Microwave Indirect Holographic Imaging Using an Adaptation of Optical Techniques

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***Abstract*—Indirect holography provides a quick and inexpensive three-dimensional (3-D) imaging technique at optical frequencies which has not been directly adapted to microwave imaging. This letter describes a technique whereby a radiated offset reference plane wave can be electronically synthesized allowing this technique to be used at microwave frequencies. In this letter, this technique has been applied to the problem of determining antenna radiation patterns and reconstructing complex near fields. Early experimental results compare favorably with results taken using traditional methods.**

***Index Terms*—Antenna measurements, holography, microwave imaging.**

I. Introduction

HOLOGRAPHIC techniques provide methods for the reconstruction of true three-dimensional (3-D) images by preserving information about both the amplitude and phase of the original scattered wave. At optical frequencies this is normally achieved using an indirect approach where measurements are taken of the intensity pattern resulting from the interference between the scattered wave and a phase coherent offset plane reference wave. [1] This offers a fast, low-cost method for holographic measurement. The practical implementation of a similar technique at microwave frequencies has proved difficult due to the problems associated with generating a radiated offset reference plane wave.

Much of the recent work in microwave holography, for the determination of antenna radiation patterns and imaging antenna fields, has concentrated upon a direct approach where the complex near fields are recorded. [2] In comparison with the indirect approach this is slow and expensive.

Bennett *et al.* [3] have discussed using an indirect holographic technique at microwave frequencies but they were limited by the use of a radiated spherical reference signal.

This letter outlines a method for overcoming these limitations and allows the indirect holographic method to be employed at microwave frequencies. It describes a technique for electronically synthesizing an offset reference plane wave which considerably simplifies the processing and reconstruction of images. It also describes how this technique can be applied to the task of determining radiation characteristics of antennas and imaging antenna fields. Experimental results taken using this indirect technique compare favorably with far field radiation patterns and complex near fields measured using a vector network analyzer.

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II. Theory

In the indirect holographic approach adopted here the complex near field of the antenna under test, $E(x, y)$, is combined with a phase coherent reference signal of constant amplitude and linearly increasing phase shift, $R(x, y)$. The resulting scalar intensity pattern, $I'(x, y)$, is then recorded using simple inexpensive power detectors

$$\begin{aligned} I'(x,y) &= |E(x,y)+R(x,y)|^2 \\ &= |E(x,y)|^2 + |R(x,y)|^2 + E(x,y)\cdot R^*(x,y) \\ &\quad + E^*(x,y)\cdot R(x,y). \end{aligned}$$

Taking the Fourier Transform of this intensity pattern produces

$$\begin{aligned} F\{I'(x,y)\} =& F\left\{|E(x,y)|^2\right\} + F\left\{|R(x,y)|^2\right\} \\ &+ F\{E(x,y)\}\otimes F\{R^*(x,y)\} \\ &+ F\{E^*(x,y)\}\otimes F\{R(x,y)\}. \end{aligned}$$

The first two terms of the right hand side of the above equation

$$F\left\{|E(x,y)|^2\right\} + F\left\{|R(x,y)|^2\right\}$$

relate to the autocorrelation functions of the antenna aperture field and the offset reference wave in the spatial frequency domain.

The third term

$$F\{E(x,y)\}\otimes F\{R^*(x,y)\}$$

corresponds to the spatial frequency spectrum, or Plane Wave Spectrum, of the antenna under test translated in the spatial frequency domain in the negative direction by the offset angle of the reference wave.

The fourth term

$$F\{E^*(x,y)\}\otimes F\{R(x,y)\}$$

similarly corresponds to the spatial frequency spectrum of the complex conjugate of the antenna under test similarly translated in the positive direction.

