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CORNING GLASS WORKS

ELECTRO-OPTICS LABORATORY

RALEIGH, NORTH CAROLINA

IMPROVED SCREEN FOR REAR PROJECTION VIEWERS

Technical Report No.: 3
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I. Accomplishments

1. Literature Search

A. Open Literature

The reading and assimilation of this is near to being concluded. The articles directly related to rear projection screens and their performance is being condensed into a single complete treatment. From this foundation various areas will be defined requiring either new or further theoretical work which will be undertaken in the next phase of the program.

The other articles which have been obtained relate to the measurement of the scattering function and theoretical developments relating to scattering theory and the effects of particle size, refractive index, and concentration on the scattering function. Also there are many good articles on techniques which allow the determination of the physical parameters of the particle given the desired scattering function.

B. Patent Literature

The patent literature has been read and digested. It contains 43 different articles; of these, only 27 relate specifically to screens. The other 16 articles cover such topics as baffeling to protect against strong ambient light, portable structures to support various screens, and a variety of other unrelated topics.

Those patents directly relating to rear projection screens can be classified as follows:

1) Lenticular Screens
   a. General
   b. Designed to reduce the total internal reflection of light trapped between the two surfaces.
   c. Designed to be relatively insensitive to ambient light.
2) Fresnel Screens
   a. Screens made up of Fresnel surfaces.
   b. Fresnel surfaces used in conjunction with other lenticular elements and diffusing layers.
3) A new type of rear projection screen which combines the advantages of both front and rear screen but does not have their disadvantages.
4) Techniques to accomplish dynamic scanning of projection screens.
5) Techniques used in making screens.

These topics will be discussed in detail in the interim report which will be part of technical report #4.

2. Preliminary Theoretical Investigation:

A. Screen Resolution

After presenting the mathematical foundations of modulation transfer function theory and considering conventional techniques compatable for measuring the MTF of rear projection screens, there seems to be no justification for thinking any extention of present theory is required. Certain conventional techniques are not applicable to projection screens because the spatial coherence of the wavefront is not preserved. However, very many techniques are still valid if the physical characteristics of the screen are properly considered. Of these the size of the irregularities producing the scattering is the most important. Some techniques are highly sensitive to these while others are not.

The influence of nonuniform illumination across the observing optics was investigated. The specific influence depends upon the scattered intensity distribution and also very much on the specific details of the viewing system.

Scanning and additional electronic processing can yield directly the resolution characteristics of a screen or complete display system.

This study has shown the applicability of conventional resolution theory to light scattering display media and also has uncovered many interesting topics to be given further study in the theoretical and experimental phases of the program. This study of screen resolution will also be included as part of the interim report.

3. Familiarization with Corning Manufacturing Facilities

A trip to our facilities at Corning, New York, was made during this period. Many technologies applicable to the manufacture of rear projection screens were seen and discussed with various research personnel from a number of different departments.

Five major classes of materials to be investigated in detail are:

A. Glass Ceramics

Glass ceramics are materials that have been converted into crystalline ceramics from their original glassy state by the use of nucleating agents and heat treatment. A glass batch containing a suitable nucleating agent is melted and formed into a transparent glass by conventional glassmaking techniques. It is then cooled to temperatures inducing precipitation of the nucleating agents. Then, the nucleated material is heated to a temperature range in which growth of the nucleated crystals takes place and where typical crystal size is .1 to .3 microns. Composition of the material and degree of heat treatment determine the type of crystallization and final properties such as its translucency and scattering properties. Three different samples of this material have been obtained.

B. Photosensitive Glasses

Photosensitive glass when exposed to ultraviolet light and heat behaves much like a photographic film or paper. An image is formed that is a permanent part of the glass and extends in depth throughout the body of the glass. Exposed areas turn an opalescent white after development by a heat treatment. The unexposed areas remain clear. Thus, any pattern can be reproduced in this glass by exposing and developing it. Screens containing over 350,000 precisely-located holes per square inch are produced by this technique. This material is known by the trademark "Fotoform". The Fotoform glasses can be converted by further heat treatment into a crystalline ceramic material. In this state the material can be translucent or opaque depending on how it is treated and it is mechanically harder and stronger than it was in the glassy state. It is marketed under the trademark "Fotoceram".

C. Multiform Glasses

These are formed by powdering a glass, pressing or slip casting the particles to shape and then firing at a high temperature. The particles are consolidated or sintered by fusion into a vacuum-tight structure.

