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DF62ELS-41


# T.I.R.P. OPTICAL PROJECTION OF SURFACE DEFORMABLE MEDIA

by

M.L. Noble


GENERAL ELECTRIC

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**TITLE** T.I.R.P. Optical Projection of Surface Deformable Media

**ABSTRACT** A new method of projecting large-screen bright displays from surface deformable media is discussed. The technique, called T.I.R.P. (total internal reflection prism) is based on the principle of total reflection at a boundary.

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**CONCLUSIONS**

T.I.R.P. optics, incorporating a Schmidt catadioptric projection system, offer a means of achieving high brightness displays. Primarily this is due to the fact that a quasi-collimated light source of reasonable area may be utilized in contrast to the point or slit source required in conventional Schlieren optics. Since the T.I.R.P. system is independent of format, it offers a possible means of projecting PPI images from TPR or oil films. The system is equally suitable for the projection of standard photographic film.

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# T.I.R.P. OPTICAL PROJECTION OF SURFACE DEFORMABLE MEDIA RECORDINGS

## A. INTRODUCTION

Ever since the inception of surface deformation modulation recordings, oil films or TPR, their projection has necessitated the use of Schlieren type optical systems. Basically, the Schlieren optical system transforms the phase variations impressed by a surface deformable media recording on a projecting light beam to amplitude variations which form an intensity modulated image on a screen. Projection of a phase modulated (Surface deformation modulation) object is a far different matter from projection of an amplitude modulated object, such as a photographic transparency. Unfortunately, most Schlieren projectors are expensive to build (employ fine optics), are sensitive to misalignment by vibration or handling and have an optical efficiency (or alternatively highlight brightness capability) far below that obtained with photographic projectors.

As a result of a continuing effort in the General Electric Electronics Laboratory, to advance the state-of-the art of surface deformation modulation recording, a new concept has been generated which shows promise of yielding optical projection systems with efficiencies roughly comparable to those of photographic systems. This new concept involves total internal reflection and therefore this optical system is termed a "T.I.R.P. Projection System" for the total internal reflection prism which is employed. A working model of this projection system has been demonstrated and those knowledgeable in the display field have definitely been impressed with the potential of this concept. As verified by demonstration, T.I.R.P. optics can be used to project not only the thermoplastic or oil film deformation recordings but photographic images as well. Since this system is not particularly sensitive to the direction of the written raster lines, it is admirably suited to the projection of PPI information (where the raster lines are arrayed radially from $0^{\circ}$ to $360^{\circ}$).

B. THE T.I.R.P. OPTICAL PROJECTION SYSTEM

The basic principles of the T.I.R.P. concept are explained in the brief discussion which follows.

When a beam of light strikes the boundary between two different media, a refracted beam and a reflected beam result. This familar situation is shown in Figure 1. Snell's Law states that

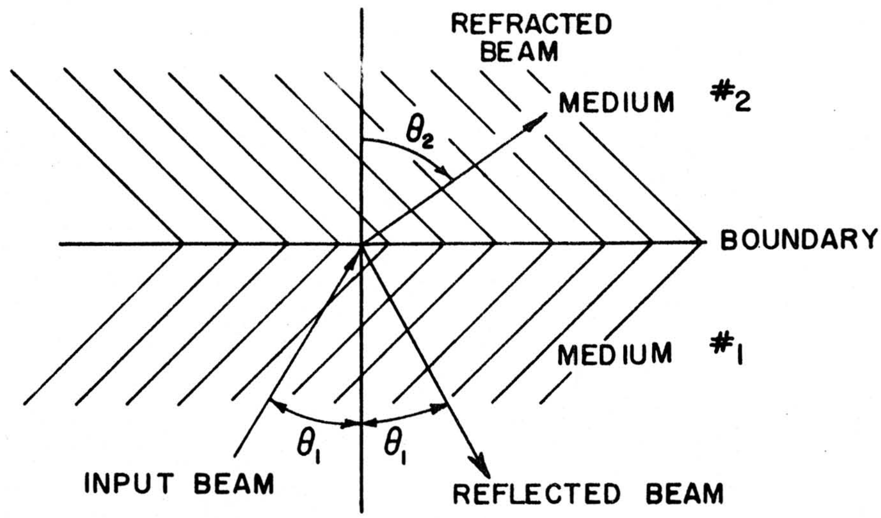
$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2$$

