Screen Size: The Impact on Picture and Sound

By Ioan Allen

Over the years, the film industry has seen cyclical changes in the range of screen sizes, some dictated by film format, and some by exhibition economics. The small screens of the 1930s were eclipsed by the large format screens of the 1950s; today, the "pill-box," screens of the 1970s are being supplanted by relatively huge screens for 35mm film projection. The impact of large screens for audience involvement is obviously beneficial, but there can be significant technical tradeoffs. Perhaps surprisingly, not only picture but also sound quality can be affected by screen size, and the following material discusses the impact of screen size on various presentation parameters including acoustics and image contrast.

What does "screen size" mean?

Theatre designers frequently refer to screen size by linear width—for example: "the Bijou 9 has a 50 ft screen." But this definition has no meaning without reference to theatre size. A 4,000 seat auditorium with a 50 ft screen would provide a picture to someone in the back row little better than a 19 in. TV in a large living room—but the same screen in a 50 seat screening room would seem as large as the Grand Canyon when viewed by a flea!

The best measure of screen size as perceived by the audience is that of subtended angle. Folk legend has it that the first person walking into an empty theatre will choose a seat 2/3 of the way back from the screen, possibly 1/2 of the way back in the seated area, depending on the clear space between the screen and the front row of seats. The best measure of perceived screen size is that of subtended angle. The audience is conscious of screen size not by absolute dimension, but by angular percentage of vision. "Rational man" sitting in the prime seat 2/3 of the way back will see a screen which subtends a horizontal width of 35, 40, 45, 50, or 55° width (Fig. 1).

From a projector's point-of-view, the most obvious significance of increased screen size is the need for more projection illumination, if the standard 16fL illumination is to be maintained, and the implications of this will be discussed further.

First order effects

There are obvious relationships between subtended screen angle and the filmgoer's experience. As the screen angle gets larger, the story impact gets greater (Fig. 2)—the audience feels less like TV watchers, and more like participants in the action on the screen. The eye's theoretical field-of-view is 110°—a movie screen subtending such an angle is hard to ignore! All the connections between eye and brain are derived from the film, and the observer is potentially completely involved in the film.

But as the perceived picture size increases, the picture flaws become more apparent, whether we are looking at film or TV (Fig. 3). As a TV image is blown up, the flaws become glaringly apparent—the line structure, lack of definition, convergence problems etc. A TV image (even from HDTV) is far inferior to 35mm film, but even film has technical flaws when the picture is examined closely, or indeed blown up too large.

