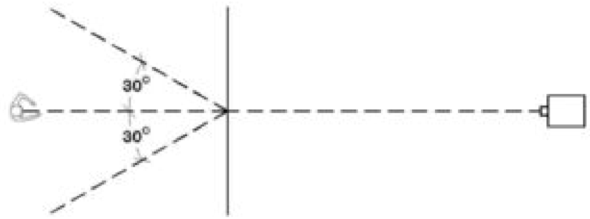


Figure 2

Figure 2 shows a plane view of the half-angle idea and, if we think about it, a reasonable design conclusion is that we ought to try and have all of our audience positioned inside the 60º cone formed by the two 30º half-angles. As with the measurement of gain itself, however, we need to note that all we have measured so far is the centermost light ray from the projector and perhaps there are others also worthy of our attention. So let's have a look at Figure 3.

Here we trace another light ray, the one passing through an outside edge of the screen, and we note that if we are to position a viewer within its 30º half-angle, we have to seat him inside a much smaller and asymmetrically off-axis cone.

Or do we?

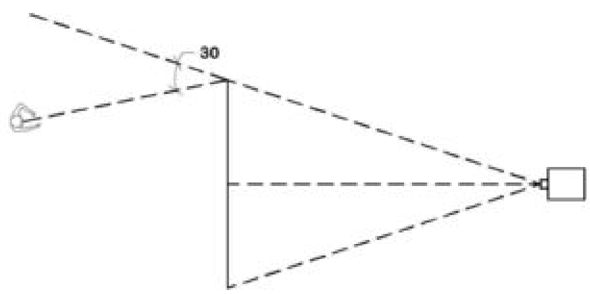


Figure 3

To find out for sure, lets look at another couple of sketches to see what light they can shed upon the question. Figure 4 illustrates that the brightest light ray which our off-axis viewer can (will) see is not the centermost light ray but is in fact whichever is the ray aimed by the projector directly into his eyes. The amplitude of that ray defines the brightest portion of the image as seen by this off-axis viewer and, thus, the half angle for that viewer will be ± 30º on either side of that ray.

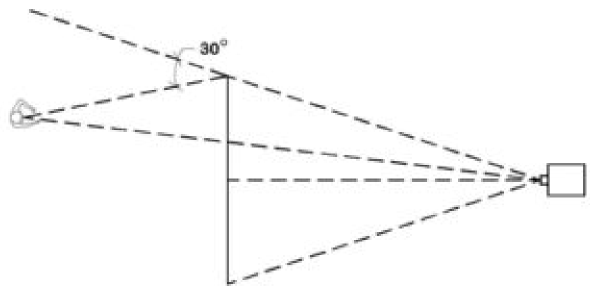


Figure 4

A common real life scenario which should make this point particularly clear is the case of an operator seated in a command-and-control facility which often include a matrix of screens more than one row high. Figure 5 shows in elevation the inclination of the centermost light ray in the vertical axis and its 30º half-angles. Note that their bisection is not perpendicular to the screen.

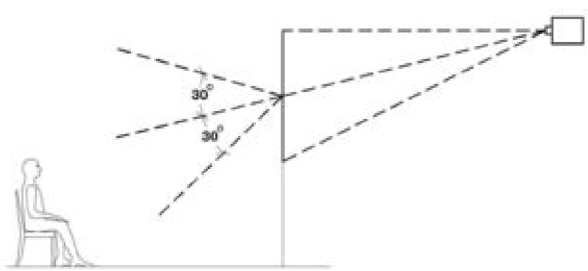


Figure 5

Figure 6 adds an upper screen which is geometrically identical to the lower but, because of its greater elevation is seen much differently by the operator. Notice particularly that the path of the centermost light ray emanating from the upper projector travels well above the operator's head .

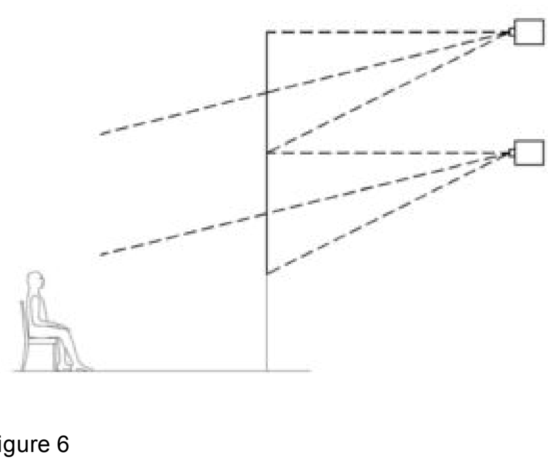


Figure 6

At first glance this significant brightness differential between the two displays might appear visually insuperable. But in fact it is not. What saves the day is that the operator can't regard both screens at once. When he directs his attention to the bottom screen his viewing geometry is described by Figure 5. But when he looks up at the top screen, what he sees is instead Figure 7.

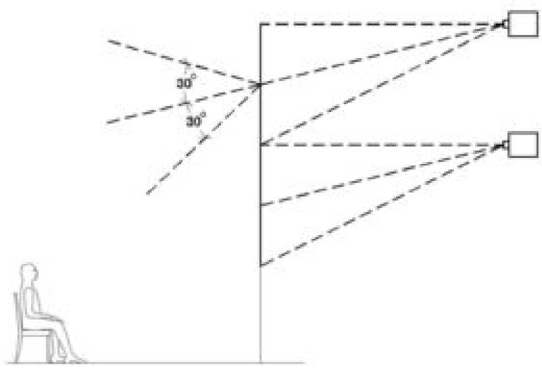


Figure 7

Now, in Figure 7, what are the critical areas of the screen for the designer to try to keep within 50% of each other's brightness? Obviously the answer is at the top and at the bottom. The center and whatever may be its specified gain become, for this analysis at least, irrelevant. It is the bottommost light ray which is directed straight at this viewer's eyes and it is the topmost ray (traveling parallel) to the ceiling which is directed farthest away.

Half-angles, then, can be looked at from many vantage points and usefully measured in many ways. While a gain curve (Figure 1) can tell us how to make Figure 2, note that its sketch results exclusively from the positioning of the projector relative to the screen. Figures 3 through 7, on the other hand, extend to include and account for viewers and, once again, their various and varying angles of view.

Angles Of View

Vol. V, 10 ©Da-Lite Screen Company October 1999

The proliferation of projection devices which are being pointed at or through Da-Lite screens these days continues to be remarkable. Because, however, in virtually every case each projector type is hard pressed not to add something of its own special signature to the image it casts, sometime viewers can become confused by what they see on a screen that is extra to that image. Sometimes these extraneous phenomena are visually quite bothersome, sometimes they are barely noticeable. This article will seek to help distinguish among them by

Telling the Difference - Attributes and Artifacts

The resolution of the real world, everybody knows, is effectively infinite. Especially by using instruments like telescopes and microscopes, there is almost no limit to the visual detail we can extract from it. When we make a visual representation of some aspect of the real, world, however, our capacity to duplicate the full detail of the original becomes limited and circumscribed. Yes, sometimes those limits cannot be discerned by our unaided eyes, but they are always there. Much more typically, and particularly when it comes to looking at electronic displays, our eyes are more than capable of perceiving that the image they are looking at includes extraneous elements beyond itself.

The origin of these non-image phenomena is sometimes not easy to pinpoint. Does they result from a defect in the screen material? Is there something not right about the way the projector has been set up? Could they be coming from the computer? Or are they something contained in the software making up the image?

Each of these components possesses some number of *attributes*, a term which we will here define as intrinsic characteristics of its design and function. When attributes intrude into the viewing experience, however, they become *artifacts*, a term which we will here define as visible phenomena that are extrinsic to image quality.

Let's start first by looking at screen surfaces. Whenever a front projection screen is illuminated by a projector, you should not be able to see any discontinuities across its surface. If you do see something suspicious, the easiest way to decide whether it's in the screen or not is to jiggle or move the screen surface slightly. If the aberration moves too, you've got a problem in the screen. If it doesn't, the problem is sited somewhere else.

In the case of rear projection screens, the same test can't be performed because rigid screens can't be jiggled so easily. What you can do easily, however, is go around to the back of the screen and place a piece of white paper over the area where you saw the aberration from the front. If you see the aberration on the paper, it's within the image, if you don't, it's within the screen.

In both screen cases, two additional standards must be mentioned. The first is that no screen should be judged defective by the way it appears under ambient light alone. Screens are designed to display light from a projector (which is to say, light that is emanating from the equivalent of a point source). Artifacts, discontinuities, or occlusions that do not appear under projection but which may otherwise be visible under ambient alone do not count and deserve to be ignored. Obviously, the reverse is not true.

The second standard has to do with the viewing distance from which screen artifacts, even under projection, may be discerned. If any such aberration can be seen only from a distance that is less than one diagonal, we would suggest that it may safely be ignored. If, however, the surface blemish is visible from a distance greater than one screen diagonal, then a responsible screen company should be willing to help you repair or replace your surface.

Now, what about projectors? Can we discern artifacts or attributes according to the type of projector we choose? Indeed we can, especially if the imagery we are considering is stationary and not kinetic. Moving imagery (entertainment, etc.) will not be considered in the descriptions which follow. Furthermore, only projectors capable of displaying information generated directly by a computer will be considered.

An artifact which everybody notices right away whenever it is present is aliasing. Aliasing is a phenomenon which occurs because the image being displayed is not an analog (which is to say, continuous) picture. Instead all computer generated imagery have been sampled some finite number of times at particular finite spatial and temporal frequencies. The coordinates of the spatial sampling of a display are, of course, its resolution and will thereby disclose into exactly how many pixels the image has been broken. Since these pixels are arranged in a neat, orderly X/Y grid, they seldom have any problem displaying realistic lines that are parallel to either of those axes. Aliasing enters the picture

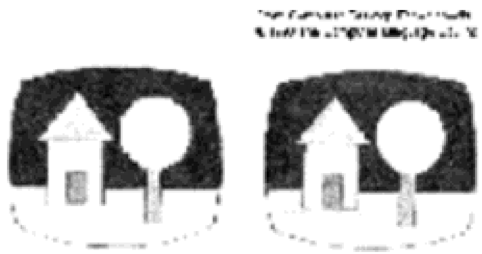


Figure 1

when some of its elements include curved or diagonal lines. Unless you have a very large number of pixels (each of which is, therefore, very small) or unless you're looking from a large viewing distance (which is the geometric equivalent), its pretty easy to see that the roof lines are not smooth and that the circumferences of the trees are not truly circular. That's aliasing.

