

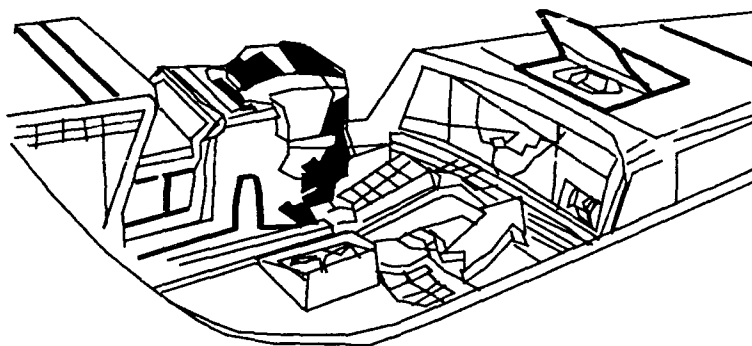
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LIMITATIONS OF A HOLOGRAPHIC 3-D PIXEL PROJECTOR FOR COCKPIT DISPLAYS



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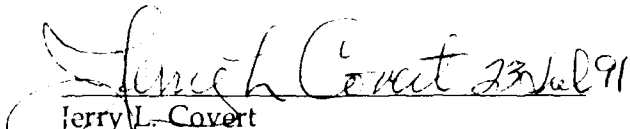


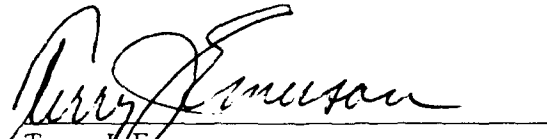
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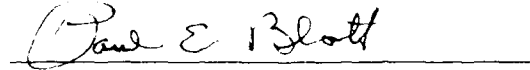
FOREWORD

This Technical Memorandum (TM) documents the results of an in-house research effort accomplished for the United States Air Force at the Wright Laboratory's Joint Cockpit Office (WL/XPK), Wright-Patterson AFB, Ohio. The purpose of this TM is to inform the technical community of the results of three-dimensional display developments within XPK.

This Technical Memorandum has been reviewed and is approved.


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LIMITATIONS OF A HOLOGRAPHIC 3-D PIXEL PROJECTOR FOR COCKPIT DISPLAYS

INTRODUCTION.

One popular approach to increasing the combat capability of an aircraft is to reduce the pilot workload imposed by the interpretation of large quantities of displayed data into useful information. One facet of that workload is the mental exercise required by the pilot to visualize his dynamic three-dimensional (3-D) environment given data presented on two-dimensional (2-D) cockpit displays. It is therefore a primary thrust of cockpit research to explore, develop and test new display devices which can present data with the full 3-D image characteristics of stereopsis, full look-around and ocular accommodation so that the magnitude of required mental visualization is greatly reduced.

While currently available 3-D displays generally invoke stereoscopic approaches, the full advantage of 3-D requires a display which incorporates all three 3-D characteristics. This study explores a method of projecting such 3-D images by the use of a Compound Holographic Optical Element (CHOE) to image a 2-D array of monochromatic point sources to a 3-D array of point images (3-D pixels). Illumination of specific patterns of point sources on the 2-D array will consequently project a 3-D image comprised of the corresponding point images (just as a 2-D image can be comprised of 2-D pixels). Of course, without a one-to-one relation between each source and its respective point image, no point image could be turned on without at least partially illuminating other image points. The purpose of this study is to understand the limitations of a CHOE as a method of achieving such a relationship

and consequently to determine the practicality of this 3-D display approach for cockpit displays.

ANGULAR SELECTIVITY OF PHASE VOLUME HOLOGRAMS.

The most practical CHOE would employ a phase volume material to holographically store a unique 3-D point holographic image for each 2-D source acting as a holographic reference. A one-to-one relation will exist if the illumination of each source results in the subsequent illumination of only the unique 3-D point image associated with that source by the creation of the CHOE. A convenient method of determining if this condition can be adequately achieved is to analyze the angular selectivity function of the hologram. This function relates the diffraction efficiency (that percent of illuminating energy which is diffracted by the hologram) to the angular deviation between the direction of input light used to access the hologram (the read beam) and the direction of light originally used to form that hologram (either the write or reference beam). The most desirable angular selectivity function for each source/image hologram would be that resulting in zero diffracted energy for any input source direction other than that with which the hologram was created.

