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Holographic Production Unit

Holograms
- Operation -

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Holograms-Operation

Introduction

Holography, from the Greek words "holos" meaning whole and "graphos" meaning picture, was first described by a Hungarian scientist, Denis Gabor, working in England in 1948. It was not, however, satisfactorily demonstrated until 1960 when two American scientists, Emmet Leith and Joseph Upatnieks used coherent light from the newly developed laser to record the first hologram. As the name implies, the major use of these first holograms was to produce a three dimensional image of physical objects. This is still the most common usage of the technique but there are a number of other possibilities. The hologram can be used to store optical properties or large amounts of data as well as images. It is the ability of the hologram to store optical properties which is of importance in Head-Up Display (HUD) design.

To see why this property is so useful in HUD design it is worth while to examine the limitations on conventional HUD systems. Figure 1 shows a typical HUD, Pilots Display Unit configuration. There are three main problems associated with such an arrangement.

1. The display can only be viewed when the eye is looking through the porthole-like image of the exit (collimation) lens. This image, by the laws of optics, is created in front of the combiner at the same distance from the combiner's semi-reflective surface as the exit lens itself is below that surface. A large field of view, thus, requires a large exit optic and hence a large and heavy HUD.

2. As indicated in figure 2 the total amount of reflected light and transmitted light at the semi-reflected surface can never be more than 100%. For adequate legibility against a bright sun-lit background this requires that the display be wastefully bright.

3. The physical arrangement of the HUD is such that the combiner glass must be well forward of the ejection line. In this location it is constrained in size by the canopy arrangement and in addition the "porthole" is moved further from the pilot's eyes thus further reducing his field of view.

For daylight operation these problems are not that serious since a small eye movement will enable the pilot to view the entire display, which is included in the total field of view angle, even though his instantaneous field of view is somewhat less. When using a night vision sensor picture superimposed on the HUD symbology to fly at night, the situation is quite different. The pilot can no longer look around his display to spot the visual flight cues which make low level flight possible. The only visual information available to him is that presented on his HUD plus, depending on ambient light conditions, a comparatively shadowy and indistinct impression of the real world. Numerous flight trials have shown the importance of a large field of view for low level flight at night. Holographic lens coatings make HUD configurations such as the Marconi LANTIRN HUD system (figure 3) possible.

In this sytem the hologram provides three major advantages overcoming the problems of the conventional HUD.

1. Collimation is performed at the combiner surface itself, eliminating the porthole effect and greatly increasing the display area.

2. Reflection and transmission at each surface are no longer restricted to a total of less than 100% but can be as high as 90% for each.

3. The combiner is moved back to the ejection line thus maximizing the field of view possible from a combiner of any given size.

To show how this is accomplished it is necessary to examine the properties of holograms.