There are three obvious problems

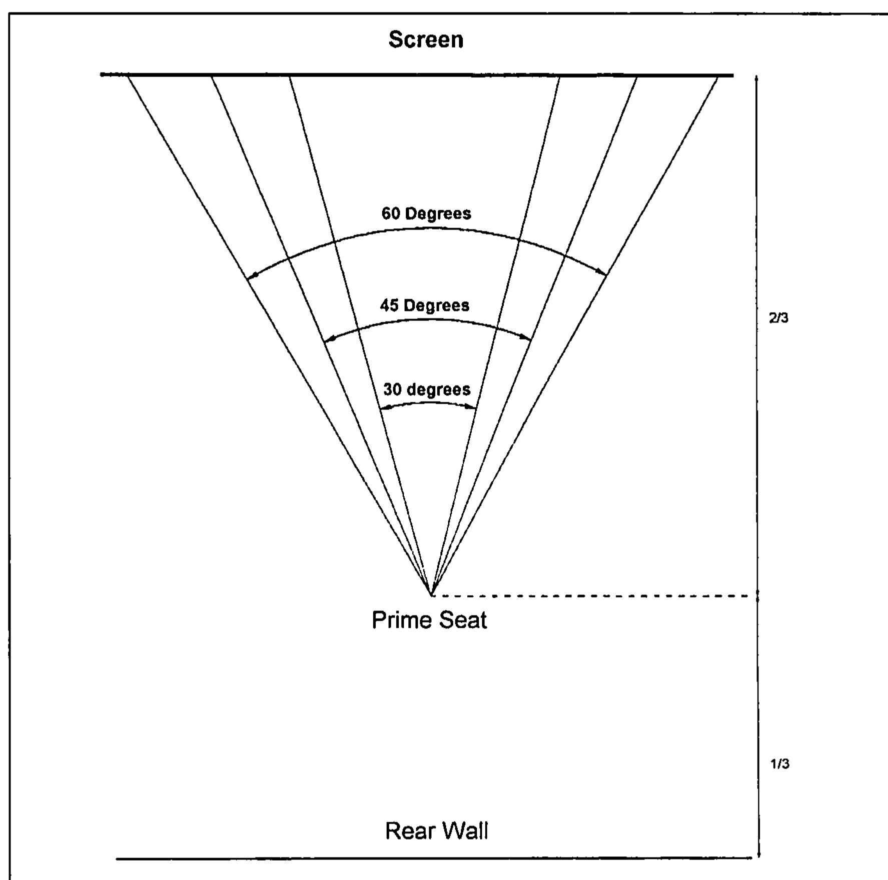

Figure 1. Subtended screen angles.

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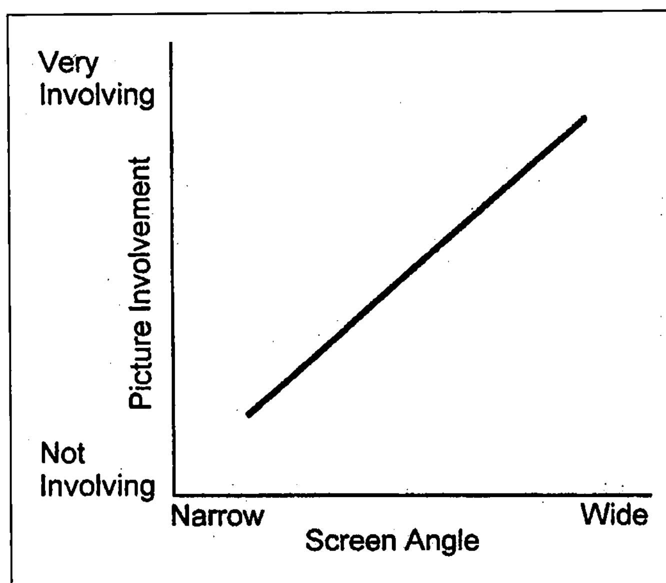

Figure 2. Subtended screen angle and picture involvement.

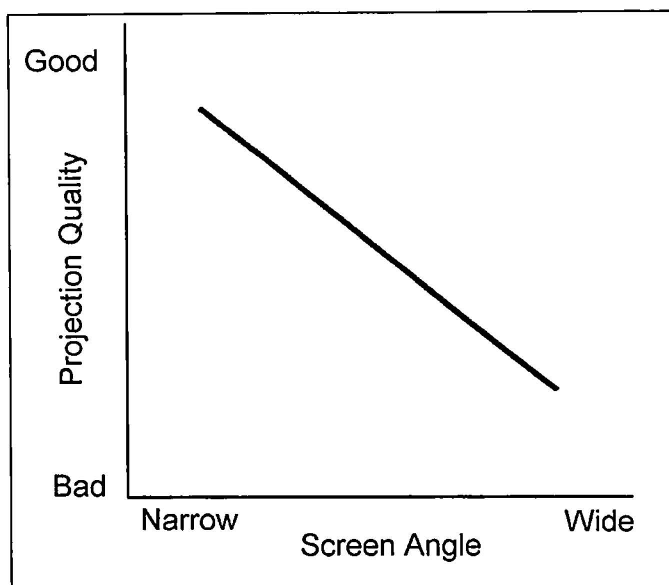

Figure 3. Screen angle and picture flaws.

visible when a film image is examined closely, or blown up large as on an excessively big screen. The first is the grain, which can be paralleled with the line-structure of a TV image. Even though camera-negative stock, inter-positive and inter-negative stocks, and release print stocks have been improved over the years, granularity is still visible, and the greater the enlargement (or subtended picture angle) the more visible the grain will become.

Next, the film in a projector gate is never held perfectly steady. Jump (vertical irregularities) and weave (horizontal irregularities) seem unavoidable in conventional 35mm projection, and the greater the subtended screen angle, the more obvious the unsteadiness. And even with a steady projector, image unsteadiness can be caused in the laboratory printer or during the generational process—sometimes clearly visible with titles superimposed over static images. Again, the greater the enlargement, the more apparent the unsteadiness.

