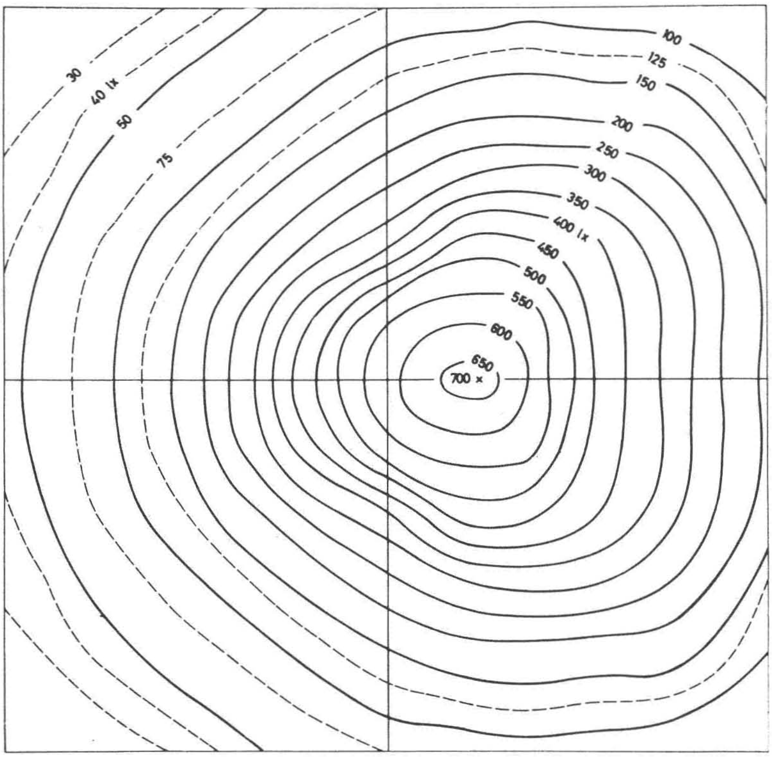

FIG. 10. Lines of equal lux values in the plane of projection with white light and an enlargement ratio of 1:8.

over the ellipsoidal reflector systems, the latter must still be regarded as the method of illumination for projection-type instruments offering the greatest technical simplicity, lowest cost and trouble free operation.

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A Study of Rear Projection Screen Materials[*]

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(Abstract is on next page)

IN THE last ten years, there has been an ever increasing demand for photo interpretation equipment which utilizes the rear projection method of image display. The advent of this requirement was somewhat concurrent with the shift in emphasis from photographic prints to transparencies as the interpretative media. Similarly there has been an advance

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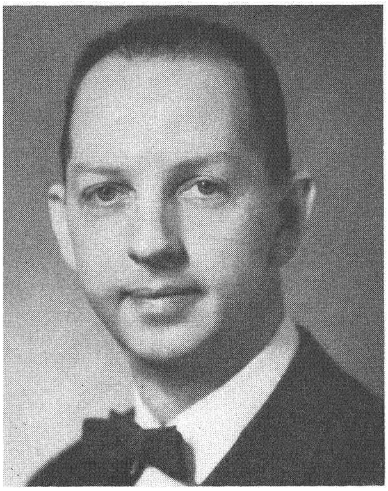
in the state-of-the-art of lenses and photographic materials.

As the photographic quality increased, it soon became apparent that the screen material used in rear projection instruments imposed a source of information limitation. This study was undertaken to analyze the properties of a number of different types of representative screen materials to better determine their behavior in rear projection optical systems.

The first phase of the study was an analysis of the process of image formation in a diffuse media. Basically, a projection optical system forms an image at the screen plane and this pattern, because of the scattering of light within the medium, is seen multidirectionally at the screen. This scattering process may be caused by any one or a combination of such physical properties as surface roughness, pigmentation, layers of small spheres, or other types of light scattering particles.



