

Autostereoscopic Projector and Display Screens

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ABSTRACT

Investigated H1-H2 transfer analogue and digitally printed reflection holograms suitability for autostereoscopic projection displays. Proved that reflection hologram, having part of replayed image in front of its surface may be used as autostereoscopic display. Assembled 3D streaming images projection device, incorporating digitally printed reflection hologram. Given recommendation for digitally printed holograms use as 3D projection screens.

Keywords: autostereoscopic, 3D projection, 3D television, holographic, LED projection screen.

1. INTRODUCTION

Classical H1-H2 transfer holograms are widely known and used in holographic imaging applications such as holographic portraiture, decorative imaging, new products visualization etc. Recently digitally printed holograms were introduced and used for the same purpose, adding a possibility to show spatial images movement in front or behind holographic media as well as more precise control of replayed image position in space. However, until now all such holograms researchers and manufacturers were concentrated on obtaining a perfect undistorted image and were paying very little attention on physical properties of spatial image formation. This gap, we hope will be started to be filled up with a present work. Moreover, investigation of the image formed by reflection hologram in front of holographic media opens new possibilities for industrial scale manufacturing of simple autostereoscopic reflection screens. Such screens can be used in all applications where are used complicated holographic optical elements or other types of complicated light directing devices. The most convenient way of such screen manufacture can be their digital holographic printing on one of the digital printers described in [1, 2]. Once manufactured or printed with digital holographic printer, the autostereoscopic holographic screen can be then copied by contact copying means [2,4].

2. ORIGIN OF THE REFLECTION TRANSFER HOLOGRAM

First of all I would like to mention how the reflection transfer holograms are manufactured. In the classical process H1 -H2 transfer holograms production, first the master or H1 hologram should be made. This process is called mastering and is done in a setup where a laser radiation beam is split into two parts. One of those laser radiation parts is directed to unexposed high -resolution photomaterial and is called a reference beam. Other part of laser radiation is directed to object to be holographed, reflecting from it to high -resolution photomaterial where interference pattern of those two beams is recorded. While processed high -resolution photomaterial that we will call in the further text “holographic media” is then illuminated by laser beam in reference beam direction – the image of holographed object is formed in space. Physically such image formation happens due to laser light passing through holographic media modulation and redirection performed by holographic media. Laser light, modulated and redirected by holographic media is forming in space an image of holographed object (Fig. 1).

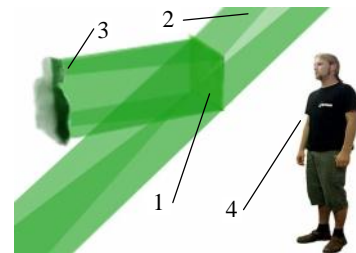


Fig. 1. Viewing a master hologram. 1 - holographic media; 2 - laser beam illuminating holographic media; 3 - reconstructed image; 4 - observer.

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From this master hologram, or H1 hologram is then performed an image transfer to another unexposed high-resolution photomaterial. As it is seen on Fig. 1b, the spatial image of the holographed subject is reconstructed at a certain distance from master hologram. This distance is a same distance where subject was placed during master recording and it cannot be changed – reconstructed image will always appear at this distance. On Fig. 2 is shown the copying process of such master hologram – H1-H2 transfer. During the transfer laser beam again is split into two parts. One of them is used to illuminate master or H1 hologram. This beam passed through master and is forming in space the spatial light shape of image recorded on holographic media. If another unexposed high-resolution photomaterial is placed nearby the formed image and is illuminated with second part of split laser beam, then both beams interfere in photomaterial and H2 copy of H1 master hologram is recorded on said photomaterial.

Unexposed high-resolution photomaterial can be placed in front, into, or behind the image formed in space – from that will depend spatial position of the image reconstructed by H2 copy.