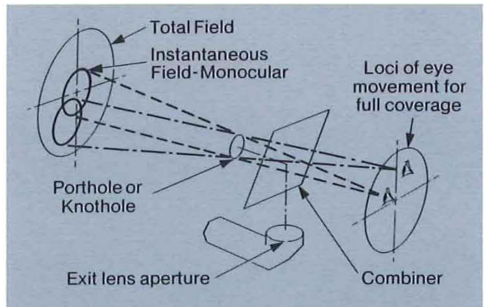

Fig. 1 Typical HUD PDU Configuration

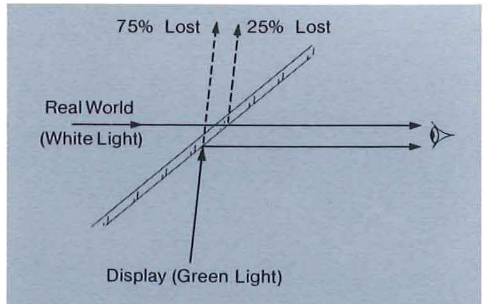

Fig. 2 Losses at Semi-Reflective Surface

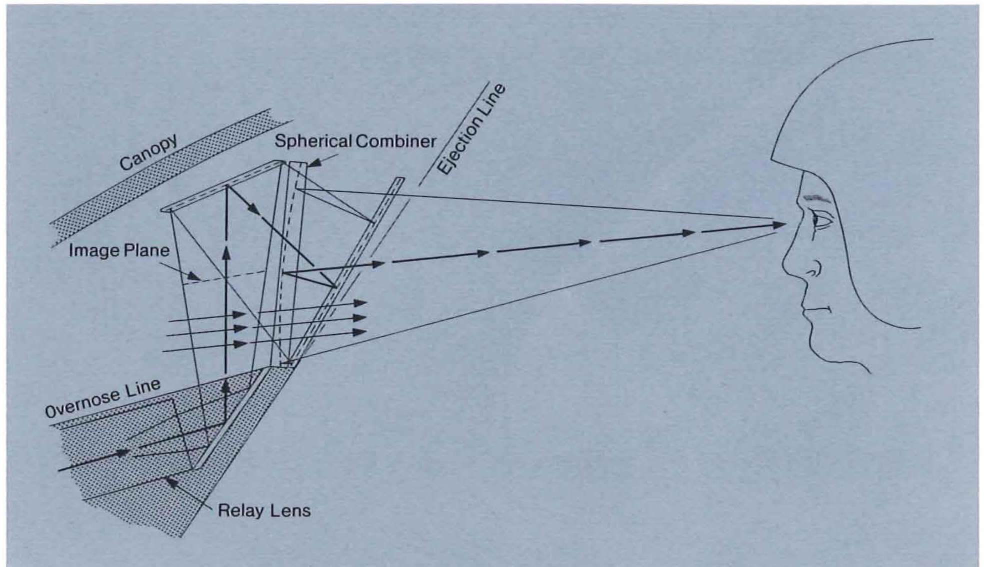

Fig. 3 LANTIRN HUD Configuration

How Holograms Function

Conventional image holograms are created when two beams of coherent light from the same source interact to form interference fringe patterns. If one of these beams, the object beam, is reflected from a three dimensional object onto a sensitive plate which is also exposed to the other, the reference beam, and the two beams are in phase, the plate will record interference fringes. Because of the wave nature of light these fringes will have been formed by light rays which have impinged on surfaces of the object more than 90° apart and been diffracted back to interact with the overall wave front of the object beam. The stored image then represents a three dimensional hologram of the exposed object and if illuminated by light of the same frequency will display its three dimensional image. If two pairs of object beams and reference beams are employed, one each in red and blue/green light, the hologram image will appear in full colour in ordinary white light. This is the conventional usage with which most people are familiar.

The principle behind the storage of an optical property is identical to that of image storage but the mechanization is slightly different. In this case the object beam is acted on by an optical element which can be very simple, such as a mirror, or complex such as a lens arrangement. The fringe arrangement created when the affected object beam interacts with the reference beam is then a hologram which will interact with light of the same wavelength in the same manner as the original optical element. As might be expected, the fringe pattern from a simple optical device such as a mirror is itself simple and its action straight forward. Figure 4 shows the fringe arrangement in a mirror hologram.

The incident ray i encounters a surface of index of refraction n1, at R, passes through this and encounters a series of fringes whose index of refraction is n2. At each discontinuity, a part of the energy in the ray is absorbed and re-radiated. If the path length between such changes in index of refraction is a whole number of half wave lengths of the incident light, the light returning to R will reinforce the incident beam and on re-radiation from this point, will create a wave front emerging as the mirror image (i2) of the original ray. If the path length is not a whole number of half wave lengths no reinforcement occurs and the ray will not reflect but pass through with some losses caused by scattering at the various fringes. Typically, such a hologram will reflect more than 90% of the frequency for which it is matched and transmit more than 90% of the rest of the spectrum. From the diagram it is apparent that the hologram is not only frequency selective, but also very sensitive to the angle of incidence. A change in angle of incidence alters the path length and hence the hologram can both reflect and transmit a particular frequency depending on the angle of incidence.