The third result of increased subtended screen size is the difficulty of maintaining focus. The problem at first seems not to be so much that of maintaining focus, but more that the increased subtended screen size makes soft focus more obvious.

So, as the perceived screen size increases, first order effects lead to several apparent picture flaws. Too large a picture leads to excessive grain visibility, picture jump and weave visibility, and soft focus.

Now consider the effect of an increased screen size on the demand for illumination. If the same illumination at the screen is to be maintained, increasing screen size (and consequently illuminated area) will demand increasing lamp power. As this lamp power is increased, the heat at the film plane will also increase. Two problems result; first, the film will flex in the film gate, making accurate focus more difficult to achieve, and second the heat may cause permanent deformation of the film, resulting in the impossibility of ever achieving precise focus over the entire film field.

An ideal screen size?

The varying compromise between screen size (subtended angle) and picture quality has been ongoing for as long as there have been movies. Back in 1953 Twentieth Century-Fox introduced CinemaScope.[1] The wider aspect ratio (originally 2.55:1, then 2.35:1 and now standardized as 2.39:1) obviously provided a significantly greater picture involvement than a 1.33:1 image at the same height. But Fox evaluated the ideal subtended screen angle as 45°,[2] as this proved to be the point where the subjective curve of image involvement crossed the curve of visual technical flaws (Fig. 4).

Quality Improvements

There is no doubt that some issues relating to film performance have improved since 1953. Release print stock, in particular, now has much finer grain than 40 years ago. On the other hand, jump and weave in many modern projectors are probably no better than they used to be, and the lack of permanent projectionists assigned to each screen means that focus is less accurately maintained than used to be the case. It probably would be optimistic to think that the optimum screen angle for CinemaScope has progressed much above 45°. Perhaps the same evaluation carried out today would lead to a number no greater than 50°.

1.85 v Scope

The 1.85:1 aspect ratio is extremely inefficient, in that approximately 35% of the film frame area is thrown away (Fig. 5). Eighty percent of U.S. movies are shot with this aspect ratio. (The choice of this image was not chosen for image quality, but for image shape—a cheaper alternative than CinemaScope, providing a "wide-angle" image but using spherical, non-anamorphic, lenses.)

Now, to maintain a constant image quality with the two most common (at least in the U.S.) aspect ratios, 1.85:1 and 2.39:1, the screen sizes should take account of the size of the actual film image size. As the "scope" film

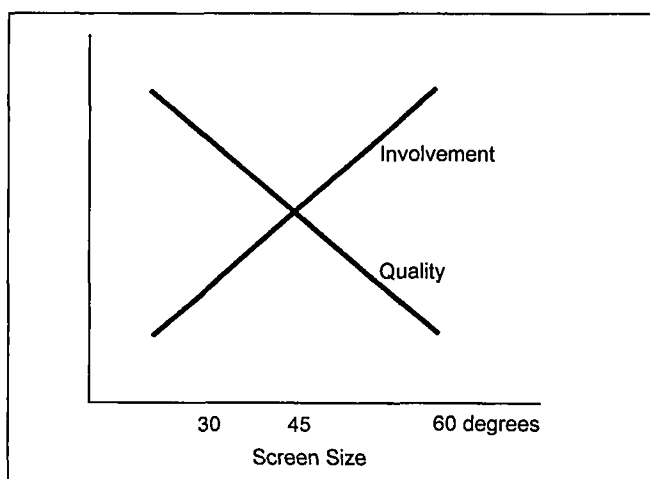

Figure 4. Optimum "screen size"—1953 CinemaScope.