REX R. MCHAIL

ABSTRACT: *The basic purpose of this study was to evaluate the performance of materials of various physical properties to be used as screens in rear projection instruments which utilize the projection of high definition photographic records. The basic fundamentals underlying the process of image formation in a turbid or diffusing media were analyzed. The apparent "granularity" of a screen is determined to be the major factor controlling the image fidelity presented to the viewer in terms of dimensional alteration of the image and its contrast. Tests substantiating this concept were conducted using various target images. In addition, luminance, transmission, polarization, and surface roughness tests were performed. Microdensitometric scans and photomicrographs were taken of representative samples.*

Perhaps the best example for purposes of illustration is the ground glass material. Its performance as a rear projection screen is attributed to the ground surface which has two optical characteristics; an array of microsurfaces of random *TILT* with respect to the datum, and a random *DEPTH* or layer thickness. A light bundle striking this surface is, therefore, scattered by a combined prismatic-lenticular action. That is, each microsurface deviates the rays intercepted by its area as a function of angle of incidence on the microsurface and the material index of refraction. The random deviations within the material direct the rays in all angles from the points of incidence, up to the condition wherein the critical angle is exceeded. The angle of the emergent cone indicates the distance off the optical axis that the observer may see the image. In most instances the majority of light will pass straight through the scattering layer because the relatively small deviations off axis of the incident bundle. The condition known as a "hot spot" is the result.

To increase and improve the scattering, it has been a common practice to provide a diffusing surface on both sides of the material. Several results become apparent, first the light scattering is indeed multiplied, and the hot spot is reduced. However, there are considerably more internal reflections which lower the contrast, and reduce the total transmission. The image spread becomes greater, and fundamentally, at least, the image is formed at two planes separated by the material thickness.

Another method for producing the desired diffuse condition in a screen material is to suspend small particles in a thin layer of transparent material such that the particles are evenly spaced, semi-identical in form and small enough that they in themselves do not destroy the image. An example would be a matrix of tiny glass or plastic spheres on the surface of a supporting substrate. Incidentally, this is the principle of certain reflective sign materials. Since there are gaps between nesting spheres, it becomes necessary to increase the number of layers. It is apparent with this progression that as the thickness of the diffusing layer increases, the incident image is spread over a larger area on the emergent side. This type of spreading causes an image of a point to appear as having a central peak with gradient edges.

In these two examples, there has been discussed the basic manner of image spread which is the result of light scattering and diffusion, similar in concept to that spread which occurs in the image formation process of a photographic emulsion. This process has been treated extensively in literature and theory and need not become a part of this discussion.

The apparent granularity of a screen, regardless of how the diffusion is caused, becomes the major factor controlling the image fidelity presented to the viewer in terms of dimensional alteration of the image and its contrast. To function as a rear projection screen, it must always present an image that is distorted in size and contrast with reference to the original object. It can be deduced that a screen material with zero granularity and no contrast reduction would be perfectly clear, hardly a worthy screen.

A testing procedure was developed which would provide data regarding the performance of materials according to the screen and image structure considerations that have just been given. A total of 114 specimens were collected with particular effort to include representative types of materials such as ground glass, matte plastic, beads on glass, chemicals deposited on plastic, single layer, double layer and homogeneous and lenticular configurations. The following basic tests were performed on the samples; definition threshold tests, contact resolution, transmission, polarization, surface profile tests, photomicrographic, and microdensitometric tests. First the *definition threshold* test. A variable magnification projection test fixture was constructed as illustrated in Figure 1. It consisted of a nine-foot lens bench upon which a target object could be projected through a variable magnification range of from 40 to 1 down to 1 to 1. The screen sample was fixed at one end and viewed with a Bausch & Lomb StereoZoom microscope system set to match the projection ranges. Thus, the apparent image size to the operator could be kept equal to the 40 to 1 condition. The process began with the conjugates set so the target object (in this case a high-resolution aerial photograph) was projected onto the screen sample at the highest magnification. The StereoZoom microscope was used to view the image at its lowest

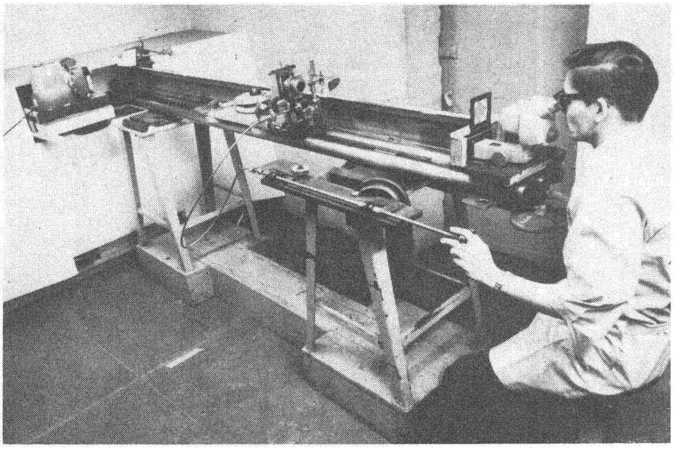


FIG. 1. Definition threshold test equipment.