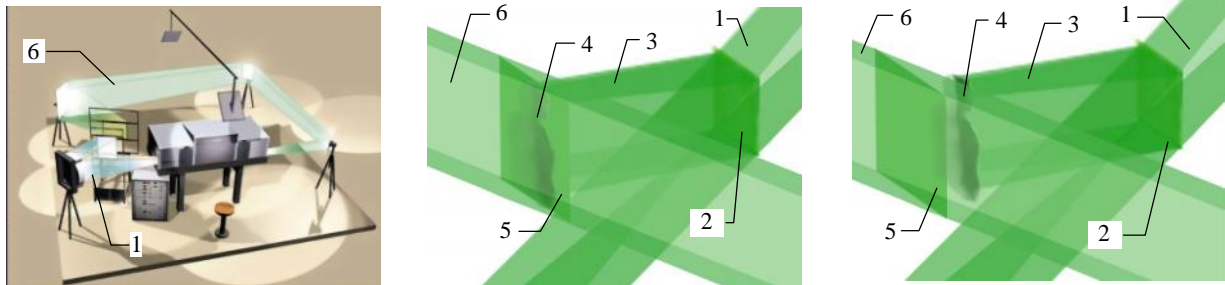


Fig. 2. Copying - H1-H2 transfer using Geola's pulsed holographic camera. Left – general view of the copying setup. Center – H1-H2 transfer when the spatial image is formed in the middle of unexposed photomaterial. Right - H1-H2 transfer when the spatial image is formed in the front of unexposed photomaterial. 1 – Object beam directed to holographic media; reference beam; 2- holographic media with recorded master hologram; 3- object beam forming image in space; 4 – spatial shape of the image recorded in master holographic media and reconstructed in space; 5 – unexposed photomaterial; 6 – reference laser beam.

When the high-resolution photomaterial is exposed as shown on Fig. 2, it is then processed chemically or in other way and is illuminated in the direction opposite to the reference beam used for its exposure. The white -light viewable image is appearing (Fig.3) at distance designed during H1 -H2 transfer.

But the nature of such image appearance is different - the spatial light image in front of the holographic media is formed by illuminating light that is modulated, reflected by holographic media and directed to the places in space where it forms an image. An illusion of the image behind holographic media is formed by the illuminating light interference in holographic media itself.

Illuminated reflection hologram for holographic image formation in front of the holographic media indeed can reflect noticeable amount of illuminating light. Moreover, H2 holograms made from H1 masters always have viewing angle of less than 180 degrees, because they are that are always made of H1 master hologram that is placed at certain distance from H2 copy.

One can say that reflection H2-type holograms has three fundamental properties:

- Hologram reflects in image creation zone only certain light wavelengths;
- Image formed in front of holographic media is formed by reflected light;
- Image that appears in hologram's image plane has biggest brightness and limited viewing angle.

Exploration of those three fundamental reflection hologram properties in conjunction with digital generation of such holograms opens new possibilities for hologram use as image projection screens. If holographic image of flat white plane is recorded in the hologram image plane, such hologram can be used as a screen for usual video projection.

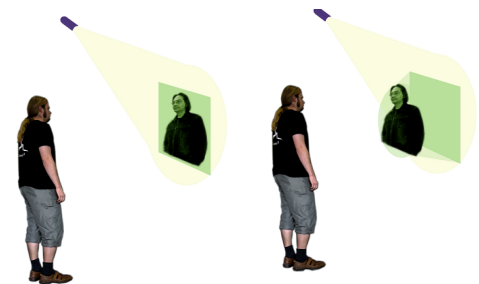


Fig. 3. Viewing H2 transfer hologram. Left – holographic image formed nearby holographic media. Right – holographic image is formed further in front of the holographic media.

However, if holographic image appears in front of the holographic media – such reflection hologram can be used as autostereoscopic screen as it will be shown below. By using digital holography tools, there is possible not only to design all hologram elements digitally, but also to define exact position in space of each designed holographic image element.

3. DIGITAL REFLECTION HOLOGRAMS AS AUTOSTEREOSCOPIC SCREENS

We have investigated reflection holograms possibilities to act as autostereoscopic screens [2,4]. In this work we have chemically processed the holographic screen in such a way that its holographic response wavelength in green spectrum region would correspond to bulb light projector wavelength. Also we have also investigated how our holographic screens works in conjunction with LED projectors. Since any illuminated reflection hologram having image elements appearing in front of the image plane, sends the light to form those image elements, this reflection hologram ability to redirect its illumination light into certain places in space can be used for autostereoscopy needs. And in the digital hologram case, it is quite easy to print reflection holograms with desired characteristics.

