A 40 GHZ CATR BASED ON A HOLOGRAM

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***Abstract* – A hologram type of compact antenna test range (CATR) is a promising method for testing large reflector antennas at millimeter wavelengths. In a hologram type of CATR, the needed plane wave is formed with the use of a binarized amplitude hologram. The hologram consists of narrow curved slots etched on a metal plated dielectric film. This paper presents the optimizing procedure of the hologram for two CATRs at 40 GHz. A 1.2 m × 0.7 m hologram has been used for measurements of a linear antenna array. A 1.5 m × 1.4 m hologram has been designed for tests of a planar link antenna. Keywords: hologram, CATR, antenna measurement**

1. INTRODUCTION

Testing of large reflector antennas is difficult at millimeter and submillimeter wavelengths. Far-field measurements are affected by atmospheric effects, near-field measurements are technically complicated and expensive, and conventional compact antenna test range measurements are difficult due to high surface accuracy requirement of the reflectors. A hologram type of CATR is a relatively new method for testing large reflector antennas [1]. In the hologram CATR, the feed antenna transmits a spherical wave onto one side of a hologram structure which modulates the field such that a planar wave is emanated on the other side of the structure (Figure 1). The hologram is designed such that the plane wave leaves the hologram at an angle of 33° with respect to the hologram normal for avoiding disturbing diffraction modes.

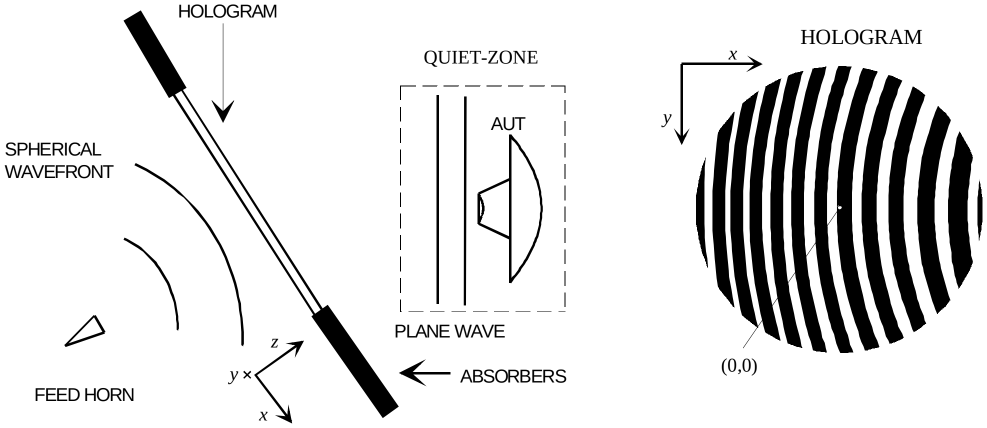

Figure 1. A hologram CATR, and an example of a hologram.

The antenna under test (AUT) is situated in the quiet-zone where the field satisfies the requirements of the plane wave. Typical requirements are a peak-to-peak amplitude ripple less than 1 dB and a peak-to-peak phase ripple less than 10°. The hologram pattern is a computer generated structure based on the amplitude and phase patterns of the feed horn and the desired output plane wave. The hologram consists of narrow curved slots in a metal plated dielectric film.

The simulation of the hologram CATR is based on finite difference time domain method (FDTD) and physical optics (PO) [2,3]. The interactions of the field at the hologram plane are simulated with FDTD, and the result of the FDTD-simulation is the aperture field of the hologram. When the aperture field is known, the quiet-zone field can be calculated by PO.

A 40 GHz CATR based on a 1.2 m × 0.7 m hologram has been designed and fabricated. The test range was used for testing a 22 cm × 2 cm linear array antenna, which was an early development version of a planar array reported in [4]. Measurement results of this antenna array will be presented and compared with the results obtained from near-field measurements. A larger 1.5 m × 1.4 m hologram has been designed for testing a planar 20 cm × 30 cm antenna at 40 GHz [4]. The hologram is under construction, but theoretical results of the quiet-zone field will be shown.

2. SIMULATION OF A HOLOGRAM CATR

2.1. FDTD

The hologram is always very large compared to a wavelength. A discretation of the whole hologram in three dimensions is impossible. Also forming integral equations for this relatively complicated structure is very difficult. Therefore, the structure of the hologram has to be simplified for the simulations. Figure 2 illustrates the simplification made: only one cut of the hologram is simulated at one time. The simulated structure is assumed to be infinite in the *y*-direction.