CRT projectors draw their pictures by scanning them in with sequential horizontal lines. Because the number of lines (top to bottom) doesn't change as the image size gets bigger, it's often easy to detect these rasters or, really, the increasingly large spaces between them. When those spaces become sufficiently noticeable, the CRT's raster attribute has become an artifact.

Another attribute of CRT projectors is that they almost always include three, spatially separated light sources - the R, G, and B guns which made them famous. If the size of the projected image is not large, the absolute distance between the centers of those guns (e.g. 6, 7, or 9 inches) can be trigonometrically significant relative to the device's requisite throw distance. When this happens the colors in the perceived image will tend to shift toward the red when looked from a points opposing the B gun and toward blue when seen from opposite the R. This 3-gun artifact turns back into an attribute as the throw distance (image size) is increased.

Then there are all the matrix display projectors which rely on some sort of chip or chips to create their imagery. All of these are alike in that whatever chip they contain will have one and only one "native" resolution. Thus, for example, to know that the matrix of a particular projector is made up of 1024 x 768 "elements" is to know that the best that projector can ever do is to divide its imagery up into a number of pixels equaling the product of those two numbers. That's one of such a projector's attributes. An artifact often appears not from the limited number of pixels but from the spaces between them.

Whether the chips in matrix projectors are transmissive or reflective there must always be some degree of separation between one pixel and another. Using LCD panels as an example, if each liquid crystal pixel is a little window whose shade may be positioned at any instant anywhere between full open or full shut (and through which, therefore, varying amounts of light are permitted to pass), the mechanism to "motor" that shade is contained in the brickwork of the wall surrounding it. If we consider the entire wall, we can determine exactly what percentage of it is made up of windows (and, hence, is "not brick"). This percentage is called the chips' aperture ratio. If it's high (like 90%) it won't be easy to distinguish one pixel from another and we merely describing an attribute. If its low (like 40%) then the majority of the image's area will be made up of the visible "chicken wire" which prominently and discernibly outlines each and every pixel. That's an artifact.

In the case of dmd projectors, the "motors" which cause the mirrors to flicker back and forth are not adjacent to but below them. Even so there must still be space at all four sides of each mirror so that as it is rotated out of flat none of its edges touches those of its neighbors. Equally, reflective LCD projectors are able to produce very high aspect ratios because they, too, have their "motors" behind the pixels.

There are, of course, numerous other display attributes which can be artifacts and the cases mentioned above are meant merely to be illustrative. The point most worth making regarding artifacts, however, is that they tend to be required viewing. When they show up, we can't *not* look at them. Artifacts are not helpful; they obstruct our ability efficiently to assimilate projected information. Unfortunately, they often must be tolerated; but they should never be welcomed.

Angles Of View

Vol. V, 11 ©Da-Lite Screen Company November 1999

As the 20th century draws to a close, the A/V industry is enjoying nearly unparalleled prosperity and is looking forward to the new millennium with justifiable optimism. Our popularity derives, of course, from our customers' perception that our equipment and our knowledge will improve their communications facilities. And, considering the plethora of greatly improved hardware currently available to us, it is tempting to assume that virtually any system we install can meet its owner's expectations. Yet to create a communication facility is not necessarily to create a facility to communicate. This article will contend that our industry should prefer the latter product to the former. Otherwise, we may be in some real danger of

Missing the Point - The Meaning of Failure

Let us define an effective audio/visual system as a collection of equipment that, when turned on, can enhance its users' abilities to transmit information. Whether the presenter using the system wishes to train, sell, persuade, or teach, it is in fact probable that audio/visual equipment is the best carrying medium for that information if its audience is an assembled group.

To subvert the hoary cliché, however, although an A/V system may indeed have become the medium of choice, it certainly should not become the message. Not only is the "message" not hardware, it is not software either, if what we mean by software is whatever sort of application program that gets used to create the presentation. The real "message" is what this article will call the *content* of the presentation and a look at how it gets created may be instructive.

Most of us who inhabit the A/V world have long appreciated that developments and advances within our industry are actually by-products of developments and advances within another, and much larger enterprise, the computer industry. It is simply our good luck that computers comprise a technology which can completely obsolesce itself at astonishingly short intervals.

Gordon Moore, a founder of Intel, famously observed way back in 1965, that the number of transistors per square inch on integrated circuits had doubled each and every year since the integrated circuit was invented. After some smoothing and additional history, this perception became Moore's Law which states that the data density achievable by CPUs doubles approximately every eighteen months. Figure 1 shows how closely, in fact, Moore's Law has been borne out by the progression of Intel processors. Although, for quantum mechanical reasons, the trend cannot and will not continue indefinitely, it is not likely to stop for about another decade and a half.

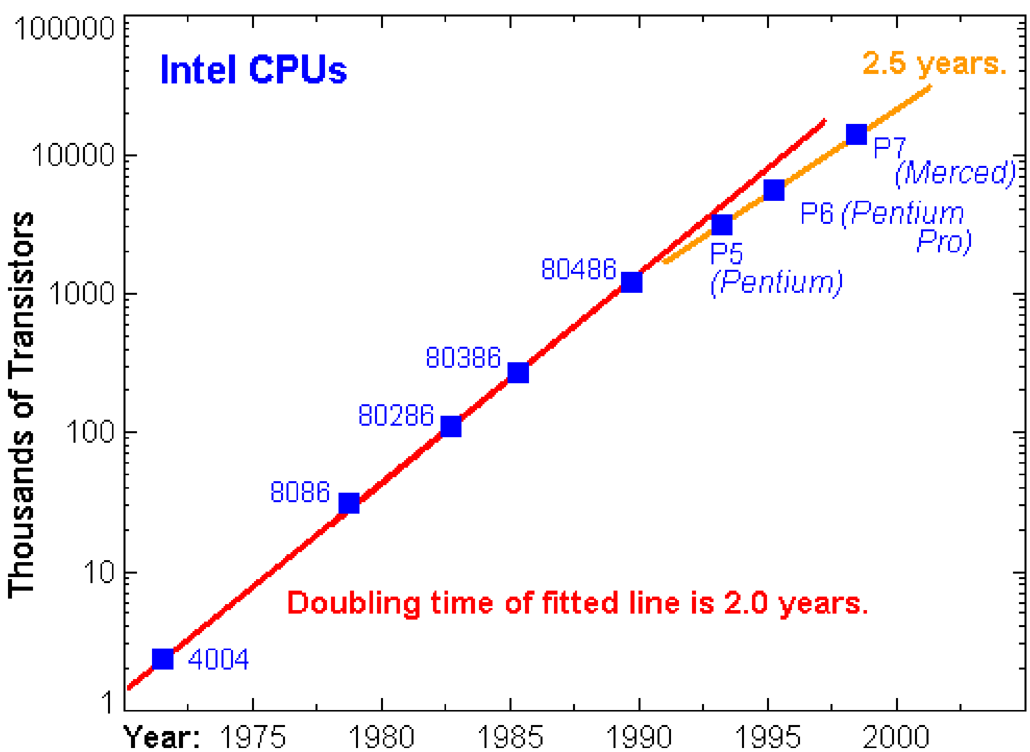


Figure 1

An inevitable consequence of this periodic doubling of "data density" is that all the rest of the computer's components enlarge accordingly. Thus, your new computer always comes with a bigger hard disc than your old one had, and the amount of RAM recommended to run its bundled software will also be larger. Et cetera.

The software industry, of course, is typically the first to exploit and benefit from this development spiral. By having faster and more capacious hardware available to them, software manufacturers can produce applications which are capable of manipulating increasingly complicated and complex types of information.

What happens next is that computer users, in possession of the faster and more powerful hardware, can now run the larger and more complex software applications which, thereby, enable them to manipulate and process commensurately more sophisticated and complex "content."

Once the computer user has mastered the upgraded software and, thereby, begun to produce upgraded "content", the first thing she is likely to do is want to present her output to others. And the moment she wishes to present that content to a group too large to cluster around her computer monitor is the moment when she turns to the A/V industry and asks for help. Our products, then, must be integrated into systems whose fundamental purpose is the presentation of our customers' "content".

In our industry's parlance, the best synonym for "content" is, naturally, "resolution." True, the number of pixels we use to make up our newest images is not doubling every eighteen months, but it is inexorably growing. Similarly, the brightness of our projectors also does not double at a computerlike pace, but it is certainly accelerating. Think back for a moment on how long it took projectors to get from one or two hundred lumens to one thousand lumens. And then think how long it has taken them to get from 1,000 lumens to 2,000 lumens....

These extraordinary developments in our industry's available hardware have doubtless contributed greatly to the worldwide demand for our goods and services. After all, not only is the equipment we manufacture and sell demonstrably better than its last year's versions, it is also less expensive. Small wonder as an industry we are currently enjoying such phenomenal success.

Given all that good news, what possibly could go wrong? Absent some cataclysm in the macro economy, how could the future of A/V be anything but bright? With the hundreds of rooms that our industry will design and build over the next few years, however might there be room for failure?

The room is built and its presentation system installed. Every Tuesday afternoon a group, let us say, of 22 people gather in the room so that they may be provided with updated information which will be presented to them in order that, subsequently, they may make appropriate decisions regarding it.

During the first year, everything about the system seems wonderful. When their buttons are pushed, the screen invariably comes down and the projector unfailingly lights up. None of the other equipment malfunctions, either. This happy state of affairs continues through the second year except that, now, the quality of the decisions produced by the group mysteriously starts to slip. Departments that previously were quite reliable in carrying out their specific directives have grown uncertain and worrisomely tentative.

The executive in charge of the meetings is at first stumped and then angered. Quite understandably, none of these people knows anything about projection screens and devices, few know much about their computers (other than how to use them), all know a great deal about their business, whatever it may be.

This is how come, of course, they don't notice that the participants whose judgements seem suddenly to have become the most faulty are those who tend to come in late and who, therefore, get relegated to seats in the back row. And they also didn't pay much attention to the new projector they were sold, satisfied instead to believe that it was better and brighter (and it was!). And, lastly, they were all so delighted to see their computers finally upgraded that they paid no attention at all to what it did to their content.

Yet whereas once all 22 people would leave that Tuesday afternoon meeting having, as it were, gotten the message. Now there are only 14 that continue to get it. The other 8 don't get it and they don't get it because they can't. And when that happens (and it does, it does) the system has failed. No piece of equipment or component has given out, mind you. In fact, several ironically may have been improved or upgraded. But there is major system failure nonetheless because the medium can no longer deliver the message and the critical meaning of it all, the *content*, is lost.