Fig. 4 illustrates reflection hologram (3) ability to send the point source (1) light (2) for holographic image (6) formation in front of the hologram. When observer is at the position (7), which is far enough from hologram surface – he sees holographic image element (6) hanging in space in front of the hologram. But when observer's eye is placed at position (6), which is near or inside this holographic image element – it sees holographic media surface that sent light to form said image element as shining area on holographic media surface.

It is possible to make a reflection hologram, which has said image element replaying at a greater distance from hologram surface – 0.3÷2.5m, depending on hologram size. In this case, the whole holographic media surface will participate in this image element formation and viewer in position 6 will see shining hologram surface area filling whole holographic media surface.

Let's see what will happen when two light sources are used for reflection hologram illumination – Fig. 5. Two light sources illuminating reflection hologram (3) will cause two holographic images formation in space. Now, if holographic image element (5) size is bigger than human eyeball and smaller than average distance between human eyes, it is possible to find such light sources' distance between each other such that both observer's eyes at position 6 would see hologram surface illuminated by only one light source. Fig. 5. shows how holographic image elements (5) and (5') are formed by light sources (1') and (1) respectively.

Since reflection hologram allows viewer to see hologram surface illuminated by two light sources in such a way that each of the two eyes sees only one light source illumination – reflection hologram can be used as autostereoscopic projection display.

When for hologram illumination two video projectors are used as light sources, and projected images are focused on hologram surface, each viewer's eye in position (6) will see image projected by

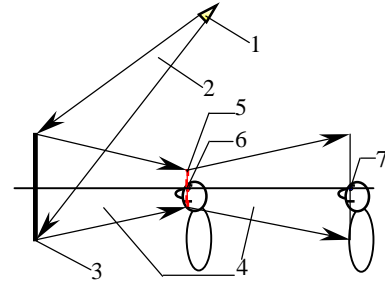


Fig. 4. Reflection hologram with image element replaying in front of the holographic media.

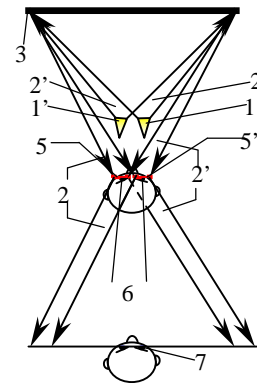


Fig. 5. Reflection hologram with image element in front of the holographic media. Hologram is illuminated by two light sources and two image elements are visible.

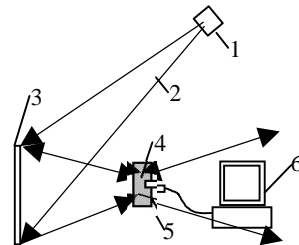


Fig. 6. Reflection hologram reflectivity investigation. 1 – Digital video projector, 2 – digital video projector light illuminating the hologram, 3 – digital reflection hologram, 4 – digital hologram image, 5 – digital spectrometer sensor, 6 – computer.

different projector. If projectors project a stereo image pair, viewer perceps the projected stereo image pair as a three-dimensional scene.

4. AUTOSTEREOSCOPIC PROJECTOR

Holographic autostereoscopic projector implementing this reflection hologram feature was assembled in our laboratory. As screen we have used two digital reflection holograms in size of 64x48cm and 40x30cm. Vertical white stripe image appearing at a distance of correspondingly 1 and 0.5 meter from hologram surface was imprinted on the hologram.

Right hologram illumination angle was found by illuminating it with usual halogen lamp at a distance of 1,7 meters from hologram surface. Then Halogen lamp was replaced with video projector keeping the same hologram illumination angle and projecting just uniform white light. Projector was set with the required keystoneing compensation to display a rectilinear image. Measurements were performed for projectors incorporating bulbs and for projectors with LEDs. Bigger screen was used in conjunction with bulb projectors and smaller was investigated in conjunction with LED projectors (Samsung SP-P400B). As spectrum measure devise we have used Ocean Optics digital spectrometer PC2000. Bulb light source projectors spectrums were measured with integration constant of 300ms and those of LED projectors – with 500ms.

