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# Cylindrical Electromagnetic Bandgap Structures for Directive Base Station Antennas

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**Abstract**—This paper presents a new method to realize directive base station antennas by incorporating cylindrical electromagnetic bandgap (EBG) structures. The EBG structure behaves as a partially reflecting surface (PRS) and significantly enhances the E-plane directivity of a simple radiating dipole positioned in front of a metallic cylinder. A novel cylindrical antenna that operates at 2.4 GHz is simulated and presented.

**Index Terms**—Antennas, arrays, base station, electromagnetic bandgap, periodic structures.

## I. INTRODUCTION

BASE station antennas with broad beamwidth in the azimuth ( $H$ -) plane and narrow (directive) beamwidth in the elevation ( $E$ -) plane are an important requirement for modern wireless communication applications [1]. Omnidirectional azimuthal patterns are also required for specific designs [2]. One-dimensional antenna arrays with complex feeding mechanisms have been commonly used to produce high directivity in the elevation plane and wide horizontal beams [1]. However, a way of producing highly directive planar antennas with a simple feed, has been presented in the past [3] and revisited recently [4]. According to this method, planar electromagnetic bandgap (EBG) arrays, [5], have been used as superstrate layers to enhance the directivity of microstrip patches and waveguide-fed apertures in a ground plane.

In this letter, we present the application of cylindrical EBG arrays to the design of directive base station antennas. A cylindrical EBG surface is designed and used as a means to significantly increase the directivity of a simple dipole. The EBG surrounds a metallic cylinder at a specific radial distance. A dipole is used as the feeding source positioned between the EBG and the metallic cylinder that acts as the ground. The cylindrical EBG array behaves as a partially reflective surface (PRS) forming a resonant cavity with the metallic ground. A significant enhancement of the directivity in the elevation plane is achieved, whereas the wide horizontal pattern of the dipole is maintained. An approximate analysis has been used in order to provide with design guidelines and physical insight. Full-wave three-dimensional (3-D) simulations of the structure have been carried out using Micro-stripes, a TLM-based software [6]. The antenna directivity, radiation patterns, and field distribution are presented.

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## II. ANTENNA DESCRIPTION

The proposed antenna configuration is shown in Fig. 1. It consists of a metallic cylinder (ground), a simple dipole source and a cylindrical EBG-PRS (referred to henceforth as PRS) comprised of a periodic array of rectangular patches.

A ray analysis has been initially employed to model the antenna performance in the  $E$ -plane as a resonant cavity effect. Following this method a simple equation that expresses the resonance condition of the cavity has been derived. The resonant distance  $L_r$  (Fig. 1) that produces maximum directivity in the  $E$ -plane is determined by [3]

$$L_r = \left( \frac{\phi(0)}{\pi} - 1 \right) \frac{\lambda_0}{4} + N \frac{\lambda_0}{2}, \quad N = 1, 2, 3, \dots \quad (1)$$

where  $\lambda_0$  is the free-space wavelength, and  $\phi(0)$  is the reflection coefficient phase of the PRS. From the same analysis, an approximate qualitative equation for the maximum directivity at resonance can be derived [4]

$$D = \frac{1 + R}{1 - R} \quad (2)$$

(see Fig. 1). The antenna is sectorised in two parts using metallic sheets along the vertical axis of the cylindrical structure. The metallic sheets were used in order to reduce backward radiation. Following (2) high reflectivity values result in high directivity. The above equations assume planar surfaces (PRS and ground) of infinite extent (no edge effects) and ignore higher order mode coupling. Here, they are used in order to predict approximately the resonant distance and the antenna directivity in the  $E$ -plane, where the structure resembles the planar configuration. The PRS reflection response is simulated using Floquet modal analysis of infinite planar arrays [7]. A PRS of  $L_D = 61$  mm,  $W_D = 26$  mm,  $D_x = 28$  mm and  $D_y = 64$  mm [Fig. 2(a)] has been designed. The complex reflection coefficient of the planar PRS is shown in Fig. 2(b). High reflectivity values are obtained from the PRS at about 2.4 GHz which, according to (2), translates to high directivity in the elevation plane. For practical implementation a readily available thin (e.g., 25  $\mu$ m) dielectric substrate can be used together with a cylindrically shaped foam ( $\epsilon_r = 1.05$ ) to support the PRS. However, the effect of these substrates to the reflection response is negligible, and will not be taken into account.