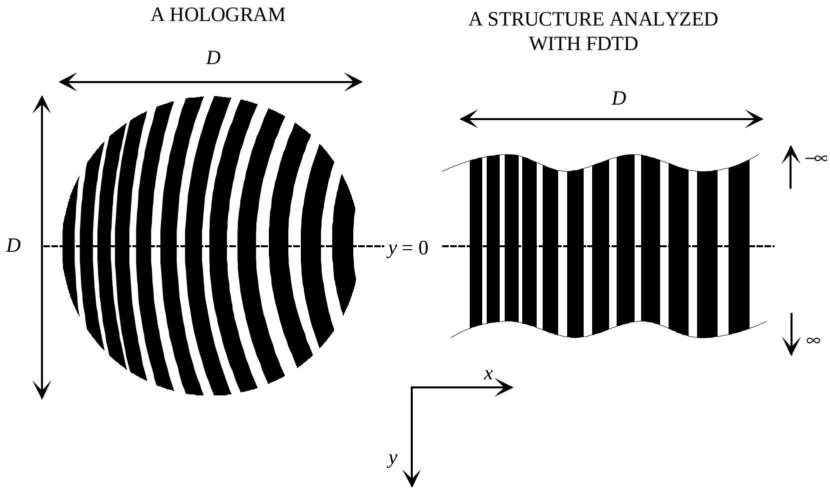

Figure 2. A hologram structure simplification for the simulation.

In Figure 2, the cut has been taken at plane $y = 0$, but the hologram can also be analyzed at different y values and a two (or three) dimensional quiet-zone field can be achieved. The error of the simplification increases when the absolute value of the y increases because the direction of the slots differs more from the direction of the y-axis. This kind of simplification does not predict any cross polarization.

FDTD is a versatile method for electromagnetics and two-dimensional FDTD suits very well for the simulation of the simplified hologram structure [2,3]. A schematic calculation domain of the FDTD-simulations is presented in Figure 3.

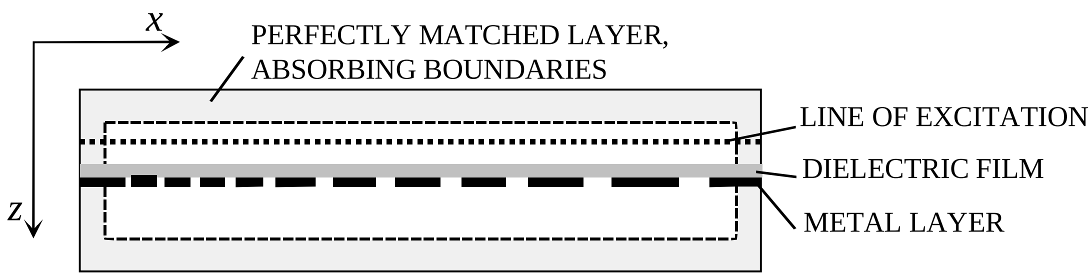

Figure 3. A schematic calculation domain of the FDTD-simulation.

Absorbing boundary conditions used are Berenger’s Perfectly Matched Layers (PML) [5], which are proved to be very effective absorbing boundaries. The excitation is the radiation pattern of the feed horn at the hologram plane. The thickness of the dielectric film is 75 µm, which determines the step size in the z-direction Δz = 75 µm. The thickness of the copper layer is 17 µm, but in the simulations it is assumed to be of zero thickness and its conductivity is assumed to be infinite.

In the *x*-direction a nonuniform grid is used [3], such that the cell sizes near metal edges are smaller. Smallest cell sizes are 1/100 of the wavelength and largest 1/10 of the wavelength, however, the ratio between two neighboring cells has to be between 0.5 and 2.0 [6].

