Television Transmission of Holograms Using a Narrow-Band Video Signal

By J. E. BERRANG

(Manuscript received December 18, 1969)

It has been experimentally verified that holograms can be transmitted via television using the synthesized carrier-frequency method. A vidicon camera system was used to transmit three on-axis holograms to the receiver where the video signal was used to amplitude modulate a 15 MHz carrier. This modulated carrier was applied to the control grid of a cathode-ray tube, and the synthesized carrier-frequency hologram was then photographed from the tube screen. Several of the experimental problem areas, such as mechanical stability, camera tube storage effects, and display-recording process optimization, are considered in detail.

I. INTRODUCTION

Enloe, Murphy, and Rubinstein transmitted off-axis or carrier-frequency holograms by means of television.[1] Although they were successful, they were severely restricted by the limited resolution of the television camera tube. This fundamental difficulty has its roots in the fact that a carrier-frequency hologram has spatial frequencies at least four times higher than the highest spatial frequency contained in the subject. (This fact is elaborated on in Ref. 2.)

Burckhardt and Doherty[3] were later able to produce carrier-frequency holograms using an on-axis reference beam. Figure 1 shows the arrangement they used. A Mach-Zehnder interferometer was used to align the subject and reference beams, and a means was provided for shifting the phase of the reference beam. A transmission grating was placed in front of the photographic plate used to record the hologram. A series of four exposures was made on a single photographic plate. Between exposures, the transmission grating was translated laterally by one-fourth of its spatial period, and the reference beam was shifted in phase by 90°; the resulting synthesis at the photographic plate was a carrier-frequency hologram.

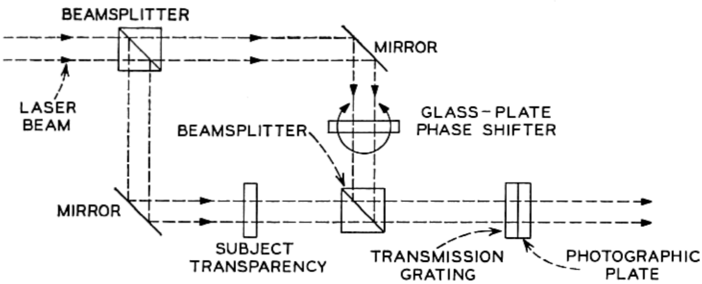

Fig. 1—Experimental arrangement used by Burckhardt and Doherty to synthesize carrier-frequency holograms from multiple on-axis holograms.

Burckhardt and Enloe[2] suggested that this method is applicable to the transmission of holograms over a television system and showed that its use would lower the resolution requirements on the television camera by a factor of four. They also indicated that the minimum number of on-axis holograms required to synthesize a carrier-frequency hologram is three, with corresponding phase shifts of 120° being used. This paper reports on the implementation of their proposal. Figure 2 shows the basic technique.

A hologram of a subject transparency is formed with an on-axis reference beam at the photosensitive surface of a vidicon camera tube and is transmitted as a baseband signal to a receiver where it is multiplied with an electrical grating signal and applied to the control grid of a cathode-ray tube. The resulting display is captured photographically.

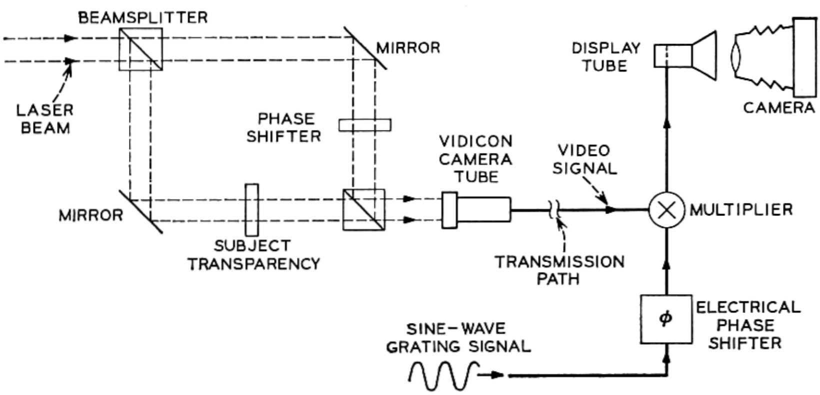

Fig. 2—Hologram transmission via television, with reduced resolution requirements on the camera tube.