## III. RESULTS

The cylindrical antenna was modeled in a 3-D TLM based software (Microstripes). The code uses a nonuniform

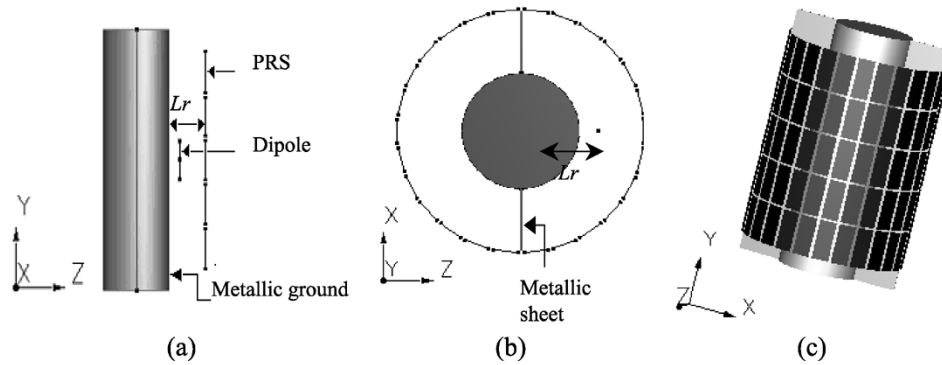


Fig. 1. Schematic representation of the proposed base station antenna. (a) Side view. (b) Top view. (c) 3-D view.

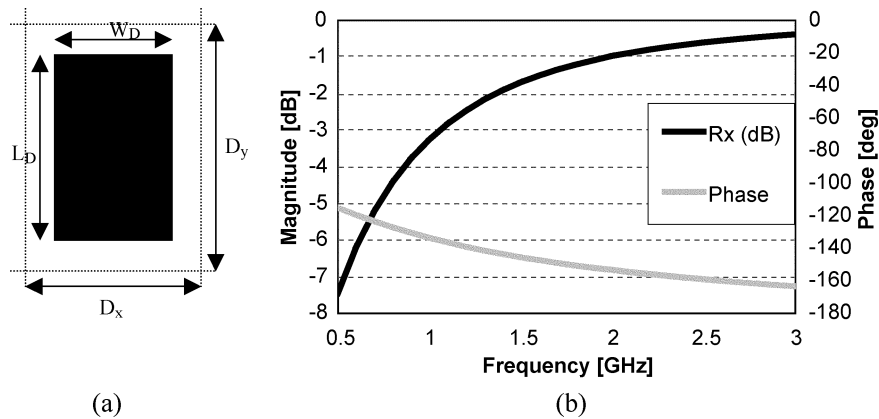


Fig. 2. (a) Unit cell of planar rectangular patch array. (b) Complex reflection coefficients of PRS.

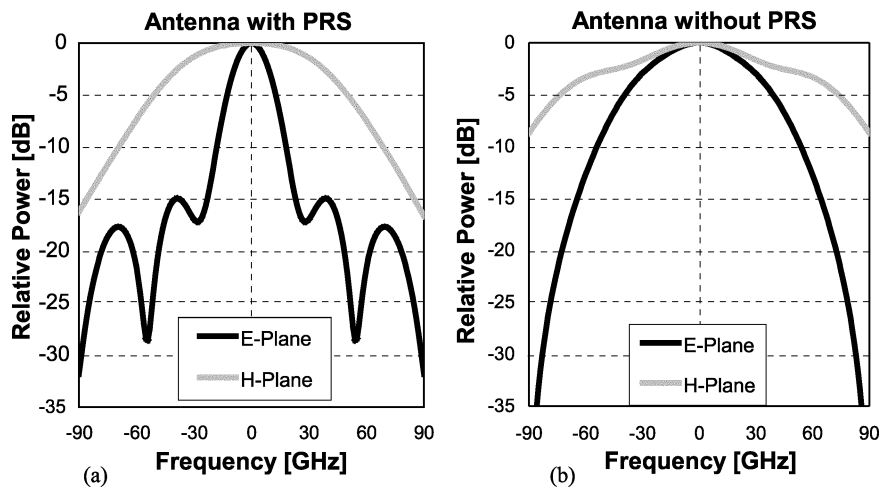


Fig. 3. Simulated radiation patterns of cylindrical antenna (a) with and (b) without PRS at 2.4 GHz.

rectangular meshing. A high resolution mesh has been employed in order to model the curved cylindrical faces with a good accuracy. A 3-D view of the model is shown in Fig. 1(c). A metallic cylinder of length 380 mm and radius 60 mm was used as the ground. The length of the cylinder was restricted due to limited computational resources. The total number of cells was 6.9 million with a minimum cell size of 0.5 mm. The simulation was carried out on a 2.8-GHz dual-processor Pentium 4 computer and required 702 MB of memory. For an antenna design at 2.4 GHz, the PRS was positioned at a resonant distance of  $L_r = 66$  mm from the ground as calculated

from (1). It was comprised of five rows of rectangular patch elements. The feeding of the antenna was done by a wire dipole model of 56 mm length placed 20 mm from the ground.

The  $H$ - and  $E$ -plane radiation patterns of the antenna are shown in Fig. 3(a). The corresponding patterns of the antenna without the PRS are shown in Fig. 3(b). It is evident that the directivity in the  $E$ -plane increases significantly, by virtue of the PRS. However, the  $H$ -plane pattern is only slightly affected. This is expected due to the azimuthal symmetry of the cylindrical structure. The overall directivity increased from 7.9 to 13.4 dBi. The sidelobe level in the  $E$ -plane is below  $-15$  dB.