2.2. Physical Optics

The quiet-zone field can be calculated with the physical optics (PO) when the aperture field of the hologram is known. A three-dimensional PO equation is used [2,3]

$$\bar{E}(x,y,z) = \int_S \frac{E_a(\bar{r}')}{2\pi}\left(\frac{jk}{R^2}+\frac{1}{R^3}\right)e^{-jkR}\,[(z-z')\bar{u}_y - (y-y')\bar{u}_z]\,dS', \tag{1}$$

where $\bar{E}(x,y,z)$ is the quiet-zone field and $R=\sqrt{(x-x')^2+(y-y')^2+(z-z')^2}$ is the distance from a point in the aperture (hologram) to a point in the quiet-zone. Equation (1) is for *y*-polarized field, and for *x*-polarized field the terms in the brackets have to be changed to $(z-z')\bar{u}_x - (x-x')\bar{u}_z$.

The FDTD simulation gives the aperture field only at one line. When the integration is calculated over one line only, as a result of Equation (1), the field radiated by the hologram behaves as that radiated by a line source of a finite length. This predicts that the hologram radiates a cylindrical wave and that the level of the field will decrease as the square root of the distance. However, the three dimensional physical optics formula predicts the transversal field correctly.

An alternative choice is to use two-dimensional physical optics formula, and the hologram can be seen as a strip source. The width of the strip is the width of the hologram in the *x*-direction and the strip is infinite long in the *y*-direction (Figure 2). Near the hologram this predicts that the level of the field will stay almost constant. If the behavior of the field in the z-direction is studied, two-dimensional physical optics has to be used. An equation for the *y*-polarized quiet-zone field can be written as

$$\bar{E}(x,z) = -2jk\int_S \sqrt{\frac{2}{\pi k|\bar{r}-\bar{r}'|}}\,e^{-j(k|\bar{r}-\bar{r}'|-\frac{\pi}{4})}\,E_a(\bar{r}')\bar{u}_y\,dS'. \tag{2}$$

For the *x*-polarized field the equation is a little more complicated:

$$\bar{E}(x,z) = -2jk\int_S \sqrt{\frac{2}{\pi k|\bar{r}-\bar{r}'|}}\,e^{-j(k|\bar{r}-\bar{r}'|-\frac{\pi}{4})}\,E_a(\bar{r}')\left\{\left(1-\frac{(x-x')^2}{|\bar{r}-\bar{r}'|^2}-\frac{j}{k|\bar{r}-\bar{r}'|}\right)\bar{u}_x+\frac{(x-x')(z-z')}{|\bar{r}-\bar{r}'|^2}\bar{u}_z\right\}dS'. \tag{3}$$

3. OPTIMIZATION OF A HOLOGRAM

The optimization of a hologram CATR is an iterative procedure. At each iteration round a time-consuming simulation has to be carried out. In an ideal case, the hologram structure is generated with known radiaton pattern of the feed and desired plane wave. Due to the binarization of the hologram, it does not act ideally. Therefore, the structure of the hologram has to be modified.

For the amplitude correction of the quiet-zone field, the amplitude of the plane wave has to be weighted by a weighting function. The modified hologram structure is generated with a weighted plane wave. A change in the weighting function affects the widths of the slots. If the amplitude of the field in a certain part of the quiet-zone is wanted to be increased, the amplitude of the plane wave used in the hologram generation has also to be increased. In the generated hologram structure, the widths of the slots are increased in the corresponding part of the hologram. The phase of the quiet-zone field can be corrected changing slightly the location of the slots, which can be done modifying the direction of the propagation of the plane wave locally in different parts of the hologram.

First in the optimization procedure, a weighting function has to be chosen. The edge taper to reduce edge diffraction has to be included in the weighting function. Secondly the binarized hologram structure is generated. Then the FDTD-simulation is carried out and the aperture field is obtained. Finally the quiet-zone field is calculated with PO. The optimization iteration is continued until a satisfactory amplitude distribution in the quiet-zone is achieved.

After the amplitude optimization, the phase has often to be corrected. The iteration of the phase optimization is similar to that of the amplitude optimization. A phase correction usually slightly affects also the amplitude of the quiet-zone such that the amplitude might have to be corrected after a phase correction.

In the optimization of the 1.2 m × 0.7 m hologram, the feed horn is placed 3 m away from the hologram and the quiet-zone field is optimized 3 m behind the hologram. The hologram is optimized for y-polarized field and the field is parallel to the slots. Both the amplitude and the phase of the quiet-zone have had to be corrected.