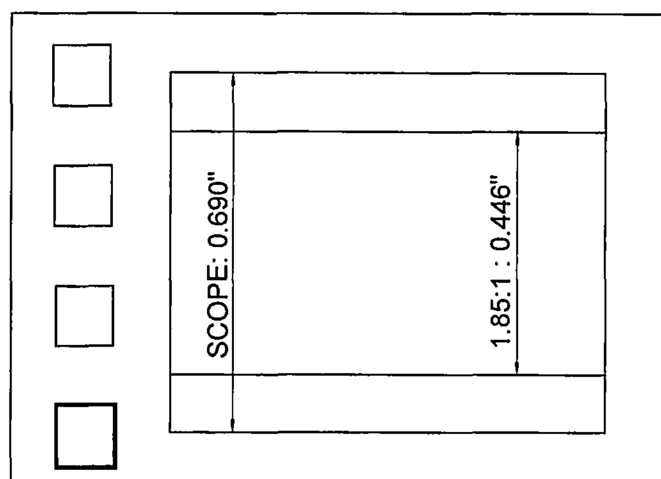

Figure 5. Film image heights.

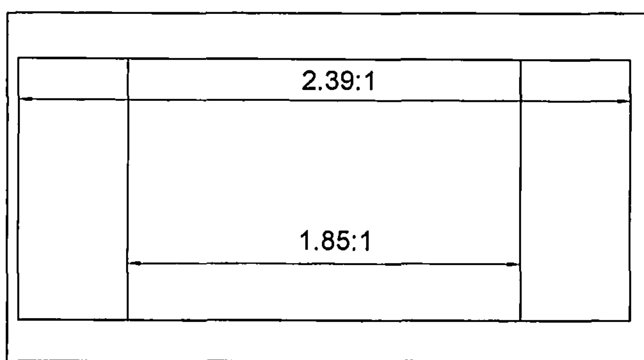

Figure 6. Common height, scope, and 1.85:1.

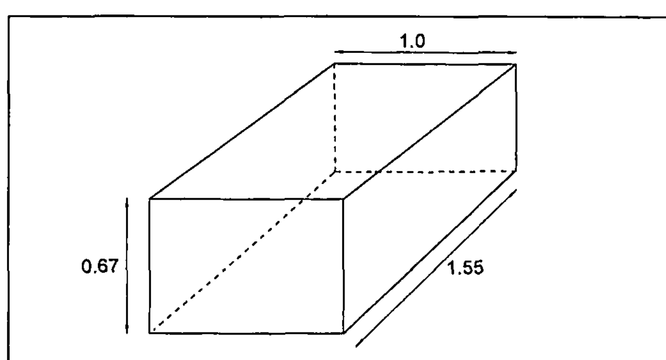

Figure 7. An acoustically optimum shape.

frame uses most of the available space, and the 1.85:1 frame uses only 65% of the frame, the "scope" screen should exhibit 35% more area to show the same image quality.

Some simple mathematics show that equal image quality with 1.85:1 and 2.39:1 can only be achieved with a screen height actually slightly higher with "scope" than 1.85:1. In fact, a result close to optimum is achieved when the "scope" image is achieved by expanding the left and right horizontal masking (Fig. 6). Certainly the practice of common width (i.e., a 1.85:1 image 35% higher than "scope") is the wrong way round, and provides a great disservice to the projected image.

Limiting Contrast—a New Concept

The maximum contrast that can be achieved with a motion picture presentation depends on several factors—lens flare, port-glass design, ambient light, etc. A less obvious effect reducing contrast is that of reflected light coming back onto the screen after hitting sidewalls, ceiling, or back walls. The film itself has a potential contrast of at least 300:1, the range from bright to dark. But for a worst case, consider a screen that is illuminated with a picture that is 90% all white, with just a small black patch. All the white light bounces off the walls, and, depending on the surface reflectivity, a certain percentage will bounce back to the screen. The small black patch will now turn dark grey, and the potential contrast is now much reduced—a typical reduction to 50:1 is not uncommon. This much worse number we shall call "limiting contrast."

What may seem surprising is that limiting contrast is not only affected by the surface reflectivity of the walls and ceiling, but is also significantly affected by screen size. The greater the screen size, with a constant illumination level, the smaller the limiting contrast. A simple model can be visualized by consideration of a sphere, and internal visual conditions varied according to light source areas and reflective materials.

First, consider a sphere which has a uniform internal surface with a reflectivity of (for the sake of this example) 0.25, or in subjective terms, dark grey. At some point in the sphere a puncture is made, to allow light in; alongside this minimal sized hole there is a test patch of the same dark grey, of a size comparable to the light source, certainly a trivial percentage of the total internal surface of the sphere. A light source outside the sphere is switched on, visible through the small hole. A viewer at the centre of the sphere uses a light meter with a narrow acceptance angle to read the light level at the test patch. With the minimal amount of light passing through the small hole, being reflected from the grey internal surface back at the test patch, the measured luminance is very low.

