DA-LITE®

# *Ang∠es of View*

## EDUCATIONAL SERIES

# Ang∠es 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 per cent. 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 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 uniformity can be degraded only by projector limitations.

When the diffusion coating contains more than a diffuser, however, uniformity 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-WA N 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 uniformity 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 & 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 & 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 uniformity.

Another recognition of the importance of uniformity 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 uniformity 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 uniformity 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 uniformity 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 uniformity available from our screens and our understanding of the factors which create it remain essential components of our job as salespeople and as manufacturers.

—MKMjr
Polacoat® Division

# Ang∠es of View

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*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's bandwidth, image resolution on a screen will depend principally on what we can perceive visually and therefore the appropriate measuring techniques will change.

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.

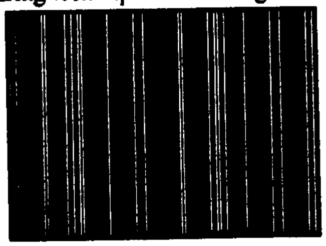

Figure 1

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-degree horizontal field-of-view. Fields broader than 30° 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°.

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 .00029.)

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. Thus from different viewing angles some amount of visual data can be lost if the pixel size approaches the lenticular size.

To meet this challenge Da-Lite has designed and is completing the manufacture of a unique lenticulated profile which preserves resolution to an unprecedented extent. Even though the pitch of this new rear projection screen is .5 mm, the profile can actually display 4 lines/mm. Here's how.

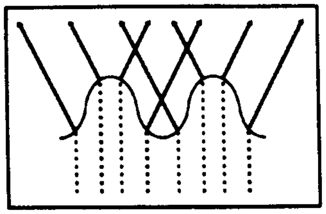

Figure 2

When looked at on edge a lenticulated surface resembles a series of ridges and valleys. In most profiles of this type it is only the ridges which are optically active. The valleys function solely as spacing between the ridges. As you can see from the figure above, however, the new Da-Lite profile is dimensionally symmetric: its valleys are precise mirror images of its ridges. Since light rays do not care whether they are refracted by curvatures that are concave or convex, the valleys of this lenticulation perform identically to the ridges. It is this doubling of the profile's efficiency which enables its resolution to exceed its pitch.

The dashed lines coming up from the bottom of Figure 2 represent light rays from the projector. The section of profile shown is exactly 1 millimeter wide. The incident light rays are bent according to which part of the profile they strike, but in total 4 lines of information will be distributed to the right side of the audience field and 4 lines will go to the left. Effectively, then, when this profile is expanded out across even a modestly sized 100-inch diagonal screen, the display could accept imagery from a projector with 8,000 lines of resolution and not degrade it.

Although it is unlikely that such a projector will be developed any time soon, it is certain that all of 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.

—MKMjr
Polacoat® Division

# *Ang∠es of View*

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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 ⅔ 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.

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?

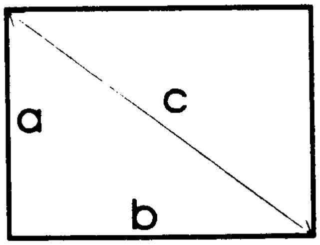

Figure 1

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 $4 = 1.33 \times 3$.

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 9" feet. Also from the "7 screen heights" number we can determine that the image we're watching will occupy only 10° in our horizontal field-of-view.

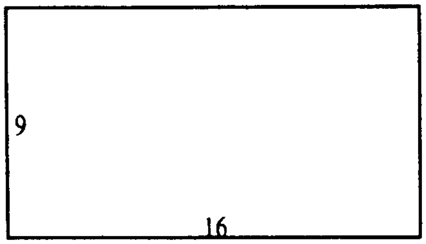

Figure 2

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° 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 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. —MKMjr

Polacoat® Division

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

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

# Ang∠es of View

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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.)

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.)

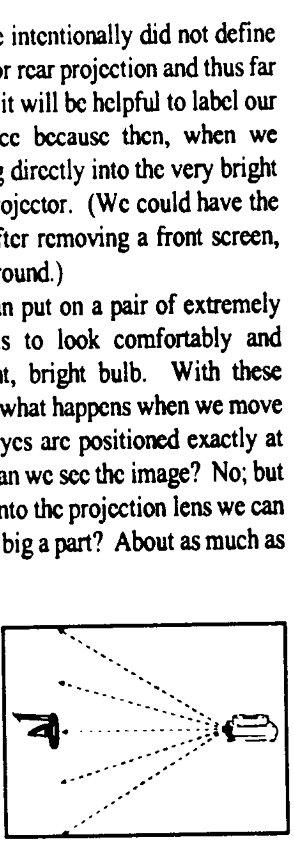

Figure 1

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.

