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Monopole Antenna Gain Enhancement by Using Layered Dielectrics Medium

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Abstract

Gain enhancement of a monopole antenna by adding a trimmed cylindrical shell shaped dielectric around it is presented. The added dielectric is cluster of five stacked cylindrical superstrates with same relative dielectric permittivity but with different thicknesses. By modifying electrical field phases transmitted through the layers, the antenna gain can be enhanced. In order to produce same phased field, the effective dielectric permittivity at each point is controlled by trimming the dielectric cylindrical shells. The simulation results prove that the gain of monopole antenna is increased 2.2 dB (82% gain enhancement) by this method.

1. Introduction

Antenna gain enhancement has ample profits such as expansion of transmission distance and reduction of power consumption in the transmitter. For modifying the antenna gain, employing array antenna is a common strategy [1]. However, complexity and loss in feeding system are increased due to the expansion of antenna elements. In order to decrease feeding loss, a Fabry-Perot antenna has been suggested [2]. Even though simplicity of holey Fabry-Perot antenna is interesting, the gain of this antenna is too sensitive to the air gap between the frequency selective surface and the ground, and its impedance bandwidth is low. Recently, the concept of phase compensation in flat artificial lens has been introduced to enhance the gain of wide band antennas [3]. By implementing the lens made of composite metamaterial over a horn antenna, the antenna gain has been increased which has some fabrication difficulty, also. A dielectric layer consists of many holes with various radius has been presented to compensate phase difference of horn and patch antennas radiated electric fields, recently [4-6].

In this paper, five dielectric-air cylindrical layers with different thicknesses are employed to compensate phase difference of monopole antenna radiated electric field at 2.8 GHz frequency. In order to achieve same electrical field phase behavior from the layered dielectric structure, the effective electric permittivity idea is used. The effective electric permittivity can be controlled by choosing the dielectric and air thicknesses. The simulation results prove that the antenna gain is increased from 3.14 dB to 5.73 dB by employing this method.

2. Theoretical Approach

2.1 Concept

Radiation pattern of an antenna is determined by Fourier transform calculation of electric field distribution on antenna aperture. With respect to this fact, instead of enlarging antenna aperture, the gain of antenna can be enhanced by compensating phase difference on the antenna aperture.

Assuming a point source as shown in figure 1(a), the electric field phase in a point far from the source directly depends on the distance between it and the observation point, p_2. The phase difference ($\Delta\xi$) between point p_1 and p_2 can be calculated by the following equation [5]:

$$2n\pi + \Delta\xi = \beta_0\left(\sqrt{d^2 + l^2} - d\right) \qquad (1).$$

Where β_0 is the propagation constant in free space, d is the distance between the closest point to the point source (p_1), and l is the distance between p_1 and p_2. With respect to this equation, only when the value of l equals to zero, the electric field in p_1 and p_2 has the same phase. Another way to compensate the phase difference between these points is adding a new term to the right hand side of (1). As it shown in figure. 2 (b), by adding some cylindrical shaped dielectric layers with d_2 thicknesses and different electric permittivity constants at p_1 and p_2 points at the distance d_1 around the source, (1) can be expanded as [5]:

$$2n\pi + \Delta\xi = \beta_0\left(\sqrt{d_1^2 + l^2} - d_1\right) + d_2\beta_0\left(\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}\right) \quad (2).$$

While ε_1 and ε_2 demonstrate the electric permittivity of p_1 and p_2 points, respectively. According to this equation, the phase difference between p_1 and p_2 can be properly compensated by selecting a suitable ε_2 .

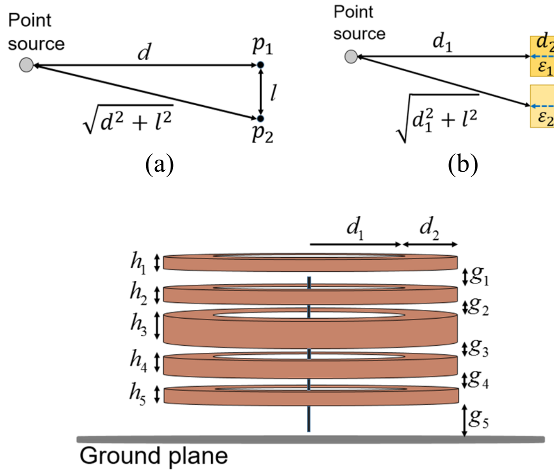

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Figure 1. (a) Point source and phase difference between two points in a same plane, (b) adding dielectric layers around the point source, (c) overall view of the proposed enhanced gain monopole antenna.

