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Directional Monopole using Holographic Surfaces with Reduced Sidelobe Level

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Abstract

This work presents the systematic approach for improving the radiation patterns of monopole holographic antenna. Most of the present works show unwanted high sidelobe level (SLL) for monopole holographic antenna. The radiation patterns from such designs have another beam of high gain near the main beam. By changing the location of the monopole feed over the holographic surface, this extra unwanted beam can be altered and eventually removed. This helps to improve SLL significantly. This study compares results of different designs and presents guidelines to achieve proposed design with very low SLL.

1 Introduction

Metasurfaces are making many wonders and among them is the artificial impedance surface (AIS) which helps to modulate the surface waves to get a desired radiation pattern in the intended direction. One of the outcomes of AIS is holographic impedance surface antenna (HISA) which employs the principle of holography [1]. HISA employs dielectric grounded surfaces with isotropic metal patches. In recent years, HISA has gained popularity in high gain antennas for various applications such as radar and satellite communications [2].

Holography theory has originated from the principle of optics used in [3] and [4]. A source antenna produces a reference wave, which can be a surface wave [5] and the object wave is the desired radiation pattern. HISA makes use of a leaky wave concept to excite the patches on the grounded dielectric substrate [6]. Different types of source antennas can be used with holographic surfaces and monopoles are one of them. The problem with monopole antennas as feed is that its use creates high SLL [6-7]. This paper explains about the structural changes required to reduce the SLL when a monopole antenna is used as a wave launcher. It is demonstrated with various designs of HISAs to reduce SLL.

2 Layout

The construction of hologram is carried out by the interference pattern produced by the object wave and the reference wave. The source antenna generates the reference wave and the object wave produces the desired radiation beam [5]. A monopole is used as a reference wave generator in this work, the currents generated by the antenna is given by

$$\Psi_{ref} = e^{-jknr} \quad (1)$$

where n represents the effective refractive index observed by the surface current, r is the radial distance from the antenna and k corresponds to the free space propagation vector.

The desired beam or radiation beam or the object wave to generate a narrow pencil beam in the direction of (θ_0, ϕ_0) is defined by

$$\Psi_{rad} = e^{jkx\sin\theta_0\cos\phi_0 + jky\sin\theta_0\sin\phi_0} \quad (2)$$

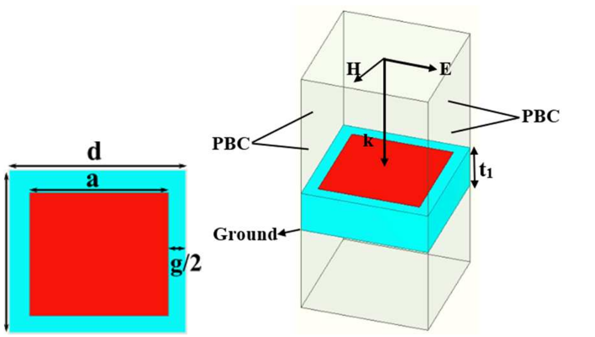
The surface impedance at a point (x, y) on the impedance surface is expressed as a pattern of interference between these two waves and is defined as

$$Z(x, y) = j[X + MRe(\Psi_{rad}\Psi^*_{ref})] \quad (3)$$

Where X represents the average impedance offered by holographic surface and M is a modulation index. Generally M is chosen in such a way that it offers a total span of impedance range. Different values of Z can be obtained by periodic unit cells of patches (see Figure 1) by different gap values as in accordance with [6]-[7].