Multiform products display properties similar to those of the parent glass. By controlling the size of the glass particles, the firing temperature and the firing time, multiform glasses can be made to have a wide variety of light scattering characteristics. The normal particle size is 5 microns but canbe made as small as 3 microns with no large size limit and also can be made with a given distribution of particle sizes.

D. Porous Glasses

These glasses are composed of two different glasses with one being very much more soluable than the other. After the glass has been formed it is placed in a solution which leaches out the soluable glass leaving a very porous skeleton. The size of pores range from 10 Angstroms to 500 Angstroms. This gives the material a milky look but they eventually discolor because of the collection of organic substance in the pores. This can be avoided by covering the surfaces with a resin or similiar sealing material. The porous glasses can be made more translucent by filling the pores with an opalizing agent, the concentration of which can be varied to change the translucent properties to suit a particular application. We have one sample of this material and expect more in the near future.

E. Optical Fibers and Matrices

Reference is made to discussions in previous reports and elsewhere in this one and will not be considered further here.

4. Progress on Rear View Screen Materials

A. Manufacture of Hollow Fibers and Matrices

As earlier reported, we are considering the feasibility of using hollow fibers which have been assembled into a matrix as a rear projection screen material. The group working in the Television Products, Market Development Department at Corning, New York, has made such hollow tubes down to 10 microns in inside diameter with good control of open area to wall area. In the 10 - 20 micron diameter region this can be as much as 70/30. At smaller diameters, wall thickness remains constant but the hole gets smaller and smaller until it becomes a solid fiber. This may be the most difficult material, at least initially, to obtain samples of as they must be made specially to order and can be of any desired shape both inside and outside. We can obtain samples by December consisting of a matrix of 10 - 20 micron diameter hollow fibers measuring up to 2" x 2".

B. Metalizing of Hollow Fiber Cores

At present the Advanced Products Department of the Technical Products Division at our Corning, New York, facility is attempting to coat the inside of hollow fibers using a new type of coating material from Hanovia. This is a mixture of solvents, organic compounds, and metallic salts. After a coating of this the fibers are fired which breaks up the organic material and creates a reducing atmosphere leaving a fresh metallic coating on the fiber. All wastes becomes trapped in the vapor and are vented off. Many of the popular plating materials can be handled in this way. This is expected to give us an early estimate of the feasibility of plating both fibers and matrices in this fashion and also gives an estimate of the requirements, in terms of time and facilities to do this type of work if it proves successful. The results of this effort are expected next period.

C. Losses in an Uncoated Hollow Glass Fiber

A theoretical study was made to determine the transmission losses through a hollow uncoated opaque glass fiber.

The loss of power through such a fiber is due primarily to penetration of energy through the inner fiber wall. This is either absorbed if the fiber is not clear or else it is simply refracted out of the fiber and into the surrounding media.

The power penetrating the walls of the fiber as a function of incident angle θ and refractive index n of the wall relative to the hollow core, for two orthogonal polarizations is given by the familiar Fresnel equations.

parallel $$\tau_p(\theta) = \mathrm{Tan}^2\,(\theta - \phi)/\mathrm{Tan}^2\,(\theta + \phi) \qquad (1)$$

normal $$\tau_n(\theta) = \mathrm{Sin}^2\,(\theta - \phi)/\mathrm{Sin}^2\,(\theta + \phi) \qquad (2)$$

where $\tau_p(\theta)$, $\tau_n(\theta)$ are the transmission coefficients for the electric vector parallel and normal to the plane of incidence respectively, and ϕ is the angle of refraction given by Snell's law,