2.2 Enhanced Monopole Antenna

The required ε_2 value for compensating phase difference is calculated by the following equation achieved by modifying (2) as

$$\varepsilon_2 = \left[\frac{2n\pi}{\beta_0 d_2} + \sqrt{\varepsilon_1} - \frac{\sqrt{d_1^2 + l^2} - d_1}{d_2}\right]^2 \qquad (3$$

Table 1 shows the selected values for the right hand of (3). Figure 2 shows the ideal required electric permittivity of added dielectric at each point from point source center in order to obtain a same electric field phase on the whole cylindrical surface.

To obtain variable electric permittivity around the monopole antenna, some cylindrical shaped dielectric layer shells should be stacked over each other with air gaps between them. The required ε_2 presented in figure 2 can be achieved by air gap heights tuning. In fact, the effective electric permittivity of the stacked layers can be controlled by changing the height of these air gaps. As shown in figure 2, by increasing the distance from p_1, the value of ε_2 should be decreased to compensate the phase difference. Accordingly, while receding from the center of antenna gain pattern which is around θ=56°, the heights of the inserted air gaps should be increased to compensate the electric field phase.

Table 1. The designed antenna parameter values

Parameter	h_1	h_2	$h3$	$h4$	h_5	d_1	d_2
Value (mm)	1	3	7	2	1	20	55
Parameter	g_1	g_2	g_3	g_4	g_5	ε_1	
Value (mm)	1.5	1	1	2	6.94	10	

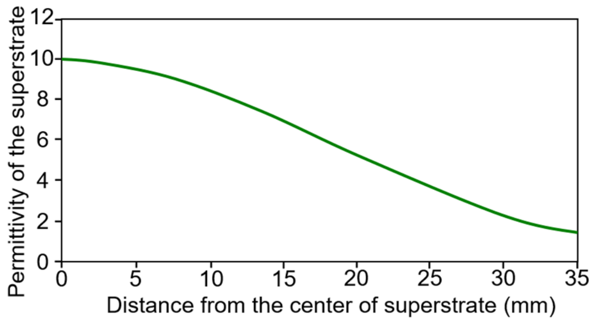

Figure 2. The ideal electric permittivity based on distance from center to have constant electric field phase.

