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A Broadside Three-Port Antenna for 5G Massive MIMO Antenna Systems

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***Abstract*—This paper presents a broadside antenna with three ports operating at the same frequency. The TM_{030} and TM_{003} modes of a patch are excited by two coaxial cables to generate two orthogonal linear polarizations. The patch can be transformed into a slotted SIW cavity whose TE_{201} and TE_{102} modes are jointly excited by the third cable. A matching cavity and a matching patch are introduced to broaden the impedance bandwidth of the third port. The simulated results show that the isolations between these three ports are higher than 18 dB, even though the radiation patterns of the three ports are all broadside. The proposed three-port antenna can provide a solution to increase the number of the ports per unit area in outdoor massive MIMO antennas.**

I. Introduction

Multiple-input multiple-output (MIMO) technology is an important feature of advanced cellular wireless communication systems [1]. To practically realize multi-user MIMO, massive MIMO was proposed in [2] to achieve more dramatic gains and simplify the required signal processing. Generally, the number of antennas in a massive MIMO base station (BS) should be significantly larger than the number of users, which means each BS is equipped with orders of magnitude more antennas than a conventional BS [3]. As a consequence, the size of a massive MIMO BS array is physically large, especially for frequency bands below 6 GHz. A large BS array is undesirable due to a large wind load, requiring a stronger and hence more expensive BS tower structure. Moreover, a large BS tower is aesthetically unattractive. Therefore, it is important to reduce the size and weight of massive MIMO antennas.

Introducing loaded slot and truncated corner [4] can make the antenna element smaller. However, the size reduction is limited. Recently, metamaterial loading and artificial magnetic conductors were proposed to make the antenna element or array more compact [5], [6]. However, the additional structures make the array more complicated. In [7], the number of ports of each array element was increased to achieve a more compact massive MIMO array, but the array is only suitable for an indoor BS since not all radiation patterns are broadside.

In this paper, a three-port antenna with broadside radiation pattern is proposed to increase the number of ports per element and hence reduce the size of the antenna array. The envelope correlation coefficients (ECCs) between all pairs of ports are lower than 0.29 due to differences in polarization and pattern shape. A matching cavity and a matching patch are used to broaden the bandwidth of the cavity-slot antenna, making the design suitable for the 3.5 GHz 5G band.

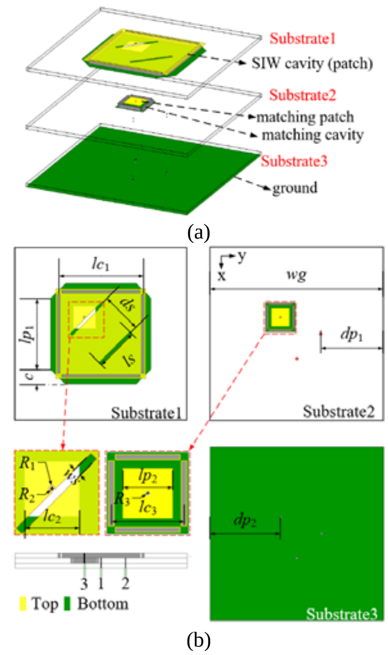

Fig. 1 Configuration of the proposed three-port antenna: (a) 3D view, (b) detail dimensions of each layer (wg = 105.5, lp_1 = 43.5, c = 9, lc_1 = 51.5, lc_2 = 14, lc_3 = 16, lp_2 = 11, ls = 26.8, ws = 2, ds =25, dp_1 = 15.75, dp_2 = 20.75, R_1 = 0.8, R_2 = 0.5, R_3 = 0.5, unit: mm).

II. Three-Port Antenna Design and Results

A. Antenna Design

Figure 1 presents the structure of the proposed antenna, which is a stacked structure consisting of three boards. The slotted SIW cavity with four rectangular metal grooves is arranged in substrate1. A square slot is etched on the bottom of the SIW cavity to connect the SIW cavity to the matching cavity formed in substrate2. The two substrates are Rogers RO4350 with relative permittivity (ε_r) of 3.66, loss tangent (tan δ) of 0.004 and thickness (d) of 2 mm. A matching patch located in the center of the square slot is printed on the top side of substrate2. The TE_{201} and TE_{102} modes of the cavity are simultaneously excited by a coaxial probe in the center of the matching cavity. The impedance bandwidth can be largely improved by optimizing the dimensions of the matching cavity and matching patch. The combination of the SIW cavity and the matching cavity can be regarded as a patch. The ground is printed on the bottom of substrate3 (FR4-epoxy with ε_r = 4.4, tan δ = 0.02, d = 2 mm). Two coaxial cables along the x- and y-axis, respectively, are used to excite the TM_{030} and TM_{003}

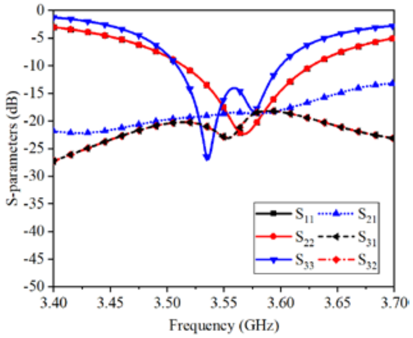

Fig. 2 Simulated S-parameters of the three-port antenna.

modes of the patch.

