

High-gain holographic screens

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A high-gain screen can be made as a sandwich of a hologram and a retroreflective screen material. When a hologram is used in front of the screen instead of the screen material alone, the position of high-brightness viewing can be moved to any desired angle rather than being directed back along the projection beam.

Introduction

A problem in the use of high-gain retroreflective screens, such as commercially available beaded screens, cat's eye screens, fly's eye screens, or corner-cube arrays, is that the maximum reflected radiance is always along the ray bundle from the projector to the screen.¹ Thus it is impossible to place the viewer's eye in a position to intercept the maximum light from the screen without using a beam splitter or blocking the projection beam. For high brightness, the viewer must be placed close to the incident ray bundle, and the retroreflected diffraction lobe must be widened (for example, in a beaded screen by changing the size and index of the beads² or in a lenticular screen by varying the index and shape of the lenticular elements³) to include the viewer. This results in geometric constraints in the design of viewing theaters and lower-than-optimum screen brightness.

A solution to this problem is to place a hologram or diffraction grating in front of the retroreflection screen. A portion of the incident beam is split away and retro-reflected at a different angle, allowing the viewer to be placed at the maximum of this split-off reflected beam. The width of the reflected diffraction lobe can then be decreased, substantially increasing the amount of light intercepted by the viewer. Figure 1 illustrates the problem and the conceptual solution to the problem. A similar suggestion to increase gain for rear-projection screens by using a hologram was suggested by Meyerhofer.⁴

Theoretical Description

An example of a holographic high-gain screen is a sine-wave transmission grating placed in front of and in contact with a retroreflecting beaded screen. A situation in which this particular hologram would be useful would be a screen for a pilot simulator in which an argon laser is raster scanned and electro-optically modulated to paint a TV-type picture on a large dome. A high-gain screen is required to achieve reasonable brightness levels for the pilot and copilot, who are placed at an angle of $\pm\phi$ from the exit pupil of the projector as shown in Fig. 2.

The incident beam diffracts into a ± 1 order and an undiffracted 0 order. Each order is then reflected back

to the hologram by the screen and is again diffracted into three orders. Thus there is a total of 3×3 or 9 orders reflected from the hologram-screen sandwich. However, several of the return orders overlap so there are only five beams leaving the screen at $\theta = 0$, $\theta = \pm\phi$, and $\theta = \pm 2\phi$, where ϕ is the diffraction angle determined by the wavelength λ and the grating spacing d .

Figure 3 shows an unfolded view of this process; for clarity we have separated the hologram from the screen. The first number labels the first pass (left to right) through the hologram; the second number, the return pass.

If the hologram has an efficiency of η , then the percentage P of incident light diffracted into each of the return beams from the screen is given by

$$P_{\theta=0} = 6\eta^2 - 4\eta + 1, \quad (1)$$

$$P_{\theta=\pm\phi} = 2\eta(1 - 2\eta), \quad (2)$$

$$P_{\theta=\pm 2\phi} = \eta^2. \quad (3)$$

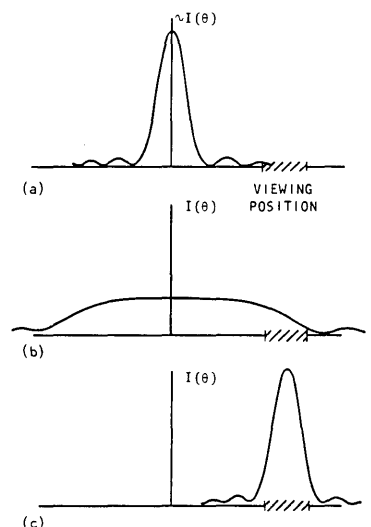


Fig. 1. Reflected screen radiance: (a) ordinary retroreflected beaded screen, (b) ordinary retroreflective screen with the diffraction lobe increased to contain the viewing angle, (c) holographic retroreflective screen sandwich in which the diffraction lobe is moved to the viewing angle.

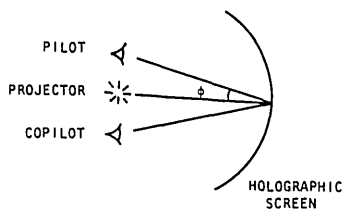


Fig. 2. Geometry for a simulator screen.