$$\phi = \sin^{-1} \left(\frac{\sin\theta}{n}\right) \tag{3}$$

The reflection coefficients $R_p(\theta)$ and $R_n(\theta)$ are simply

$$R_p(\theta) = 1 - T_p(\theta) \tag{4}$$

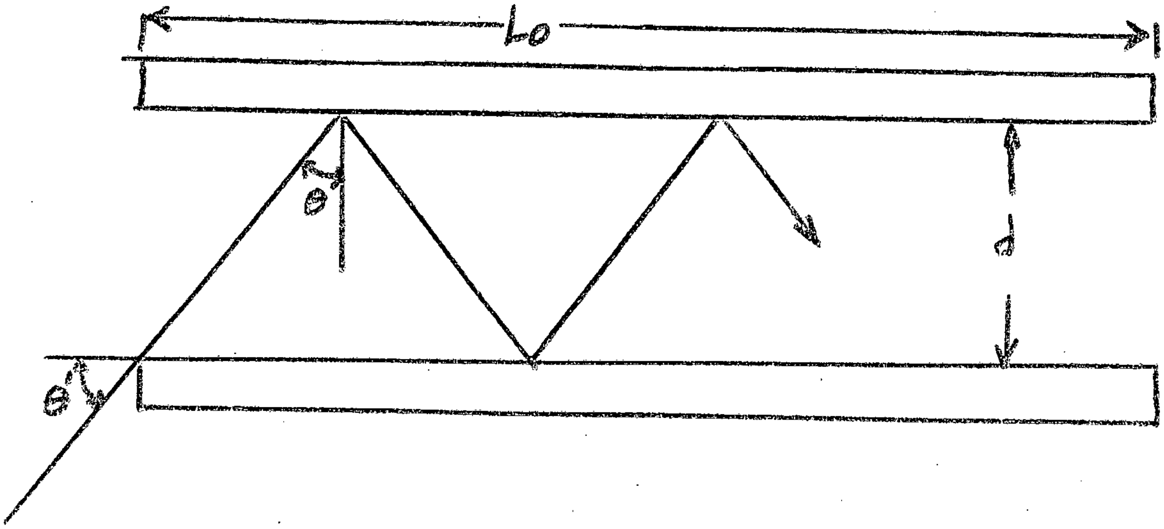
$$R_n(\theta) = 1 - T_n(\theta) \tag{5}$$

For the Molybdenum impregnated glass all energy which passes through the first wall is absorbed hence $R_p(\theta)$ and $R_n(\theta)$ are valid reflection coefficients and describe the losses per reflection. For a clear non-absorbing glass fiber only a few percent of the energy incident at a point on the wall will be returned to the hollow core by reflection from the second wall if it is uncoated. Because total internal reflection is no longer responsible for the propagation of light down the fiber the numerical aperture must be given in terms of the angle at which the transmission coefficient $T(\theta, r)$ falls below some predetermined value.

It should be mentioned that a black glass is not necessarily more reflective than one which is clear. The contrast of the image in the black glass is much higher and subjectively influences the observer's evaluation of the reflected image seen. However absorbing glasses prevent cross-talk between fibers when used in a matrix.

The total loss of power at a given angle of incidence is determined by the length of the fiber, i. e., the number of reflection and the reflectivity. The number of reflections in a fiber of length L_o and diameter d, $r = \frac{L_o}{d}$, as a function of $\theta' = 90-\theta$ is found from the geometry of Figure 1 to be,

$$N(\theta,r) = r \operatorname{Tan}\theta' \qquad (6)$$



Therefore the total transmission coefficient $T(\theta,r)$ for the fiber becomes,

$$T_p(\theta,r) = R_p(\theta)^{N(\theta,r)} \qquad (7)$$

$$T_n(\theta,r) = R_n(\theta)^{N(\theta,r)} \qquad (8)$$

writing (7) and (8) out,

$$T_p(\theta,r) = \left[1 - \frac{\operatorname{Tan}^2(\theta-\phi)}{\operatorname{Tan}^2(\theta+\phi)}\right]^{r \operatorname{Tan}\theta} \qquad (9)$$

$$T_n(\theta,r) = \left[1 - \frac{\operatorname{Sin}^2(\theta-\phi)}{\operatorname{Sin}^2(\theta+\phi)}\right]^{r \operatorname{Tan}\theta} \qquad (10)$$

It is clear from (9) and (10) the losses are compounded as θ' increases. This is because both the reflection coefficient decreases and the number of reflections increases with increasing θ'.

One measure of the transmission properties through such fibers is the number of reflection n required to reduce the transmission coefficient to some given value. As an example Figure 2 gives n as function of the angle θ to reduce the transmission coefficient to .01. It is clear, even at large angles that only a very few reflections are required. It should be noted in using Figure 2, n must be integer. An equivalent measure is the ratio L_o/d, for which the transmission coefficient drops to .01 and is shown in Figure 3. Consider what these means in terms of fiber diameter, length, and angle of incidence.

The maximum length of a fiber with a diameter of 50 microns at $\theta = 75^o$; is .9 mm for the parallel component which undergoes 5 reflections and .4 mm for the normal component which reflects twice. It should be remembered each polarization is being considered independently. In view of the data given in Figures 2 and 3 and this example, it seems impractical to consider uncoated hollow fibers as a component for rear projection screens because of their high losses.