Practical our holographic screen ability to reflect video projector's light and its efficiency were evaluated by placing a digital spectroscope sensor at a distance of 100 cm from the bigger screen and at a distance of 50cm for smaller one, inside holographic image element forming zone, measuring reflected light intensity and comparing it with intensity of the light directed to same place by usual white screen of same size with 75% reflectivity. Experiment schematics shown on Fig. 6

We have also evaluated ambient light influence to holographic screen reflecting properties. For that holographic screen was additionally illuminated from side (thus nor creating a holographic image) with halogen lamp(s) giving the parasitic light intensity of ~3 kLux on holographic screen surface. Same procedure was performed replacing hologram with white screen of same size. The measured spectrums are shown on Fig. 7 and summarized in the table 1 and 2.

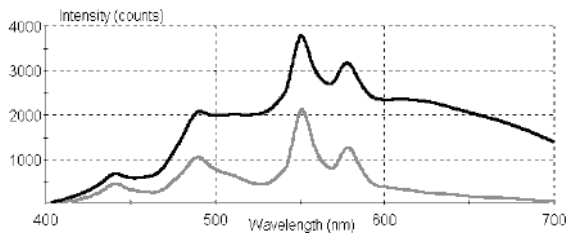


Fig 7a Reflection spectrums of white screen illuminated by bulb image projector only (gray) and by digital image projector and white sidelight (black).

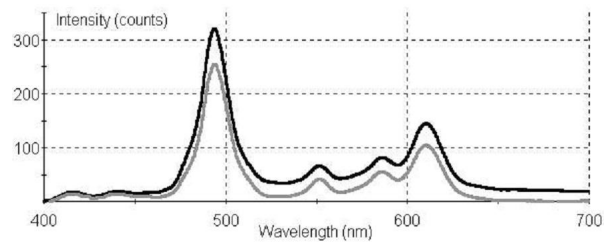


Fig 7b Reflection spectrums of holographic screen illuminated by bulb image projector only (gray) and by digital bulb image projector and white sidelight (black).

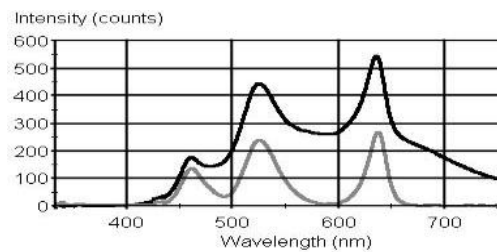


Fig 7c Reflection spectrums of white screen illuminated by digital LED image projector only (gray) and by digital image projector and white sidelight (black).

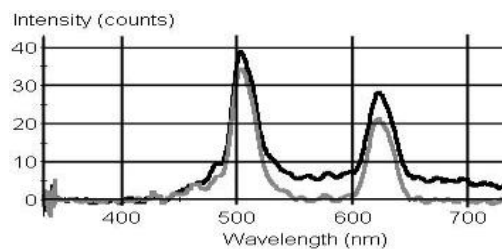


Fig 7d Reflection spectrums of holographic screen illuminated by digital LED image projector only (gray) and by digital image projector and white sidelight (black).

Measurement results show that holographic autostereoscopic screen has better noise/signal ratio than conventional white screen. Moreover, we think that holographic reflection screen is a tool that will allow LED projectors usage in high ambient light conditions. While holographic autostereoscopic screen is less reflective than conventional white screen, it is also less sensitive to parasitic ambient light, which always affects the performance of a projection screen and reduces projected image's perception quality. Bigger holographic screen reflectance can be achieved by using LED video projectors, which light sources would have maximum light emission at the wavelengths corresponding to hologram replay maximum wavelengths.