Three exposures are recorded on a single transparency with the reference beam and electrical grating signal each shifted in phase by 120° between exposures. The result is a synthesized carrier-frequency hologram which, when illuminated with coherent light, reconstructs an image of the subject.

II. DESCRIPTION OF THE EXPERIMENT

2.1 *General*

Figure 3 is a diagram of the system that was used for producing and recording synthesized carrier-frequency holograms with a television system. The light source used was a Spectra-Physics, model 124, 15 milliwatt, helium-neon laser operating at 6328 Angstroms; an attenuator was used to reduce the light intensity to a level suitable for application to the vidicon camera tube. An on-axis hologram of a two-dimensional transparency was formed directly on the photosensitive surface of the vidicon camera tube, no camera lens being used. A rotatable glass plate was used in the reference beam path to provide phase shift.

The television camera system used was a RAM (Canoga Electronics) V1000 closed-circuit television system, and the cathode-ray display tube was a Westinghouse WX-30176P-4 with dynamic focusing. The dynamic-focusing system provided a component of focus voltage which was a function of the distance from the scanning spot to the center of the display screen. This system was designed by M. E. Lukacs.[4]

The output of a 30 MHz crystal oscillator was divided by two in a single binary count-down stage to give the 15 MHz signal which was used to provide the electrical equivalent of the optical transmission grating used by Burckhardt and Doherty. This electrical grating signal was then shifted in phase by passing it through appropriate lengths of coaxial cable to provide three phases with 120° separation between them. The desired phase shift was selected by means of a manual switch. This grating signal was then amplitude modulated with the holographic video information from the television camera, amplified in a tuned amplifier, and applied to the control grid of the cathode-ray tube.

The 15 MHz grating frequency was divided by 1024 in a ten-stage binary count-down circuit giving the system horizontal line rate and at the same time insuring that the grating remained fixed with respect to the horizontal dimension of the cathode-ray tube display.

The vertical scanning rate was 60 Hz, synchronized to the ac power line; consequently, any 60 or 120 Hz modulation of the horizontal scanning due to power-frequency hum was fixed on the cathode-ray tube