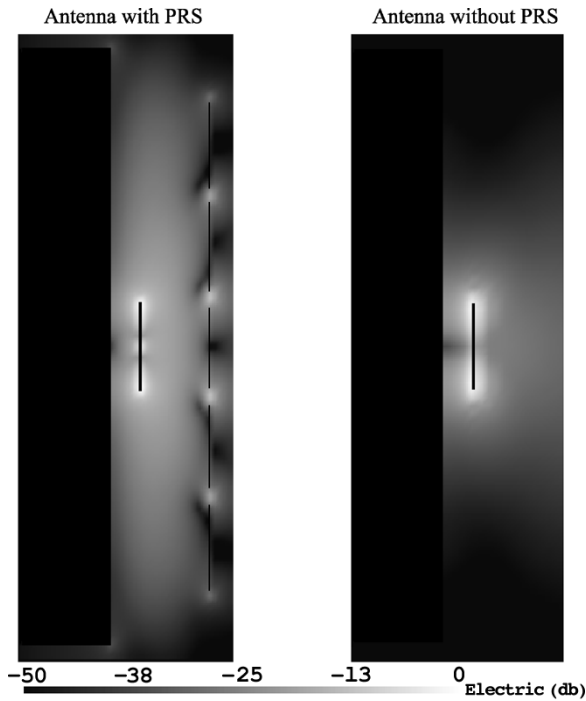


Fig. 4. Field distribution at the antenna cross-section ( $yz$ -plane) with and without the PRS at 2.4 GHz.

This can be further reduced by increasing the overall length of the cylindrical antenna. The electric field distribution at the  $yz$ -plane cross section of the antenna is shown in Fig. 4, for both cases (with and without the PRS). The metallic cylinder, dipole and PRS appear in black. As shown in Fig. 4, by employing the PRS strong fields are produced in the resonant cavity. The fields extend until the edges of the PRS with a quite uniform distribution. This increases the antenna radiating aperture and hence the directivity. Fig. 5 shows the directivity of the antenna with and without the PRS for a range of frequencies. Based on Fig. 5 the center operating frequency of the antenna is about 2.4 GHz. For practical implementation, matching of the dipole can be done at this frequency of maximum directivity using conventional techniques (e.g., stubs on the feeding line).

#### IV. CONCLUSION

A new application of EBG-PRS arrays to the design of base station antennas has been presented. Cylindrical PRS arrays have been utilized to increase the  $E$ -plane directivity of a

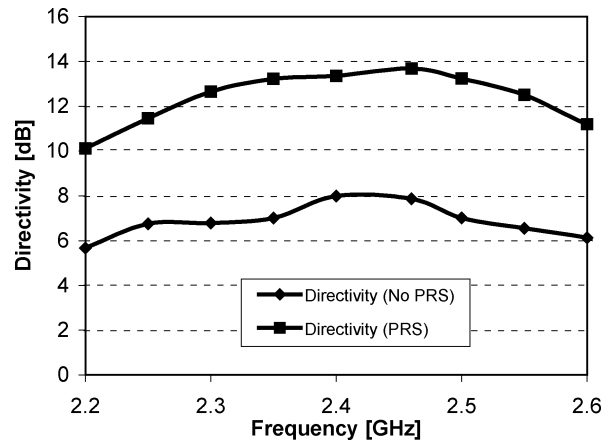


Fig. 5. Antenna directivity with and without the PRS.

simple dipole placed in front of a cylindrical metallic ground. The overall directivity as obtained in 3-D simulations almost doubled. The  $E$ -plane pattern becomes more directive whereas the  $H$ -plane changes slightly. The proposed structure dispenses with the need for complex feeding mechanisms of dipole array antennas.

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#### REFERENCES

- [1] X. M. Zhang, K. M. Luk, C. H. Chan, J. R. James, and C. H. Liang, "Design of a shaped beam cylindrical dipole array for cellular base stations," *Proc. Inst. Elect. Eng. Microwaves, Antennas Propagat.*, vol. 147, pp. 295–299, Aug. 2000.
- [2] N. Herscovici, Z. Sipus, and P. S. Kildal, "The cylindrical omnidirectional patch antenna," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 1746–1753, Dec. 2001.
- [3] G. V. Trentini, "Partially reflecting sheet arrays," *IRE Trans. Antennas Propagat.*, vol. AP-4, pp. 666–671, Oct. 1956.
- [4] A. P. Feresidis and J. C. Vardaxoglou, "High gain planar antenna using optimized partially reflective surfaces," *Proc. Inst. Elect. Eng. Microwave, Antennas Propagat.*, vol. 148, pp. 345–350, Dec. 2001.
- [5] P. De Maagt, R. Gonzalo, J. C. Vardaxoglou, and J. M. Baracco, "Photonic bandgap antennas and components for microwave and (sub)millimeter wave applications," *IEEE Trans. Antennas Propagat.—Special Issue Metamater.*, vol. 51, pp. 2667–2677, Oct. 2003.
- [6] *Micro-Stripes 6.0 Reference Manual*, Flomerics Ltd., Surrey, U.K., 2002.
- [7] J. C. Vardaxoglou, *Frequency Selective Surfaces: Analysis and Design*. Somerset, U.K.: Research Studies, 1997.