Now consider the case where the small hole to allow light in is expanded, until half the internal surface of the sphere is open. In the middle, the same small test patch remains unchanged. This time, the reflected light from the

Table 1: Effect on Limiting Contrast of Changed Screen Size

70mm

	Left	Centre	Right
Screen illumination (ft lamberts):	12.30	13.70	13.50
Shadow illumination (ft lamberts):	00.22	00.27	00.25
Ratio	55.90	50.74	54.00

Average Ratio (limiting contrast): 53.54

"Academy" 1.33:1

	Left	Centre	Right
Screen illumination (ft lamberts),	11.20	13.30	11.00
Shadow illumination (ft lamberts)-.	00.11	00.14	00.10
Ratio:	101.80	95.00	110.00

Average Ratio (limiting contrast)- 102.26

Ratio of limiting contrasts 102.26 : 53.54 = 1.92

7Omm screen area: 23.3 feet x 10.58 feet = 246.9 sq feet
1.33:1 screen area: 13.5 feet x 9.5 feet = 128.25 sq feet

Ratio of screen sizes 70 mm : 1.33:1 = 246.9/128.25 = 1.91

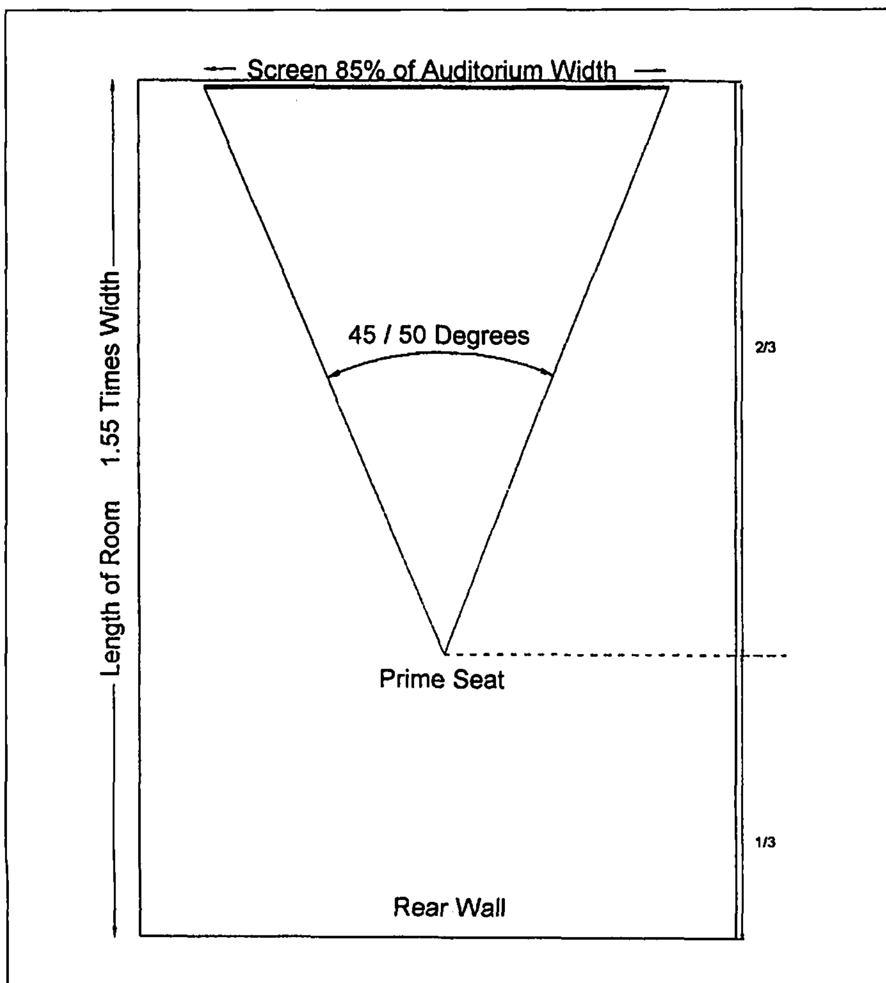

Figure 8. Ideal room geometry.

