C—4—2 MICROWAVE HOLOGRAPHY BY ROTATIONAL SCANNING OF OBJECT

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INTRODUCTION

In scanned microwave or ultrasonic holography, the receiver, source or object may be scanned for constructing the hologram.[1] Usually the scan surface has been taken to a flat plane, although occasionally spherical or cylindrical surface has been used as in sector scanning.[2,3] In any case, the scan surface must cover a wide erea of the field for the purpose of reconstructing high resolution image. Consequently, the apparatus for scanning cannot but become large in scale. On the contrary, the object-rotational-scan which is in relative relationship with the sector-scan make it possible to record the wide area without so large apparatus.

In this paper, we present the holography using such rotational scan technique. Since this technique makes the available recorded area wide, a higher resolution image can be obtained. In addition, its paticular recording method by sinusoidal scaling is useful to construct a lensless Fourier transform hologram in microwave region.

FIELD AREA DETECTED BY ROTATIONAL SCANNING OF OBJECT

An arrangement of the object-rotational-scan system for recording the hologram is shown in Fig.1. In this case, the object plane is rotated about its center in the radar beam. Consequently, the echo signal arrived at the radar is varied with the directional angle of the object plane, and its amplitude is recorded as a hologram.

Now we think about the field area detected by such scanning. This scanning may be replaced the sector scanning of the radar apparatus as shown in Fig.2, which is relative relationship with the original scanning. As is obvious from Fig.1 and 2, the object-rotational-scan coverd over $\pm\theta$ seems to be equivalent to the radar-sector-scan extended over $\pm(L\times\theta)$. This means that the object-rotational-scan system with large distance L between the radar and the object is very useful to detect the wide field area.

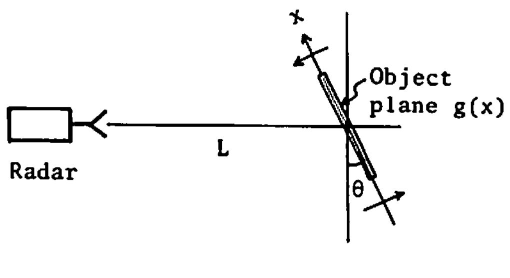


Fig. 1

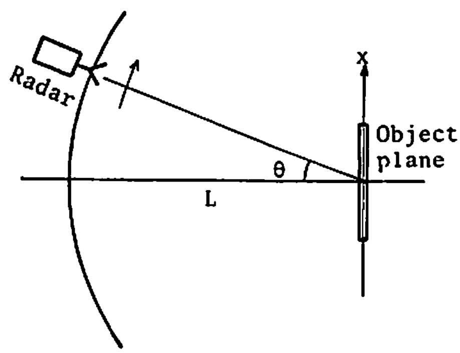


Fig. 2

CONSTRUCTION AND RECONSTRUCTION OF HOLOGRAM

The echo signal detected by the object-rotational-scan system, shown in Fig.1, may be expressed as

$$E(\theta) \propto \int_{\infty} g(x)\exp(-j2k\sqrt{L^2+x^2-2xL\sin\theta})\,dx\ , \tag{1}$$

as complex quantity, where $g(x)$ is the distribution of the reflection coefficient on the object plane. Such complex amplitude may be detected by means of a phase comparator.

If we now record the complex amplitude $E(\theta)$ as a function of $L\sin\theta = \xi$ on the computer memory bank, it forms into a complex hologram as follows

$$E(\xi) \propto \int_{\infty} g(x)\exp(-j2k\sqrt{L^2+x^2-2x\xi})\,dx\ , \tag{2}$$

