EXPERIMENTAL DEMONSTRATION OF A 35 GHz HOLOGRAPHIC ANTENNA

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Abstract — **We have developed a novel two-dimensional grating antenna based on microwave holography. The two-dimensional grating (hologram) is formed on a dielectric substrate and fed by an integrated surface wave exciter. Various design issues will be presented, as will a 35 GHz demonstration prototype antenna designed, fabricated, and tested. Measured radiation patterns closely agreed with the theoretical prediction.**

I. INTRODUCTION

The new antenna, illustrated in Fig. 1, uses a diffraction pattern formed on a dielectric substrate. The conductive diffraction pattern is fed using a surface wave. The surface wave is launched into the multi-layer dielectric employing a suitable coupling arrangement. To form a one-sided radiation pattern, a ground plane is placed at a quarter-wave distance from the dielectric substrate. The surface wave, rather than space wave feed, combines with the ground plane to enable elimination of common disadvantages of previously published holographic antenna designs [1,2]. Thus, as the surface wave propagation is largely confined to the dielectric layer, a far more efficient coupling to the secondary radiators can be achieved using a compact exciter. Also, the surface wave propagates with a phase velocity less than that of light in free space; the wavelength over the dielectric surface is shorter. This leads to a far denser location of the secondary radiators, eliminating the grating lobes over most of the scan range. Meanwhile, the presence of the back plane and the fact direct radiation from the exciter can be easily suppressed, with negligible effect on the surface wave portion, leads to a highly efficient antenna.

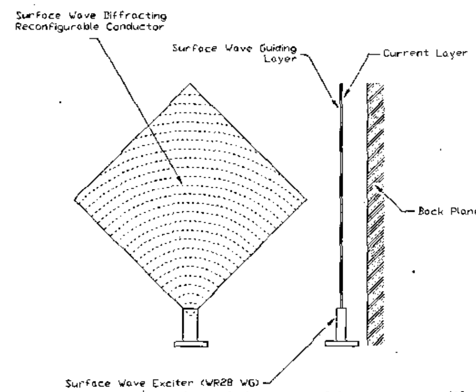

Fig. 1. Our new developed holographic antenna illustrating the main concept.

II. DESIGN ISSUES

We have developed an antenna EM- layered structure model to which can be applied rigorous analysis based on field equations. The developed model is utilized to derive a system of equations describing the excitation of the antenna by a complex current distribution corresponding to the set of metallic radiators (the holograms). Necessary guidelines for the design of the holographic antennas will be discussed in detail.

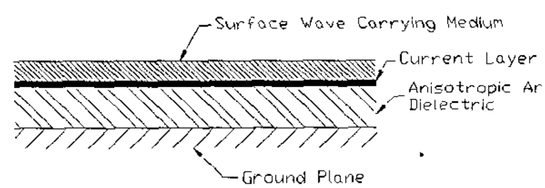

Fig. 2. An EM model showing a surface wave-carrying region, a current layer, and an anisotropic artificial dielectric, and the ground plane.

A. Guiding Structure Requirements

The overall frequency range over which the antenna can be operated depends mainly on two factors: the bandwidth of the surface wave launcher, and the range of single mode propagation of the lowest LSE mode. The lowest LSE mode is the useful mode in excitation of the antenna because it is the slowest mode; the field power is confined mostly within the dielectric layer. Moreover, the electric field is tangential to the layer surface and therefore allows for adequate coupling to the secondary radiators. In most designs, composite layers are needed to independently control the mode phase velocity and the degree of coupling to the radiators, i.e. the dielectric parameters are chosen to reduce the mode phase velocity by an amount necessary to suppress grating lobes over the required scanning range keeping single mode operation.

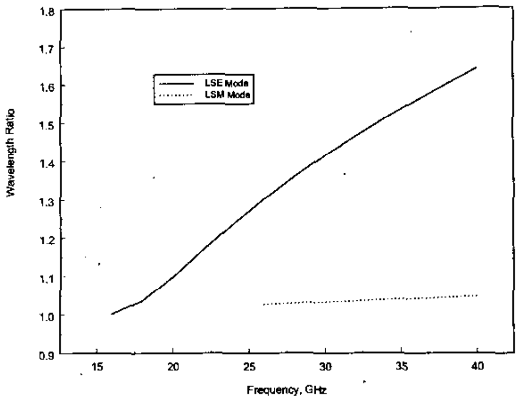

Fig. 3. Composite material surface wave mode normalized wavelength for both the LSE and LSM mode. The LSM mode is weakly coupled to the strips.