To belabor the point just a little more, the reason content can become compromised is not because its data density is too low but because it has been allowed to become too high. The ability of computers to pack more and more information simultaneously onto their screens is not, we would suggest, an unmixed blessing. Yes, all our new projectors can reproduce that resolution handsomely and, yes, all our new Da-Lite screens can contain and display all that content effortlessly. But that does not mean that all viewers from all viewing distances will be able to comprehend it.

Sure, if all we're trying to project is seven or eight word, 28 point, text strings inside a PowerPoint presentation, most of the concerns expressed here are groundless. But what if the content to be presented is something quite different, the company's web site, for example? The data density of that content is hugely higher and if the strictures its presentation thereby impose are not carefully accounted for, the communications system delivering it will fail.

More, you see, is not always better. More, in fact, can sometimes be just Moore.

Angles Of View

Vol. V, 12 ©Da-Lite Screen Company December 1999

This article marks the end of this series' fifth consecutive year. Throughout that time, Angles of View have sought to present and explain the various aspects and attributes of visual displays. Even though many of those attributes are independent of the technologies which produce them, some are not. Even though some of these attributes demand the same priority they deserved five years ago, many do not. Predicated, then, on the accumulated texts of the nearly sixty previous articles, this last essay of the millennium will stick its neck out, peer into a crystal ball, and hazard a few

Speculations - Reflections, Transmissions, & Projections

One of the things that is fun to think about at the end of any millennium is whatever we might expect to see in the next. Venturing such prognostications, of course, risks not only error (bad) but ridicule (worse) and, as such, is always fraught with peril. Nevertheless, as long as we are careful not to take ourselves too seriously, some forecasts can still be made.

Before we begin looking forward, however, let's look back to 1909, exactly ninety years ago, when a young woman in Chicago by the name of Adele deBerri founded Da-Lite Screen Company. She did that at a time when women weren't generally doing such things but she did it anyway seeing, as she did, the enormous potentiality of the still nascent movie business. It was in service, then, to that industry that the first real projection screen came to be developed.

Looking at that same event from a longer, millennial point of view, a case can be made that film was the first technology that enabled the assembling of people together for the sole purpose of looking at something that wasn't there. What we mean by that, of course, is that what you saw when you went to the movies was and is completely illusory. What you watch is "motion pictures." Neither the actors, nor the sets and stages surrounding them are real. Nevertheless, the projection of their images onto a large screen can involve and excite us in ways and to degrees which previously were unimaginable.

Roll the clock forward ninety years and we can see that the number and types of display screens in the world has proliferated greatly. Quite apart from the myriad applications which rely on CRTs for their imaging, there have emerged toward the end of our century scads of alternative projection devices with which, surely, our industry is the most conversant. Yet despite their superficial dissimilarities, every one of those display types have this one interesting thing in common: they are specifically designed to present imagery to audiences whose number is greater than one. (By virtue only of its typical usage, your computer monitor may perhaps be an exception to this observation, but there is nothing implicit to its manufacture that requires that this be so.)

Only recently have we seen the arrival of credible single-person display devices, but if their appearance is only sporadic today, by Da-Lite's 100th birthday, there will be few among us who will not regularly be relying on many of them. In your house, in your dashboard, and probably on your person will exist small and visual displays which can show you not only who's just rung your doorbell, but which way you should turn to avoid the stalled tractor trailer blocking the intersection of Route 30 and Detroit Street. You might even have a *really* small display projecting PIM information for you embossed in the inside frame of your sunglasses. You just might.

Then, there's virtual reality. To date, the problem with that phrase is its second word, not its first. The human organism has received an awful lot of extensive training over an awful lot of millennia in being able to distinguish the image of a tiger from its actual and, thus, incarnate cousin in the bush. Those of our ancestors who failed to learn this lesson... well, probably weren't our ancestors after all.

Yet, given the certainty of ever greater computer power and the consequently certain future developments in projector design, the time will certainly arrive when each one of us may be so totally immersed in a displayed environment that none or all of our faculties will be able to tell that it's not, in fact, "real". Thinking, then, of virtual reality as a kind of super "special effect", it is interesting to note that the maximum effectiveness of its effects is likely still to require that its subjects experience it solitarily. VR at its future best is unlikely ever to be a group experience. The illusion of exploring fantasy galaxies or Escher architected castles is too susceptible to being compromised by the intrusive other reality of a giggle emanating from some "real" flesh-and-blood creature who just happens to be with us along for the "ride".

On the other side of this millennial divide are the displays whose audiences will continue to be gathered together to look at something projected on a large screen *together*. These are the venues which our industry will certainly continue to serve. Before taking a stab at describing what the 21st Century A/V system might look like, however, a word about plasma displays is probably in order.

Many of us at Da-Lite Screen Company these days are being confronted by predictions that the increasingly popular and increasingly handsome plasma displays portend the imminent demise of the projection screen. This notion arises, of course, from the concept of the "flat screen" which technologists have been forecasting for at least the past thirty years. This is the device that will be just an inch or two thick, that will hang on your wall and look exactly like your favorite Rembrandt when it's in its "off" state, and that, when you do turn it on, will display 5,000 channels of content in exquisite resolution and at unparalleled brightness.... We want one too.

The plasma screens get associated with this idealized display of the future because, in fact, they're flat and self-luminous. But, in the context of the Pro A/V market, the resemblance ends there. The reason that all those jillions of ¥en have been invested in the development of plasma screens is not, fortunately, so that they will supplant the Cosmopolitan Electrol. (A little research into the plasma technology itself reveals that even its most enthusiastic advocates doubt that, one day, they could make one with a diagonal greater than 72-inches.) It is not the boardroom that plasma is aiming at, nor is it the bank lobby, nor the airport. It is the living room. Plasma wants to be your new TV set and, given the number of consumer living rooms available to receive it, who can blame it?

At sizes greater than those appropriate for a self-contained living room "set", the screens that everyone will still need to use when they create a *large* screen display will, of course, remain the ones manufactured by Da-Lite. Yet the selection of those sundry surfaces and the choice between their attributes is certain to become simpler and simpler as the next century progresses. So many of those surfaces and so many of those attributes have been designed and developed primarily as compensations or corrections for deficiencies in brightness in the projection devices. One way or another, every single screen that Da-Lite or any other screen manufacturer makes with a gain that is greater than 1 is superfluous if mated with a projector that by itself can produce enough brightness for the instant application.

Therefore: Although Da-Lite will most assuredly continue to have available a variety of special application screen surfaces for quite a long time still to come, it would surprise us if the enormous majority of the screens that we sell don't all come to have a gain of 1. In rear projection this will mean that the *DA-100* or the yet better Fresnel-backed *DA-100* ***Ultra*** will be the dominant models. And in front projection it will be the matte white surfaces which will prevail.

Can the efficiency and utility of these surfaces be improved? Yes and no. There are theoretically techniques which may improve the transmission of rear projection screens or, really, rear projection substrates. To the extent to which Da-Lite's research in this regard will be successful, will be the extent to which the answer is Yes.

With front projection surfaces, however, we will firmly contend that the answer is no. Despite its pedestrian reputation, despite its apparent lack of glamor, despite even the degree to which it is generally taken for granted, the fact remains that no front projection screen surface is closer to true "state-of-the-art" than *Matte White* or *Da-Mat*. Its perfect uniformity and unrestricted viewing angles make it today the unequivocal choice for the best front screen of the next century. Recalling further that its luminous efficiency is to all intents and purposes 100%, it is hard even to imagine how it might be made better.

Our last prediction forecasts that the defacto aspect ratio of our entire industry, the ubiquitous 3:4, is about to become extinct, its primacy to be overthrown by the emerging 9:16 of HDTV. While opinions may vary as to how fast this change will sweep over us, few doubt that, inexorably, it will.

That shift from regarding our images in 12:16 to looking at them in 9:16 is going, absolutely, to be paradigmatic. Nothing, we might say, is ever going to look the same again.

Have we forgotten or ignored something that hindsight in the years ahead will make us understand we should have emphasized? Guaranteed. But one thing we shall not forget is certainly to wish all of our customers and friends a most prosperous and *Happy New Year*!

Angles of View VOLUME VI – 2000

A series of articles which discuss "Special Venues"
Applications for Display Technology

Angles Of View

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When this series began (sometime towards the end of the last century) discussing and describing the attributes of visual displays, both its author and its readers understood exactly in what sort of environment pro A/V systems were likely to appear. The venue for this sort of equipment - video projectors and projection screens-was limited to the board and training rooms of corporations and to university classrooms and lecture halls. Only rarely did one encounter a "systems" application which could succeed in a setting other than those. Today, however, all that is changed and the enormous advancements in display technology have accelerated the evolution of several

Special Venues - Other Markets

Before looking into what attributes and conditions might be peculiar to *special* venues, let's make sure we recognize what are the properties which make our regular venue regular. What similarities are there between all of the thousands of "rooms" into which our industry has installed a pro A/V system?

Here, in no particular priority, are what we suggest are some of any such room's common denominators.

1. It's inside.
   a. It is comprised of an enclosed internal space which, although it certainly may contain windows to the outside, is nevertheless a controlled (if not always completely controllable) environment.

2. Its functional purpose is to serve multiple viewers simultaneously.
   a. Its audience, then, is a group whose members have been assembled so that they all will perform the same visual task at the same time.
   b. The only way, therefore, in which one member of the audience may be distinguished from any other is according to viewing distance and angle .

3. The venue will always be illuminated by light sources other than and in addition to the projector.

4. The material being presented has come to be primarily computer generated.

5. That material is now almost invariably information which its audience is expected to read.

6. Because of 4 and 5, the projected imagery in commercial venues is, typically, static.
   a. Its resolution, however, can be extremely high.
   b. It has no "real time" component and, theoretically, is completely repeatable.

7. When the imagery *is* kinetic, its source is either video tape or video conferencing.
   a. Its resolution is typically low.

8. The aspect ratio of the displayed imagery is constant.

9. With only rare exceptions, the importance of accurate color rendition within a presentation is unimportant.

10. The size and placement of the projection screen are dependent on that segment of its audience which is farthest away from it.

While that list may not be complete, we will still hazard that some majority of its ten conditions surrounds at least 90% of the systems our industry has installed during the past decade. In a certain way, there is nothing remarkable about this. *Of course* groups of people have meetings inside inside rooms. *Of course* they want or need to leave the lights on. *Of course* they want their principal business tool, their computer, to integrate with the presentation hardware and software. Of course.