Solving this equation for $\sin \Theta_2$ yields

$$\sin \Theta_2 = \frac{n_1}{n_2} \sin \Theta_1 .$$

If one assumes that $n_1 >> n_2$, i.e., that the light is approaching the boundary from the more dense medium, it can be seen that an angle $\Theta_1$ (angle of incidence) exists which will produce an angle of refraction ($\Theta_2$) equal to $\frac{\pi}{2}$. At this point the refracted beam, for all practical purposes, ceases to exist. The particular angle at which this occurs is called the critical angle. Any further increase of the angle of incidence past the critical angle only serves to alter the angle of reflection, as noted in Figure 1. Since little or no energy is transferred across the boundary, this phenomenon is termed total internal reflection. The general nature of the energy in the reflected beam as a function of the angle of incidence, $\Theta_1$, is illustrated in Figure 2. If a projecting beam is inclined at an angle of incidence greater than critical, all the incident light will be reflected from the boundary.

If one places a deformable medium (such as thermoplastic), which has an index of refraction close to that of $n_1$, on the boundary of Figure 1, the boundary will shift to the interface between the deformable medium and medium No. 2. Variation of the angle of incidence would vary the intensity in the reflected beam according to the curve given in Figure 2. Since the angle of incidence is a relative parameter, one could hold the incident light beam constant and incline the surface of the deformable medium to obtain the same results. In fact, if the surface of the deformable medium is suitably inclined to the mean surface, it is possible to produce a density



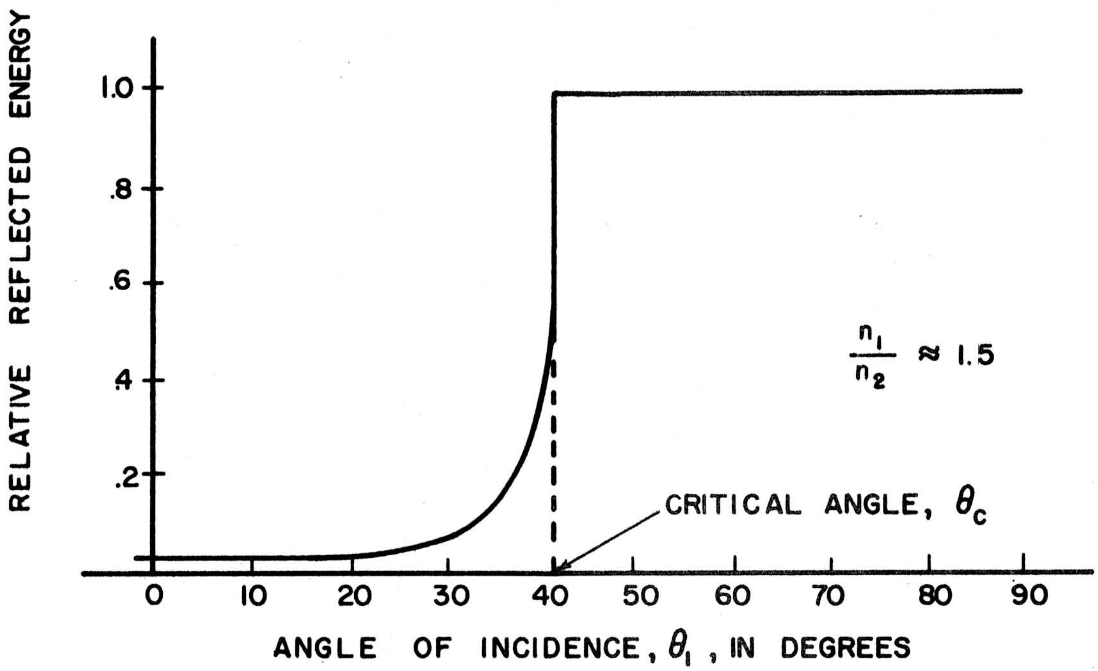

INDEX OF REFRACTION OF MEDIUM #1 = $n_1$

INDEX OF REFRACTION OF MEDIUM #2 = $n_2$

$n_1 > n_2$

LIGHT BEAM BEHAVIOR AT BOUNDARY

FIGURE 1




RELATIVE ENERGY IN REFLECTED BEAM VS. ANGLE OF INCIDENCE.

