ANTENNA RADIATION PATTERN CONTROL BASED ON 3D PRINTED DESIGN

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ABSTRACT

Dielectric materials have been applied in modifying the antenna radiation pattern, but it is usually limited to single-beam applications. The goal of this paper is to present a novel methodology to control the antenna radiation pattern based on 3D printing technology. 3D printing enables arbitrary dielectric distribution at different locations. As a result, different radiation patterns can be realized by loading an optimized dielectric material with varied permittivity. In this work, we propose a design of a quarter-wavelength monopole antenna surrounded by a low-profile 3D-printed polymer structure with an optimized dielectric distribution. Unlike the conventional omnidirectional pattern of the monopole antenna, single-beam and multiple-beam patterns are achieved using genetic algorithm (GA) optimization.

INTRODUCTION

Reconfigurable antenna arrays are commonly used to control the radiation pattern. The gain of the antenna array increases with the increase of the number of elements, but at the expenses of the increase of feed network complexity. On the other hand, homogenous dielectric loading mechanism has also been used in the radiation pattern control using only one antenna element [1,2,3,4]. Nevertheless, these designs are limited to single-beam applications. Besides, they require increasing the size of the antenna for tens of wavelengths. Similarly, inhomogeneous dielectrics have also been applied to tailor the antenna radiation pattern [5,6], which provide compact solutions for the radiation pattern control. Nonetheless, they are still limited to single-beam applications and the radiation pattern is restricted to the feed antenna pattern.

In this paper, we present a novel design of a quarter-wavelength monopole antenna surrounded by dielectric structures. The dielectric structure has optimized dielectric distributions to control the antenna radiation pattern. The optimization process is carried out using GA. The dielectric inhomogeneity can be experimentally realized using the 3D printing technology [7], which has the advantage of low cost and fast prototyping. This design is capable of changing the omnidirectional pattern of the monopole antenna to different shapes, including single-beam and multiple-beams. This design technique provides a compact and effective way to manipulate the radiation pattern of a single-element antenna, which offers another degree of freedom for antenna design.

ANTENNA DESIGN

The proposed design is a monopole antenna above the ground plane, shown in Figure 1. The monopole has 0.5 mm diameter and 4 mm height, which is a quarter-wavelength at 15 GHz after dielectric loading. The monopole is surrounded by 100 (10 × 10) dielectric blocks. Each block has a dimension of 4 mm × 4 mm × 4 mm. Each side corresponds to $0.2\lambda_0$ at 15 GHz, which means a decent condition for effective medium approximation. Each unit cell has a dielectric constant between 1.1 to 2.4 with 0.1 discretion, which is realizable based on current 3D printing technology.

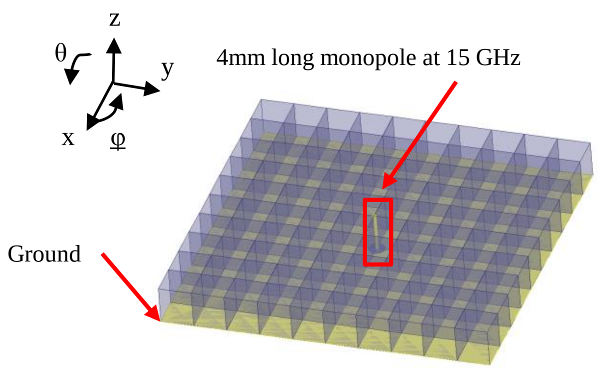

Figure 1 HFSS model of a monopole surrounded by inhomogeneous dielectrics discretized into 4×4×4 mm^3 blocks.

A quarter-wavelength monopole commonly has a donut-like radiation pattern. Nevertheless, it is found that the radiation pattern of the antenna can be controlled by adjusting the dielectric constants of dielectric blocks. The control is realized by MATLAB GA code controlling ANSYS HFSS 3D field simulation software.