For a typical dual-polarized patch antenna operating in the odd modes of the patch, high isolation between the two ports is achieved due to the orthogonality in polarization. In this design, the feeding coaxial cable of the cavity slot antenna plays the role of a shorting post, which may disturb the field of the patch antenna. To reduce the shorting effect, the feeding coaxial cable should be as closed as to the minimum electric field area of the patch. Therefore, TM_{030} and TM_{003} modes of the patch are chosen in this design, which also ensures that the patch antenna and the cavity slot can work at the same frequency. The polarizations of port1 and port2 are along the *x*- and *y*-axis, respectively, so that low ECC is obtained for these two ports. The radiation pattern of port3 is slightly different from that of the other two ports and the polarization of this port is along +45º, which helps to lower the ECCs between port3 and the other two ports.

B. Simulation Results

The proposed antenna is simulated using frequency domain solver in CST2018. The simulated S-parameters of the proposed design are given in Fig. 2. The 10 dB impedance bandwidths are 3.1% (3.514-3.627 GHz) for port1, port2, and 2.8% (3.5-3.6 GHz) for port3. The isolation of any two ports is above 18 dB. Fig. 3 shows the radiation patterns for the three ports at 3.58 GHz when one port is excited and others are matched to 50Ω. The results show that the radiation patterns of all three ports are broadside. As shown in Fig. 4, the realized peak gains are higher than 8.7 dB for port1 and port2 and higher than 4.2 dB for port3 in the operating band (3.52-3.60 GHz). The ECC in the operating band is lower than 0.01 for any antenna pair.

III. Conclusion

To increase the density of the antenna ports in massive MIMO antenna systems, a low-profile three-port stacked antenna with broadside patterns is proposed in this paper. The cavity-slot antenna can be regarded as a patch antenna and its impedance bandwidth is broadened using a matching cavity and a matching patch. The isolation between ports can be higher than 18 dB due to proper arrangement of the feeding location for port3 and differences in polarization and pattern shape. The proposed antenna element is expected to be applied in massive MIMO array to reduce its size and weight.

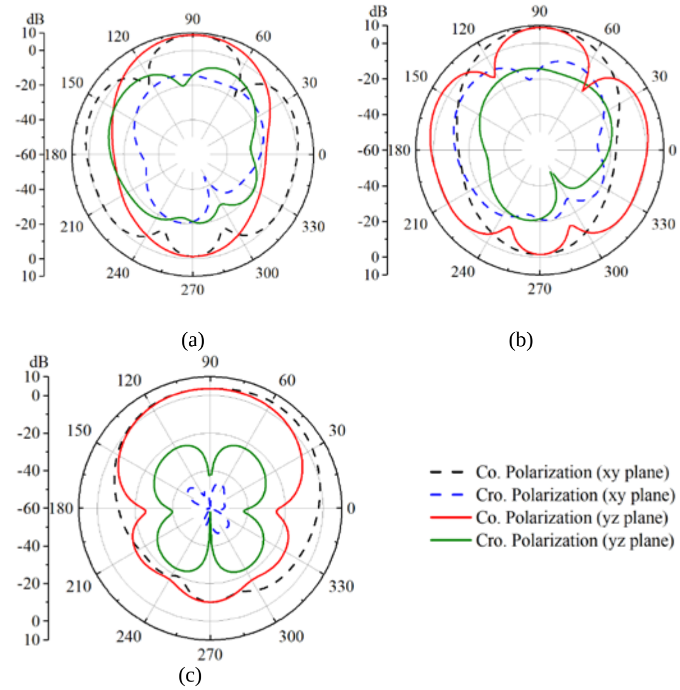

Fig. 3 Radiation patterns of (a) port1 (b) port2, and (c) port3 at 3.58 GHz (*x*- and *y*-axis are rotated by +45º for port3).

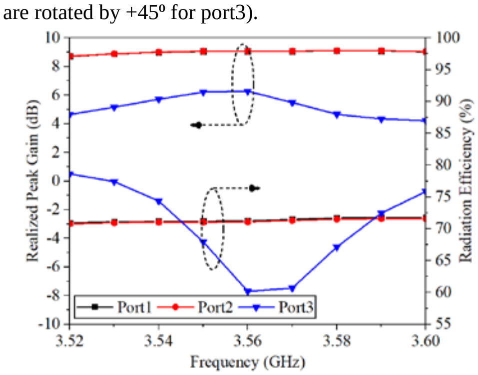

Fig. 4 Simulated realized peak gain and radiation efficiency of the proposed three port antenna

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