Because of the different purpose of the optical property hologram it is frequently referred to as a 'diffraction optics system' to distinguish it from conventional image holography (figure 5).

The changes in index of refraction which form the hologram are created when the exposed plate is treated after the exposure process. For simple mirror holograms such as those used in the LANTIRN HUD the fringe arrangement can be considered as a simple sinusoidal variation in index of refraction through the depth of the sensitive film. The index modulation of this sinusoid and the thickness of the film employed determine the selectivity of the coating. A high index and thick coating provide very selective frequency and angle of incidence sensitivity but restrict the angle through which the image can be viewed. A low index and thin coating increase this angle but absorb more of the spectrum. The thickness and index modulation suitable for any particular application are thus design trade-offs depending on the particular properties desired.

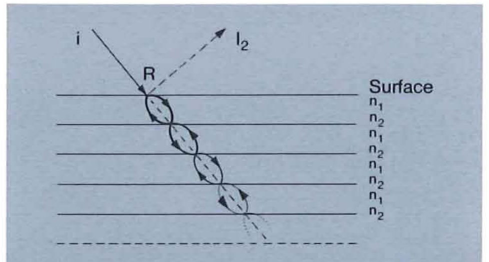

Fig. 4 Fringe Arrangement in a Mirror Hologram

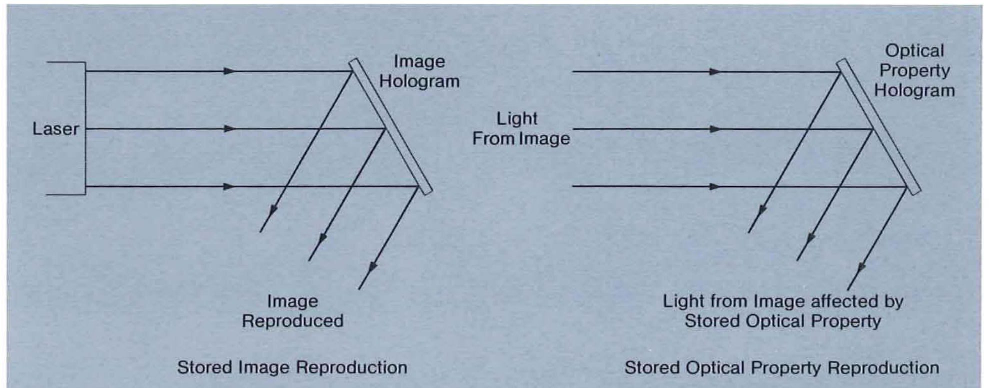

Fig. 5 Holography vs Diffraction Optics

How Holograms are made

The process of creating a hologram is very similar in principle to that used in normal photography. A sensitized film is exposed, then processed to produce a fixed record of the object or property (in the case of optical property holograms) viewed by the system. There are, however, major differences at each stage of the process. In place of the silver halides common in photography, holography requires a variety of sensitizing media depending on the type of hologram to be produced. For optical property holograms, dichromated gelatines are normally employed. In place of the camera and white light of photography, holography requires lasers and coherent light and the treatment of exposed holograms is complicated by the requirement to maintain exact fringe spacing.

The exposure process for a hologram depends on the purpose for which the hologram is required. The exposure process for creating a white light visible image hologram is shown in figure 6; that for a lens hologram in figure 7 and that for a mirror hologram in figure 8.

One of the major problems of the exposure process is the maintainance of phase coherence between the reference beam and the object (or property) beam. The phase shift between these two must be a small fraction of the wave length of the laser beam employed or in the case of the image hologram the image will become blurred and in the case of the property hologram, undesired side effects will be produced. In the case of the mirror hologram it can be seen that the distance over which phase coherence must be maintained is very short. This greatly eases the exposure problem and accounts, in large part, for the relative ease of manufacture of this type of hologram.