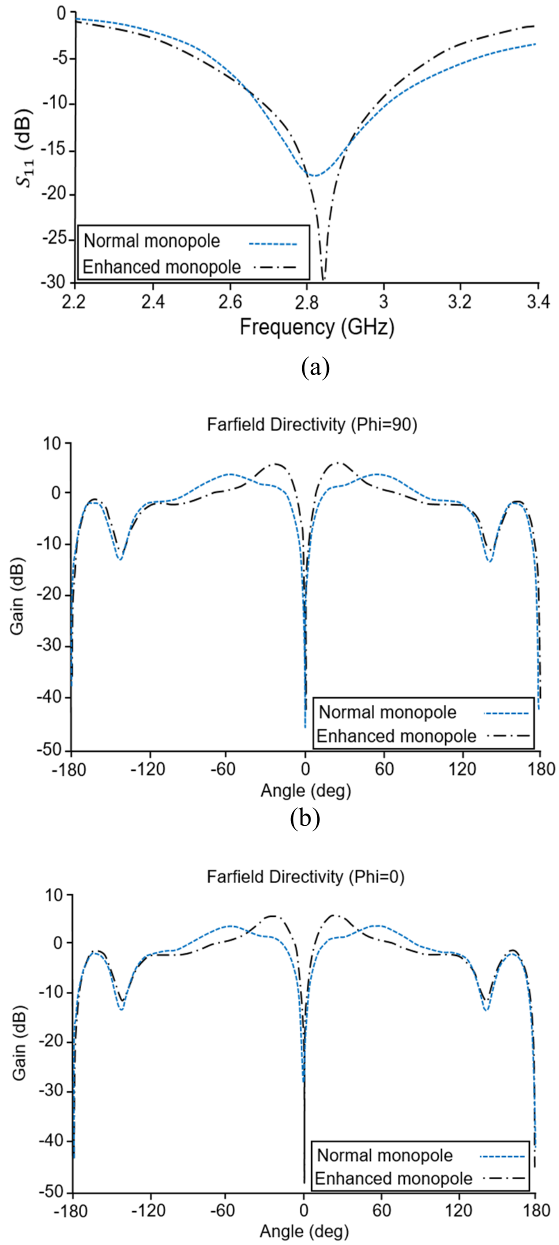

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Figure 3. (a) Simulation results of $|S_{11}|$, (b) E-Plane radiation pattern of the proposed antenna at 2.8 GHz, (c) H-Plane radiation pattern of the proposed antenna at 2.8 GHz.

3. Simulation Results

A conventional monopole antenna at 2.8 GHz resonance frequency with 100 mm radius circular perfect electric conductor (PEC) plane, and a metallic wire with 35 mm length and 0.03 mm radius above the center of PEC plane is simulated by using commercially available full wave simulation software, HFSS. For the enhanced antenna design concept presented in the previous section, the optimized values of the parameters are available in Table I. Fig. 3 (a) shows the simulation result of $|S_{11}|$ parameter for monopole antenna with and without the dielectric layers. As it is demonstrated, the frequency resonance of antenna is almost same in the both circumstances.
The radiation patterns of the normal and enhanced monopole antenna at 2.8 GHz frequency at E and H-Plane are shown in figure 3(b) and 3(c), respectively. While the maximum gain of the normal monopole antenna is 3.14 dB, adding the designed layered enhances the antenna gain to 5.73 dB (82% gain enhancement) which proves the veracity of the method.

4. Conclusion

A method for enhancing the antenna gain by implementing five cylindrical shaped layered shells around a normal monopole antenna was presented. By stacking many cylindrical shaped dielectric layers with different thicknesses and air gaps between them, effective electric permittivity around the antenna was controlled. The thicknesses of the added cylindrical layers and air gaps directly determine the variation of effective electrical permittivity at each point. The full wave simulation of the enhanced antenna shown same resonance frequency with the normal monopole antenna, while the antenna gain was enhanced over 80% percent (from 3.14 dB to 5.73 dB).

5. References

1. Y. J. Cheng, Y. X. Guo, and Z. G. Liu, "W-band large-scale high-gain planar integrated antenna array,"*IEEE Trans. Antennas Propag.*, **62**, 6, June 2014, pp. 3370–3373, doi: 10.1109/TAP.2014.2310483.

2. A. Hosseini, F. Capolino, and F. De Flaviis, "Gain enhancement of a Vband antenna using a Fabry-Pérot Cavity with a self-sustained all metal cap with FSS," *IEEE Trans. Antennas Propag.*, **63**, 3, March 2015, pp. 909–921, doi: 10.1109/TAP.2014.2386358.

3. D. Ramaccia, F. Scattone, F. Bilotti, and A. Toscano, "Broadband compact horn antennas by using EPS-ENZ metamaterial lens," *IEEE Trans. Antennas Propag.*, **61**, 6, June 2013, pp. 2929–2937, doi: 10.1109/TAP.2013.2250235.

4. M. T. Al-Nuaimi, W. Hong, and Y. Zhang, "Design of high-directivity compact-size conical horn antenna," *IEEE Antennas Wireless Propag. Lett*, **13**, March 2014, pp. 467–470, doi: 10.1109/LAWP.2013.2297519.

5. J. H. Kim, C. H. Ahn and J. K. Bang, "Antenna gain enhancement using a holey superstarte," *IEEE Trans. Antennas Propag.*, **64**, 3, March 2016, pp. 1164-1167, doi: 10.1109/TAP.2016.2518650.

6. M. S. M. Mollaei, E. Zanganeh, and M. F. Farahani, "Enhancement of patch antenna gain using cylindrical shell shaped superstrate," *IEEE Antenna Wireless Propag. Lett*, **16**, August 2017, pp. 2570-2573, doi: 10.1109/LAWP.2017.2734802.