magnification. Then, as the projection magnification decreased, the viewing magnification inversely increased. It was found that for each sample, there was a magnification point at which the image appeared to break up, and details were no longer resolved. This became the measure of value or "definition threshold" of that particular sample.

The second test performed was the *contact resolution* test which is illustrated in Figure 2. It entailed the examination of a high-contrast resolving power target in direct contact with the diffusing surface of the sample. The values were determined with the aid of a StereoZoom Microscope with a variable magnification range of 7× to 60×. This was a very simple test, easy to perform, but not always conclusive of a screen's true performance. The reason was that the image is formed at the surface of the sample, not in or on the screen as is the operational case. Thus, the screen acts somewhat of a filter rather than an image transducer.

Another important test series was the *luminance and transmission tests.* The brightness ratio or fall-off with angle is an important factor in the performance of a rear projection system because of the common requirement of off-axis viewing by multiple observers. In such cases where there is more than one observer, this factor becomes a prime consideration.

A breadboard goniophotometer schematically illustrated in Figure 3 was assembled to determine the distribution of *photometric brightness* of each of the sample screen materials as a function of angle from the normal. The photometer portion of the apparatus was a Brightness Spotmeter with a $1\frac{1}{2}$ degree acceptance angle. The photometer was mounted to pivot in an arc around a point beneath the