25% grey surface has a major impact on the luminance measured of the small grey test patch. In essence, a secondary light source has been created by reflection from the increased total light being reflected from the sphere's internal surface.

In practical terms, this spherical model translates to a real theatre as follows:

a) As the reflectivity of surfaces facing the screen increases (the material becomes lighter), the more the screen limiting contrast will be reduced.

b) As the screen size increases (as a percentage of the total theatre surface area), and with the same constant spot luminance (for example, the standard 16fL) the more the screen limiting contrast will be reduced.

In effect only matte black walls and ceilings will allow the full contrast ratio of the film to be revealed. If the walls and ceilings are not matte black (a more typical case!), then the larger the screen, the more the limiting contrast is reduced.

Practical Tests

To determine the relationship between limiting contrast and screen size for a given set of wall and ceiling surfaces, a test was set up with a 70mm sized screen, and then an Academy 1.33:1 sized screen of approximately common height. Actual screen sizes are 23.3 ft by 10.6 ft, and 13.5 ft by 9.5 ft. Illumination was measured at screen left, centre, and right, and was matched as close as possible between the large and small screens. A matte black square was then inserted about 6 ft from the screen, which created a shadow approximately 2 sq. ft. at sequentially screen left, centre, and right. The screen illumination and illumination in the shadow area are shown in Table 1.

This example showed a correlation far more precise than the author anticipated, and it is doubtful that such a precise proportionality would be found in every case! Nevertheless, the relationship clearly shows; as the screen gets bigger, the limiting contrast goes down.

Not shown in the table is a further test with only a small illuminated area, approximately 2 sq. ft.—here the lim-

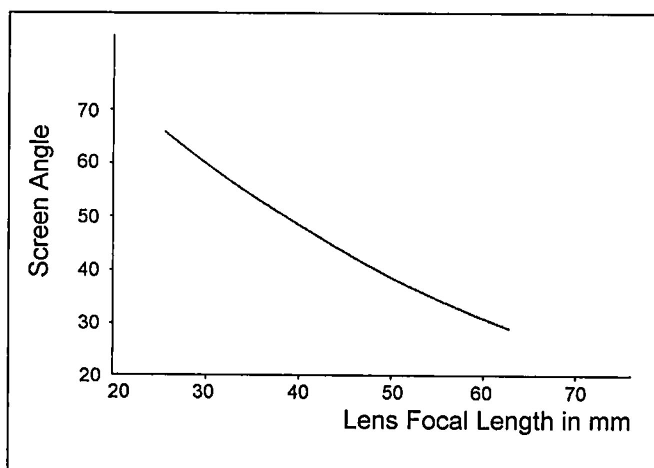

Figure 9. Lens focal length and subtended angle.

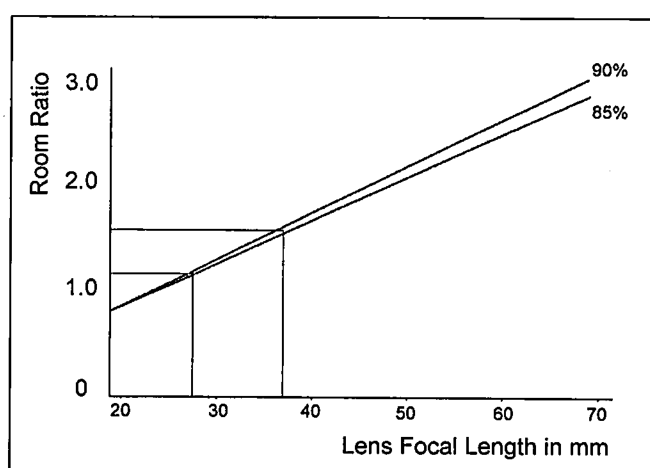

Figure 10. Lens focal length and room ratio.

iting contrast was in excess of 800:1, presumably greater than the film's own contrast capability.

A simple procedure is described in the addendum at the end of this paper which gives an approximate method of calculating anticipated limiting contrast, taking into account room and screen dimensions and material reflectivity.