In this experiment, several materials were considered. The most suitable candidates were found to be Alumina as the basic dielectric and the synthetic material TMM-4 as the buffer layer. After several attempts, a composite layer of 0.015" thick Alumina 99% and 0.015" thick TMM-4 materials was found to provide acceptable mode velocity, dielectric loss, and radiator coupling level (see Fig. 3).

B. Surface Wave Launcher Design.

Although alternatives exist, the most useful type of exciter at 35 GHz is through an open-ended waveguide. Its two major advantages are low loss feed and the ability to suppress the unwanted direct radiation from the transition region. The theoretical design of such a launcher is highly involved, however, because it is truly 3-dimensional (3-D). The design was accomplished using the finite element program (HFSS). It was discovered that a simple dielectric sheet to waveguide transition is possible when the corner of the square sheet is inserted to a certain depth into the waveguide. The two variables, the insertion depth and the location within the waveguide cross-section, were initially selected based on the numerical simulation. Fig. 4 shows the geometry of the interface using waveguide WR-28, and the simulation's results. The predicted results show better than 13 dB return loss and lead to a low level of direct aperture radiation.

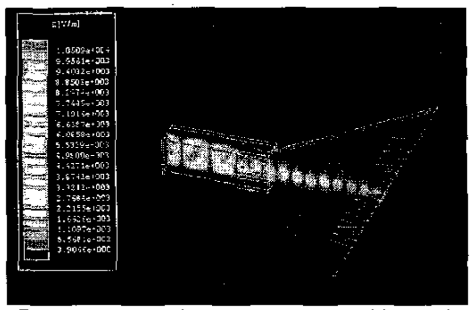

Fig. 4. Geometry, simulation of waveguide multi-layer interface.

C. Grating Structure

A diffraction pattern utilizing individual non-contacting dipoles of the same dimension was found the most suitable because it provides current uniformity and thus peak efficiency. However, it leads to strongly influencing the field diffraction. The dipole length was selected arbitrarily to be 1.5 mm, thus the dipole length is $0.175\lambda_o$. The dipole width is, however, determined by the required diffraction coefficient of the individual secondary radiators. Too strong diffraction leads to rapid decay of the signal over the antenna aperture, and low effective aperture, gain and efficiency. Too weak diffraction leaves much of the signal feed unradiated. Based on studying similar grating antennas [3], the condition maximizing the gain occurs when the total signal decay across the aperture is in the range of 7-10 dB. Thus, based on analytical calculations, a dipole width of 0.2 mm was sufficient to prevent noticeable residual radiation in the end-fire direction even though $L>12\lambda_o$ for the printed metallic dipoles. A minimum of 10 fringes is sufficient to provide sufficient radiation, and η >90%. As a check, numerical simulation of a strip of 1.5 mm x 0.2 mm dimensions in a 2-port waveguide simulator with the same composite sheet and ground spacing was performed. The strip was found to cause an attenuation of 0.40 dB and return loss of 13.6 dB at 35 GHz. Over the aperture length of 120 mm, the total attenuation for a broadside beam is about 9 dB, i.e., within the optimum range. The simulation geometry and the resulting field are shown in Fig. 5.

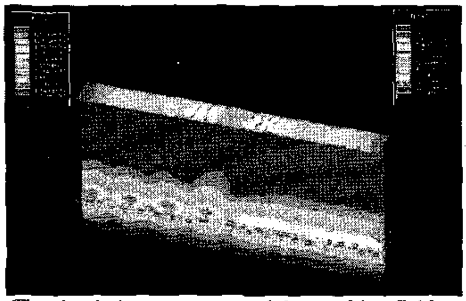

Fig. 5. The simulation geometry and the resulting field.

D. Antenna Patterns and Radiator Locations

Once the dielectric layer configuration and the radiator dimensions have been decided, the beam direction of the antenna is implemented through properly designed hologram. The location of the secondary radiators, given the required beam characteristics, is performed using the usual method of hologram generation, but in a computational form. Thus the desired far field pattern determines the phase distribution of the aperture, and secondary radiators at this point are defined, generating a set of radiator locations, or a phase-only hologram in optical terms [1-2]. The set of radiator locations thus generated is used to generate the coupled system of equations for the active radiators [4]. Further pattern optimization may be required that can include dipole length, width, and optimum location such as some form of genetic optimization algorithms.