The transformation of $L\sin\theta$ to ξ can be easily achieved by use of the angular signal from the scan system. The phase term in above equation may be expanded in a series to be

$$2k\{\ L+\frac{x^2-2x\xi}{2L}-\frac{(x^2-2x\xi)^2}{8L^3}+\cdots\ \} = 2k(\ L+\frac{x^2}{2L}-\frac{x\xi}{L})-\Delta\phi\ , \tag{3}$$

where $\Delta\phi$ is the excess phase angle caused by the higher order terms of $(x^2-2x\xi)$. Noting Eq.(3) and the constant distance L, we have

$$E(\xi) \propto \int_{\infty} g(x)\exp\ j(-\frac{kx^2}{L}+\frac{2kx\xi}{L}+\Delta\phi)\,dx\ , \tag{4}$$

which, for small $\Delta\phi$, is proportional to Fourier transformation of $g(x)\times \exp(-jkx^2/L)$, as

$$E(\xi) \propto \mathscr{F}[g(x)\cdot\exp(-jkx^2/L)]\ . \tag{5}$$

This means that a lensless Fourier transform hologram in microwave region can be constructed. The assumption of small $\Delta\phi$ may be satisfied by taking L large compared to the maximum dimension x_{max} of the object plane.

Since we are dealing here with a Fourier transform hologram, the recording of the hologram can be done with less sampling points than required to record the Fresnel diffraction patterns. Moreover, the reconstruction process may be extremely simplified, and the image can be easily obtained by inverse Fourier transformation using the FFT algorithm.

Next, let us evaluate the resolution of the reconstructed image. Since the resolution Δx in Fourier transform holography must agree with a reciprocal of the maximum spatial frequency recorded on the hologram, we have

$$\Delta x = \frac{\lambda}{4\sin\theta_{max}} = \frac{\lambda L}{4\xi_{max}}\ , \tag{6}$$

where θ_{max} is the maximum directional angle of the object plane in the scanning, and ξ_{max} $(= L\sin\theta_{max})$ is the maximum dimension of the hologram. The last equation indicates that Δx is equal to the resolution of the standard planar scanned hologram along the track over $\pm\xi_{max}$.

EXPANSION TO TWO-DIMENSIONAL HOLOGRAPHY

We have considered only a one-dimensional holography, but it can be easily expanded to a two-dimensional holography by use of the scan system as shown in Fig.3. In this scan system, while the object plane is rotated about y-axis, the axis is gradually tilted to the direction of the radar antenna. The change of the directional angle of the object plane caused by the scanning may be illustrated as a locus on the spherical surface shown in Fig.4 (a). As is obvious from the figure, the obtainable echo signal is considered to be corresponding to the field distribution on the spherical surface. Then we transform the signal to one of the form of a distribution on a flat plane as shown in Fig.4(b) for the convenience of reconstruction, and record it as a two-dimensional complex hologram on the memory bank of computer. The transformation may be expressed as the following equations.

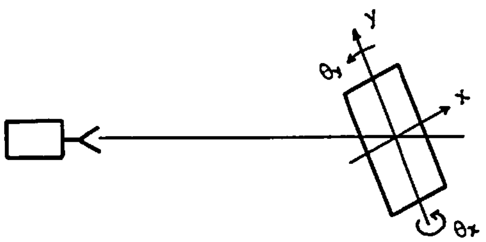
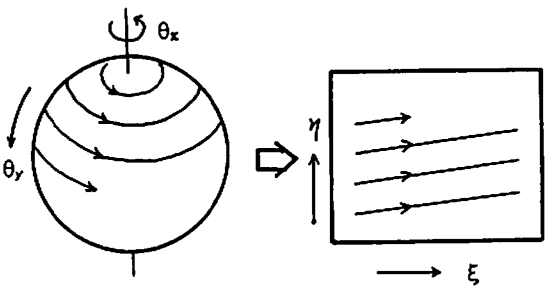


Fig. 3



(a) (b)

Fig. 4

$$L \sin \theta_x = \xi$$
$$L \sin \theta_y = \eta \qquad (7)$$

Under the condition that

$$L^2 \gg x^2+y^2-2(\xi x+\eta y) \quad , \qquad (8)$$

the resultant hologram may be expressed as

$$E(\xi,\eta) \propto \mathcal{F}[g(x,y)\cdot\exp\{-jk(x^2+y^2)/L\}] \qquad (9)$$

The above equation describes the hologram is nothing else than the result of two-dimensional Fourier transformation of the quantity proportional to the distribution of the object plane. Accordingly the reconstruction can be performed by two-dimensional inverse Fourier transfomation.

