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Dual-antenna system composed of patch array and open-ended waveguide for eliminating blindness of wireless communications

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Abstract: In mobile communications in urban area, it is a significant problem that blind spots of in the narrow street are caused by high buildings. In this research, a new dual-antenna system is proposed, including a receiving and a reradiating antenna and feeding networks to realize a broad-angle beam control. An equivalent bistatic radar cross section (BRCS) is deduced to evaluate the antenna performance. The main advantage of this design over ordinary reflectarray antenna as a passive RF booster is its flexible beam control capabilities.

Keywords: reflectarray, communication blindness, radar cross section

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

It is a serious problem that the propagation channel of mobile communications is blocked by high and dense buildings in urban area, especially in narrow streets, which are called blind spot problem. Generally, RF boosters are used to eliminate these blind spots, but they are at very high cost because receivers, transmitters, power supplies are required. In our previous works [1], a reflectarray antenna was developed to solve the problem, where a broadband reflectarray antenna was designed as a passive booster to solve the blind spot problem. However, the gain of reflectarray is greatly degraded when a very broad scattering angle is desired. In this research, a new dual-antenna system is proposed, including a receiving and a reradiating antenna to realize a broad-angle beam control. An equivalent bistatic radar cross section (BRCS) is deduced to evaluate the dual-antenna performance.

2 Equivalent BRCS of dual-antenna system

Figure 1 shows the schematic of propagation channel in an urban area, where Antennas #1, #2, #3, and #4 represent the antennas for base station, receiving and reradiating antennas of the dual-antenna system, and the user, respectively. The distance between Antennas #1 and #2, #3 and #4 are denoted by R_{21} and R_{43}, respectively. In this design, the electromagnetic (EM) waves for downlink propagation as follows: first, Antenna #2 receives the EM waves from the base station; then, the received waves are guided by a low-loss transmission line and reradiated by Antenna #3, and finally received by Antenna #4. Here the dual-antenna system can be evaluated in terms of an equivalent BRCS, similar to an ordinary scattering object. The channel gain can be calculated by two methods: Friis transmission equation in Equation (1) and radar range equation in Equation (2):

$$\frac{P_{r4}}{P_{t1}} = \left(\frac{\lambda}{4\pi}\right)^4 \left(\frac{1}{R_{21}R_{43}}\right)^2 G_{t1}G_{r2}G_{t3}G_{r4}. \tag{1}$$

where G_{t1}, G_{r2}, G_{t3}, and G_{r4} are gains of Antennas #1, #2, #3, and #4, respectively, if we introduce a parameter σ_{eq} as the equivalent BRCS of the

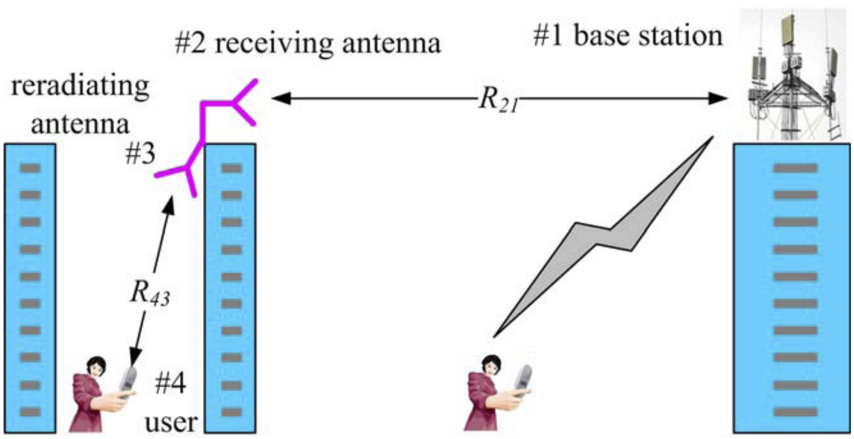

Fig. 1. Schematic of propagation channel in urban area.