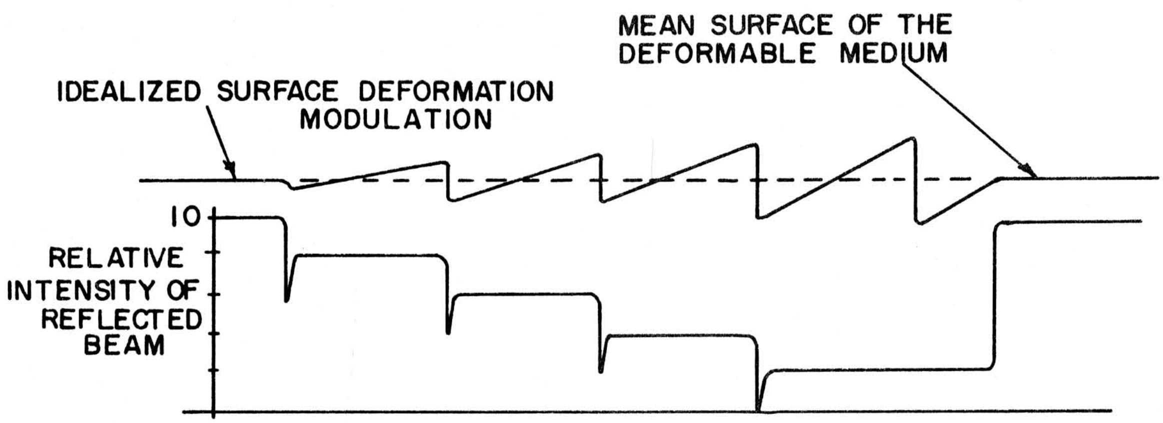
FIGURE 2

modulated bright image. This situation is illustrated in Figure 3 where the surface deformations are assumed to be modulated by a triangular wave of varying slope. The intensity of the reflected light may be determined from Figure 2 by measuring the angle of incidence at the point in question.

The concept of T.I.R.P. projection may be carried out in a practical fashion by use of the physical configuration shown in Figure 4. Experiments have confirmed that the implementation of the T.I.R.P. concept is as simple an optical system as the results are strikingly effective. Because of the very nature of total internal reflection, all the light incident on the undeformed surface is reflected. For this reason and several others, not yet mentioned, it is believed that the T.I.R.P. projection system is capable of producing extremely bright images with an efficiency approaching that of photographic projection (or even more important, peak brightness).

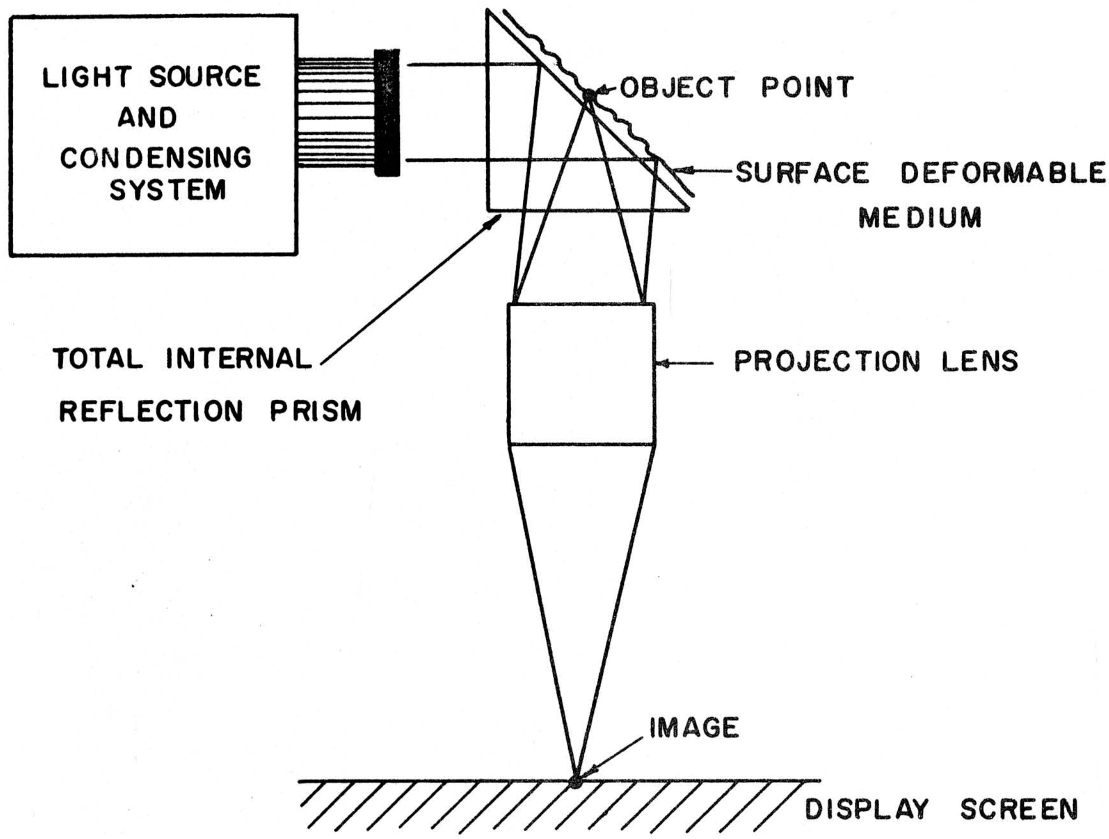
In the T.I.R.P. projector a well-collimated beam of light is brought into the T.I.R.P. prism normal to the first surface. The light continues through the prism and into the surface deformable medium where it encounters the surface boundary. Light is reflected internally at the boundary and collected by the projection lens to form the image. The deformations remove light from the beam, thus producing a positive image on the projection screen when a negative image is applied to the surface deformable medium.