In the GA code, the population size is chosen as 3 for each generation, which is a compromise of parallel HFSS simulation and the computer's capability. Each chromosome represents a dielectric block's ε_r (1.1-2.4), which is the floating point representation. Based on the optimization goal, i.e. the fitness function, the best two candidates among all individuals are selected and crossover to get the new generation. For simplicity, one-point crossover method is utilized. The chromosome matrix is 10 by 10. Each time a random two dimensional point (x, y) is generated as the crossover point, where $x, y \in [1,9]$ and $x, y \subset N_+$. One parent offers chromosomes before the point (x, y) and the other parent offers chromosomes after (x, y). After crossover, mutation operation is carried out and the mutation rate of each chromosome is 0.1. This generational process is repeated so that the gene, i.e., dielectric constant distribution, of the best individuals are kept and the optimal solution is found.

SIMULATION RESULTS

A quarter-wavelength monopole on infinite ground has its maximal radiation at elevation angle of $\theta = 90°$ plane. In this design, due to the limited ground size, the maximal radiation direction shifts to $\theta = 60°$. Consequently, the radiation pattern at $\theta = 60°$ is discussed in this paper.

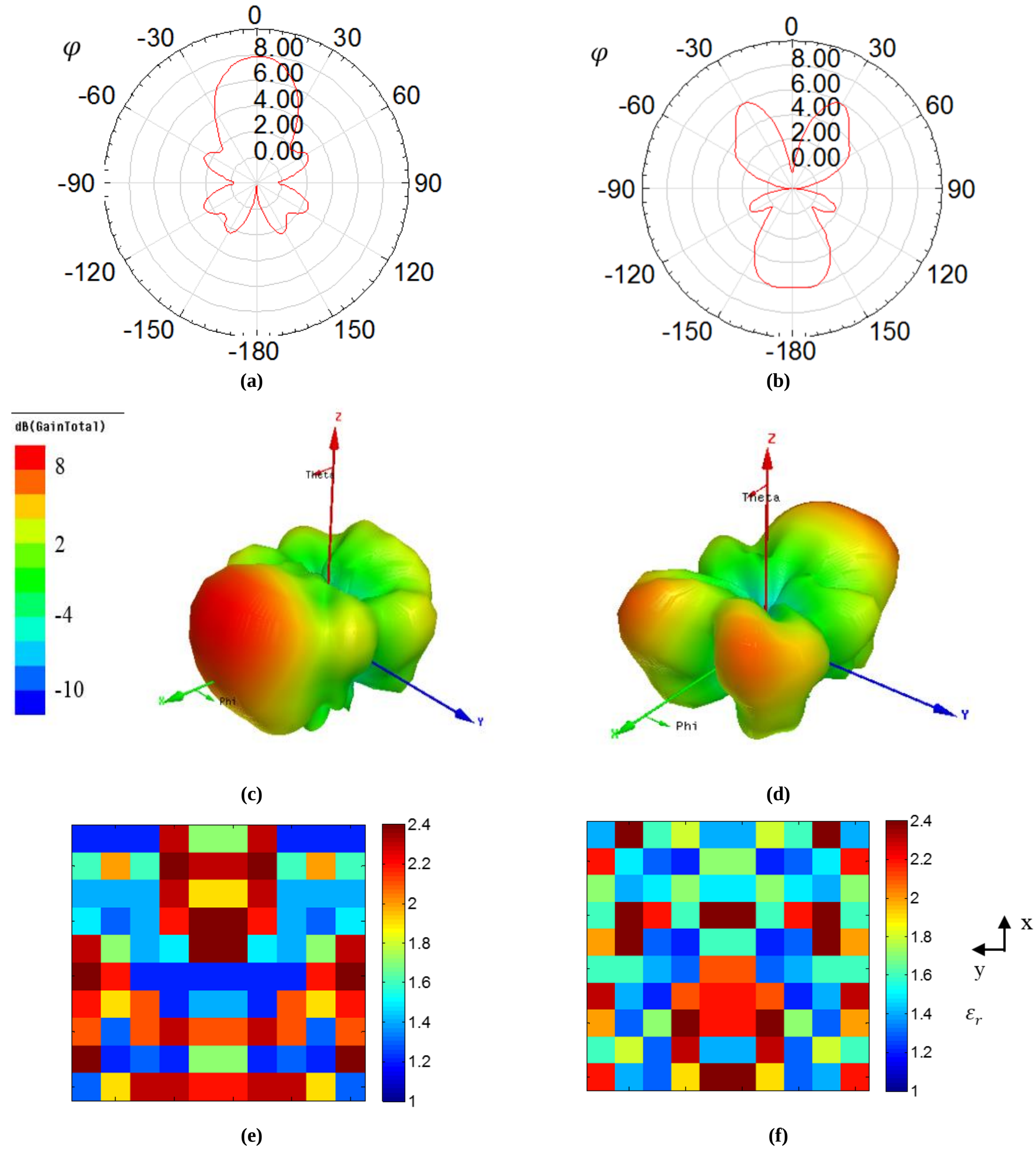

Figure 2 Simulated radiation pattern at θ = 60° and at 15 GHz of the (a) one-beam antenna (b) three-beam antenna. 3D radiation pattern plot at 15 GHz of the (c) one-beam antenna (d) three-beam antenna. Dielectric constant distribution around the monopole for the (e) one-beam antenna (f) three-beam antenna.

Two antenna radiation patterns are optimized with the proposed method, one-beam pattern and three-beam pattern. The one-beam antenna has an optimization goal of achieving maximal gain for φ = 0° and minimal gain for $\varphi \notin [-20°, 20°]$. The three-beam antenna aims at achieving maximal gain for $\varphi = \pm 30°, 180°$ and minimal gain for $\varphi \in [-150°, -60°], [60°, 150°], [0°]$. The simulated radiation patterns at $\theta = 60°$ direction is shown in Figure 2(a) and (b). The one-beam antenna has nearly 8 dB gain at φ = 0° and the side lobe level is less than -6 dB. The three-beam antenna's gain approaches about 6 dB and 7 dB at $\varphi = \pm 30°,\ 180°$, respectively, and the side lobe level is less than -6 dB. The 3D antenna radiation patterns are shown in Figure 2(c) and (d). These results demonstrate that a single-beam and a multi-beam antenna has been successfully achieved through dielectric loading. The dielectric constant distributions are shown in Figure 2(e) and (f), in which the monopoles are at the center of the dielectric loaded structure.

The dielectric loading around the monopole changes the effective dielectric constants thus will influence the input impedance as well as the impedance bandwidth of the antenna. The reflection coefficient for both the one-beam and three-beam antennas are depicted in Figure 3. The reflection coefficient of a regular quarter-wavelength monopole at 15 GHz is shown in Figure 3 as well. It is apparent that the dielectric loading just has a little influence on the impedance bandwidth for both cases. All three antennas have acceptable fractional impedance bandwidth of around 15%.

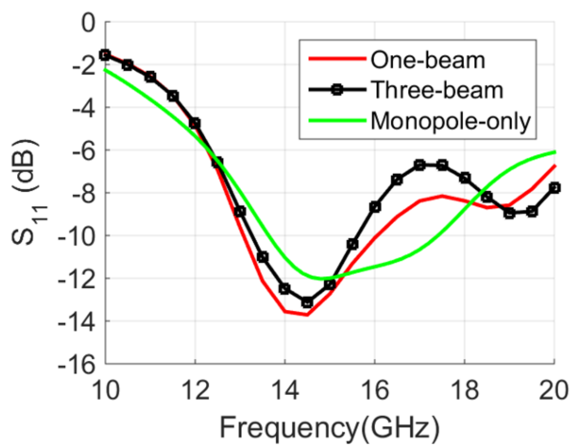

Figure 3 Reflection coefficient of the the one-beam antenna, the three beam antenna and the quarter-wavelength antenna in the air.

CONCLUSIONS

This work studies a new technique to control the antenna radiation pattern based on inhomogeneous dielectric loading. By loading different dielectrics around a quarter-wavelength monopole, one-beam and multi-beam antenna radiation pattern can be achieved. Such dielectric loading can be easily realized by 3D printing technology. This concept is also promising to be combined with agile materials, e.g. liquid crystal, to realize reconfigurable beam forming without complex feeding network and expensive active devices.

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