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proposed dual-antenna system, Equation (1) can be expressed as

$$\frac{P_{r4}}{P_{t1}} = \left(\frac{G_{t1}}{4\pi R_{21}^2}\right)\left(\frac{\sigma_{eq}}{4\pi R_{43}^2}\right)\left(\frac{G_{r4}\lambda^2}{4\pi}\right). \tag{2}$$

and σ_{eq} can be calculated from Equations (1) and (2):

$$\sigma_{eq} = \frac{\lambda^2}{4\pi}G_{t2}G_{r3}. \tag{3}$$

It is clear that σ_{eq} is proportional to the gains of Antennas #2 and #3. Therefore, if a large σ_{eq} is expected, we should make the gains of Antennas #2 and #3 as high as possible. It should be noted that the complicated scattering process of dual-antenna system in practice will deteriorate the accuracy of this equation which is assumed in an ideal situation, but the equivalent BRCS can still give us a qualitative evaluation of the performance.

3 Geometry of dual-antenna system

The next important step is to realize this kind of dual-antenna system by designing proper Antennas #2 and #3. In our design, a microstrip patch antenna in [2] is employed to build a 4×1 array as the receiving Antenna #2, and an open-ended waveguide antenna with a flare angle as the transmitting Antenna #3. A power divider/combiner based on strip line structure is used to feed the patch array for easy connection consideration, and a wideband transition from strip line to rectangular waveguide is also employed to lead

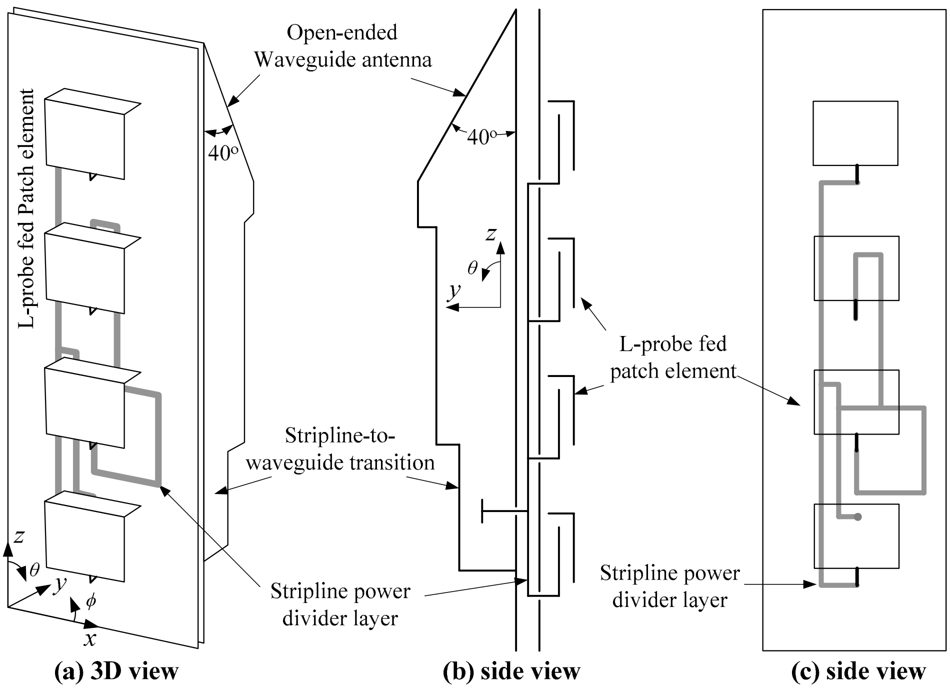

Fig. 2. Geometry of dual-antenna system composed of a patch array, a feeding network for patch array, a transition from rectangular waveguide to strip line, and an open-ended waveguide antenna.

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the received EM power from Antenna #2 to Antenna #3. Figure 2 shows the geometry of this dual-antenna system operating at 2 GHz, where the flare angle of the open-ended waveguide antenna is 40°, which is called one unit in this paper. The size of one unit is 115 mm, 75 mm and 335 mm along x, y and z directions, respectively. We can closely combine this kind of units as many as desired together to increase σ_{eq}, and to further improve the gains of receiving and reradiating antennas.