Table 1. Holographic flat screen lighted with bulb projector versus white screen with 75% reflectivity

	Holographic screen		White screen		
Reflected bulb projector's light picks wavelengths, (nm)	494	610	490	552	575
Reflection without side light Intensity (counts)	253	105	1050	2100	1250
Reflection with side light Intensity (counts)	320	145	2050	3800	3150
Noise/signal ratio %	26	38	95	80	152

Table 2. Holographic flat screen lighted with LED projector versus white screen with 75% reflectivity

	Holographic screen		White screen		
Reflected projector's light picks wavelengths, (nm)	504	623	460	524	634
Reflection without side light Intensity (counts)	34	20.5	140	240	260
Reflection with side light Intensity (counts)	38	28	175	440	540
Noise/signal ratio, %	11	20.5	25	83	107

For the autostereoscopic projector assemble we have used same two holograms containing one image of white vertical stripe appearing at the distance of 100 or 50 cm from holographic media. But instead of one video projector as in experiments described above, pairs of two identical video projectors were used. For bigger holographic screen lighting we have used conventional bulb light projectors and for smaller one – LED projectors. Video projectors were connected to conventional PC having video card with two independent outputs and independent image keystoneing for each output. Our experimental autostereoscopic projector setup is shown on Fig. 8. The video projectors were placed in a space on top of the hologram horizontally, each shifted to opposite direction from the place, used in the previous experiment, for 6.5cm. In such a way, two images of vertical stripe were obtained.

Photograph of holographic image element's appearance in front of the holographic media while two video projectors illuminate hologram is shown on Fig. 9. The width of each stripe image was 5cm and distance between them was 1cm.

Whole hologram surface was participating in those holographic images forming in space, reflecting to each white stripe image the light coming from corresponding projector. Therefore, while we have started to project onto hologram surface stereo pairs image streams and focused projected images onto hologram surface, this images on hologram surface were clearly visible when observer's eyes were placed inside holographic image.

Since each projector was projecting stereo pair image that was viewed only by one observer's eye, both images were perceived as 3D scene. Images on the holographic screen surface were seen as bright and shining at the distance of 92÷108 (or 45-55) cm from holographic screen surface, so within viewing zone, zone depth was 10-16 cm– i.e.

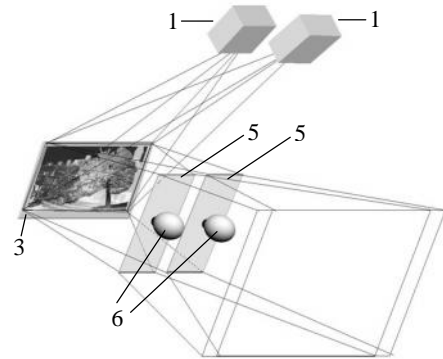


Fig. 8. Autostereoscopic image projector setup



Fig. 9. Photograph of its projection at white screen placed at a distance of 1m from hologram surface.

viewer was not strictly bounded to certain distance from holographic screen, which is the case for majority of autostereoscopic screens based on holographic optical elements.

Each observer's eye sees not only stereo pair image devoted for this eye and projected to hologram surface by the corresponding projector, but also the image, which is projected by another projector and is designated to another eye. As a result, each observer's eye is viewing stereo pair image from the projector together with ghost image from another projector. That happens because of the wide spectrum of the bulbs used in the majority of projectors.

In order to evaluate the intensity of this cross-talk illumination we have measured light, reflected from hologram surface intensity at the place close to the viewing zone. Cross-talk light spectrum measured for usual projector with bulb is shown on Fig. 10.

Cross-talk light reflected from screen surface spectrum has two wavelengths picks, which corresponds to some wavelengths picks of projector's emitted light (Fig. 7a). This cross-talk light is not very intensive. But human eye sensitivity to the light is not linear, but exponential. Let's compare light intensity from Fig. 7b. at wavelengths picks similar to those on Fig. 8. in exponential scale - Table 2. Cross-talk light for 490 nm in natural logarithm scale is only 1.6-1.74 times smaller, than signal light directed by holographic screen into the viewing zone. Visually this cross-talk light do not disturb much viewer's perception of 3d scene projected by projectors pair, however in the case of bulb light projectors it shall be taken into account while designing 3d projectors for mass-market.