III. EXPERIMENTAL DEMONSTRATION

A demonstration prototype was designed and fabricated. The mechanical design of the prototype is shown in Fig. 6. An absorbing material was deposited on the bottom of the Alumina surface to suppress the excess RF signal that escapes coupling to the radiators. Suppressing this excess signal is necessary to prevent uncontrolled radiation off the layer edges and hence distortion of the antenna pattern. The metallic radiators for the required pattern were lithographically printed on the lower surface of the TMM-4 substrate. An aluminum plate, which serves as a backplate for the antenna and the ground plane, was used. A distance of 2.143 mm was maintained between the ground plane and the bottom side of the composite layer, carrying the antenna hologram. The used surface wave launcher comprises an open WR-28 waveguide slotted in the middle of the cross-section, where the dielectric sheet is inserted into the waveguide opening. The insertion depth is adjustable and was experimentally set to minimize the return loss (best match) in the input waveguide. Fig. 7 shows the different parts of the fabricated prototype, while Fig. 8 shows the return loss vs. frequency of the surface wave launcher used. The far field radiation patterns of the demonstration antenna were measured using a standard set-up. Fig. 9 shows an example of the holographic pattern and the corresponding beam steered at broadside $\varphi = 0^0$, $\theta = 0^0$ in the x-z plane, with a 24 dB gain. Fig.s 9a and 9b show the measured and simulated patterns. The experimental results for broadside and other off-axis patterns show good agreement with theoretical predictions, and hence prove the feasibility of the holographic antenna concept investigated.

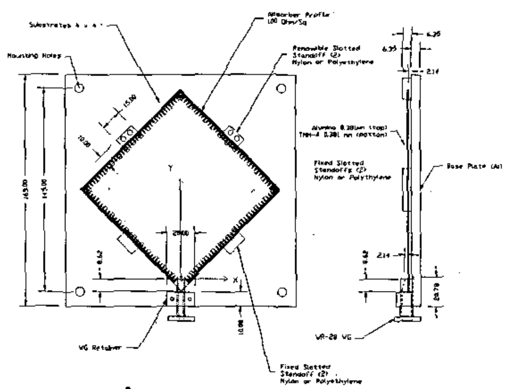

Fig. 6. Mechanical parts.

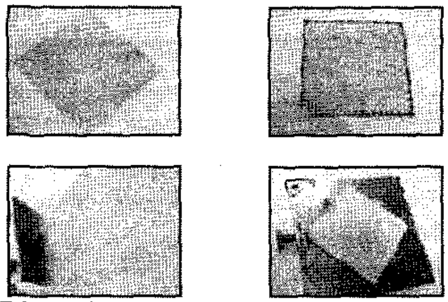

Fig. 7. Fabricated parts.

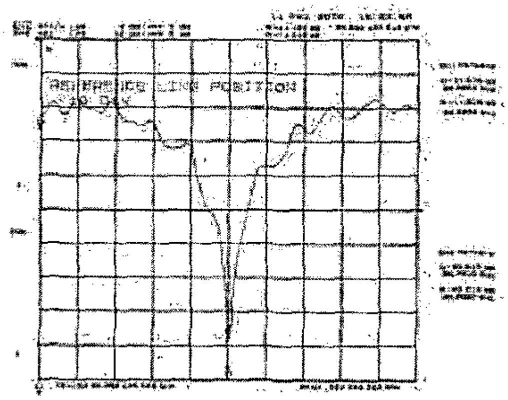

Fig. 8. Measured return loss.

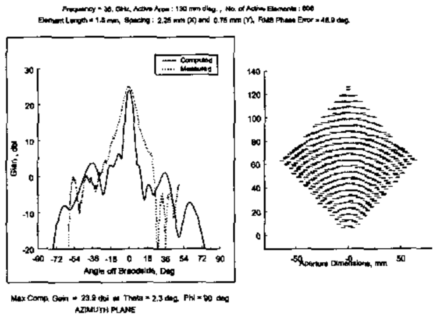

Fig. 9a. Simulated vs. measured results (Elevation).

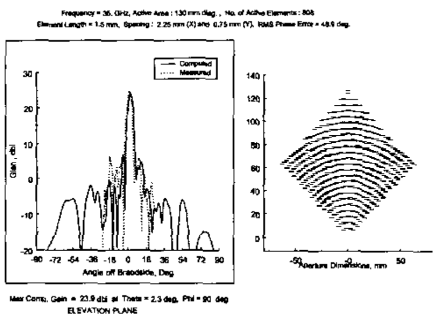

Fig. 9b. Simulated vs. measured results (Azimuth plane).

IV. Conclusions

A demonstration prototype holographic antenna with integrated feed, was designed, fabricated, and tested. The measured radiation patterns at 35 GHz showed good agreement with the theoretical prediction, proving the feasibility of this approach. This work can be extended for dynamically beam steering using reconfigurable holograms. Methods have been recommended for obtaining this reconfigurability [5].

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