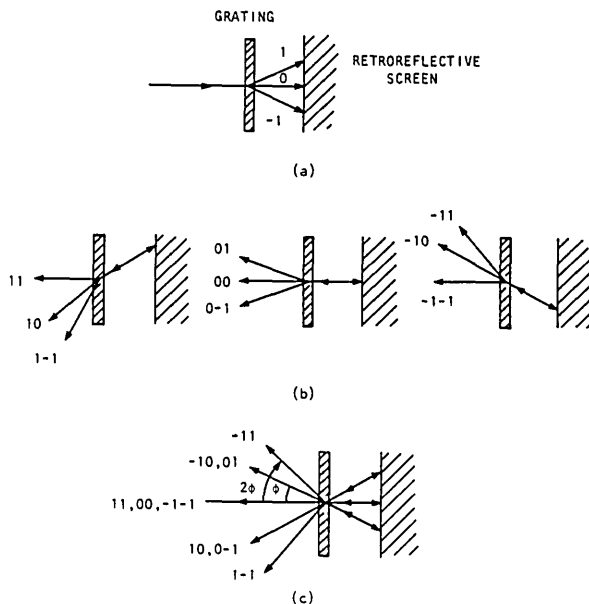


Fig. 3. Reflected beams produced by holographic retroreflective screen sandwich: (a) incident beam undergoing diffraction at the hologram, (b) each incident beam being retroreflected and undergoing diffraction in the return direction at the hologram. (c) composite of all the return beams leaving the hologram-screen sandwich.

Maximizing the radiance in the $\pm\phi$ beams as a function of diffraction efficiency [Eq. (2)] yields $\eta_{\max} = 1/4$. The percentage of light in the 0, $\pm\phi$, and $\pm 2\phi$ beams becomes 37.5%, 25%, and 6.25%, respectively. The approximate increase in light over a high-gain beaded screen is given by the percentage of light in the ± 1 order divided by the ratio of the solid-angle diffraction lobe of the holographic screen to the solid-angle diffraction lobe necessary to encompass pilot and copilot by an ordinary high-gain screen.

Experimental Verification

A bleached sine-wave grating of 5% efficiency was placed in contact with a 3M Model 7615 high-gain beaded screen. The retroreflected diffraction lobe from the screen itself is a $J_1(x)/x$ function with the first zero

at $\theta = 0.47^\circ$. The hologram-screen sandwich was illuminated with light from the 488-nm line of an argon laser. From Eqs. (1)–(3) we expect the percentage of incident light in the 0, $\pm\phi$, and $\pm 2\phi$ beams to be 81.5%, 9%, and 0.25%, respectively. The measured percentage into the 0 and ± 1 beams was found to be 64% and 7%, respectively. The radiance in the $\pm 2\phi$ beams was too small to measure. The discrepancy occurs because of losses at the air-hologram-screen interfaces and because the screen material is not a 100% retroreflector. Losses at the interfaces could be reduced by coating the screen with photoresist and developing the hologram directly on the screen material.

Even though the hologram used had such low efficiency, the improvement in brightness over an ordinary front-projection screen is dramatic to the viewer.

Conclusions

Holographic screens may be applied to display geometries for which high brightness is required but viewing angle is limited. The general approach is to make an appropriate hologram so that when it is illuminated by the projection ray bundle, a reconstructed ray bundle generated by the hologram is reflected into the required viewing area. There is also the possibility of using two-frequency gratings or a double-exposure hologram for projecting stereo scenes.

A drawback to these schemes is chromatic aberration in multicolor displays. In some situations this can be corrected by varying the illumination angle for differing wavelengths so that the reconstructed beams register correctly. In other systems the retroreflected diffraction lobes could be made larger than the angular spread that is due to wavelength so that the reconstructed beams would register correctly over the central portion of the viewing area.

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References

1. An excellent description of these screens is found in T. Okoshi, *Three Dimensional Imaging Techniques* (Academic, New York, 1976).
2. K. Vedar and M. D. Stoudt, "Retroreflection from spherical glass beads in highway pavement markings," *Appl. Opt.* **17**, 1859 (1978).
3. E. W. Marchand, "Diffraction effects with lenticular projection screens," *J. Opt. Soc. Am.* **65**, 139 (1975).
4. D. Meyerhofer, "Holographic and interferometric viewing screens," *Appl. Opt.* **12**, 2180 (1973).