On the other hand, the list may seem so obvious because many of us in the "systems" end of the business believe its assumptions to be so true that, well, they hardly bear repeating. But that, of course, would not be true.

There are, in fact, other venues and other rooms in which just possibly few, if any of those ten parameters are valid or make any sense. Yet because these venues are burgeoning new markets in addition, perhaps, to being new design challenges, they merit our industry's close and respectful attention.

The foremost of them, unsurprisingly, is the Home Theater market. Once a kind of neglected stepchild of the A/V business, Home Theater has turned into a veritable Cinderella whose attractions promise not merely to equal our own but possibly even to exceed them. And, although once Home Theater systems and installations were the province of a group of specialists whose backgrounds were primarily in high-end audio, the confluence of projector and display technologies that has occurred over the past several years has effectively blurred any sharp distinction between the two industries.

It should also be noted that endemic to the enduser population for Home Theater systems is a passion for technical sophistication and excellence which in some ways exceeds anything to be found in the professional commercial marketplace. One of the important areas this series intends to discover in its forthcoming issues is what exactly are the design requirements of a high quality visual display within this venue. It may be supposed that the answers will vary considerably from many of the assumptions and rules of thumb which are listed above.

A second venue that is evidencing explosive growth is the church market. Worship centers all across America are rapidly coming to believe that the inclusion of often quite sophisticated audio visual systems within their venue can greatly enhance its desirability. Some of the reasons that this is so are interestingly (and entertainingly) described by Gary Kayye in the December issue of Da-Lite's **Reflections** series: **The New Age Church: Attracting Generation X** .

Certainly churches comprise a venue which, if only because of its size, differs greatly from the more industrial applications with which most of our business is familiar. Recognizing this, several of the nation's largest systems dealers are establishing separate and individualized sales and marketing teams whose missions will be to specialize in the Worship market exclusively. The details and circumstances justifying that specialization will also be the subjects of several of this series' upcoming articles.

The third special venue which merits attention is the one called Command-and-Control. As that title implies, the genesis of this application was military.

Imagine, for example, some sort of military border monitoring operation where the strip of geography separating two politically restive nations is lengthy. An efficient and reliable way to keep close tabs on such a frontier is to divide it up into a number of much smaller pieces each of which can, therefore, be kept under continuous electronic surveillance by watchers who themselves may be stationed far, far away from it. Assembled in a single, large room, each of these watchers typically is assigned the task of detecting unexpected or untoward activity anywhere within or along whatever sector of the frontier that is displayed on the screen before him.

In the beginning, of course, only the military would have had the resources (satellites, etc.) to carry out such a job effectively. But, over the years, the proliferation of elaborate commercial communications networks (satellites, etc.) has enabled the Command-and-Control function to migrate into all sorts of private enterprises and non-governmental activities. In addition, then, to the purely military facilities, there are now "Command & Process Control" facilities that, for instance, allocate and shift the resources of a municipal utility company. Also, there are Network Operations Centers (NOCs) which superintend various sorts of large communications facilities such as long distance telephone carriers. And, lastly, there are Trading Floors like the stock exchanges, which need to process, update, and display vast amounts of rapidly changing information in real, or nearly real time.

All of these applications will utilize what at Da-Lite we call matrix displays. These are an aggregation of many individual screens which, though installed in close proximity to one another, nevertheless will each display a dedicated and quite specific subset of the total information being output by the centralized computing system.

At its inception, this venue was cultivated by a small number of highly sophisticated A/V companies who specialized in it almost exclusively. As its technology became less rarefied, however, numerous other commercial entities are vigorously pursuing its opportunities. Prominent among these is Da-Lite's newest U.S. acquisition, Visual Structures, Inc. (http://www.vsitrooper.com), whose Trooper® product line has long been at the forefront of Command Center display technology. What special design and display requirements are unique to this venue will also be presented in some articles to follow. By looking carefully at each of these alternative venues, we hope to extend our angles of view in all of them.

Angles Of View

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The phrase "Home Theater" brings to mind a series of images which are, well, nearly as diverse as what is seen within them. There are private houses today which contain exactly that, an actual movie theater with auditorium seating, a projection booth, and, doubtless, a working popcorn machine and soda fountain in its lobby. At the other end of the spectrum is what we might call a souped-up televison set that has some auxiliary sound speakers attached to it. And everything in between. Across this gamut runs a range of products and designs which get combined to create, at minimum, a viewing experience which is somehow enhanced beyond what we normally think of as old- fashioned "watching televison." How all this came to pass is interesting and this article will look at a few of the most important elements which have gone into the development of

Home Theater - Setting the Stage

"Home Theater" as a phrase and as an industry is dedicated to the presentation of moving, kinetic images. The "purpose" of those images is principally to entertain; it is not generally to inform. The distinction between those two verbs is important and many of the design parameters which enhance one detract from the other.

To illustrate what we mean by this, let us imagine that we enter, some weekday morning, the corporate boardroom of a valued customer. We will seat ourselves in upright chairs along or around a large conference table and our attention will be directed towards a screen either handsomely encased before, or neatly installed within one of the walls before us.

Typically, the "show" will be controlled by a fellow member of our audience and the way that we'll know that it has begun is because he himself will provide the "soundtrack" intended to accompany the series of images before us. These images will change at intervals no faster than once a minute and often much more slowly. Even though the images have been designed to be as individually recognizable as possible, and even though their technical values may well be high, to understand them fully their audience is still likely to require an accompanying narrative from the person speaking their soundtrack.

Of course, while we're experiencing this show the room lights have been left on to help us not only see the soundtrack producer but also the other members of the audience and the yellow pad before us onto which we are expected diligently to scribble notes. Those notes, by the way, will not contain (except surreptitiously) our opinion or review of the show. They will instead more typically contain its summary. Lastly, while the list of objectives for such a show will often be long, only rarely will our entertainment or enjoyment be at its head.

Long before any of us ever saw a show of the kind just described, all of us have been familiar with two other kinds of shows: the movies and television. Historically, even though the creation of the former much preceded the development of the latter, in the experience of most of the readers of this article, the exact reverse is more probably the case. Anybody who is under fifty has certainly spent many, many more hours before a television set than she has ever sat in the movies. Paradoxically, then, even though the phrase Home Theater connotes the reproduction of cinema-like entertainment within the home, its actual historical roots are much more tightly entwined around blueish CRT tubes than silver screens.

Part of the decision to format Television as a 3:4 medium was done to avoid the necessity of cropping the vast reservoir of Hollywood films from which the fledgling industry expected to draw for desperately needed programming filler. However, the derivation of the NTSC broadcast standard (and its aspect ratio) emerged from other, non-cinematic limitations as well.

Looking back from the perspective of the 21st century, it may be hard to remember what an astonishing development Television in fact was. A clunky box could be plugged in in our living rooms and, at the mere twist of a dial, not only miniaturized movies, but images of real, live talking people were there before our very eyes every single evening we wanted to watch them. It was, truly, a watershed development which, it might be argued, has by itself irreversibly and profoundly changed our culture.

Quite mistakenly terrified by the sweeping popularity of this upstart medium, Hollywood reacted by making lots of movies in aspect ratios which, it hoped, would compellingly attract mass audiences back into its theaters. Screens and budgets became huge and images became wide (often very wide) and any number of efforts were made to reveal what film could do that TV could not. (It is interesting to speculate whether the genesis of the film industry's high-tech special effects emphasis might not be found in this original and frantic effort to distinguish itself from TV.)

With respect to Home Theater, this historical separation between film and TV can now be seen ironically to have vanished. Television is about to become wide-screen and the movies are about to become electronic. Both are interested in the big picture and both are big business. So, by now, is Home Theater.

In the pro A/V world, the development of big pictures, projected on big screens, was a function of the size of the audience. Commercial organizations weren't interested in spending money on presentation systems suitable for only two or three viewers. Quite to the contrary, their conference rooms had to be designed to serve groups much larger than those. In Home Theater, however, the virtue of a Big Picture was exactly that, a big picture.

Throughout the 1980's television manufacturers struggled to establish wide market acceptance of the first "big screen" projection television (PTV) sets. It was in service to this product line that the first Fresnel/Lenticular rear projection screens were developed. Because the 3-gun CRT projectors utilized by those early sets were anything but powerful, the inclusion of some sort of high gain screen system was mandatary if the consumer was to be tempted by the picture quality. Yes, at 67 inches in diagonal, it was certainly bigger than his TV, but it had also to be at least roughly as bright as well.

Another benefit which screen manufacturers brought to these early PTVs was a molded matrix of black stripes which when placed as a third element in front of the lenticulated and Fresnel layers, did an admirable job of increasing the set's perceived contrast even under relatively high ambient light conditions. Because the resolution of the broadcast source material (NTSC or PAL) was relatively low and because the direction of both the stripes and the lenticulations beneath them was perpendicular to the raster, moiré fringing and other interference patterns often created by black matrix screens could initially largely be ignored.

Early front projection alternatives in homes that wanted a picture bigger than what could be seen on a self-contained direct view set, tended to rely on curved screens because, once again, the projectors back then were extremely dim but, at least with a parabolic screen, if you sat directly in front of it, you could watch a reasonably bright picture.

By the middle 1990's, however, the Home Theater industry had begun to acquire a much broader currency which in no small part was due to two men who spent quite a lot of time and energy telling everybody in it how bad it was. These, of course, are Joel Silver of the Imaging Science Foundation www.imagingscience.com/ and Joe Kane of Joe Kane Productions www.videoessentials.com/.

Together they set out to teach anybody and everybody interested in enjoying a good picture from their home entertainment systems (whether direct view or projected) just what a good picture was and how to create it. That often meant that the manufacturers' factory settings on much of the hardware had to be completely discarded in favor of a quite radically different group of settings which, when accomplished faithfully, greatly improved the quality of the resultant picture and of its sound.

Since so much of the programming which gets watched in Home Theater has a quite specific and very well defined set of production values, those values should, assert Silver and Kane, be respected and thus reproduced as closely as possible in their viewers' living rooms. Thus, if the director of a film we are watching has been careful to costume his heroine in a gown that is robin's egg blue, it is, aesthetically at least, regrettable if we see it on our screen as being some other color, like, for instance, purple.