The coupled wave theory, applied to holography first by Helwig Kogelnik, is the most pervasive and experimentally validated explanation of the physics of phase volume holograms available and is the basis for the following analysis.¹ While the fabrication geometry of the CHOE may be quite

involved, considerable insight can be gained by examining the diffraction efficiency of holograms formed and read through the use of collimated light beams (plane waves). Accordingly, for transmission holograms, the monochromatic plane wave diffraction efficiency function is

$$\eta_t = \frac{\sin(\sqrt{\alpha^2 + \beta^2})}{(1 + \frac{\alpha^2}{\beta^2})} \quad (1)$$

whereas for reflection holograms, that function is

$$\eta_r = \frac{1}{\frac{\alpha^2}{\beta^2} + (1 - \frac{\alpha^2}{\beta^2}) \coth^2(\sqrt{\beta^2 - \alpha^2})} \quad (2)$$

where

$$\alpha = \frac{\delta \pi T n_0}{C_s \lambda_a} \sin(2\Theta_b) \quad (3)$$

$$\beta = \frac{i \pi n_1 T}{\lambda_a \sqrt{\cos(\theta_r) \cos(\theta_i)}} \quad (4)$$

and where T is thickness of the recording material, n_0 is the average index of refraction of that material, λ_a is the wavelength of the recording beam in air, Θ_b is the Bragg angle of the recorded grating, δ is the angular deviation between the read beam and the write beam used to form the hologram, n_1 is the maximum amplitude of the holographically imposed index variation around n_0 and θ_r and θ_i are the angles of

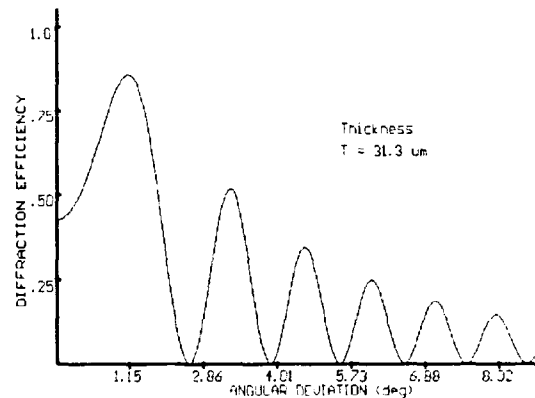
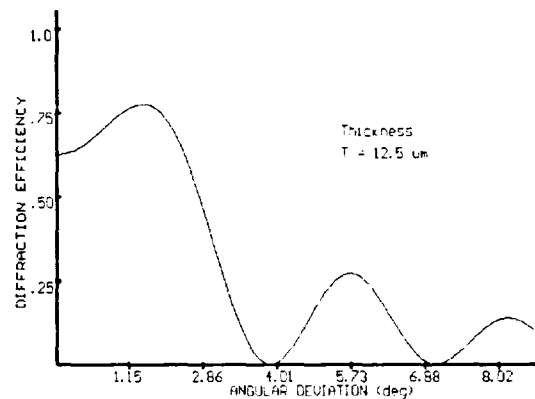
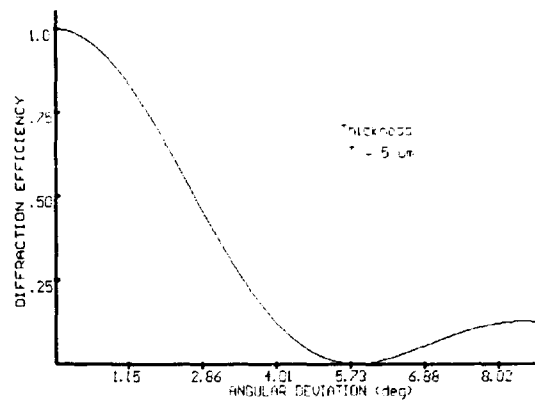


Figure 1. Diffraction efficiency vs. read/write beam angular deviation for transmission holograms.

incidence of the respective reference and image source beams used to form the grating. The reader is referred to Kogelnik's work for the assumed and approximated

conditions under which these equations are valid.