3 Results

The holographic designs presented in Figure 2 are the interference pattern formed by a reference wave and an



(a) (b)

Figure 1. Unit cell design (a) top view and (b) isometric view

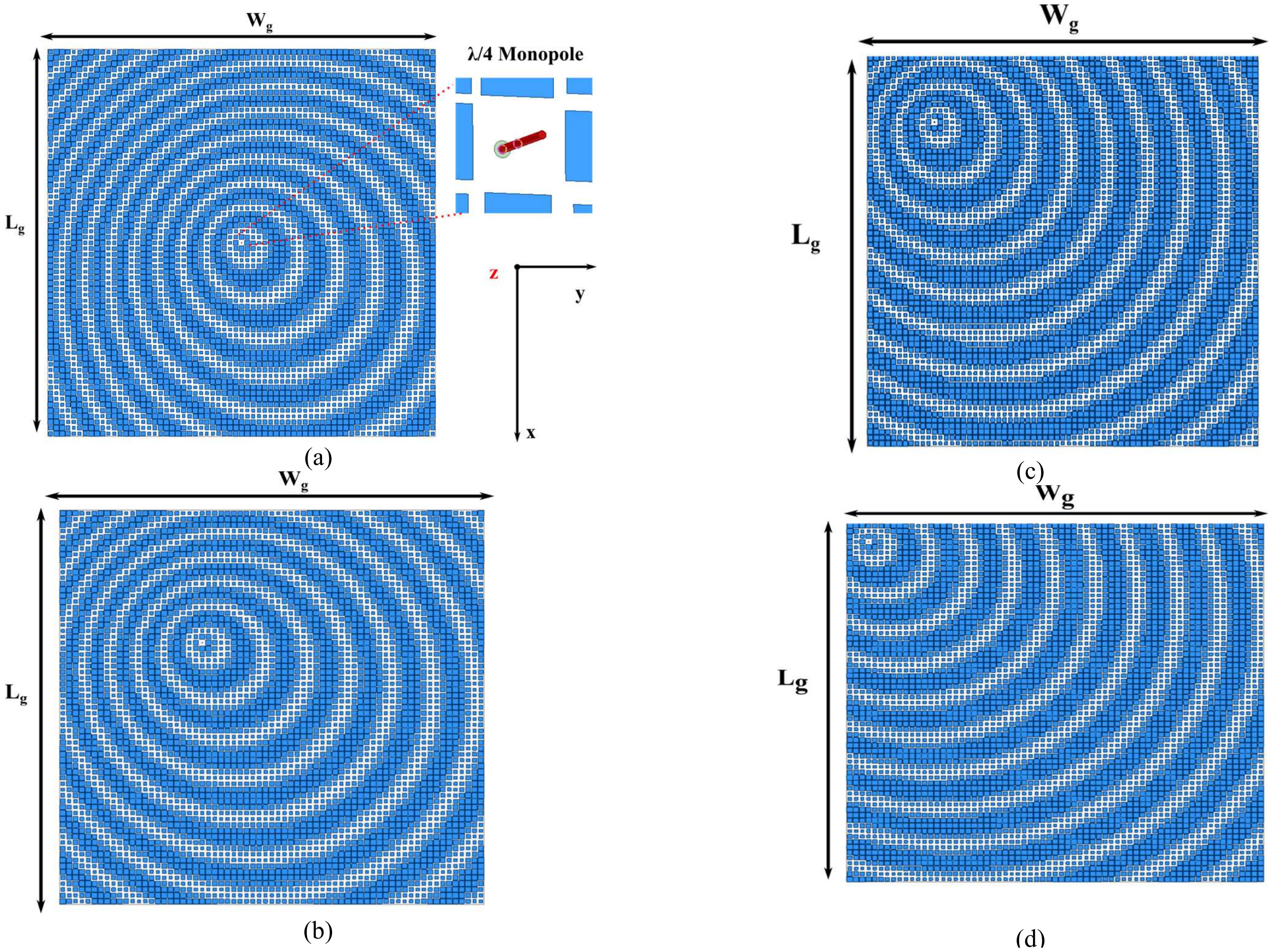


Figure 2. Different antenna designs (a) design-1 (b) design-2 (c) design-3 (d) design-4

object wave propagating along($\theta = 20^0, \emptyset = 45^0$). For our study, we create 4 designs of the HAIS antennas. In all these designs, the surface area of the antenna is the same but the feed position changes as shown in Figure 2 to alter the radiation patterns. We use total 67×67 unit cells made of patches with a total size of 201 mm×201 mm for all designs for the holographic surface [6]. This holographic surface is then fed with a monopole of size $\lambda/4$ (i.e. 4.1mm) operating at 18.4 GHz. The monopole feed is located at (102 mm, 102 mm), (69 mm, 69 mm), (36 mm, 36 mm), (12 mm, 12 mm) from the top left corner (origin) for design-1, design-2, design-3 and design-4 respectively. The modulation index M used for these designs is 51.70 while X is 193.4Ω.