In some sense, inaccurate colors in entertainment media deserve to be thought of as artifacts-attributes or qualities of the presentation which by their presence distract attention from the presentation itself. If as a result of having a big screen, we see widely spaced raster lines threading across our picture, we are not going to be content. Similarly, if the grayscale or contrast ratio of that same picture are not properly set and calibrated, we should be equally dissatisfied. How exactly to avoid these and other picture imperfections are what Silver and Kane have so admirably taught. How to select and install the optimal projection screen is now what we have to learn.

Angles Of View

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In several

Home Theater - The Big Picture

The reason all of us enjoy going to the movies is that in some often unconscious way we are transported into other worlds where, for two hours or so, we are encouraged to share and experience loves, lives, adventures, and characters that are otherwise extraneous to ourselves. The cinematic techniques which comprise this experience are as numerous and varied as the degree to which their results are successful. However, whenever the purpose of the finished product is our entertainment, it will depend greatly on the convolution of two fundamental attributes: illusion and immersion. The accomplishment of the first, of course, generally determines the extent of the second.

Developing these concepts of illusion and immersion so that they acquire particular focus, we can see that whatever success they may have as a result of the software seeking to stimulate them (the movie) can be grossly undermined if not destroyed by the environment of their presentation. Beginning to watch a film in a theater where the management has forgotten to extinguish the house lights is an experience no one finds satisfactory. Neither do we appreciate for very long listening to a suddenly silenced soundtrack.

To state these conditions positively, when we go to the movies, we expect to view the projected software in zero ambient light and to have its images in focus and its soundtrack in synch. Many of the other attributes of the visual display are, if not exactly ignored, typically taken for granted. Even we in the A/V industry are not likely to comment on the resolution or contrast of a film that we have just seen. Nor are we able to say anything qualitative about the color values that informed its various scenes.

True, we might as readily appreciate its photography and the content of its soundtrack as we simultaneously appraise its acting and its plotline, but none of these has anything whatsoever to do with a film's presentation. If the projection lamp is bright enough and if the print being shown is in synch and unscratched, if the sound system is adequately amplifying and properly "playing" the soundtrack, and if the house lights are sufficiently low, then the presentation may be termed effectual. Presentation values improve, then, in precisely inverse proportion to the degree to which we notice them.

Now, what about when we seek to take the experience we have enjoyed so many times at the movies home with us? What will it take to enable us to go to the movies without, as it were, going to the movies?

Broadcast television has for years been beaming movie programming through our sets and, thus, into our homes. No one, however, was ever tempted to confuse what she was watching on whatever "...Night at the Movies" with the real thing. If we worked very hard at ignoring the increasing frequency of intrusively interruptive commercials, we might be able to muster some slight feelings of *illusion*, but *immersion from*, at least, a 19-inch television set and its single, tinny speaker was never even a possibility.

That was the first medium through which movies were seen at home. The second, of course, was the VCR which, while not much better looking than TV, at least got rid of the commercials and thereby increased the illusion factor by restoring to the movie being watched its original continuity. Nevertheless, even though the diagonal of its tube might have increased to 27 inches, we were still watching a TV set.

The advent of 3-gun CRT video projectors enabled, for the first time, the conversion of a TV into a PTV (projection televison) and the age of the at-home big screen began. In their first iterations, PTVs had 67- inch diagonal screens and while by today's standards that's hardly huge, back then it was a non-trivial 500% bigger than its tube based predecessor. And if, once that device was set up in your living room or den, you didn't move your chair any farther back from where you were accustomed to watching your old TV, your home screen for the first time filled enough of your visual field to look actually "big." The trouble was even though the size of your picture had grown more closely to resemble the scale of the movies, that very enlargement allowed other, much less welcome artifacts to pop out of the picture and annoy you.

Five-hundred and twenty-five raster lines, for instance, get a whole lot easier to notice if they are scanning across a screen that's no longer 16 inches high but 40. NTSC television, with those 525 lines of resolution, required a viewing distance of about 10 screen heights if they were not to be discernable. If you sat before your new PTV at what was now only a distance of about four screen heights, those lines were, as it were, in your face.

One other obvious point is worth mentioning here. The aspect ratio of your PTV screen was still the TV- inspired (but hardly inspiring) 3:4 and few, if any of the movies then being made were shot in that antiquated aspect ratio. So you watched even on your new big screen imagery that was severely truncated from its original shape.

But then came laser discs and they did have resolutions higher than the TV signal and they were able to exhibit their source material in its original aspect ratio, albeit at the cost of cropping the top and bottom of your screen into various "letter boxed" rectangles. They also contained audio information which was capable of being distributed into a five-channel sound system which really was capable of surrounding you.

Maybe the picture you were watching still didn't really look like it would have in a movie theater, but it now began to do a pretty good imitation of sounding just as convincing as the movies themselves did. The helicopter *did* sound as though it were flying in from behind you from the left and then *did* sound as though it were thundering off in front of you to the right. So while *hearing* may not be believing, surround sound was a big boost both to illusion and immersion.

Nevertheless, we do not speak of going to "hear a movie." We speak of going to see one; so, of the two, the visual part of the experience will always dominate the audio. And if the reference standard for what we can reproduce at home is film itself, the bar we have to surpass is high indeed.

Film, of course, is an analog medium. This means that its resolution, its capacity to display very fine detail, is neither low nor fixed. It also means that there aren't any raster lines or pixels making up its images and that its dynamic range (the available differential between its brightest brights and its darkest blacks) can be very large. Regrettably, when film gets transferred to video a lot of these virtues can become significantly compromised.

Video, of course, is not an analog medium. Its resolutions are fixed and its raster lines countable. But also because it's not analog, video (or what we are here loosely calling video) can be manipulated electronically in some crafty and extremely helpful ways. There are black magic boxes which can multiply those raster lines such that they're harder to see and much harder to count.

For the whole host of new projectors which are not CRTs, the thresholds of brightness and resolution routinely being crossed are increasingly impressive. And, where once it was the CRT and only the CRT that had the ability to display accurately a wide range of resolutions, the deployment of the new magic boxes, the scalers, are permitting devices with fixed resolution to display quite commendable imagery whose own native resolution is other than theirs.

That being so, it doesn't take much percipience to predict the eventual disappearance of CRT projectors altogether from home entertainment environments. The DLP and LCD alternatives are already a whole lot brighter and, as their innate resolutions inexorably grow to XGA and beyond, the pictures that they project (scaled or otherwise) are looking, these days, extremely good.

So if you get yourself a dark room and you shine one of these new projectors at a good sized Da-Lite screen and you play a good quality DVD with a soundtrack that will envelop you through your five speakers and can rattle your breastbone through your sub-woofer, is there at last as much illusion and immersion in your home as you'd get from seeing the same movie in a theater?

The answer is, pretty close. For sure, you have to have bought high quality equipment and you have to have taken quite a lot of care with its setup. Even then, the quality of the audio portion of your experience is very much the more reliable. And it should be, as the physical properties of the sound waves issuing from your speakers need differ hardly at all from the sound waves generated by a real helicopter. Whether the levels of illusion and immersion are as adequate to convince your own visual system of a comparable reality depends, of course, on its particular pair of i's

Angles Of View

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Deciding on a screen for your Home Theater involves a variety of choices not all of which may be obvious. This article will try to present some of the most important criteria for screen selection so that you can enjoy the very best

Home Theater - Behind the Scenes

When it comes to looking at front projection screens, the biggest single difference between their use in Home Theater and industrial environments is whether or not you leave the lights on while you do it. In the Pro A/V world of presentation systems, significant levels of ambient light are de rigeur and, thus, inevitable. And, for reasons explained in detail earlier in this series, well they should be. In the residential environment of Home Theater, however, exactly the opposite is the case—or at least it sure should be.

Justification for viewing your Home Theater screen in ambient light that is as low as possible is not obscure. As viewers, we are psychologically very much more likely to become immersed in (or by) the program material we are watching if, indeed, it is the only thing our eyes easily can see. Dimming the light levels of all the objects occupying our field-of-view other than the screen greatly brightens our physiological perception of it.

Before moving to consider surface and image qualities of a Home Theater projection screen, let's leave the lights on for a minute and decide how big to make it. As of this writing, this is a tricky question, obliged as it is to include in its answer a bevy of aspect ratios which are inconveniently dissimilar.

If you believe, as we at Da-Lite certainly do, that the 9:16 format is sure eventually to prevail, then you will want to procure a screen of that overall aspect ratio. Here's the way most efficiently to size it. Measure the distance from the wall in front of which you plan to hang it to the chair or couch from which you plan to watch it. Divide that distance by 3.3 and you will know how high your screen ideally should be. (Its width, of course, is 1.777 times that deduced height.)

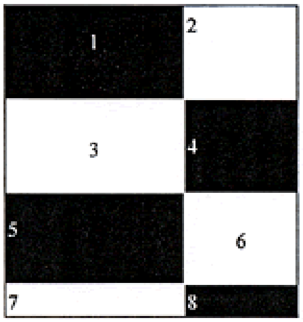
The reasoning behind that geometry is complex but reliable. (A detailed discussion can be found at http://www.da-lite.com/educational_materials/angles.php?action=details&issueid=11) Suffice to say here that if you sit back 3.3 screen heights from an image with HDTV resolution (1920 x 1080) you will have a viewing experience that has been very carefully designed to yield high degrees of immersion and illusion from your viewing experience.

If, on the other hand, you size your screen so that it may be filled by 3:4 material, your optimal screen height (for the same viewing distance) historically needed to become a good deal smaller. That is less true today because of the tremendous advances in video processing (scalers and the like). Nevertheless, because of all the varying aspect ratios which our various sources and software produce for us to look at, multiple aspect ratio screens like Da-Lite's Horizon are a particularly nifty addition to your Home Theater.

Ignoring resolution (which none of the screen surfaces discussed in this article affects at all), we can now look at the two attributes to which a screen's surface may meaningfully contribute: contrast and uniformity. We already know that the magnitude of external contrast (between screen and ambient light) should be as high as is practicable and so, in turn, should everything else possible be done to maximize the contrast internal to the screen. This, however, involves some projection issues which, while hardly more important, are nevertheless more subtle than just turning off the lights.

When we speak of contrast within an image and projected on a screen, what we're actually describing is the relative intensities of its lightest and darkest elements. The greater the disparity between those bright parts and those dim parts, the greater will be our satisfaction in looking at both of them. Since, these days, projectors with enough energy to make those bright parts really bright are commonplace, what we really need to worry about is keeping those dim parts dark.

To see why managing this "Black Level" is such a challenge, consider the following "image."