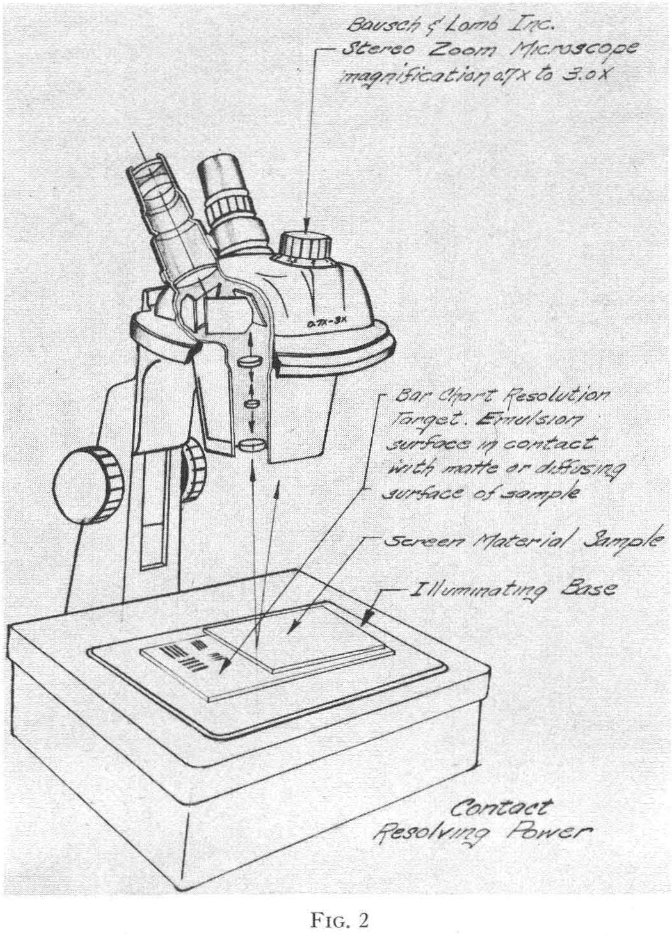


FIG. 2

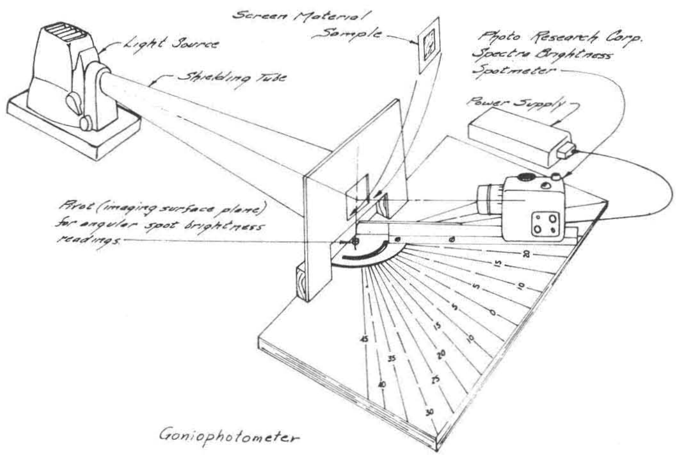


FIG. 3

sample. The illumination of the sample, provided by a 750-watt projection source, was measured with a footcandle meter at the sample plane as 1,600 foot candles. Readings with the foot Lambert meter were made of a 0.4 inch diameter portion. From these readings the relationship of screen brightness as to viewing angles were derived. Additionally, the "axial gain," or luminance divided by the illumination (foot Lamberts divided by foot candles, on axis) was calculated. This is essentially the "power rating" of a screen's performance and directional ability.

Another type of *transmission test* was conducted using a B&L Illumination Analyzer to obtain the per cent of transmission of each sample. Readings varied somewhat when the smooth side and the matte side of the sample were reversed. This, of course, along with the per cent transmission must be borne in mind by the system designer in his selection of a rear projection screen material.

Polarization tests were conducted in anticipation of screen material use with polarizing stereoscopic rear projection viewers. A simple polariscope was used in the initial sorting out process for those samples which wholly depolarized. The sample was placed between a polarizer and an analyzer, type HN32 on a light table. The polarized materials were crossed and uncrossed and the change in appearance or lack thereof indicated whether or not the material required further test and evaluation.

Those samples which had a minimum of depolarizing qualities were further tested with an apparatus which was a combination of the goniophotometer and the polariscope, discussed earlier. It provided a measurement of the efficiency by the amount of light passing through the system under crossed and uncrossed conditions of the polarizing materials. The efficiency thereby becomes a ratio of the two values. In order to illustrate the effect of projected light passing through different types of screen materials, a series of *photomicrographs* were taken of representative samples. Some of these are illustrated in Figure 4. These have been selected from the group as being representative of the general types that were investigated. All samples were photographed with a Bausch & Lomb photomicrographic camera, Model L, with their diffusing surface in contact with an opaque plate containing a pinhole measuring 121 microns in diameter. This plate was located between the light source and the sample. For comparative purposes, a separate photograph was made of the pinhole without a screen sample in place.

The relative size of the pinhole is indicated on each of the samples. Notice the variation in overall appearance among the samples. The grain structure as well as the relative contrast is markedly different from one to another. There is almost no graininess in the sample marked 47. It is of titanium oxide that has been uniformly deposited on a mylar base. Sample 81, as you might expect, is a beaded structure on a glass substrate. Samples 13 and 14 are similar, a chemical diffusing material on plastic. The difference in performance is that 13 is for "group" viewing and 14 is the better for individual observer use.