The diffraction efficiencies (η_r and η_w) of equations (1) and (2) have been plotted

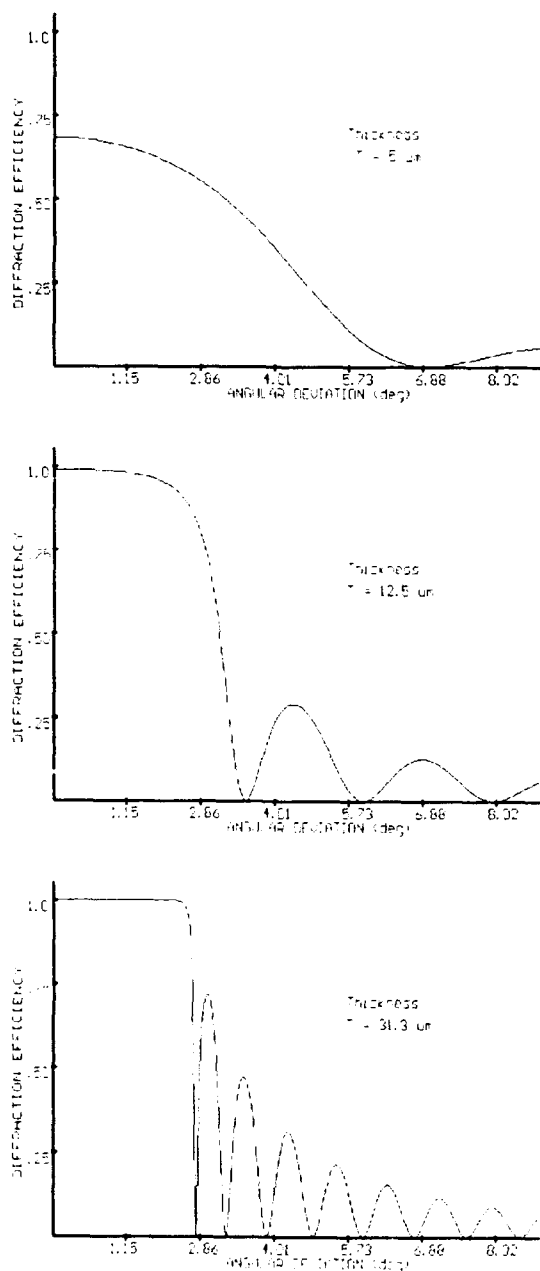


Figure 2. Diffraction efficiency vs. read/write beam angular deviation for reflection holograms.

against read/write beam deviation (δ) for a number of thicknesses in figures 1 and 2, respectively, the values of the remaining variables are: $\Theta_b = 18.6$ degrees; $\Theta_s = 60$ degrees; $\Theta_i = 0$ degrees; $\lambda_s = 514.5$ nm; $n_o = 1.5$; and $n_1 = 0.03$. These values represent a device configuration which is suitable for implementation in a cockpit.

OPTIMUM USE OF CHOE.

From the previous figures it is apparent that a phase volume hologram can not be formed with ideal angular selectivity as described earlier since the diffraction efficiency for any examined configuration does not quickly fall to zero as the read/write beam deviation increases. In fact, the minimum spacing which allows partially unique pixel illumination does not occur until the first zero of one diffraction efficiency function is placed on the peak of the next. However, in this configuration there will still be substantial crosstalk.

LIMITATIONS OF THE HOLOGRAPHIC 3-D PIXEL PROJECTOR.

The number of one-to-one source/image holograms which can be stored in a CHOE will be inherently limited by the angular separation of sources corresponding to the first zeroes of the hologram diffraction efficiency function. Referring to figures 1 and 2, the practical lower angular limit of these first zeroes corresponds to roughly 4 degrees. As a more conservative approach, at 10 degrees spacing the side lobes have fallen to roughly 10% of the peak value so that crosstalk will be reasonably low. Assuming this is valid for both directions of a 2-D source array and assuming that only a 30 degree cone is practical for placement of such point

sources, the array of those sources must be limited to 4 by 4 points. If used to produce a volume of 3-D point images, such an approach is therefore limited to 16 projected 3-D pixels.

CONCLUSION.

The storage capabilities of volume holograms are severely limited when a strict one-to-one mapping of input to output is required. Such a mapping limitation theoretically allows for the creation of a single-color holographic projector having a three-dimensional display grid of only 16 pixels (image points) with which to produce images. Such definition is insufficient to adequately display pixel based 3-D images for cockpit applications. However, since the projected images are not restricted to point sources there may be some uses for which this device is suited (i.e. threat warning or attitude/directional indicators).

REFERENCE.

1. H. Kogelnik, "Coupled Wave Theory for Thick Hologram Gratings", Bell System Tech J., 48, 2909 (November 1969).