Acoustic Issues

It may seem surprising that screen size also has a significant effect on auditorium acoustics.

One of the major challenges for the design of any performance room is to avoid pronounced room resonances. These are particular frequencies which "ring." The effect can best be imagined by the a scale played on the low-frequency notes of a church organ—in a badly designed space certain notes will sound much louder than others.

The best way to avoid these effects is to avoid repetition of a single dimension, or a multiple of a single dimension. For example, a sphere is a very bad shape, having a single dimension repeating. A cube is a bad shape, with the same length, breadth, and height dimension. A square room with a height half of the length would also be bad, as again a certain note would be emphasized.

Now, acousticians analyzing the best sounding concert halls find that there are some standard ratios that minimize the number of standing waves or resonances. The best ratio of length to breadth is about 1.55:1, and a height to width ratio of about 0.67, as shown in Fig. 7. It is interesting that both these numbers (1.55 and 1/0.67) are close to $(1+(5)^{1/2}/2)$, 1.62, which is known as the Golden Ratio.[3] The Golden ratio has been a fundamental of architecture and design for thousands of years.

As a room shape deviates further and further from these ratios, certain room resonances will begin to dominate. Let us now go back to the hypothetical picture ideal of 45° subtended screen angle 2/3 of the way back in the auditorium. Suppose that the screen is 85% of the width of the auditorium (allowing some room for black masking). Figure 8 shows that the length of the room will now be 1.54 times the width, or almost exactly the acoustic ideal of 1.55:1.

To translate this into lens focal length, look at Fig. 9. A subtended screen angle of 45° requires a lens with a focal length of around 38mm. Five years ago, a typical theatre lens had a focal length of around 45mm, suggesting a screen angle of 38°. Today the average theatre lens has a focal length of around 35mm, suggesting a screen angle of around 50°.

Some new theatres are now being planned with lenses as short as 28, 26, or even 24mm.[4]

Now look at Fig. 10, which shows the likely room ratio (length to breadth) plotted against lens focal length. Maintaining the assumption of the screen being 85% of the auditorium width, it can be seen that short focal length lenses in the area of 26mm are likely to mean a room ratio close to 1:1, i.e., close to square, with all the attendant likelihood of bad sound.

Cinematography

There is another issue that should be addressed briefly—the intention of the cinematographer. It seems apparent that a cinematographer will frame a shot differently for a feature aimed for theatrical projection than one only aimed for television. The television version will have more closeups, and less background detail, which would not resolve on the small screen. In the same way, a cinematographer presumably imagines a certain theatrical projection angle when shooting a movie for cinema. Much larger projection angles than he is framing for will result in overly large closeup images, which in an extreme case can be contrary to the intent of the storytelling process.

Conclusion

The trend to larger and larger screens may at first sight seem attractive in terms of audience appeal. But as the screen size becomes excessively large, there is a significant impact in terms of presentation quality, both picture and sound. While subtle variations in room shapes may be possible to avoid some acoustic problems, and matte black walls may help the contrast, it seems probable that any theatre design requiring a prime lens focal length of 30mm or less has a less than optimum presentation quality.

Endnotes

1. Twentieth Century-Fox Articles on CinemaScope—*SMPTE J.*, Jan. 1954.

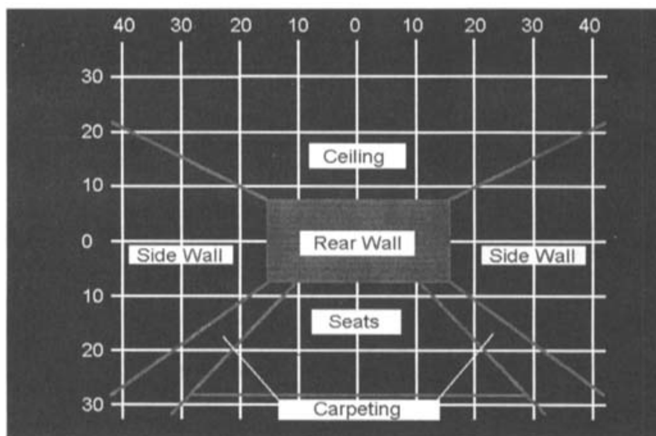

Figure 11. Isometric to calculate material/surface percentages.