EXPERIMENT

An experiment was made to verify the validity of the object-rotational-scan holography. The construction of the hologram was done at 35GHz (λ=8.6mm), and the reconstruction was carried out numerically.

The scan system was arranged as shown in Fig.5. The object was the alphabet "K" 24cm high and 17cm long, made of metallic pipes of diameter 2.5cm, and it was fastened to the center of the object plane. The plane was positioned at the range of about 3.0m from the radar antenna, and rotated over $\theta_x = \pm 30°$, $\theta_y = \pm 20°$.

The complex amplitude of echo signal was detected by use of a phase comparator, and after the conversion to complex sampled data with equal

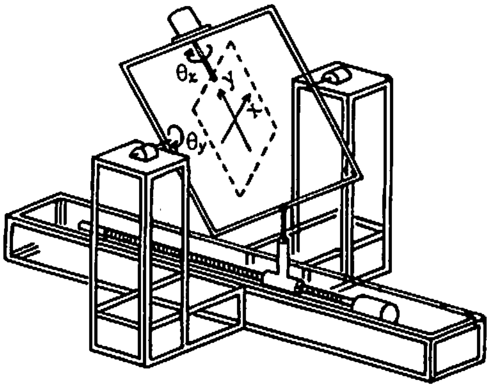
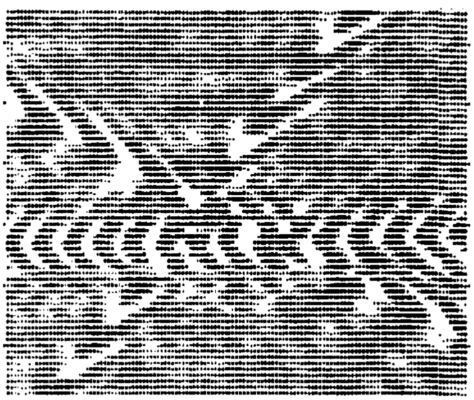
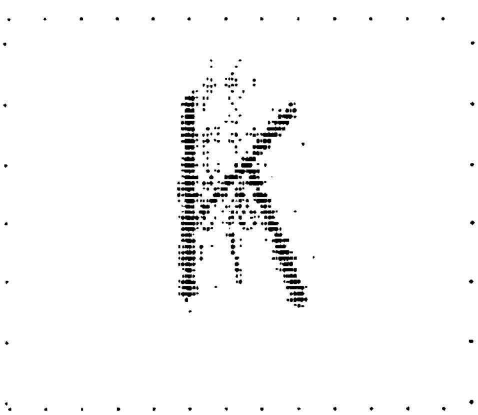


Fig. 5



(a)



(b)

Fig. 6

separation of ξ, η , it was stored into the computer memory bank.

The maximum dimension of this hologram data was estimated approximately $\xi_{max} = \pm 1.5$m and $\eta_{max} = \pm 1.0$m. Fig.6(a) shows the hologram in the form of intensity hologram.

In reconstruction process, we calculate the inverse Fourier transformation of the hologram data by use of computer algorithm FFT. As the result, we obtained the numerically reconstructed image as shown in Fig.6(b).

CONCLUSIONS

The rotational scanning technique in microwave holography has been developed. We presented the theoretical aspect of the technique, and made it clear the following feature. The hologram with large aperture required to higher resolution imaging can be easily obtained by the scan system constructed on a small scale. Moreover, a lensless Fourier transform hologram convenient to numerical reconstruction can be built up.

Also we described an experimental result to verify the validity of the theory on microwave holography by rotational scanning of object.

REFERENCES

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