A 1.5 m × 1.4 m hologram has been optimized for testing planar link antenna. The feed horn is the same as in the 1.2 m × 0.7 m hologram, but the distance between feed horn and the hologram is increased to 3.5 m, thus the amplitude and the phase pattern of the feed in the hologram plane are flatter. Flatter amplitude and phase distributions make the optimization of the hologram easier. However, if the feed horn is moved far away the hologram the compactness of the test range suffers. Also in the optimization of this hologram the amplitude and the phase of the quiet-zone have had to be corrected.

4. FABRICATION

The smaller hologram can be manufactured of one piece, but the larger has to be joined from several pieces. In Finland, there is a manufacturing equipment (silk-screen printing), where the maximum achievable size of a piece of a hologram is 1 m wide and 3.0 m long. The maximum width of the pieces is determined by the width of the Mylar film used. The larger hologram will be joined from three pieces as presented in Figure 4 for avoiding joints to be in the middle of the hologram. Vertical joints are also avoided because of possible alignment errors, which can cause severe deterioration of the quiet-zone field [7]. Pieces of the hologram will be spliced together with a thin polyester tape.

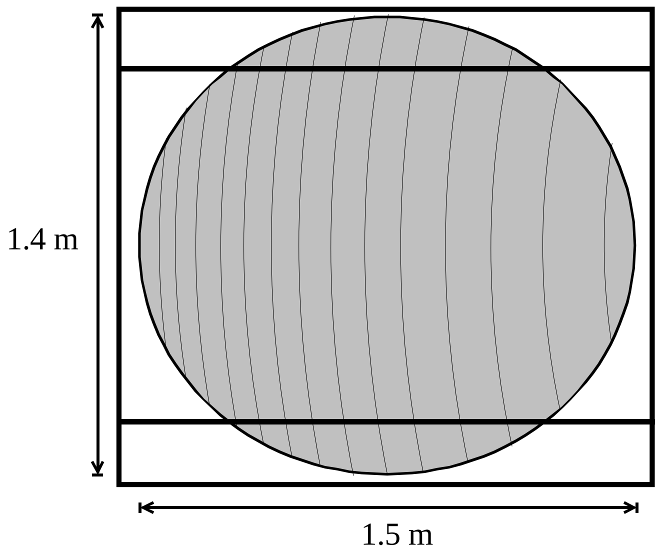

Figure 4. The hologram is joined from three pieces.

5. RESULTS

In Figure 5, measured and theoretical results of the *y*-polarized quiet-zone field of the 1.2 m × 0.7 m hologram at 40 GHz are presented. The field is measured and simulated at $y = 0$. Simulated amplitude ripple is about 1.0 dB and measured ripple is about 1.5 dB. The phase has not been measured. The measured area of the quiet-zone 3.0 m behind the hologram has been measured to be about 45 cm × 27 cm.

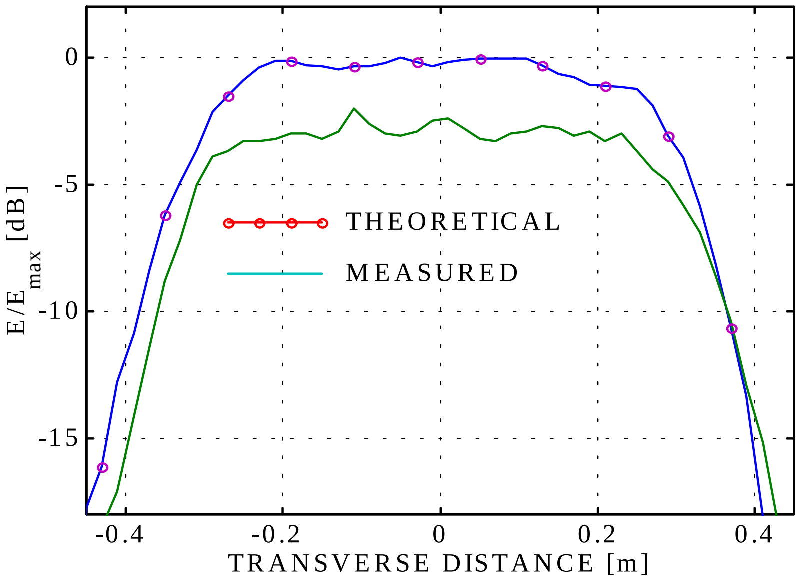

Figure 5. Measured and theoretical transversal quiet-zone fields 3 m behind the hologram, curves are shifted.