As it was said before, cross-talk lighting happens when projector's bulb has wide emission spectrum. We have tried to investigate cross-talk lighting from projectors having LED light source. No measurable cross-talk lighting was observed. That indicates the perspective to use LED video projectors in conjunction with holographic screens for 3D applications. Stereo image pairs were standard pairs used for conventional autostereoscopic projectors operating with polarized glasses. Also we have experienced 3d viewing of usual 2D video stream converted to stereo pair stream using TriDef Media Player software.

The most interesting experience was to observe life images obtained from the pair of video cameras set at the intraocular distance (i.e. the distance between human eyes). In such a manner we have observed live moving three-dimensional images, which proves that this setup also can be used as 3D television set. Since the image pairs, projected to holographic screen are formed digitally, it is possible to add additional service image pairs. For example, there is possible to add control panel that will be perceived by a viewer as hanging in the air in front of the screen. Using remote movement detectors attached to the screen such panel can be used to operate the viewing device, or to control remote processes observed through viewing zones.

Using remote head tracking system attached to the screen, it is possible to obtain exact coordinates of the viewer and direct projectors' lights in such a way, that viewing zones to the certain extent would be matching viewer's position in space.

We have investigated a possibility to use such holographic screen for more than one user. It was found that such screen with just one white stripe imprinted could be used for two viewers by placing additional pair of projectors. More research is needed for further increase in viewers' number. Big reflection hologram advantage in autostereoscopy is that image projectors can be placed at any distance from screen surface (in holographic optical elements case, projectors shall be at a certain fixed distance from the screen). Maximum autostereoscopic screen size,

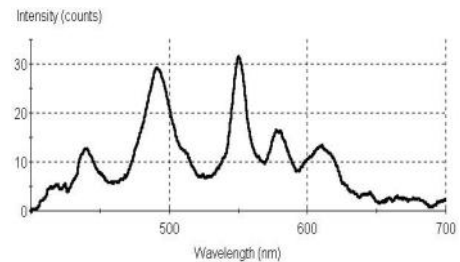


Fig. 10. Spectrums of cross-talk illumination while holographic screen is lighted by bulb light projector.

Table 3. Holographic autostereoscopic screen reflection light and surface reflection

Projector's light picks wavelengths, (nm)	494	490	610
Signal light from holographic screen, ln(intensity counts)	5.53		4.65
Cross-talk illumination, ln(intensity counts)		3.38	2.67
Cross-talk illumination / signal light (natural logarithms ratio)	1.63		1.74

which we can achieve on current photomaterial, is 100x150cm, so it can be used in numerous 3d applications for one or few viewers.

We also have investigated a digital reflection hologram containing just flat white field imprinted at the image plane. This hologram has showed similar noise/signal ratio and can be used as usual projection screen at high ambient light level conditions.

In order to improve signal/noise ratio and to reduce cross-talk light, holographic screens shall be made in such a way that maximum holographic response wavelengths would be corresponding to used projectors wavelengths. In ideal case, LED projectors shall be use in conjunction with autostereoscopic holographic screens.

4. CONCLUSIONS

1. Reflection hologram with white image element imprinted at a certain distance from the image plane form in space a viewing zone from which a whole surface of holographic media is viewed as bright shining rectangle.
2. Using pair of video projectors as the light sources, placing them in space where usually the halogen lamp illuminating the hologram is – two holographic media viewing zones are formed. Focusing projected images on holographic media surface from viewing zones are viewed corresponding projector's projected images. Therefore, reflection hologram with white image element imprinted at a certain distance from the image plane can be used as autostereoscopic screen for stereo image pairs' projection.
3. No additional eye-aid devices like anaglyph or polarizing glasses are required to percept three -dimensional image on holographic autostereoscopic screen.
4. Is possible to add control panel that will be perceived by a viewer as hanging in the air in front of the screen. Said panel may be used to operate the projecting devices as well as for observed remote processes control.
5. Head tracking device can be used to move viewing zoned synchronously with viewed head's movements.
6. Holographic reflection screens with a hologram of white flat screen image imprinted at the image plane can allow LED image projectors usage in high-intensity ambient light conditions.

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