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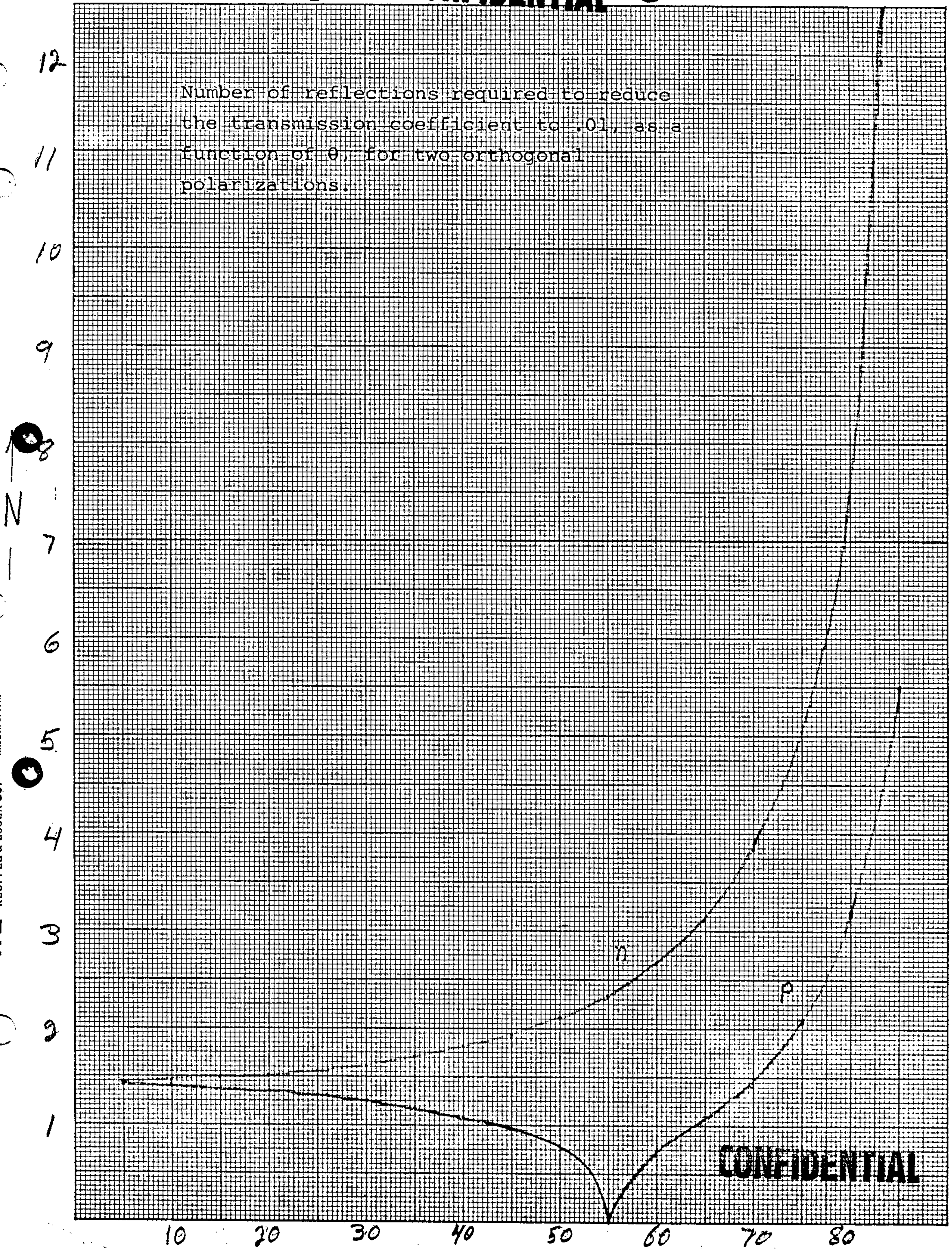

Number of reflections required to reduce the transmission coefficient to .01, as a function of θ, for two orthogonal polarizations.