Figure 6 shows the measured H-plane pattern of the linear array. The measurements are carried out with the hologram CATR and with the near-field measurement. The results agree very well with each other.

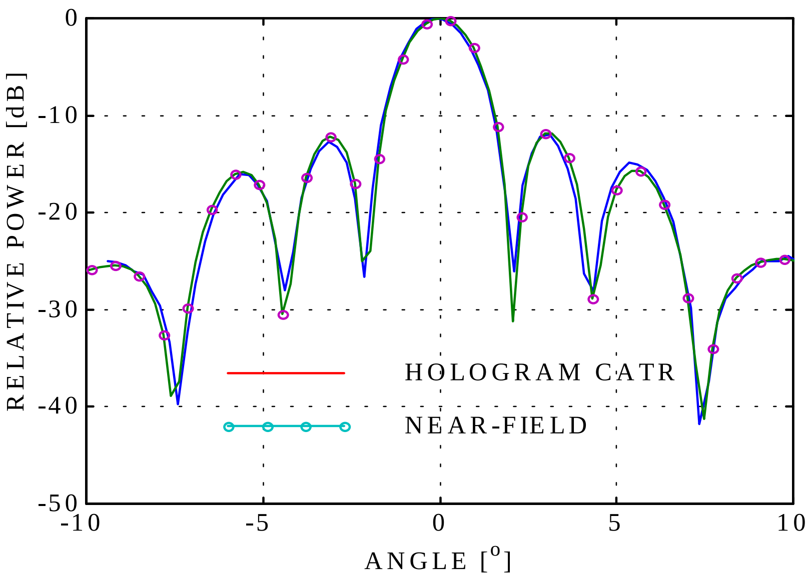

Figure 6. Measured H-plane pattern of a linear array at 40 GHz.

The designed 1.5 m × 1.4 m hologram is under construction. However, in Figure 7 the theoretical quiet-zone field is presented. Amplitude ripple is about 0.5 dB and the phase ripple is about 5°. The theoretical extent of the quiet-zone field 3.0 m behind the hologram is about 70 cm × 60 cm.

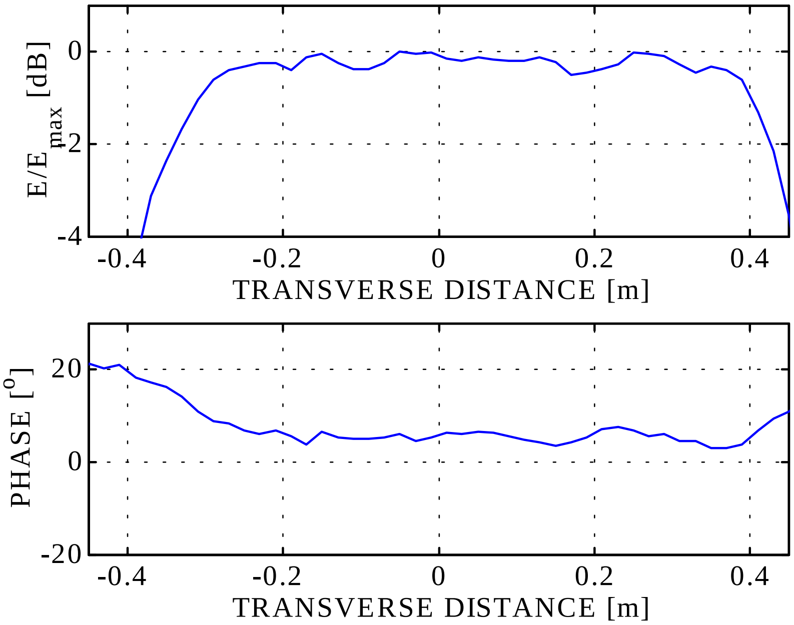

Figure 7. Theoretical transversal quiet-zone field 3.0 m behind the hologram, y-polarization.

6. CONCLUSIONS

A hologram CATR based on a 1.2 × 0.7 m hologram was designed and manufactured. A linear 22 cm antenna array has been measured with a hologram CATR and the results agree very well with the results of the near-field measurements. A larger 1.5 m × 1.4 m hologram has been designed for testing a planar link antenna. The hologram is under construction and the antenna measurements will be carried out during summer 1998.

7. REFERENCES

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