4 Simulation results

Simulated radiation patterns of the open-ended waveguide and the microstrip patch array at 2 GHz are given in Figure 3 (a) and (b). It can be seen that the peak gain of the open-ended waveguide is along $\theta \approx 45°$ in yz plane ($\phi = \pi/2$) and that of the patch array along $\theta \approx 0°$ in yz plane ($\phi = 3\pi/2$), and their simulated values are ∼8 dBi and ∼10 dBi, respectively. Simulated equivalent BRCS of 4-unit close combination along x direction is given in Figure 4, compared to that of a metal plate with the same dimensions. The maximum BRCS in the figure is along 17° direction in yz plane ($\phi = 3\pi/2$) because of the complicated scattering process when the plane wave is normally incident to the proposed dual-antenna system. The same reason causes the achieved BRCS larger than that computed by Equation (1). It is obvious that 4-unit dual-antenna system can provide much large equivalent BRCS in $\theta < 30°$ along both $\phi = \pi/2$ and $\phi = 3\pi/2$ directions than a metal plate with the same size placed in the xz plane, proving the effectiveness of this method.

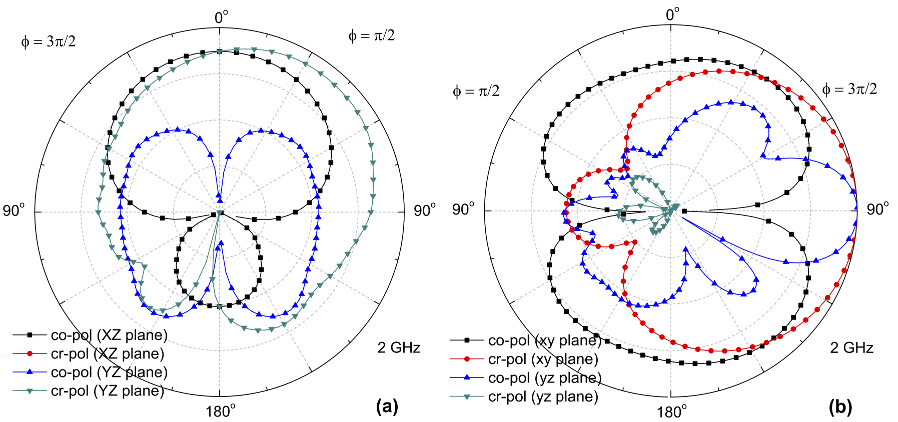

Fig. 3. Simulated radiation patterns of (a) the open-ended waveguide and (b) the microstrip patch array at 2 GHz. (10 dB/Div)

5 Conclusion

A dual-antenna system for large beam angle application to eliminate blindness of wireless communications was developed. This system can reradiate the EM wave to any desired direction which is difficult to be realized by

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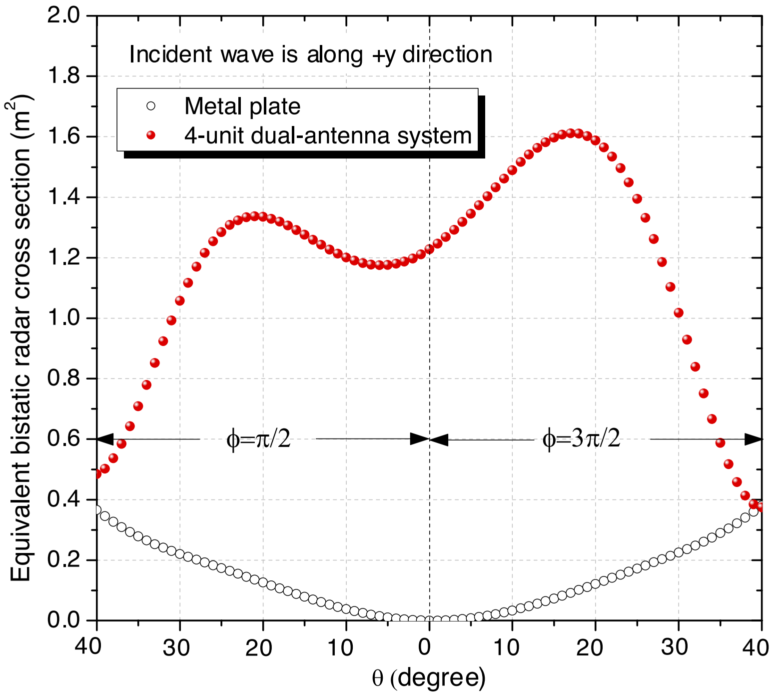

Fig. 4. Simulated equivalent BRCS of 4-unit combination along x direction, compared to that of a metal plate with the same dimensions.

reflectarray antennas. Simulated results given in this paper can effectively prove the validity of this kind of dual-antenna system.

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