Figure 4 shows a sketch of a T.I.R.P. Projection System. It is to be noted that the light from the object leaves it at a rather large angle with respect to the normal, about $40^\circ$ - $45^\circ$, but that the beam itself is quite narrow (about $5^\circ$ to $10^\circ$). Thus, with the projection lens placed in the usual position, i.e., normal to the object, little or none of the light would enter. When the projection lens is placed in the beam of light as depicted in Figure 4, two forms of distortion arise; first, the object appears to be compressed because it is being viewed at an angle. Second, since the lens is inclined with respect to the object, it is only possible to achieve sharp focus on a small section. For non-critical work the configuration given in Figure 4 might be adequate, but for high resolution displays one should employ more sophisticated techniques as exemplified by the approach described below.




PROJECTION OF SURFACE DEFORMABLE MODULATION RECORDING

FIGURE 3




T. I. R. P. PROJECTION SYSTEM

FIGURE 4

The Schmidt type of optical system is ideally suited for T.I.R.P. optics. A sketch of a T.I.R.P. system with Schmidt optics is shown in Figure 5. There is little more to a comment on other than the fact that the T.I.R.P. technique only requires a small portion of an entire Schmidt system. One could cut the latter into 8 or 10 equal sections, according to the overall size, and each section would be sufficient for one T.I.R.P. system. Due to the basic configuration of the T.I.R.P. system, only a small portion of the spherical mirror and corrector plate is needed.

