Effects of Discretization on Thin Elementary Holograms for Antenna Applications

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Abstract

The effects of binary discretization of the interference patterns of thin holograms designed for antenna applications is studied. The impact of using different rules for determining the transparent and opaque regions of the hologram is investigated by using a finite-difference time domain analysis to estimate the radiation patterns of the resultant antennas. For the selected discretization rules studied, a variation of 1.7 dB in directivity was observed, indicating the importance of properly choosing the discretization rule in obtaining the best antenna performance.

1. Introduction

The field of holography is well established at optical frequencies and is used in various applications such as microscopy, imaging, data storage, and interferometry. At microwave and millimeter-wave frequencies, holography has been adapted to such applications as synthetic aperture radar processing and imaging of hidden objects. Holographic principles have also been applied to the design of low-profile microwave and millimeter-wave antennas [1-9]. Recently, the similarities between an elementary hologram and a Fresnel zone plate have been investigated using an analytical approach [10]. It was shown in [10] that for antenna applications, the Fresnel zone plate outperforms the corresponding elementary hologram in terms of achieving higher directivity and better focusing resolution. It was found, however, that when the analog amplitude interference pattern of the hologram was digitized into binary levels, the performance of the hologram could be improved to match that of the Fresnel zone plate. In this paper, the simplified analysis presented in [10] is augmented by finite-difference time domain (FDTD) simulations, to include the electromagnetic effects which were not previously considered.

2. Elementary Hologram Antennas

The antennas investigated in this paper are based on elementary holograms, which are obtained from the interference pattern of a plane wave and a spherical wave [11]. The case selected in this investigation consists of a plane wave that is normal incident to the plane of the hologram, so that the interference pattern forms a set of concentric fringes (light and dark regions), as shown in Figure 1. The radius of these fringes is a function of the distance of the origin of the spherical wave (produced by a point source) to the plane of the hologram. The closer the point source to the hologram plane, the higher the number of fringes in a given area. Figure 1 shows the interference pattern for a hologram whose point source was located 5 wavelengths from the hologram plane. The normalized amplitude of the fringes as a function of radius, is plotted alongside the fringe pattern.

This fringing pattern is captured in the optics domain by exposing photographic film to the interfering waves. At microwave frequencies, a practical equivalent to photographic film does not exist, and the hologram has to be otherwise constructed. The most common technique is to etch metal patterns on thin dielectric substrates, where the interference pattern of the hologram is represented as a binary discretization. Various digitization schemes are possible and have been proposed to determine which areas of the hologram are to be metallized. However, a systematic study has not been performed to determine the best discretization for antenna applications.

3. Effects of Binary Discretization

In this study, the effects of four coding schemes are investigated on the far-field directivity of the elementary hologram. These four rules are shown in Figure 2, alongside diagrams of the resultant binary holograms. The discretization rule used for each case is listed in the second column of Table 1. The first three cases ((a) - (c)) use different amplitude values of the intensity (I) to set the '1' and '0' levels of the binary hologram. The last rule (d) uses the sign of the phase of the complex total field ($\boldsymbol{U}$) of the interference pattern to determine the binary levels. The resultant binary transitions coincide with the minima and maxima of the intensity and are identical to the radii of a Fresnel zone plate.

The far-field patterns of the resultant four binary holograms, when fed by a small rectangular open waveguide, were simulated using an FDTD-based commercial software package [12]. The simulated patterns are shown in Figure 3 while the directivities are listed in the third column of Table 1. The rule based on the phase of the hologram fields (case (d)) results in the highest directivity and nearly the best maximum sidelobe levels. The results obtained in this investigation follow the same trends as those obtained by the simplified analysis in [10].