Once the hologram is exposed, it must be chemically treated to create the required changes in index of refraction which constitute the fringe pattern and must then be baked dry to achieve the exact degree of fringe separation required. Finally it must be sealed to prevent the absorption of moisture which would disturb this separation.

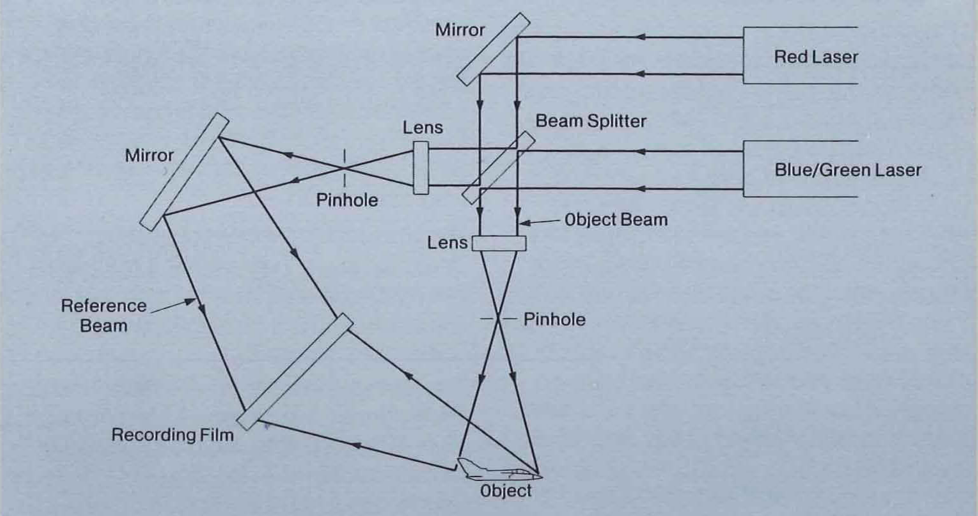

Fig. 6 White Light Visible Image Hologram Exposure Process

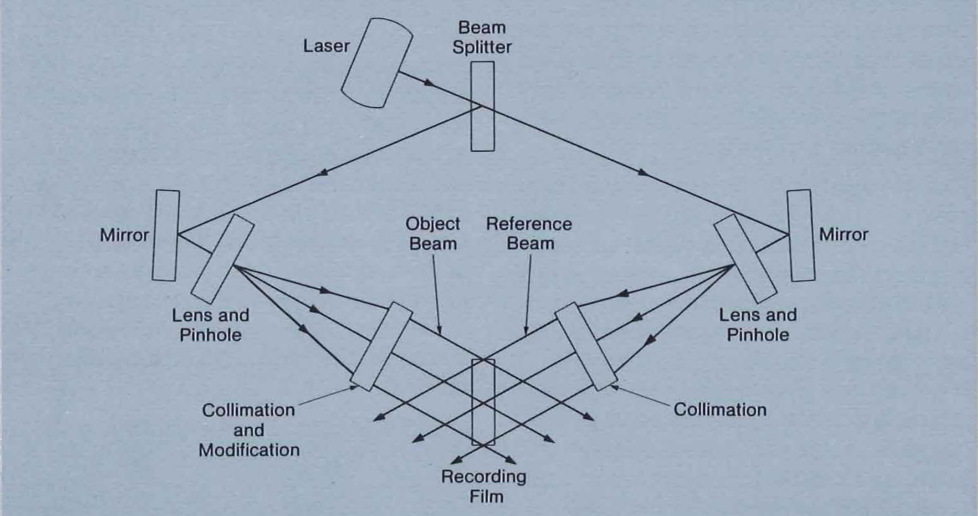

Fig. 7 Lens Hologram Exposure Process

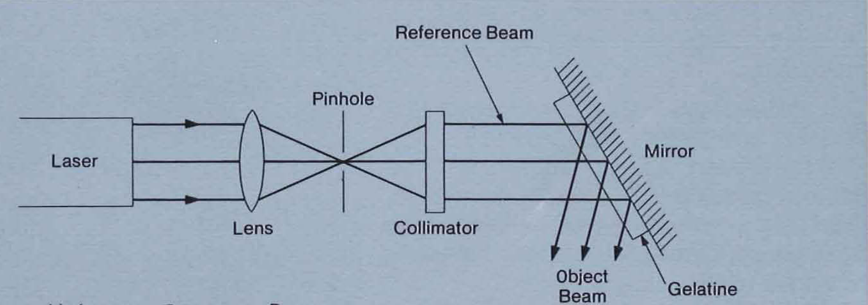

Fig. 8 Mirror Hologram Exposure Process

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Holographics – a new dimension

Introduction

As long ago as 1948, Denis Gabor proposed a novel photographic technique using coherent light which came to be known as holography. But it was not until the early 1960's that the invention of a truly coherent light source, the LASER, made hologram manufacture a reality.