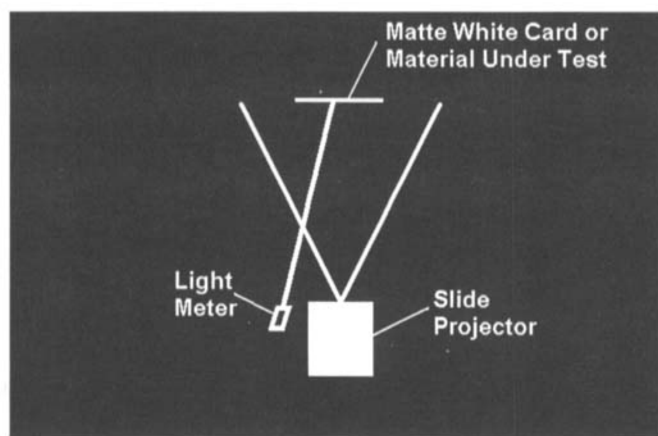

Figure 12. Measuring material reflectivity.

2. Author's conversations with Alex Alden—supervisor of CinemaScope installations for Twentieth Century-Fox, and later Engineering Director for *SMPTE*.
3. M.R. Schroeder, "Number Theory in Science and Communication," Springer Verlag 1990.
4. The author is indebted to Dwight Lindsey of Schneider Lenses for this information.

Addendum

Calculation of Anticipated Limiting Contrast

The technique described here is very approximate, and a more sophisticated version would take account of varying screen gain, curved or flat screens etc. In addition, the technique assumes matte materials, with no specular reflections. Nevertheless, it can be a useful tool to show the effect of differing wall material surfaces, variations in screen sizes etc.

Figure 11 shows an isometric of the view as seen from the screen. The ordinates are degrees. Calculate the percentage areas represented by each material such that the total is 1.0. For example:

Ceiling	0.4
Seats	0.2
Rear wall	0.2
Carpets	0.1
Side walls	0.1
Total	1.0

Measure the reflectivity of each sample material as shown in Fig. 12. A 35mm slide projector with a clear slide in the gate provides a convenient light source. Project the light onto a sheet of matte white card about 6 or 8 ft away. Use a spotlight meter to measure the light on the white card. Cover the card with a sample of each material to be tested, and measure the light value. The sample light reading divided by the reference light reading provides an approximate number for the reflectivity.

Enter a simple spreadsheet which first of all finds the sum of the products of surface area and reflectivity, i.e.:

	Area	*Reflectivity*	*Product*
Material A	0.4	0.1	0.04
Material B	0.2	0.2	0.04
Material C	0.2	0.1	0.02
Material D	0.1	0.3	0.03
Material E	0.1	0.1	0.01
Product Sum:			**0.14**

Next calculate the proportion of total cinema surface area represented by the screen, i.e.:

Screen Area: 300 sq. ft
Total Surface Area: 5000 sq. ft

Ratio Screen to
Total Surface Area: 0.06

Finally total reflectivity is
(0.14 x 0.06 x 100) = 0.84%

And the limiting contrast = 100/0.84
= 119

THE AUTHOR

Ioan Allen was educated at Rossall School and Dartmouth Royal Naval College in England.

After leaving the Royal Navy in 1959, he specialized in technical writing, including the preparation of Admiralty manuals. He joined Dolby Laboratories in 1969 and was in large part responsible for the origination and development of the Dolby Stereo film program.

A Fellow of SMPTE, Allen was the 1985 recipient of the Samuel L. Warner Memorial Award for contributions to motion picture sound. His involvement with SMPTE also includes the positions of Engineering Director-Motion Pictures and past chairman of the Audio Recording and Reproduction Technology Committee and the Projection Technology Committee. He is also a Fellow of the AES and the BKSTS; past president of the ITEA; and serves as U.S. correspondent on the ISO cinematographic sound subcommittee. Allen is a member-at-large of the Academy of Motion Picture Arts and Sciences and recipient of its Scientific and Engineering Awards in 1979 and 1987, and the Oscar in 1989.

An adjunct professor at the UCLA School of Cinema-Television, Allen holds several patents and is the author of numerous journal articles and technical papers.