The unit cell used for this work has periodicity of 3 mm. In the unit cell, a square patch is placed on a Rogers 5880 with a ε_r=2.2 dielectric with a thickness of 1.57 mm.

The various designs presented in Figure 2 show the variation in the feed position. The corresponding change in radiation patterns is shown in Figure 3. In all the designs, the gain of the main lobe remains around 20 dB (at $\theta = 27^0$). It is very common in holographic antennas to have the main beam at a higher angle than the desired one. In our case, it is at $\theta = 27^0$ instead of expected $\theta = 20^0$.

In design-1, when fed at the center of the holographic surface, the generated radiation pattern has two lobes i.e. one at 27^0 (desired) and another at 15^0 (undesired) with the same gain values of 20 dB. To improve SLL performance, the feed position is moved. By this feed movement as in design-2, the sidelobe falls by 4 dB with peak at 16.9 dB. In design-3, the feed is moved further out from the center and we found that the sidelobe falls by another 5 dB with peak at 11.4 dB Finally in the design-4 the sidelobe level improves even further after moving the feed closer to the edge. In the proposed design (design-4), the SLL is 14 dB down as compared to 0 dB for design-1. All these simulations were carried out in HFSS simulator.

It was found that instead of feeding the holographic surface in the center, it should be fed near the edge to get improved SLL. We found that for a square holographic surface, the feed should be in direction diagonally opposite as compared to desired beam direction. Moving the feed in

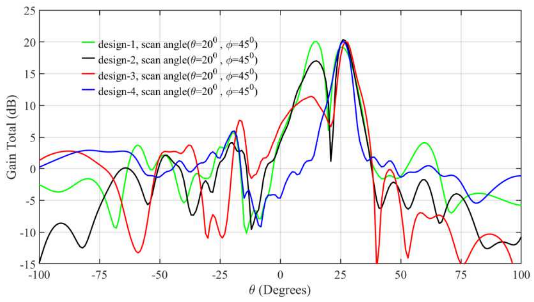


Figure 3. Radiation patterns for different designs.

this way reduces the SLL and produces a pencil beam like radiation pattern with high gain.

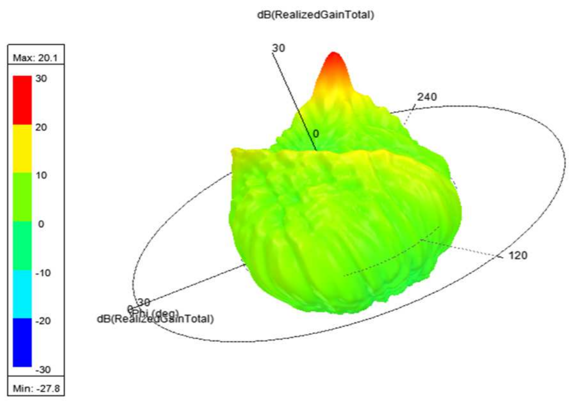


Figure 4. 3D polar radiation pattern of the proposed antenna (design-4).

Figure 4 shows the 3D polar radiation pattern of the proposed antenna (design-4). We can see from the 3D plot that the antenna has a pencil beam in the desired direction while maintaining low side lobes.

4 Conclusion

This paper has successfully demonstrated the approach to reduce the SLL for monopole holographic antennas. The SLL is reduced by 14 dB as compared to the current conventional monopole antennas with holographic impedance surfaces. It is also important to note that the gain of the antenna in desired scan direction, $\theta = 20^0, \emptyset = 45^0$ does not change while SLL is reduced.

5 References

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