Today, the holographic technique is familiar to most in the form of the display hologram where a flat photographic plate appears to contain a realistic 3D picture – a new dimension in photographic reproduction.

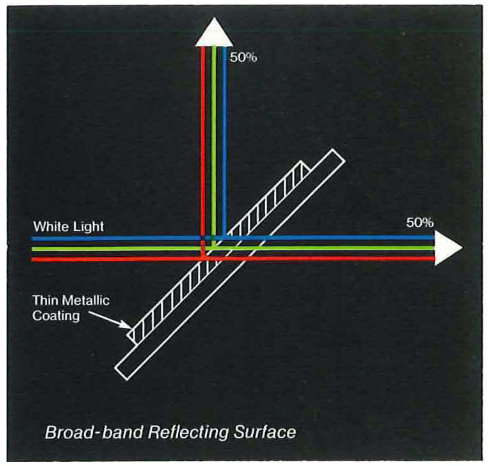
Holography also represents a new dimension for more serious scientific and commercial applications where the technique can be used to solve a range of optical problems not associated with the reproduction of pictures.

In fact, holography provides optical design capabilities which are impossible to achieve by other means and in so doing can actually reduce the cost of certain existing optical designs.

Technical Considerations

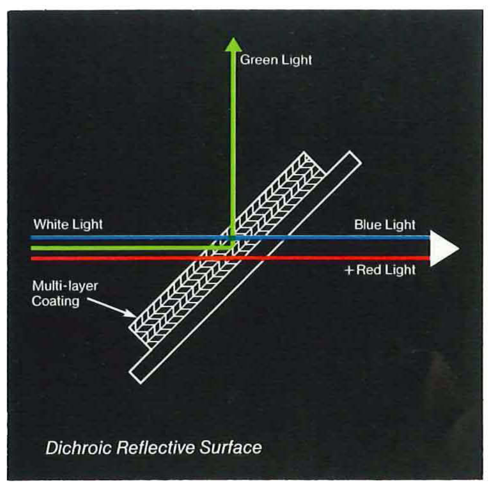
Holography can be used in a wide range of applications. As a part of its long term research programme, Marconi Avionics has developed a production technique for manufacturing optical quality mirrors and beam-splitters using holographic reflective coatings.

To appreciate the full capabilities offered by holographic reflectors, consider how conventional beam-splitters operate.