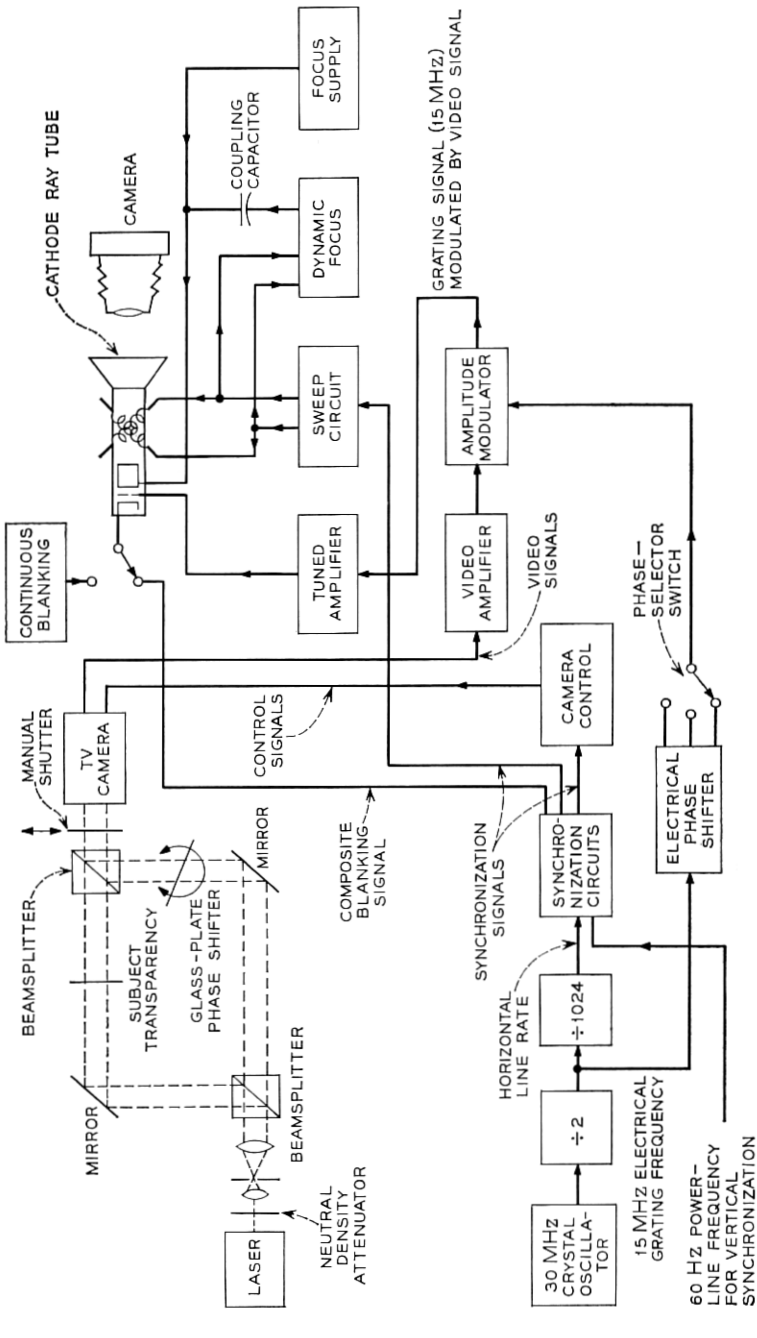

Fig. 3—Experimental arrangement used to transmit holograms over a television system.

screen. This stabilization of hum patterns was essential because of the extreme fineness of the spatial grating produced during each exposure.

The system horizontal and vertical scanning rates were not related. This scanning format allowed for removal of the scanning-line structure by means of photographic time exposures. The photographic recording system consisted of a tripod-mounted camera.

2.2 *Technique*

As part of the experimental procedure, care was taken to prevent reflections of laser light from causing unwanted interference patterns at the vidicon photosensitive surface. The front surface of the vidicon face plate was given an antireflecting coating as were both sides of the glass plate used for phase-shifting the reference beam, and light-absorbing screens were provided where they were deemed necessary.

Any differential change in the dimensions of the two legs of the interferometer during the formation of a hologram would cause the phase of the reference beam to shift with respect to that of the object beam. In this experiment, where three phases of reference beam were used, it was necessary to maintain the relative path lengths constant to about 1/30 of a wavelength of light. The interferometer, as well as the laser and television camera, were mounted on a heavy iron table which was floated on partially inflated innertubes to isolate it from building vibrations. The table was completely covered with a plexiglass shield to keep out air currents, and remote controls were provided for all adjustments which had to be made to the apparatus on the table during the production of a hologram.

If the vidicon camera tube were illuminated with one of the three phase patterns for an extended time, that pattern would remain stored on the vidicon photosensitive surface interfering with the proper addition and cancellation of the three phases of reference beam during the making of a hologram. To obviate this difficulty, the vidicon was mechanically shuttered between exposures and when not in use.

The image aspect ratio at the camera had to be faithfully reproduced at the cathode-ray tube screen. That is to say, the horizontal and vertical size relationship of an image at the cathode-ray tube was required to be the same as it was at the camera tube. Otherwise, an additional cylindrical lens would have to be used during reconstruction to overcome the resulting astigmatism.

A switch was provided to permit operation of the cathode-ray tube in either of two blanking modes: (*i*) retrace blanking, and (*ii*) continuous blanking. To prevent displacement of the recording camera during the multiple-exposure process, the camera shutter was left open for the full time (about two minutes), and the interexposure shuttering was done by blanking the cathode-ray tube. Exposure times were relatively long, and this shuttering could be performed manually.

An experimentally developed two-step photographic recording process was used. Three exposures of 25 seconds each at $f/8$ were made on a single Polaroid 55 PN film. The light output from the cathode-ray tube during this part of the recording process was about 0.15 foot-lamberts. To make the best use of the available resolution, the image size was adjusted to fill the Polaroid film. When reconstructions were made directly from the Polaroid transparencies, certain degradations (apparently due to phase distortion) were observed. Therefore, a second photographic step was introduced in which the synthesized hologram was transferred to a Kodak 649F glass plate. Because of the high resolution of the 649F emulsion and to save processing time, several (two to four) holograms were usually placed on a single plate at a proportionately reduced size. The Polaroid transparencies were placed between two glass plates and illuminated from behind with a uniform incandescent light source. The luminance of the transparencies when thus illuminated was adjusted to be about 650 foot-lamberts. The 649F plate was then exposed at $f/22$ for 3 minutes and 20 seconds.