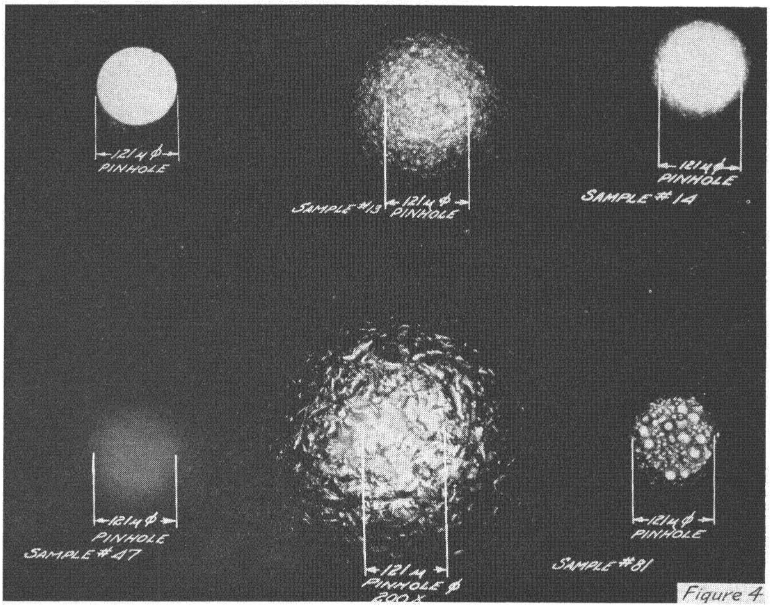


FIG. 4

The photomicrographs, at best, provide only qualitative confirmation of the spreading effect caused by diffusion. The samples were scanned with a specially-constructed *microdensitometer* shown schematically in Figure 5 to obtain some measure of the spread effect. Thus a recorded strip chart trace of the spread in terms of density differences could be compared with a similar trace of an aerial image of the same projected spot of light from a pinhole.

The microdensitometer consists basically of an illumination system, a projection microscope containing a 30 micron diameter pinhole, the sample, a scanning microscope and a photomultiplier, with associated electronics, including a strip chart recorder.

Figures 6, 7 and 8 show some of the previous photomicrographs with their associated density scans alongside for comparison. In each case the qualitative results of the photomicrographs were confirmed quantitatively by this scanning method.

Figure 9 illustrates a typical example of the cumulative results as recorded of one of the

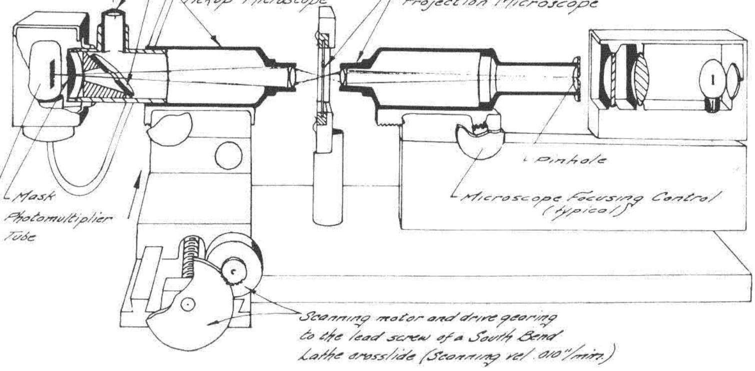
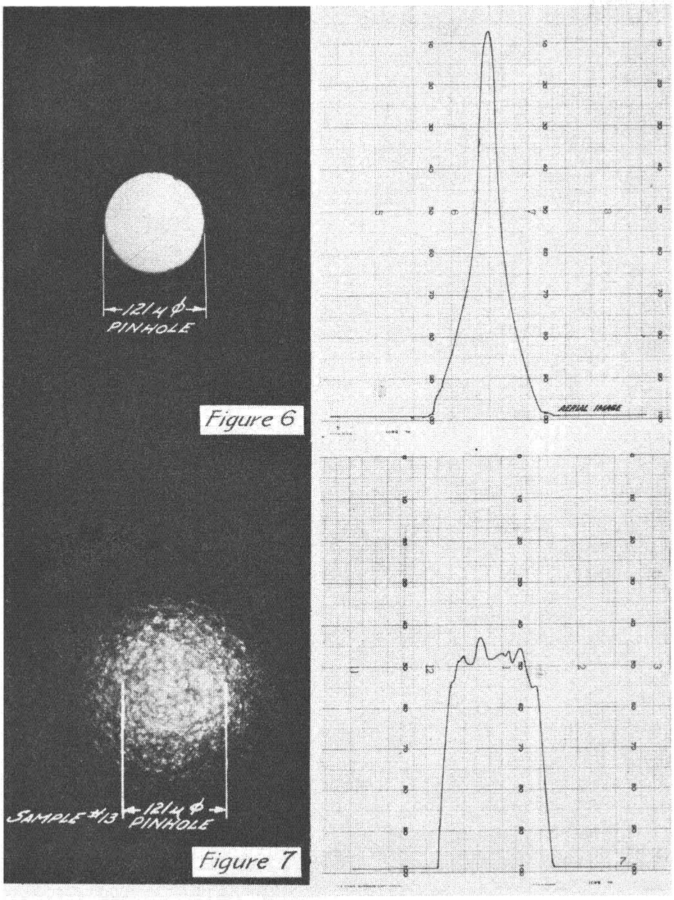