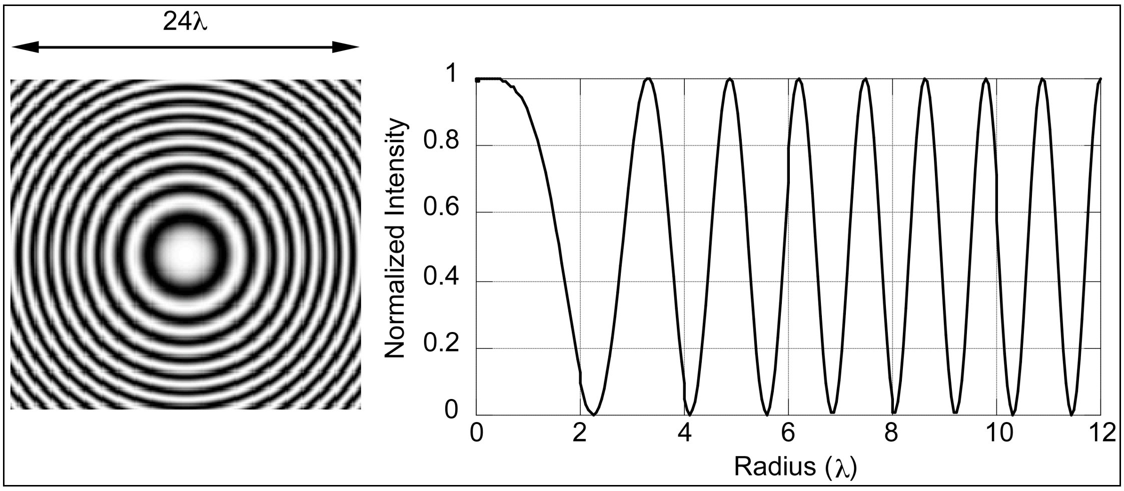

Figure 1. Interference pattern of an elementary hologram.

Table 1. Directivity for digitized holograms.

Case	Digitizing Rule	Directivity (dBi)	Maximimum Sidelobe Level (dB)
a	$I_d = \begin{cases} 1, & \lvert I\rvert \geq 0.25 \\ 0, & \lvert I\rvert < 0.25 \end{cases}$	25.8	15.3
b	$I_d = \begin{cases} 1, & \lvert I\rvert \geq 0.5 \\ 0, & \lvert I\rvert < 0.5 \end{cases}$	27.1	17.6
c	$I_d = \begin{cases} 1, & \lvert I\rvert \geq 0.707 \\ 0, & \lvert I\rvert < 0.707 \end{cases}$	25.9	19.7
d	$I_d = \begin{cases} 1, & \arg(\boldsymbol{U}) < 0 \\ 0, & \arg(\boldsymbol{U}) \geq 0 \end{cases}$	27.5	19.1

I = Normalized Amplitude of the hologram intensity pattern
U = Complex field of the hologram interference pattern