Provided that the angular spectrum of the antenna under test is small, as is the case for large antennas, and a suitable offset angle is introduced into the reference signal, $R(x, y)$, the above terms can be spatially separated. Typical results for the Fourier Transform of a one-dimensional holographic intensity pattern are shown in Fig. 1. In this case, the left hand term corresponds to the Plane Wave Spectrum of the antenna under test. The first stage is to remove the unwanted terms of the

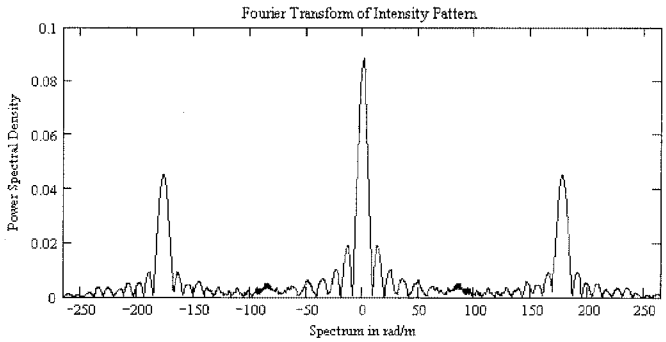

Fig. 1. Fourier transform of intensity pattern.

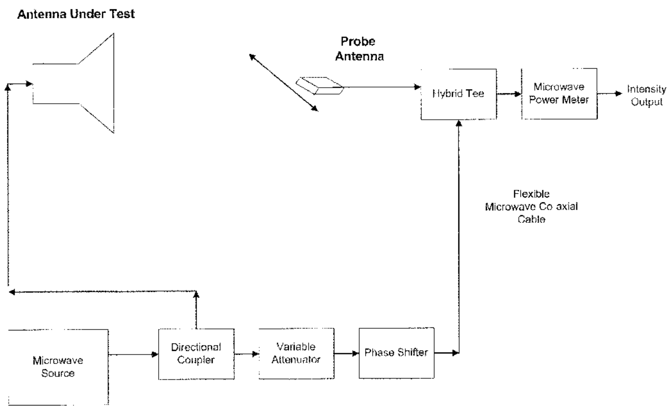

Fig. 2. Diagrammatic view of experimental system.

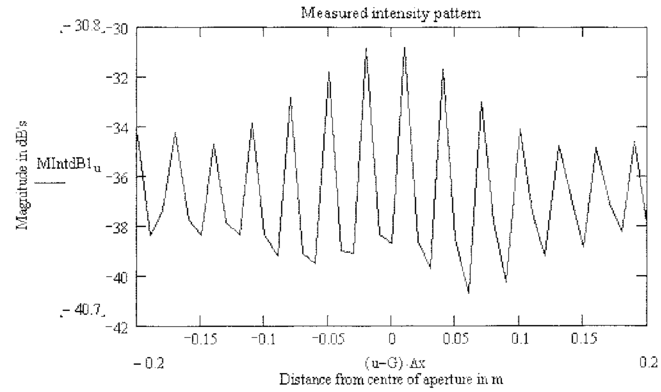

Fig. 3. Measured intensity pattern of antenna and offset reference wave.

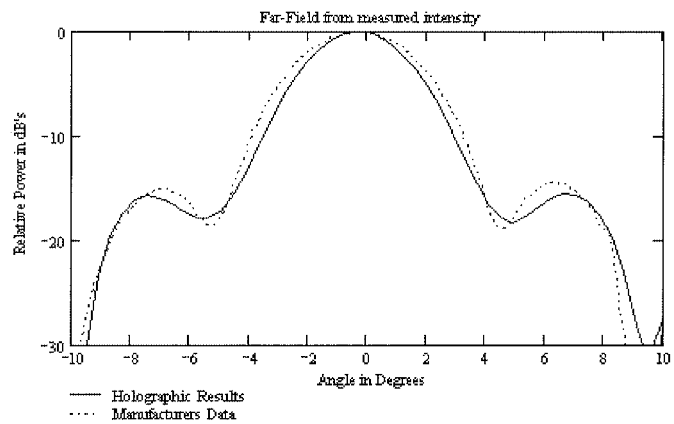

Fig. 4. Predicted far field radiation pattern and manufacturers results.