FIG. 5. Microdensitometer



FIGS. 6 AND 7

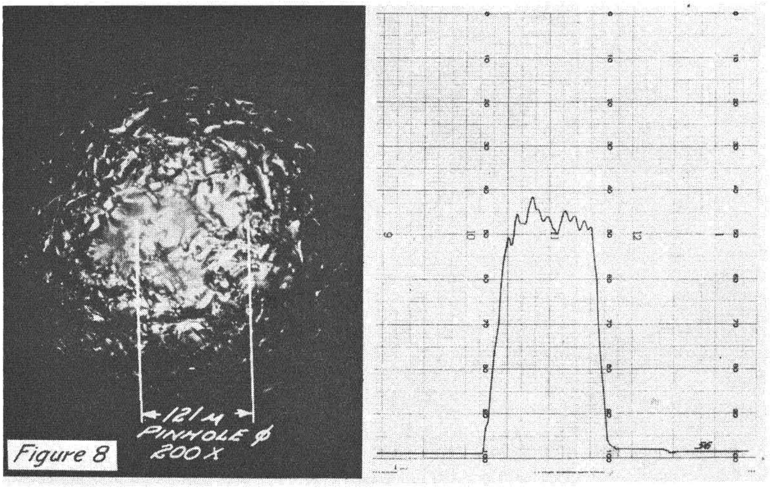


FIG. 8

PHYSICAL STRUCTURE: (20-25 RMS/ASA 46.1-1955, 030 STROKE GLASS PROFILOMETER READING of SURFACE ROUGHNESS)
TRANSMISSION (MATTE) — — — — — — — — 63 %
TRANSMISSION (SMOOTH) — — — — — — — — 61 %
AXIAL GAIN — — — — — — — — 6.18
IMAGE BREAKUP MAGNIFICATION — — — — — — — — 26.5X
POLARIZATION QUALITIES — — — — — — — — —
THICKNESS — — — — — — — — 130 INCHES
ANGLE (50% REL. LUM.) — — — — — — — — 16°

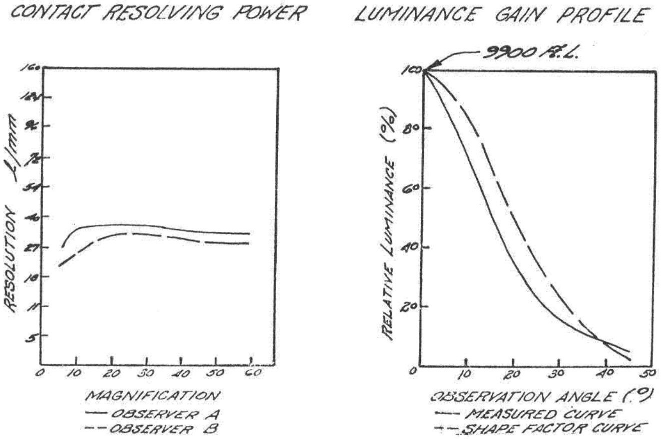


FIG. 9. Illustrative of typical data recording of a rear projection screen material.

samples. Although such a listing may summarize the measured characteristics of a particular material, the laboratory data only offer a basic clue to the merit of one over another material as the preferred screen in a particular viewer application.

In summation of the findings in this investigation, it was generally observed that, as the granularity of a screen material increases, the brightness distribution becomes more uniform, the image spread factor increases, the image formation quality decreases, and the transmission value decreases. Therefore, it is extremely important that the parameters defining a particular screen's performance be carefully weighed according to the operational use of the material. Some of the governing requirements might include: Availability of illumination, number of observers, image quality desired, screen size, ambient lighting conditions, brightess uniformity, stereo or non-stereo application, sensitivity to damage, and cost. It may be pointed out that none of the screens tested in this project is capable of handling all the requirements that might arise in rear projection viewer systems specifications. The selection of a "most suitable" screen material for a given application is governed primarily by the importance of each requirement at a sacrifice to the least important factors.