If we pretend that what we're looking at here is a screen onto which has been projected this random assortment of black and white "blocks," there are some useful things we can learn. The first is, that (unless you're reading this on the Internet) you'll never, never find a way to get blacks up on your screen as black as these printed blacks are black. Although this has already been said a thousand times, the fact is that the *only* thing your projector can project is light and, since black is the absence of light, you can never, never project it.

That being said, if we take the whole rectangle above to be some arbitrary area of our overall projection screen, what is the closest we can ever come to reproducing the color of Block 1 on our screen? You're absolutely right, the answer is Block 2 (or 3, or 5) and, therefore, the only way to fool our eyes into believing that Block 1 is "black" is to make Blocks 2 and 3 so much brighter that the ratio between them becomes convincingly large.

Now let's look at this same subsection of a screen with an eye to uniformity. What is meant by Uniformity in this context is that, if the software intends, for example, for Blocks 2 and 7 to be equally bright, that the screen does nothing to encourage our eyes to decide otherwise. A more careful way of stating that might be to say that the same percentage of the light falling on them reaches our eyes from Block 2 as from Block 7 even though the latter may proportionately be much closer to the center of the image. This concept of uniformity, leads us, then, by a slightly alternative route to the question of screen gain.

In the beginning, we screen manufacturers developed screen surfaces which, one way or another, were significantly non-uniform in the way that they reflected projected light back toward the audience looking at them. Thus, if Block 2 in our illustration were to be the upper right hand corner of such a screen and Block 7 nearly its center, a light meter positioned perpendicular to that center would read a much larger value than it would when pointed at a corner. The more we make a screen surface reflective and, thereby, raise its gain, the greater the disparity between its sections will become.

So, if you care about uniformity in you image, the one thing you don't want your screen to have is a high gain. If you select a screen with no gain, which is to say, a matte white surface whose gain is "unity", pointing a light meter at any section of it will give you *exactly* the same reading as may be taken from any other.

But what about contrast? In addition to perfect uniformity, does a non-gain screen also display the maximum potential contrast ratio? The answer, regrettably, is no. Here's why. If we point our light meter at Block 3 of a screen that is Matte White beneath and get, say, a reading of 100 and then point it at Block 5 and get a reading of 4, we know that our setup has a contrast ratio of 25:1. Now, let's switch out that screen for a new surface like Cinema Vision which has gain of 1.3 (and is, resultantly, 30% more reflective).

Repeating the same measurements, we will discover that a maximum number will vary slightly, up or down, depending on which white block we point the meter at. The black blocks, however, are the important ones because the meter will read from them much lower numbers, perhaps down in the 3 range (fully a 25% reduction from 4, you see). This lowering of the system's Black Level will conspicuously improve the contrast of our display.

It's easy to understand why this is so once we recall that in addition to the "absence" of light entering a meter when we point one at Block 5, there is also light from Blocks 2, 3, 6, and 7 leaking into it. Since the screen is Matte White, the exact same amount of light is disbursed with perfect uniformity from each and every one of those white blocks throughout the entire viewing area. This includes wherever we choose to position the light meter.

But, if all the "mini-screens" comprising the white blocks have positive gain, then, because they are all more directional, *less* of the light re-radiated from them will be spread into the lens of our light meter. And so, as the screen gain goes up, the measurable contrast ratio just gets better and better.

But, following this prescription for increasing contrast almost immediately causes side effects which so badly debilitate image uniformity that corners grow weak and the center inflamed.

A little gain, then, may be good for you; a lot, however, is uniformly toxic.

Angles Of View

Vol. VI, 5 ©Da-Lite Screen Company November 2000

Now that most of the universal screen attributes for Home Theater have been established, it is time to turn things around for a while and look at Home Theater screens from an entirely different perspective. We refer, obviously, to rear projection screens whose virtues, while considerable, are not always as obvious as those belonging to their front projected counterparts. Here, then, are a few remarks concerning

Rear Projection in Home Theater - Front to Back

Although it might at first seem a misnomer, even a contradiction in terms, a Home Theater that is rear projected is not only a viable idea, it's a really good one. Yes, it must be acknowledged, all movie theaters we attend are front projected but, then again, all of them are showing film and we in our homes are not.

This article will contend that, if you can, making your Home Theater screen a rear projection device is superior, even much superior to the more familiar front screen choices.

For starters, a rear screen is aesthetically attractive because you can take the projector and all of its ancillary equipment and hide them away behind it. Space and sight lines are thereby liberated in your living room (or wherever you look at the screen) which, therefore, can remain looking more like a living room-a benefit, we are told, particularly popular with spouses.

In addition to that physical advantage, rear screens provide a large enough variety of optical benefits that it may sometimes seem hard to choose between them. The selection may be simplified, however, if we reduce it to a few, basic principles. The first of these is that all rear screens utilize refraction to control and manipulate the light passing through them while all front screens depend for the same purpose largely on reflection. Reflection does play a role in rear projected displays as well, but never a welcome one.

Refraction is essentially the process by which light rays may be caused to change their direction when they cease traveling through a medium of one density and enter a medium of another. Any such ray when projected at a screen through air (a low density medium) will swerve by some amount away from its initial direction when it enters the back surface of a plastic rear projection screen (a higher density medium).

For completeness sake, we need to add that when that same light ray exits out of the front surface of the screen (and thus switches back to traveling through low density air), it will swerve back toward the direction in which it was originally projected. The magnitude of each of those swerves made by the ray is variable according to the angle at which it consecutively encounters each surface. By causing the front and/or back surfaces of a rear screen to become other than flat and/or other than parallel, quite a lot of clever things can be done in its manufacturing processes which usefully manipulate this angular behavior.

Some historically prominent examples of this are lenticulated rear screens which have a series of fine vertical grooves molded into their front surface and which, according to the radius of those grooves, cause the projected light rays to fan out from the screen in a pattern that is very much wider than it is high. In the days of what we can now correctly term "brightness-challenged" projectors, lenticulated screens were highly prized because their asymmetric distribution pattern ensured that a higher percentage of a projector's total (if meager) lumen output into the eyes of an audience conventionally arrayed before it. Home Theater enthusiasts are surely aware that virtually every off the shelf projection television set has been designed to include a lenticulated screen.

Unfortunately, there is a problem with lenticulations which can become pronounced and worrisome with displays whose images are projected in very high resolution. Space does not permit a full description of the mathematics which underpin this relationship (a full discussion can be found in Volume III, Issue 2), but it can be said here that the regular configuration of the vertical grooves extending horizontally across the screen can cause significant interference patterns with the equally regular horizontal rows of pixels being projected through it. The higher the pixel density becomes, the more likely it is that distracting optical artifacts will appear.

Given the bright future of projectors in Home Theater, we @Da-Lite Screen Company see no reason why lenticulated screens particularly should share in it. Instead, the entire resolution issue (which certainly is an important one) can be obviated by choosing a diffusion screen whose front surface at least is always flat and without periodic structure. Since the resolution "limit" of such a screen is way, way beyond any conceivable pixel density, one may as well characterize it as being infinite.

Our recommendations continue, however, and now that we've counseled you to pick a diffused rear projection screen we're going to go on and offer it to you in two entirely different shades. One "shade" is a pure, milky white and its virtues have to do with color. The other "shade" is a quite chromatically complicated gray and its merits have to do with contrast.

First, Video Vision, the white one. This is a unity gain surface which has exceptionally high transmission and hence is extremely uniform throughout large viewing angles. The real purpose of Video Vision, though, is to be white, so white that it will reproduce any and all colors projected through it with exact chromatic fidelity. Because, technically, Video Vision causes no shift in any wavelength, the purist may be assured when he chooses it that the blush he will see on Scarlet O'Hara's cheek can be the very same pink which was visible in the original Selznick print.

Now the type with the gray shade, the DA-100 and the DA-130. As its number indicates, the second screen has a gain of 1.3 which, therefore, is 30% higher than the DA-100. They both, however, are the same gray and it is this grayness which makes rear projection screens so superior to front projection.

Everybody knows that the color of this box is the color of the blackest black you can ever exhibit on a white front projection screen. Since black, after all, is not a color created by the presence of light, but rather by its absence, it cannot, having no wavelength, ever be projected. Thus, if you want some area of your image to look like ■ and not like , it will very helpful if the underlying "color" of the screen can be something like which is a quite reasonable approximation of what Da-Lite's Neutral Gray screens in fact look like. Not only will the resultant "black level" of your imagery be much better, but its actual contrast ratio will also be much enlarged.

To understand how this could be so, we need to recall that all screens are obliged to interact with two light sources: projected and ambient. In the case of front projection, light from both of those sources falls onto the screen in the same way and from the same direction I│. In rear projection the two sources originate on opposite sides of the screen and, thus, travel in different directions →|←.

A front projection can't do anything else than reflect both sources with equal efficiency. But since a rear projection is designed to **transmit** rather than reflect light it can be made to be a very poor reflector (which is why its coated side should **always** face its audience).

Now a word about ambient light. Some Home Theater people suppose that they can eliminate it. They can not. Even if the only light source in or behind the room is the projector, the light radiated out from the screen (front or rear) will inescapably end up illuminating a much, much bigger area than its audience's eyes. (That's how come midway through a movie in a purportedly darkened theater you can still easily see not only whether there's a person sitting next to you but whether he's wearing a blue sweater.)

Some amount of that image light will splash back up onto the screen and inevitably degrade the contrast ratio of the picture. In front projection, there's nothing the screen can do with **that** light except re-radiate it. In rear projection, however, the screen being, if you will, a two way street will re- transmit it backwards into the projection booth where it may safely be absorbed. Thus, only a very small percentage of the ambient light incident to a rear screen's gray surface actually gets reflected in such a way as to noticeably degrade contrast.

The precise color (wavelength) of the Da-Lite gray, incidentally, is quite carefully chosen so that it is "neutral" and has an exact set of coordinates in what is called color space. (Imagine a sort of oddly drawn triangle with pure Red, Green, and Blue at each of its corners and all the colors which are combinations of those three established by their spacial position within it.) The color shift, therefore, imparted by our gray is minimal.

The distinction, then, between front and rear projection may not be as sharp as Black and White. But Gray and White? We think so.