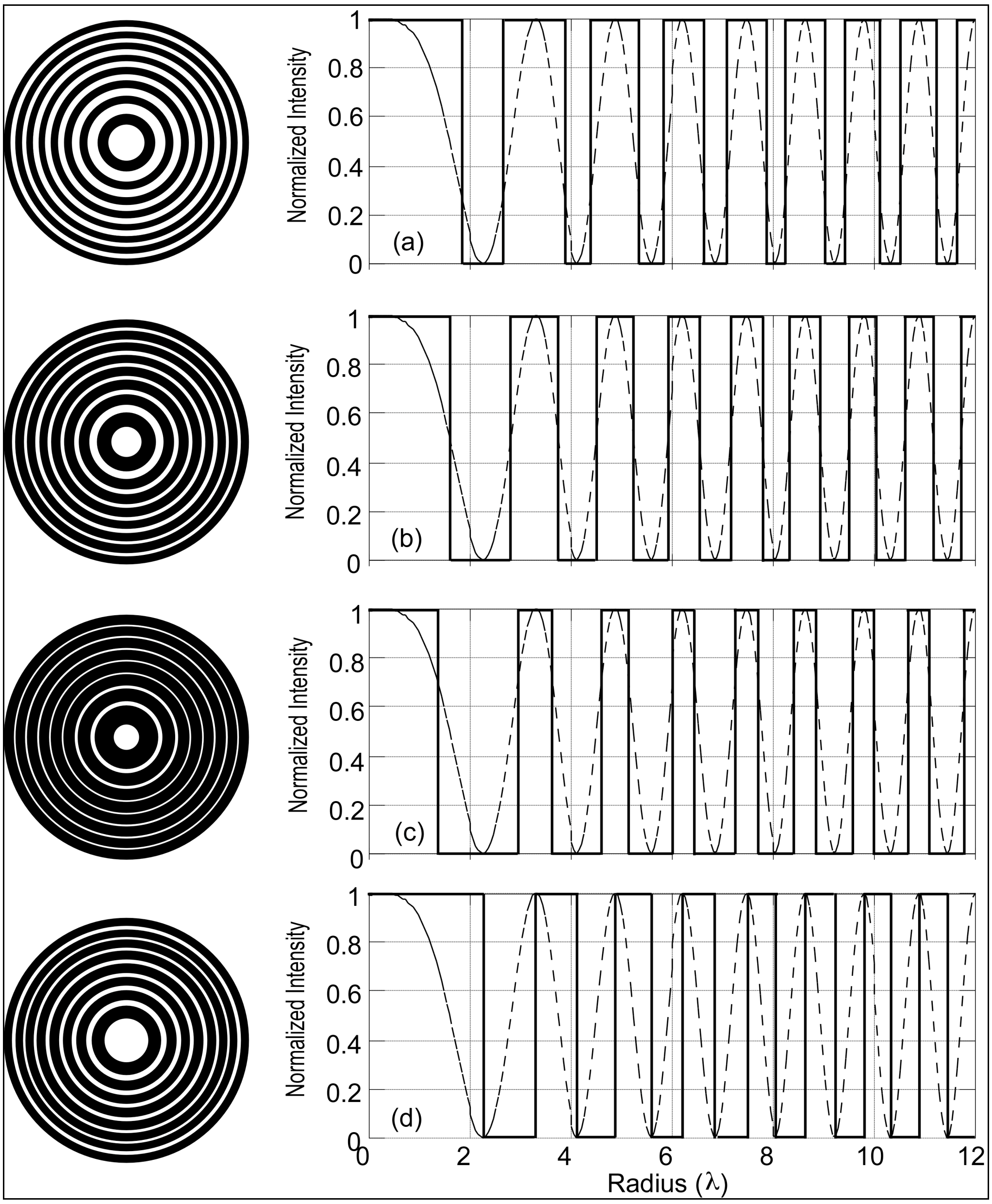

Figure 2. Digitized holograms.

4. Conclusions

This study has examined elementary holograms designed for microwave antenna applications. At microwave frequencies, holograms are usually constructed as a binary representation of the holographic intensity pattern. The set of elementary holograms considered in this study were constructed using a selection of binary discretization rules and the effects on the radiation patterns of the resultant antenna designs were investigated. For the four cases investigated, the rule based on the sign of the phase of the complex fields forming the holographic interference pattern led to the best directivity and the second best sidelobe levels. Whether this same rule leads to the best performance of antennas based on more complicated holographic patterns will require further investigation.

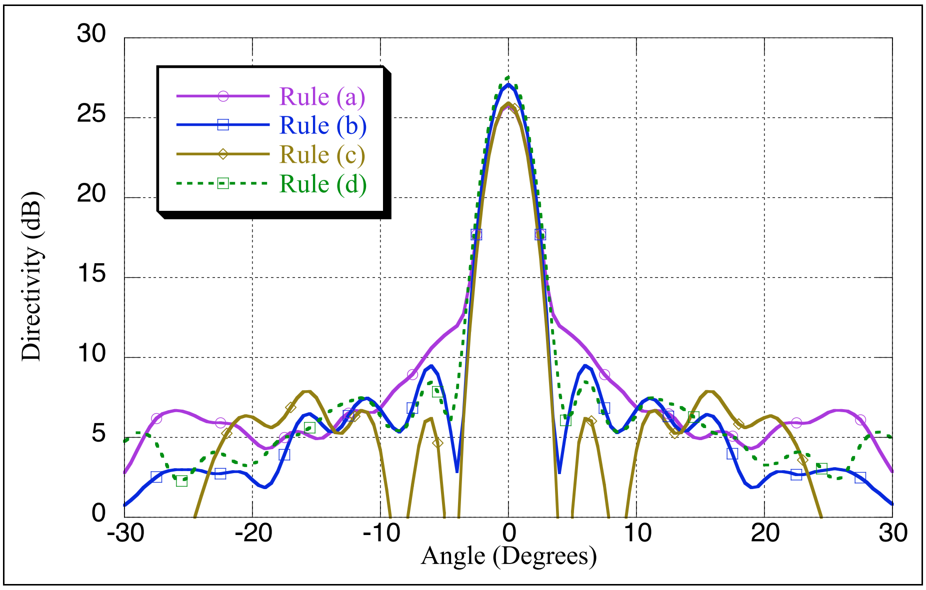

Figure 3. Simulated directivity of the digitized holograms.

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