On the planarity errors of the hologram of the CATR

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Abstract – Conventional compact antenna test ranges (CATR) are based on reflectors, the problem of which is a very tight requirement on the surface accuracy. A hologram is a transmission type of a device, thus the required surface accuracy of the hologram is not so stringent, and the manufacturing of the hologram is much less expensive than that of the reflector. In the present work, the effect of the planarity errors of the hologram on the quiet-zone field are simulated, and simulation results are compared with a simple theoretical path length approximation.

1. INTRODUCTION

In a compact antenna test range (CATR), a planar wave needed in antenna measurements is produced by a collimating element: a reflector, a lens, or a hologram. Thus, a CATR simulates the far-field conditions in a small distance, which facilitates controlled indoor measurements of electrically large antennas.

A hologram is a computer generated, binarized pattern etched on a metal plated dielectric film[1,2]. A hologram is a transmission type of a device, therefore, the surface accuracy requirement of a hologram is not as stringent as that of a reflector, which is the traditional collimating element used in CATRs. An error of less than 1/100 wavelength (corresponding to a theoretical phase error of 7.2°) is a usual RMS surface error requirement for reflectors. Earlier it has been estimated, that the acceptable RMS surface error of the hologram is at least two times as large as that of a reflector [1].

In this paper, the effects of the planarity errors of the hologram on the quiet-zone field are simulated with a method based on the two dimensional finite difference time domain method (FDTD) and physical optics (PO)[2,3]. The width and the depth of the planarity error are studying parameters. In addition, a simple theoretical path length approximation of the phase error is applied, and results are compared with the simulation results. The accuracy requirement of the hologram pattern in the plane of the film, and the errors occured in the manufacturing process are discussed, e.g., in[1,4].

2. SIMULATION OF THE PLANARITY ERRORS

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The simulation of the hologram CATR is based on the two dimensional FDTD and PO [3]. A CATR based on a 1.5 × 1.4 m^2 hologram has been designed and built for measurements of a planar link antenna at 39 GHz. This hologram has been used in the simulations of this paper. The thickness of the dielectric film is 75 μm and the relative permittivity of the film is 3.3.

The shape of the planarity error is estimated by one period of a cosine function:

$$d(x) = (0.5 + 0.5 \cdot \cos(2\pi \frac{x - x_0}{w_d}))h_d, \qquad x \in [x_0 - w_d/2, x_0 + w_d/2],$$

where x_0 is the center, w_d is the width, and h_d is the maximum depth of the planarity error. The effects of different w_d and h_d have been investigated.

A simple theoretical approximation for the error of the quiet-zone phase can be derived from the path length difference (Figure 1).

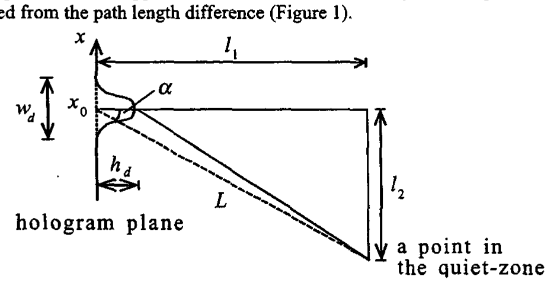

Figure 1. Geometry of the path length difference.

The difference l_d between the path lengths (solid and dashed line) is

$$l_d = d + \sqrt{(l_1 - d)^2 + l_2^2} - L.$$

The Taylor series of the square root around point $d = 0$ is

$$\sqrt{(l_1 - d)^2 + l_2^2} \approx L - \frac{l_1}{L} d + O(d^2) = L - \cos\alpha \cdot d + O(d^2),$$

where $\sqrt{l_1^2 + l_2^2} = L$, and the planar wave propagates into a direction of α. A hologram creates diffraction modes propagating into the direction of the hologram normal. Therefore, the hologram is designed such, that the planar wave propagates into a direction differing from the hologram normal to avoid disturbance of the diffraction modes. An angle of 33° is found to be a good choice and it is most often used when holograms are designed for CATRs. When angle $\alpha = 33°$ is applied to the previous equation, the path length difference is

$$l_d \approx d(1-\cos 33°) \approx 0.1613d,$$

or about one sixth of the planarity error. According to this simple path length approximation, the planarity error of the hologram can be about 12 times that of the surface error of the reflector, because the path length difference is two times the surface error in the case of a reflector.

3. RESULTS

In Figure 2, the effects of the planarity errors on the quiet-zone field are presented. In addition to the amplitude and the phase of the quiet-zone fields, the differences between the nominal phase and the phase with planarity errors are shown. The curves are vertically shifted in order to separate them from each other. The planarity error is applied in the middle of the hologram.

In Figure 2 a), the effect of the depth of the planarity error is shown. The width of the error is 10 cm and, the maximum depth is 0.08λ, 0.16λ, and 0.24λ (λ = 7.6 mm). The simulated phase differences are about 3°, 6°, and 8°, respectively. The phase errors according to the path length approximations are about 5°, 9°, and 14°, respectively. According to the simulations, the phase error depends quite linearly on the maximum depth of the planarity error.

In Figure 2 b), the effect of the width of the planarity error is shown. The depth of the error is 0.2λ (phase error according to the path length is about 12°), and the width is 4 cm, 6 cm, and 8 cm. The simulated phase errors are about 4°, 5°, and 6°, respectively. According to the simulations, only the maximum phase error in the middle of the quiet-zone depends on the width of the planarity error.

4. CONCLUSIONS

The effects of the planarity errors in the hologram film on the quiet-zone of the CATR have been studied. A simple path length approximation predicts that the planarity error of the hologram can be about 12 times that of the surface error of the reflector. The simulated results of the phase error are smaller than the predicted results of the simple path length approximation. According to the simulations, however, the planarity error affects the whole quiet-zone area. The phase error depends also on the width of the planarity in addition to the depth.

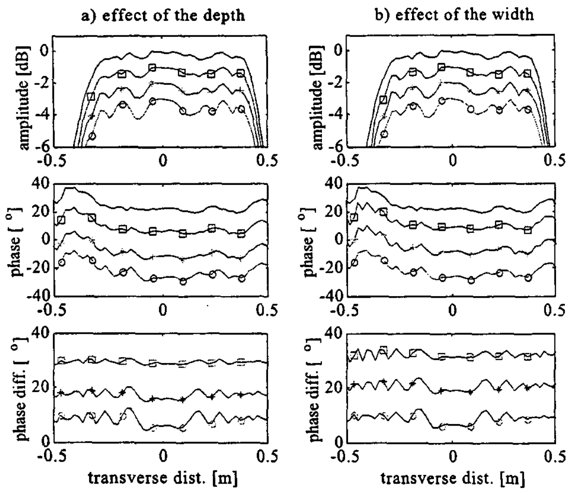

Figure 2. The quiet-zone fields, effect of **a)** the depth (nominal(-), h_d=0,08λ(•), 0,16λ (*), 0,24λ (o)) and **b)** the width (nominal (-), w_d = 4 cm(•), 6 cm (*), 8 cm (o)) of the planarity error.

5. REFERENCES

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