Angles Of View

Vol. VI, 6 ©Da-Lite Screen Company December 2000

In the issue preceding this one, efforts were made to persuade interested readers of the benefits to be had from watching entertainment media on rear projection screens. In fact, there are no optical disadvantages to rear projection whatsoever. There is, however, a physical drawback to rear projection which, of course, is the amount of floor space which must be sacrificed in order that it be enabled. This article will outline some useful ways to keep the size of that space to a bare minimum and, additionally, how to avoid certain optical problems which space compression techniques can sometimes cause. The forthcoming discussion will focus particularly, then, on

The Secondary Reflection Issue

In the world of commercial office space, it's bad enough that the square footage necessary to create a rear projection booth is, month after month, expensive to pay rent on. In the world of Home Theater, the notion of having to create some jet black closet which can't even be used to house the washer and dryer must surely in some families really be anathema.

Nevertheless, if we have done our audio/visual homework diligently we will have to acknowledge that, painful though the real estate investment may be, the benefits to be reaped are extremely profitable. How, then, may we keep our return at a maximum and make our initial investment as small as possible?

We'll do it, of course, with mirrors (blue smoke will not be necessary). By using one or two mirrors correctly positioned behind a rear projection screen, we can reduce the depth of its booth by more than 50 per cent. If we expect all of the rooms in our house to be rectangles, the width of that booth cannot be less than the width of our screen, but the depth which otherwise might need to be greater than the width can be reduced by half.

If we think about this for a moment, it all makes perfect sense. We know that light rays coming out of a projector (any projector) must pass through a lens which causes them to diverge. If they didn't do that and we shined a projector at a blank wall, the size of the image it casts could never be made bigger, no matter how far back from that wall we moved it. To say that last sentence in a different way, for whatever size image we wish to make, there will be a minimum distance back from that image at which any projector must be placed in order to cast it. In the parlance of the A/V world, this distance is called the "throw distance".

That "throw distance" is the bad news. The good news is that although the light rays making up our image have to travel that distance if they are to form a picture as big as we wish, they *don't* have to do it in unbroken straight lines. We can intersect their paths with mirrors and, as long as they are at the correct angles, no distortion of any kind will occur. Alert readers will immediately notice that a mirror will reverse an image but, relative to a front projection screen so, of course, will a rear screen. Fortunately, this is a non-issue as any projector we buy these days is certain to have a switch which, when flicked, will electronically "reverse" its image whichever way it appears.

As long, then, as the total path length of every light ray emanating from the projector is not changed by the insertion of a mirror or mirrors, the resultant image need not be degraded to any degree. Unless, that is....

There are, in fact, two "artifacts" which can intrude upon an image's quality. The first is what is called "ghosting" and the second is what is called a "secondary reflection." The first thing to say about them is that they are not the same.

"Ghosting" appears as a faint, double image wherein every object within the picture appears to be outlined by a slightly offset copy of itself. Instead of appearing sharply defined as in CLEAR, it looks something more like FUZZY. Ghosting is caused when there are, in fact, two image planes, one typically being the front surface of the screen and the other atypically being its back surface. In the case of a standard, acrylic rear projection screen, the two surfaces are separated by the thickness of the plastic sheet out of which it was made and, thus, are not more than 3/8 of an inch apart. That fractional inch, however, is quite enough to create a doubled image if the undiffused surface has had something done to it that has caused it to be other than transparent.

We, at Da-Lite, firmly recommend that the coated side of our diffusion screen always be installed facing the audience and that nothing (*nothing*) be done to the back surface including allowing it to become dusty. Lastly, it should be noted that ghosting is a phenomenon which is neither created nor worsened by mirrors.

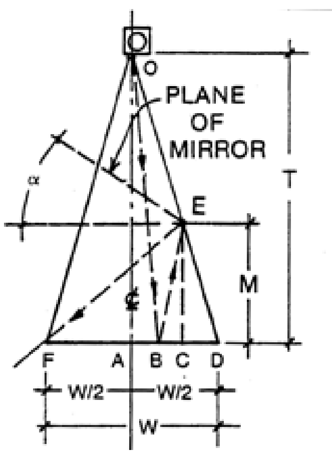
The problem which mirrors can cause is Secondary Reflection(s) and it doesn't look at all like ghosting. Instead, what is most often seen is faint repetitions of parts of the picture properly projected above the screen's equator showing up as visible artifacts below it. What causes this is as easy to define as it has been difficult reliably to avoid.

A few paragraphs ago we stressed that the back surface of our diffusion screens be kept clean and uncoated. That means consequently that such a clear surface will definitely be reflective. Some amount of light from the projector will be reflected back (towards the mirror) on its first pass through the screen. Because mirror systems generally position the projector below the screen, the mirror closest to the screen will have its bottom edge farther away from the screen than its top and thus, looked at in elevation, its vertical plane will form some angle with the plane of the screen. Sort of like this: Screen ®| \← Mirror.

Now, if we trace in our minds' eye these rays of light which are bounced back by the screen, we can follow them to see where they go. Some number of the light rays from the projector reaching the top of the screen will bounce back from it and then hit the mirror for the second time after which they will be reflected by that mirror at angles different from the one they traveled along after their first bounce. If those second paths are along angles that are too small, the secondary light rays will end up not passing below the screen but through it.

The challenge of figuring out correct geometries for mirror systems and projector angles behind a rear screen has bedeviled designers for years. The method by which Secondary Reflections can be avoided, however, has been rigorously worked out and is explained in detail on Pages 100 through 104 of Basics of Audio and Visual Systems Design written by Raymond H. Wadsworth, P.E. Although that invaluable handbook has long been out of print, an updated version (to be edited by the author of this series) is currently in the works and will be published in 2001.

In the meantime, the basic technique can be illustrated (with Mr. Wadsworth's help) as follows:



This drawing (first created in 1983, which explains why the projector icon is a slide projector and why the drawing is not in elevation but in plan) shows the various distances which need to be manipulated in order to calculate a, the angle at which the mirror must be set so that secondary reflections will not occur. In contemporary mirror systems, this drawing should be rotated 90^{o} and "W/2" should more accurately be named "H/2" as "W" stands here for width and we want "H" for height.

All the angular relationships which Wadsworth details, however, are as useful today as they were seventeen years ago. To determine the minimum value for a, his equations require three data points:
1) The Height (for him it was the width) of the screen.
2) The throw distance.
3) The distance back from the screen to the closest edge of the mirror (in his drawing this is a side edge, in our case it is the top edge).

Plugging those three numbers into his formulae yields, for any mirror system, the minimum angle at which the mirror must be set so that all of the light rays reflected back by the screen strike the mirror in such a way that, when they are reflected by it a second time, they travel along paths leading either above or below the screen but never through it.

Back in 1983, the only way to make these calculations was actually to crank the various measurements through the requisite trigonometry. While that trig is still mandatary for those same purposes today, the effort to accomplish it, as it were, manually is not.

Angles of View VOLUME VII - 2001

A series of articles examining the new and developing technologies that are constituting visual displays.

Angles Of View

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At first glance, it would appear that the development and progress of digital cinema have little direct connection to the world of ProA/V. Because of its core concentration on entertainment media, the Home Theater industry has ample reason to monitor with interest this newest entertainment medium, but the systems end of the A/V business? Kind of hard to imagine. Or is it? Let's take a closer look at this emerging technology and see if there aren't, in fact, some interesting correlations between commercial A/V and

Digital Cinema - Take 1

As this series has discussed previously (http://www.da-lite.com/educational_materials/angles.php?action=details&issueid=19), all information (of whatever kind) which can be captured, created, projected, or displayed exists only in an analog or digital format. True, any particular amalgam of information (an "image," for instance) can start out in one format and then once or many times be converted into the other as it is passed through and along the components of a display system.

Once upon a time, one could be confident that the initial collection point of that information resided firmly in the analog world. Certainly because our sense organs (eyes and ears, etc.) are exclusively analog receptors, information presented to us must always end up converted from D to A.

To use a simple example, when we set out to make a 35MM slide of, say, a friend riding her bicycle, we pointed our camera in her direction, snapped the shot, had it developed, and then, by shining a light through the resultant image, we could look at it projected and enlarged on a screen. The image we contemplated was an extremely convincing two-dimensional representation of the three-dimensional scene which we had lifted from the real world. Unless or until we blew it up to a size large enough to detect the grain of its emulsion, we could examine it as closely as we liked and still avoid noticing any of the artifacts out of which it was, nevertheless, actually made.

If this 35MM static image was inserted into a moving series of similar images each of which was only slightly altered from the ones preceding and following it, our belief in the fidelity of what we were looking at in space was enlarged to include convincing changes in time. These were, in their most literal sense, motion pictures—and the experience they came to exemplify for us was, of course, "the movies."

To belabor the point for one additional paragraph, when we aimed a movie camera at that same bicycle- riding friend, we took a series of photographs which accurately captured sequential changes in her position relative to ours. Note that our camera did not record every position she adopted during the time we were filming. Instead, it sampled just enough of them (24/sec) that when we subsequently ran them all though a movie projector, our brains were fooled into thinking that we were seeing fully as many positions of the moving bicyclist as we observed while watching the real thing. (The spokes in her wheels might appear to have been revolving backwards, but that is another discussion.)

It is this technique of using a finite number of temporal or spatial sampling elements to represent the infinite continuum of which reality is actually constituted which digital image making depends on. While its sampling scheme alone may not completely define digitized imagery, it is arguably its sine qua non.

The reason why none of this is very novel or startling to the ProA/V world is because, of course, we as an industry have been refining for years ways to improve the display of images whose origin was notthe real world and was instead the insides of a computer.

By definition, the "data" of our data displays has always been computer generated. This hasn't been true because of anything intrinsically preferable about its format. (VGA never looked very impressive, did it?) But it was true because business people, our clients, had learned how to create with their computers gigabytes of information which was useful to them to organize and present. Since those computers were universally digital, there seemed nothing whatsoever remarkable about projecting their graphical output in ways that were precisely divisible spatially.

We in ProA/V have known for years what 640 x 480 signifies and we have been the first to celebrate the advances made in that sampling rate as it has extended through 1024 x 768 toward 1920 x 1080 and, doubtless, beyond. We understand (and take for granted) that the product of these numerical pairs tells us into precisely how many pieces our imagery has been diced.

We also appreciate that the image we project on a screen, whether it be a page of text, a PowerPoint slide, or a spreadsheet, does not itself have any analog in the real world. It never, this projectable "object," had an existence whose resolution was infinite. In point of fact, the entire class of computer generated images don't have even a "native" resolution because that phrase describes machines and not the "objects" they create.