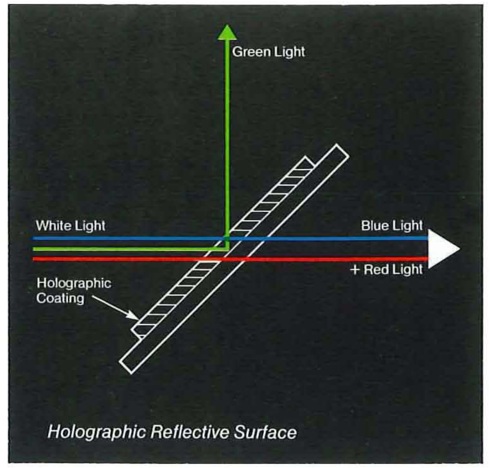
Broad-band Reflecting Surface

The reflecting surface of a simple beam-splitter usually takes the form of a layer of vacuum deposited metal which is so thin that it is partially transparent to incident light. The fraction of incident light reflected or transmitted by this surface is substantially the same for all of the colours in the visible spectrum – a broad-band reflector.



Dichroic Reflective Surface

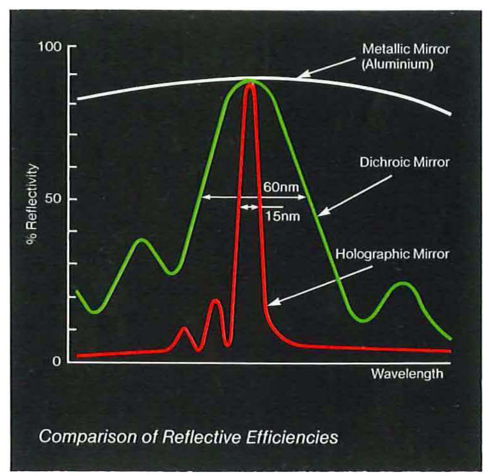
Deposition of a 'dichroic' coating as the reflecting surface produces a colour selective beam-splitter where a band of colour is reflected out of the incident beam of white light and the remaining colours are transmitted. Such coatings are very expensive since a number of layers of different materials must be vacuum deposited onto the surface of the substrate. Also, the choice of reflected colours and their bandwidths is restricted by the materials available and by the inherent difficulty of depositing multi-layer coatings.



Holographic Reflective Surface

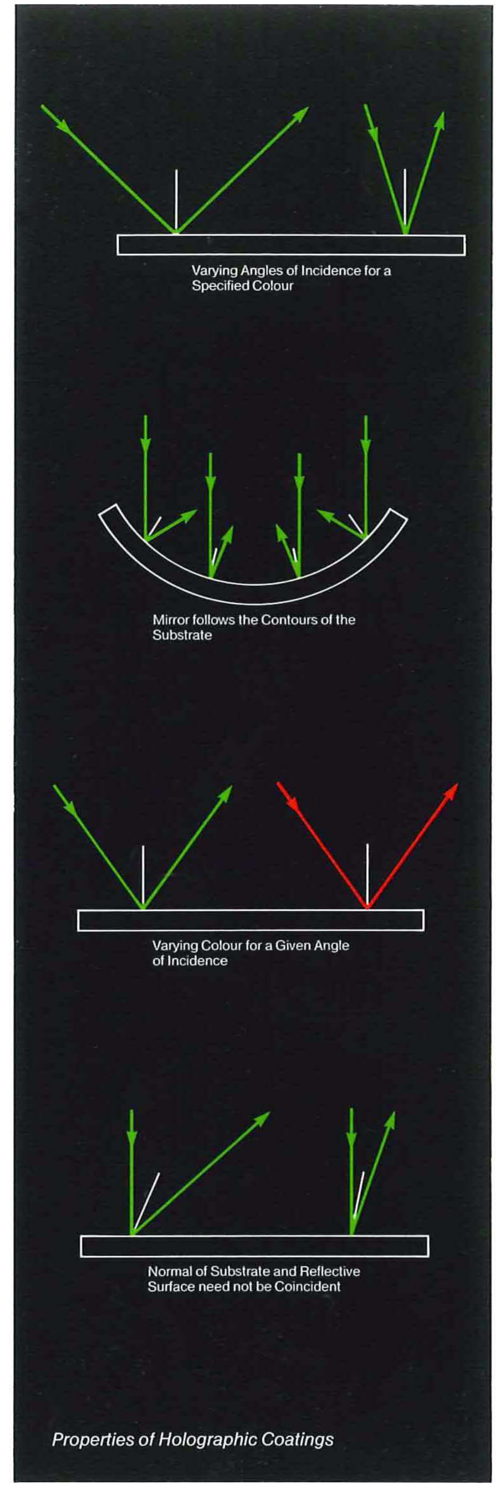
A holographic reflector is also colour selective but, in contrast, it requires only a single layer coating to realise a number of unique properties:

- Selective reflection of a wide range of colours.
- Very narrow bandwidth of reflected light.
- The angle of incidence required to reflect a specific colour can be varied across the surface.
- The substrate can be curved instead of flat.
- The normal to the substrate need not coincide with the optical normal of the reflective coating.



Comparison of Reflective Efficiencies

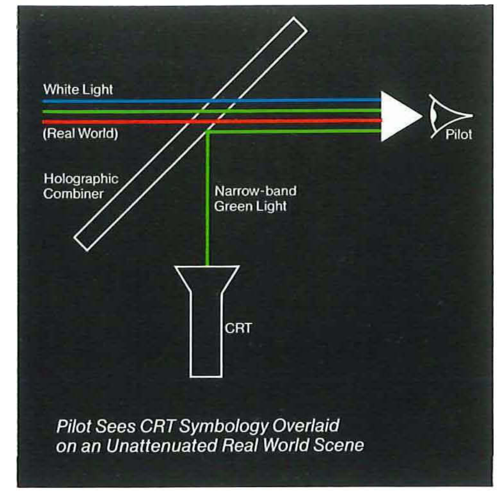
Despite their obvious versatility, holographic coatings are, in general, cheaper than comparable dichroic coatings particularly when large area reflectors are required.



Properties of Holographic Coatings

Design and Production Facilities

After extensive research and development, Marconi Avionics has built a new facility for the design, optimisation and production of reflection holograms specifically for use in engineering and scientific applications. Located at the Rochester site, the facility supplies the Company with holographic combiners for aircraft-mounted sighting systems called Head-Up Displays.



Pilot Sees CRT Symbology Overlaid on an Unattenuated Real World Scene

Holograms are manufactured using the 'dichromated gelatin' (DCG) process which offers the full range of features expected from a high quality reflective hologram while maintaining a transmitted view free from haze, dispersion and inclusions. Protection from atmospheric conditions is afforded by a glass cover-plate bonded to the finished hologram.

Marconi Avionics is now able to offer these same facilities to customers for the design and production of holographic optical elements to meet their own requirements. Optical elements can be produced in any size up to 600mm square and there is also a facility to make small display holograms if required.

Applications

With a reflection bandwidth of as little as 10 nanometers, holographic mirrors can selectively reflect a narrow portion of the visible spectrum whose wavelength can be altered merely by adjusting the angle of incidence. This and the many other features of holographic reflectors make them ideal choices for a range of commercial applications including beam-splitters, beam-combiners, laser scanners, colour filters, holographic lenses, interferometric testing and automative applications. Furthermore, the visual effects created by display holograms can be used for advertising, shop displays and general decorative applications (e.g jewellery, badges and ornaments).

Military applications include head-up displays, helmet sights, target trackers and protective visors.

Holographic reflectors also make an ideal replacement for existing dichroic reflectors and will generally cost less particularly for larger sizes where dichroic coatings are prohibitively expensive.

Information Required to Design and Produce a Holographic Element:-

1. Wavelength for Peak Reflection.
2. Bandwidth at 50% Reflection.
3. Construction Points
   or
   Overall Design of the Optical System
   or
   Assistance Required to Complete the Design
4. Size and Source of Substrate.
5. Number Required and Call-Off Rate.
6. Environmental Conditions.

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