Fourier Transform by setting unwanted values to zero. The second stage is to centralize the remaining offset term, which corresponds to the Plane Wave Spectrum, PWS, of the antenna under test. The far field radiation pattern of the antenna can be obtained from the PWS in a straightforward manner. [4] Performing an Inverse Fourier Transform operation on this term enables the original complex near field of the antenna to be reconstructed. [5]

III. Experimental Results

A diagrammatic view of the experimental system adopted for this work is shown in Fig. 2. The radiated reference wave has been replaced by an electronically synthesized signal fed forward via a microwave co-axial cable, phase shifter and variable attenuator to be combined with the sampled near field. The intensity of the resultant signal was recorded using a power meter. Intensity values were recorded at half wavelength intervals with a linearly increasing phase shift of 120° added to each sample. This corresponds to an offset angle of about 42°.

Holographic intensity patterns using this indirect method have been recorded for a 0.3 m parabolic dish antenna at a frequency of 12.7 GHz. The antenna near field was sampled, using an open ended waveguide probe antenna, at half wavelength intervals along a 0.4 m measurement plane located at a distance of 1.0 m from the antenna aperture, well outside of the evanescent region. The resultant measured intensity pattern is shown in Fig. 3. From Fig. 3 it is apparent that the total extent of the interference pattern has not been recorded. Experimental data recorded at distances of 0.7 m to 1.3 m have produced similar results. The computed far field radiation pattern is shown in Fig. 4 together with the manufacturers outdoor range results.

It can be seen that there is good agreement between the radiation pattern predicted using the indirect holographic technique and the manufacturers published data, notwithstanding the limited measurement extent of the recorded intensity pattern. The reconstructed complex near field results produced using this technique are shown in Fig. 5 together with measured complex near field results taken using a vector network analyzer. An examination of the magnitude response shows good agreement between both techniques, with similar shapes for the central sections and steep declines in field magnitude outside the antenna aperture. An examination of results for phase does not show such good agreement but again there is clear indication of rapid phase change in the area of the aperture edge.

In the present experimental arrangement it is felt that there are a number of factors which have limited the accuracy of these results and could be improved. The first factor was the limited extent of the recorded intensity pattern with results being truncated before the full extent of the holographic pattern has been obtained. A second factor was the $+/-0.5$ dB amplitude variation introduced by the phase shifters as the phase offset was introduced. Further work is currently in progress to extend the length of the measurement plane and replace the phase shifters.

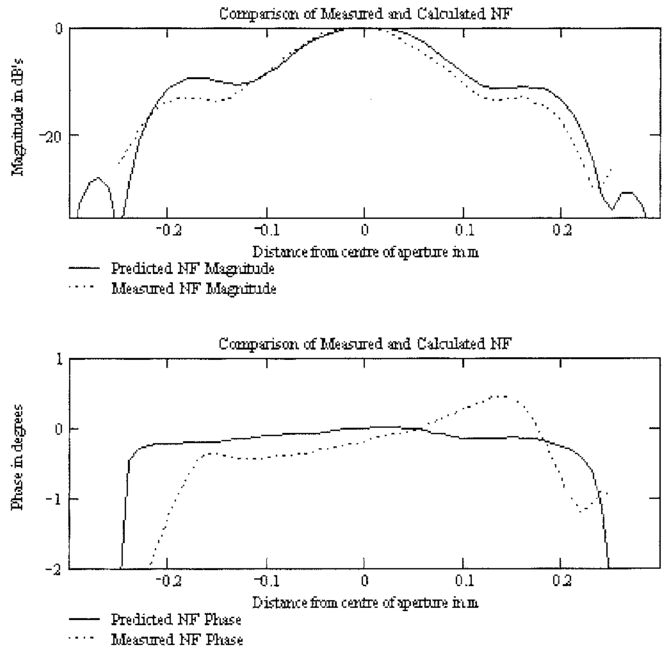

Fig. 5. Reconstructed antenna near field results.

IV. Conclusions

This letter has described how an indirect holographic technique can be employed to determine the radiation characteristic of antennas and image antenna fields. It has outlined how antenna far field radiation patterns can be obtained from a single measured intensity pattern and how complex near fields can be reconstructed from the recorded intensity pattern. Preliminary experimental results have shown good agreement with manufacturers data for antenna radiation patterns and have provided encouraging results for reconstructed images of antenna near fields.

References

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