All of us are not only familiar but comfortable with our ability to take, for instance, a PowerPoint slide and entirely reconfigure its appearance in just a small number of mouse clicks. Foreground and background, fonts and graphics, color, pattern, and even movement are all not only profoundly variable but completely independent of objects in the real world. We are empowered with this flexibility because underwriting each and every attribute we alter is nothing more than a long sequence of very simple instructions which tell each and every pixel whether to be On or Off and, if On, what color it should be.

String all of those instruction sets together and then scan through them and you can have a succession of screens, images, or pictures which you can vary and reconstitute at an iterative rate easily fast enough to convince its viewers that it contains motion.

Which brings us back to the movies.

If we think about all of the movies we have seen in our lives, we can notice that a common denominator uniting them (except cartoons) is their inclusion of "live action." In going to them, we went to see real people (actors, of course) moving about and talking to one another within environments which themselves appeared convincingly authentic even when they were in fact artful and artificial sets. Were we privileged to witness the actual filming of such a movie, we would have seen arrayed in front of the camera real actors riding real horses or sitting in real chairs while their actions and dialogue were lineally transcribed onto film.

Even when "special effects" were employed, tangible objects, whether painted matte backdrops or miniature model spaceships, had to be photographed and recorded in ways and from perspectives which had persuasively to belie their actual natures and scale.

If the director of these efforts wasn't for whatever reason satisfied with the appearance of any one of these "scenes," his only option was to set it all up and shoot it over again. Then, at the end, he could assemble all the filmstrips containing all of the takes of all of the scenes and have them edited into whatever sequence he conceived would make up their most coherent whole.

These points have nothing to do with the aesthetic values of the finished product. We are instead only interested in drawing attention to the nature of the mechanical process by which all of the imagery making up a typical movie gets deposited onto the medium through which it will be eventually copied and projected.

From a ProA/V angle of view, the whole reason why the process of classical movie making has been so arduous could be explained by the phrase "Analog Cinema." As long as the source material of its imagery had to be found or created in the real world, cinema enjoyed none of the flexibility which digital imagery ensures.

With, however, the migration of digital imaging technology from our ProA/V world to the world of the Hollywood studio, all that is changing forever. While some may suppose that the most significant aspect ofDigital Cinema is the shift its arrival signals in how a movie may be distributed and shown, the really radical development is the transformation in technique of how a movie may be made

To see this more clearly, watch what happens when traditional "live action" footage is digitized: *"It loses its privileged indexical relationship to pro- filmic reality. The computer does not distinguish between an image obtained through the photographic lens, an image created in a paint program or an image synthesized in a 3-D graphics package, since they are made from the same material—pixels. And pixels, regardless of their origin, can be easily altered, substituted one for another, and so on. Live action footage is reduced to be just another graphic. . ."1*

This begins to sound like the sort of manipulations people preparing presentations in ProA/V have long been used to, doesn't it? And so it is. Soon enough, the newly digital cinema will just be another version of what we're already calling Multi Media. Movies won't be film anymore; they'll be software:

Lights, camera, action . . . .

Cut. Paste.

1The author is indebted for these and other insightful observations to: Manovich, Len.

Angles Of View

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Now that we have completed the first year which has as its first digit 2, we can easily satisfy ourselves that our industry has before it a future that will be as informed by change as it will be underpinned by technology. Although we at Da-Lite Screen Company have a particular bias regarding the endpoint of the "V" part of A/V, we are not unmindful of some of the other, major components which will contribute to its still emerging appearance. Vol. VII of this series, then, will seek to depict attributes of visual displays which, in the light of our new century, need to be regarded in both novel and differing ways. To see what some of them are we'll start by

Watching Technology - A Moving Target

In the past, this series has proffered the following answer to the following question:
Q: *What is the primary goal of a visual display system?*
A: *To deliver as many as possible of the light rays emanating from the projector into the eyes of the audience.*

Historically, that has been a perfectly defensible answer, though, from today's vantage point, there are some tacit assumptions underlying it which may no longer be necessary. One thing that answer assumes, for instance, is that light rays are at a premium. Since, historically, there never were enough of them, it was essential that (as far as it was technically possible) none be wasted.

Does that paucity of light rays still persist? Of course not. Even "little" projectors now put out more light than is needed by the typical screen size they are designed to fill. And "big" projectors? Their illuminance specs are no longer to be measured in hundreds of ANSI lumens but *thousands*.

So; if we don't have to worry any more about having enough "brightness", what might we be concerned with instead?

That depends, we will here suggest, on how the display is going to be used. For reasons to be outlined below, it really can be said regarding display dynamics that "Form Follows Function".

Contemporary displays have become more than vehicles for presentation. That's a second and less obvious assumption which is buried in the original answer. The purpose (not quite the same thing as goal) of a display system (then) was to enable presentation of visual materials which could be assimilated by the visual systems of their audience under ambient conditions which were typically imperfect. If that information was kinetic, it was called video but was expected, in its quality, only to resemble television. Alternatively, if the content of the presentation was static, it was presumed to contain data.

In a negative sense, static imagery meant that audiences had a much easier time detecting imperfections and artifacts than if a series of continually varying images were to be flashing by at the rate of 30 frames/second. Still, another way of distinguishing between those two would be to notice the disparity of their sources—a VHS tape vs. a PC. A deeper dissimilarity is that one source was digital and the other analog....

What connected all of them, nevertheless, is the commonality of their function. They made up, independently or otherwise, presentations. People were supposed to look at them and be persuaded, sold, trained, inspired, informed, convinced, converted, or (once in a great while) impressed. Conspicuous by its absence from that list of participles is the word entertained.

Presentation as Entertainment has been the province of the Home Theater industry and has a history that, while not different from A/V in the initial technologies available to it, has nevertheless evolved in parallel and, consequentially, evaluates its displays with significantly different criteria.

Joel Silver, President of Imaging Science Foundation, Inc. (joelsilver@att.net), and an expert on designing and setting up home theaters, firmly believes that the essential purpose of his kind of display system has very little to do with light rays. Instead, he declares, the truer goal is *"The most accurate possible reproduction of the electronic signal."*

If there is an underlying assumption to that definition, it would be that the signal in question is good enough to justify being faithfully duplicated. Now that most of our home entertainment systems include DVD players, there *is* a ready source that is capable of extremely high quality imagery. From an audio/visual perspective, that imagery's evaluation criteria would include

1) Brightness
2) Uniformity
3) Resolution
4) Contrast
and (Mr. Silver insists)

5) Color Fidelity.

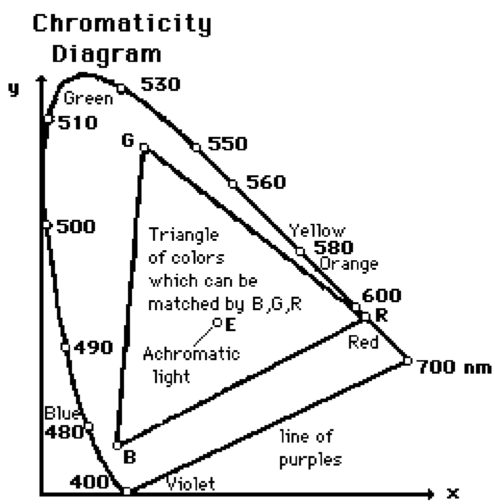
Fair enough. As the preferred projection technology in Pro A/V and Home Theater is migrating away from CRTs, the criteria of Brightness and Uniformity are, effectively, vanishing. Because more than sufficient lumen output may now be counted on from any of the chip-driven projectors, adequate Brightness may now be safely taken for granted. Since that is true, there is absolutely no routine need to utilize screen surfaces whose purpose is to manipulate perceived "brightness" (gain) at the inevitable expense of Uniformity. Readers of this series should surely have seen by now that high gain screens have outlived their usefulness and, thus, really are passé.

That leaves, then, just three remaining metrics: Resolution, Color Fidelity, and Contrast. We are all used to expressing the first as a pair of numbers which enumerate the dimensions of the matrix of square pixels which make up "the picture." In the forthcoming world of 16:9 aspect ratio, High Definition displays, those two numbers have become quite large: 1920 x 1080. The product of those two yields more than two million pixels in a single image.

Although higher resolutions are certainly possible, they aren't, for most applications, necessary because 1920 x 1080 is a resolution limit for most displays that is beyond the visual acuity threshold of the people who are watching them. If the absolute size of an image's pixels is too small to be detected by viewers looking for them, then, ipso facto, Resolution need no longer be thought of as a limiting attribute.

Color Fidelity is a trickier matter. What makes it complicated is that the core library of software accessed by Home Theater enthusiasts is film; and film is not, historically, an inherently electronic medium. Using any number of photographic techniques and exposing them onto any number of emulsions, filmmakers have had available to them a color palette limited only by their imaginations. The colors available to electronically projected imagery, on the other hand, are confined to a very much smaller spectrum.

A quick way to see the significance of this is to look at a "map" of color space that has been laid out on a two dimensional graph. The larger, dorsal-shaped triangle plots all the colors that may been seen (no matter what) by the human eye. The inner, regularly shaped triangle has as its vertices three "points" which define what exact color R, G, and B will each be in the world of electronically *projected* color space. As no real-world color can be seen which has coordinates outside the larger triangle, no color can be projected which isn't inside the smaller one.



The reasons why the smaller triangle couldn't originally be bigger had to do with certain performance limitations of the phosphors used to coat the surfaces of CRT tubes. That, however, was only true then. In the forthcoming era of Digital Cinema, it is not at all unlikely that cameras to make it will have a color space greatly larger than the triangle shown above. And, if (when) that does happen, Color Fidelity as a standard of importance will surely shift accordingly.

Now we are left looking at Contrast—an issue which has been with us since, well, the Dark Ages. Unlike resolution or even color space, there is no amount of contrast that is superfluous. Our eyes like contrast even more than brightness and, although they can't get enough of it, we can say how much they can be given.

Movies have always had the edge here. A "high contrast" film could exhibit a ratio of 250:1. Video projector manufacturers have pretended to similar ratios for years but that posturing was always recognized as adventurous. Not any more. Now there really are electronic projectors that can display contrast ratios of 500:1 and *that*, considering the intrinsic difficulties involved, is an extraordinary and extraordinarily welcome achievement

Summing up, then, it is genuinely remarkable that all (all!) the attributes of visual are changing, driven as each of them is, by underlying technologies that are themselves by no means yet mature. The time may soon be approaching, it may even, in fact, be here when looking at an image displayed up on a Da-Lite screen will be indistinguishable from looking through a similarly sized window at the real world. Now, wouldn't that be something to see?

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