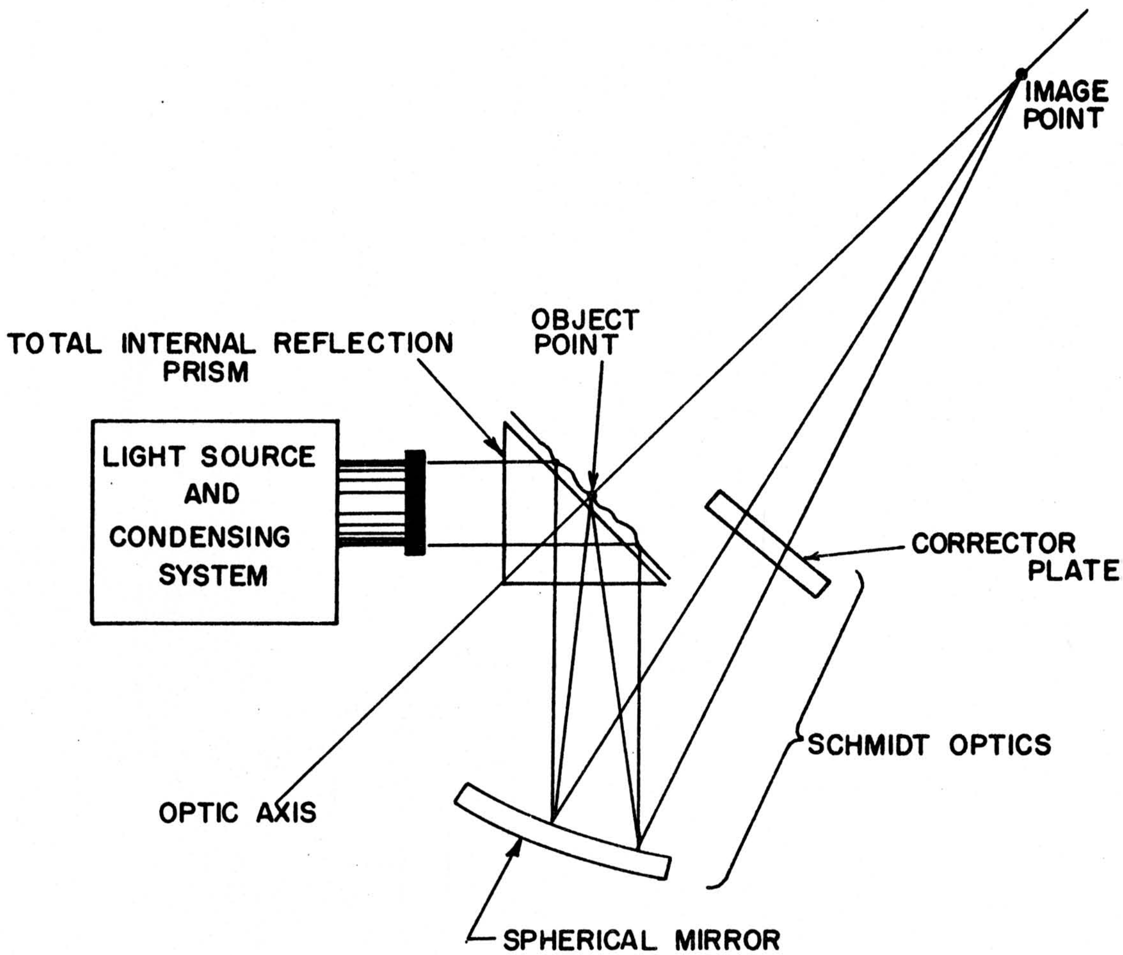
## C. PROJECTION OF THERMOPLASTIC P.P.I. DISPLAYS WITH THE T.I.R.P. CONCEPT

As stated earlier, the T.I.R.P. projector is capable of projecting a thermoplastic or oil film display without introducing the usual "sensitivity" to source shape. It has been shown experimentally that the T.I.R.P. projection system is not particularly sensitive to the angular orientation of the grooves on the thermoplastic object. In fact, the object may be slowly rotated, while in the projection frame, without showing a noticeable change in the image.

The T.I.R.P. concept may be applied to the display of TPR in several forms. The most conventional configuration would utilize a thermoplastic tape transport which maintains optical integrity between the T.I.R.P. prism and tape with a thin oil film. Figure 5 shows the physical configuration of a T.I.R.P. projector which would be modified with a tape transport that places a thin oil film between the prism and tape. It is also apparent that T.I.R.P. may be applied directly to MELVA (military electronic light valve) since several models of this machine actually employ two oil films. One oil film acts as the writing medium while the second optically couples the rotating substrate to a vacuum port. By replacing the glass port with a prism, no barrier exists which would prevent direct application of the T.I.R.P. concept.

## D. SUMMARY

In summary, several attributes of the T.I.R.P. system may be emphasized. First, its application to the oil film light valve permits use of an "on-axis"




T. I. R. P. OPTICAL SYSTEM WITH SCHMIDT PROJECTION OPTICS

FIGURE 5

writing electron gun, thus eliminating the need for keystone correction. Second, a less expensive and less complex optical system is required. Third, since T.I.R.P. is a reflective system its sensitivity is twice that of a transmission Schlieren system.

Again, the outstanding advantage in achieving high peak brightness is the fact that the light source need not be a point or slit source. This permits use of multiple sources as used in solar simulator design. Finally, because T.I.R.P. requires negative modulation of the surface deformable media, defects in the medium are displayed as "blacker than black."