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.

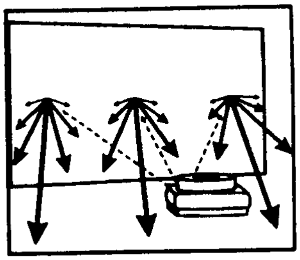

Figure 2

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

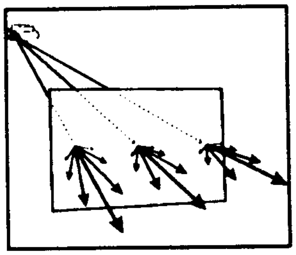

Figure 3

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. —MKMjr

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# Ang∠es of View

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*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 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.

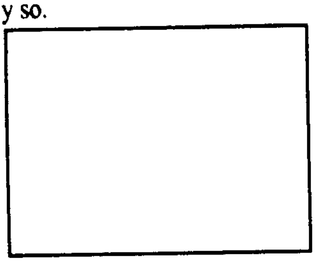

Figure 1

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

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.

Figure 2

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.

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.

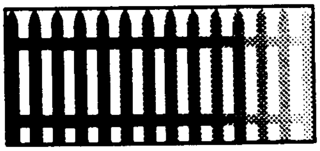
Figure 3

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.

—MKMjr
Polacoat® Division

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# Ang∠es of View

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*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° 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, Nº1] 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°.

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 ($MgCO_3$) - 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?

These crystals have had their flat sides coated with Titanium Dioxide ($TiO_2$) 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.

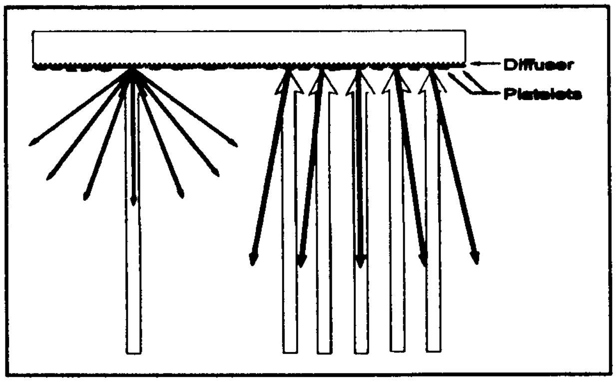

Figure 1

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 ($SiO_2$) is a typical example of a good optical transmitter for rear projection screens.

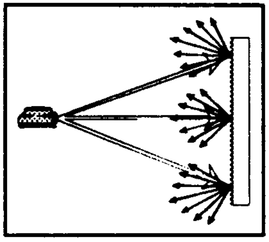

Figure 2

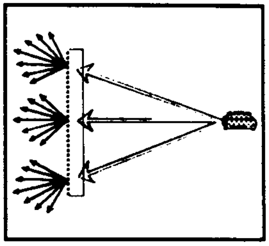

Figure 3

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. —MKMjr

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# *Ang∠es of View*

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*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 discernable 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° angle from the left will bounce off the screen at "an equal and opposite" angle of 15° 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°, then the same 15° light ray we considered above will have an incidence angle of 35° (15+20) and thus will bounce off the screen at a 35° 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°.

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 65$\mu$. 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 shows a series of brightness measurements (the Y-axis) made from just behind a projector (0° 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° 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.

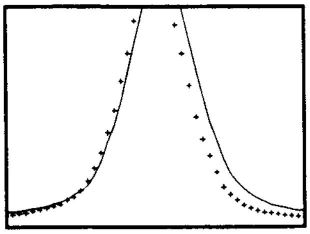

Figure 1

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.

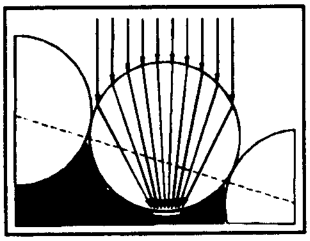

Figure 2

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.)

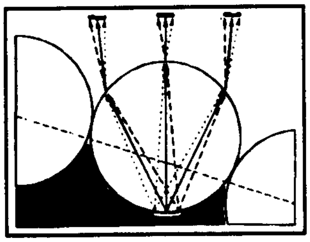

Figure 3

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°) and its outermost ray (which might be 25°). 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 Optixx Mark 30™ and Polylens™ screens which have lenticulations designed to face the projector and also sells the Da-View 4™ 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.

—MKMjr
Polacoat® Division