Care was taken during each photographic step to insure that exposure was restricted to the linear portion of the film's characteristic curve. It was experimentally determined that following the exposure data given above and the manufacturers' recommendations for processing gave good results. If clipping or compression of part of the visual information were experienced due to operation in the nonlinear regions of the transfer characteristics of either of the films involved or of the cathode-ray tube, the operating conditions outlined by Burckhardt and Enloe[2] were not achieved and poor reconstructions resulted.

2.3 *Reconstruction*

The holograms were reconstructed using the system shown in Fig. 4. A hologram was illuminated with a collimated beam of laser light and the resulting output Fourier transformed with a lens, L. A spatial-frequency filter was used to discard one image and the direct beam, leaving the other image to be viewed or photographed. Because the reconstructed image was small, an additional lens was used to magnify it. Figure 5 shows examples of reconstructed images.

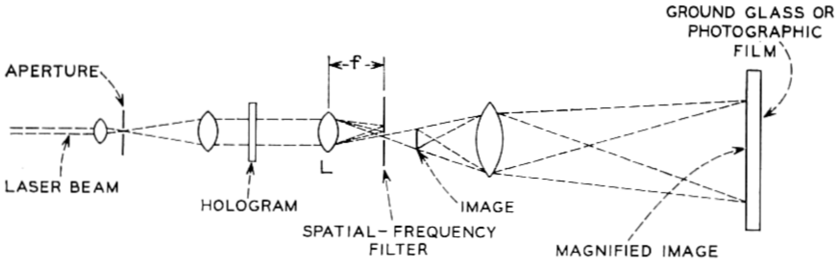

Fig. 4—Reconstruction of synthesized carrier-frequency hologram.

2.4 *Remarks*

The modulator and amplifier circuits (Fig. 3) contain broadly-tuned stages designed to have a bandwidth of 1 MHz. The finest horizontal detail that can be recognized in the reconstructions (Fig. 5) is that represented by the girl's teeth, or 45 cycles per picture width. The received holograms occupied 80 percent of the scanned width at the cathode-ray tube, and the scan-to-retrace ratio was two. The horizontal line rate was $15 \times 10^6/1024$ lines per second. The highest spatial frequency that is apparent in the reconstructions is, therefore, equivalent to an electrical frequency of

$$45 \frac{\text{cycles}}{\text{picture width}} \times 1 \frac{\text{picture width}}{0.8 \text{ scanned width}} \times 1.5 \frac{\text{scanned width}}{\text{line}} \times \frac{15 \times 10^6}{1024} \frac{\text{lines}}{\text{second}} = 1.2 \text{ MHz}.$$

Wide-band circuits could of course be used, but because of the low signal-to-noise ratio of the narrow-band reconstructions, no experiments were made with wider bandwidth signals.

Several problem areas (that is, display tube resolution, relative motion between camera and display tube, and film resolution) associated with the display and recording of the hologram could be eased by reducing the frequency of the electrical grating signal. The frequency of this signal could easily be reduced by a factor of two, even if a wider band video signal were used.

The two-step photographic process described above could be reduced to a one-step process by using a glass plate having a higher speed than the 649F plate. The Kodak Super Panchro-Press plate is four orders of