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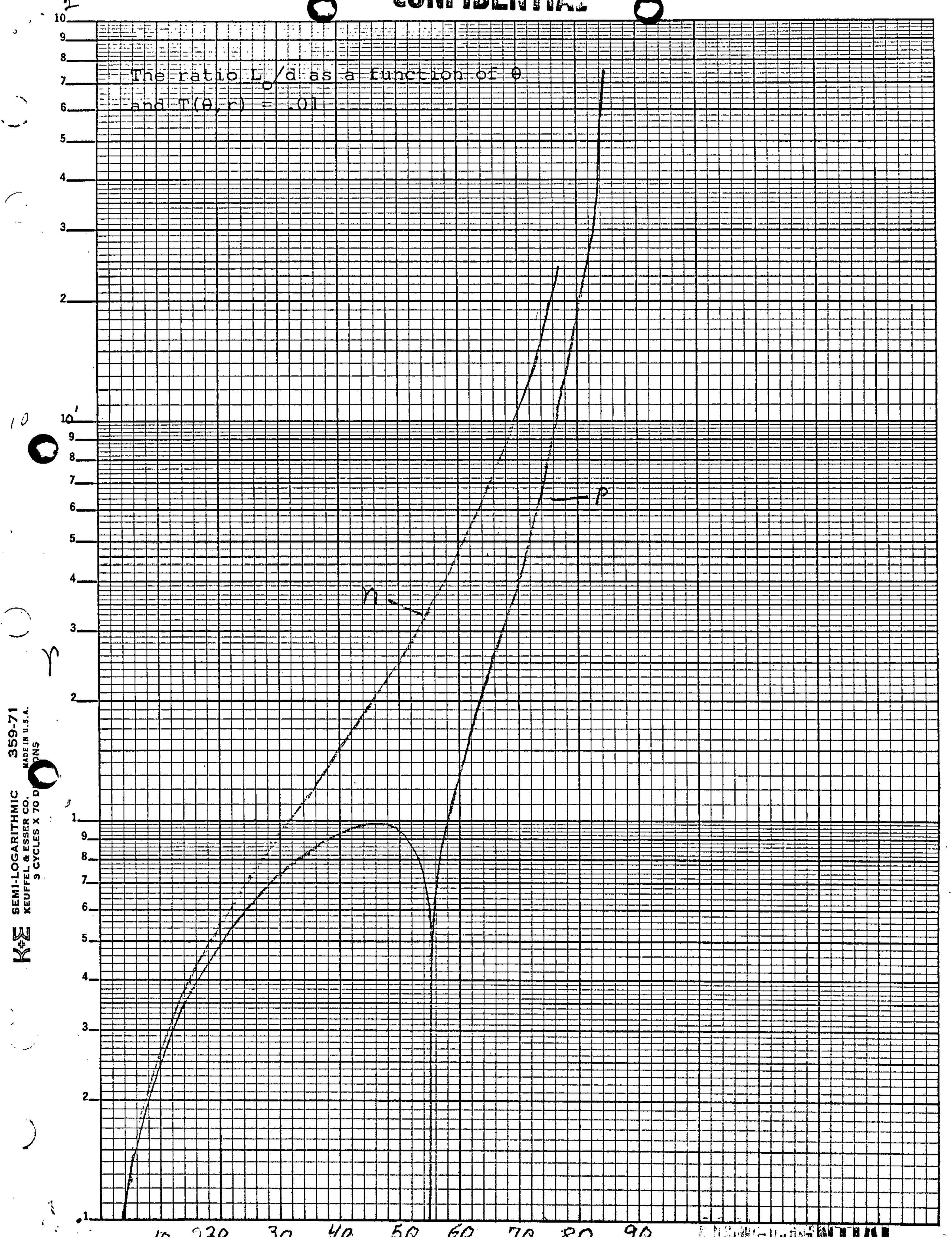

The ratio L_o/d as a function of θ and $T(\theta,r) = .01$

II. Next Period Objectives

1. Literature Search

The literature search will be concluded and the first three months'work along with a review of the literature will be documented in an interim report.

2. Familiarization with Corning Facilities

Familiarization with the various Corning facilities will continue.

3. Outline of Future Program Planning

Because many of the materials previously discussed in this report seem promising for use in rear view projection screens and because they are standard products we feel it would be advantageous to integrate the theoretical and experimental investigations. The advantages are threefold. First, the theoretical work would have specific objectives related to specific materials and properties. Second, experimental data could be used to assist in developing and checking theoretical models used in describing the properties of the various materials and would therefore be more complete than if developed using only theoretical assumptions. Third, if materials are found which are particularly suited for use in rear projection screens, production of practical sized samples could be started at the earliest date resulting in early delivery of sample screens. The analysis of these larger screens would be useful in making additional modifications of the materials.

4. Instrumentation

Specific instrumentation requirements for both a goniophotometer to measure light scattering functions, and a modulation transfer function analyzer to measure resolution characteristics, will be investigated. This is an important preliminary to acquiring the needed instrumentation to start a testing program.