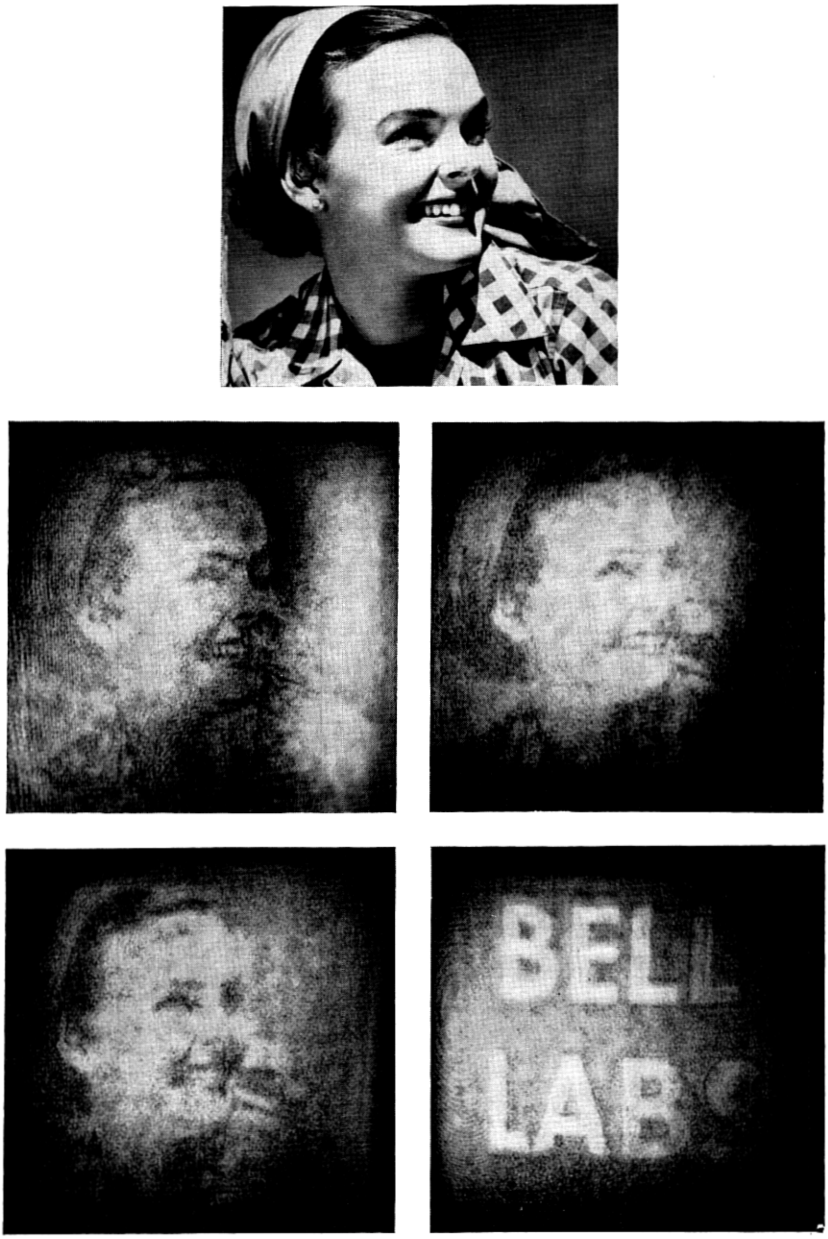

Fig. 5—Original and reconstructions of "girl in checkered shirt," and reconstruction of "BELL LABS."

magnitude faster than the 649F and has sufficient resolution but is somewhat more granular. It would be a good plate to try.

III. SUMMARY

It has been experimentally verified that holograms can be transmitted via television using the synthesized carrier-frequency method discussed by Burckhardt and Enloe.[2] A vidicon camera system was used to transmit three on-axis holograms to the receiver where the video signal was used to amplitude modulate a 15 MHz carrier. This modulated carrier was applied to the control grid of a cathode-ray tube, and the synthesized carrier-frequency hologram was then photographed from the tube screen. Reconstructions were obtained which contain resolution compatible with the video bandwidth used but which have low signal-to-noise ratios. Several of the experimental problem areas, such as mechanical stability, camera tube storage effects, and display-recording process optimization, were considered in detail, and suggestions were made for lessening some of these difficulties.

IV. ACKNOWLEDGMENTS

The author wishes to express his gratitude to D. W. Doughty for antireflecting coatings on the vidicon and the glass-plate phase shifter, to M. E. Lukacs for the design and construction of the dynamic-focusing system, and to C. B. Burckhardt, L. H. Enloe, and A. B. Larsen for many invaluable discussions.

REFERENCES

1. Enloe, L. H., Murphy, J. A., and Rubinstein, C. B., "Hologram Transmission via Television," B.S.T.J., *45*, No. 2 (February 1966), pp. 335–339.
2. Burckhardt, C. B., and Enloe, L. H., "Television Transmission of Holograms with Reduced Resolution Requirements on the Camera Tube," B.S.T.J., *48*, No. 5 (May–June 1969), pp. 1529–1535.
3. Burckhardt, C. B., and Doherty, E. T., "Formation of Carrier-Frequency Holograms with an On-Axis Reference Beam," Appl. Opt., *7*, No. 6 (June 1968), pp. 1191–1192.
4. Lukacs, M. E., unpublished work.