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A CAVITY-BACKED APERTURE-COUPLED MICROSTRIP PATCH ANTENNA ARRAY WITH SUM/DIFFERENCE BEAMS

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Abstract—This paper presents a new cavity-backed aperture-coupled microstrip patch antenna (ACMPA) array with sum/difference beams. It is composed of a feed network and two aperture-coupled elliptical patch antennas. A metallic cavity is used at the back of the antenna array to minimize the back radiation. The feed network is realized by a planar magic-T, which consists of microstrip and slotline T-junctions coupled by microstrip-slotline transitions. The antenna is designed, manufactured and tested at 35 GHz. Measurements show clean and symmetrical patterns are realized for both the sum and difference beams. The measured −3-dB E- and H-plane beamwidths of the sum pattern are 55.8° and 77.6°, respectively. A deep null of −32.4 dB is achieved for the difference pattern. Meanwhile, the measured return losses for both the sum and difference ports are less than 10 dB from 34.2–36.6 GHz corresponding to a bandwidth of 6.8%. Within this bandwidth, the isolation between the sum and the difference ports is better than 38 dB.

1. INTRODUCTION

Microstrip patch antennas have been widely used in modern communication systems due to their attractive features such as low profile, light weight and low fabrication cost. However, these antennas exhibit inherently narrow bandwidth. In recent years, intensive efforts have been invested in order to increase the bandwidth of microstrip

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patch antenna. As we known, the bandwidth of the microstrip patch antenna becomes wider as the size of the antenna becomes bigger. Consequently, common small microstrip patch antennas are typically limited to bandwidths of 2%–5%. In order to enhance the bandwidth of the patch antenna without enlarging the size of the antenna, an ACMPA was proposed by Pozar [1]. In this antenna, the patch was coupled through an aperture to a microstrip feed line on a separate parallel substrate bonded to the antenna substrate. The attractive feature of this approach is that it allows independent optimization of both the microstrip patch and feed substrates. So it can increase the bandwidth of patch antenna by designing a matching network in the feed line. Antenna of this type also provides good isolation between the radiating element and the feed circuit, thus having the potential of low cross-polar radiation. Such antennas have been widely reported in the literatures [2–9].

In this paper, an ACMPA array with sum/difference beams is presented. A metallic cavity is used at the back of the antenna array to minimize the back radiation [10-13]. This antenna array can achieve two-dimensional monopulse performance, and can be easily integrated with a dielectric lens or reflector for monopulse applications because of its simple structure [14]. A commercial software CST-MWS is used to analyze and design the antenna at 35 GHz. Details of the antenna design and experimental results are presented and discussed.

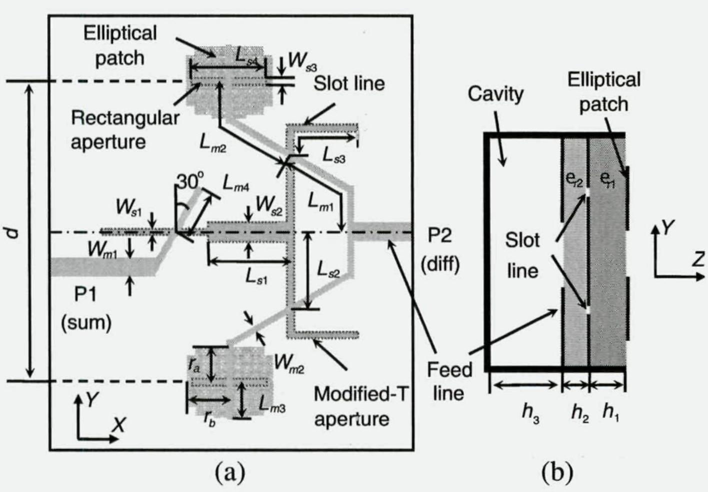


Figure 1. Structure of the proposed ACMPA array. (a) Top view. (b) Side view.

2. STRUCTURE AND THEORY

Figure 1(a) illustrates the structure of the proposed ACMPA array, which consists of two printed elliptical patch antennas and a feed network. The two patch antennas are printed on a low-permittivity substrate Arlon Di880 ($\varepsilon_{r1} = 2.2$), and the feed network with sum/difference ports is built on a high-permittivity substrate Arlon TC600 ($\varepsilon_{r2} = 6.15$). A modified T-shaped aperture and two rectangular apertures are etched on a ground plane which separates the two substrates. These choices for the substrate are made to increase the bandwidth, as well as to reduce the parasitic radiation losses due to the feed network [15].

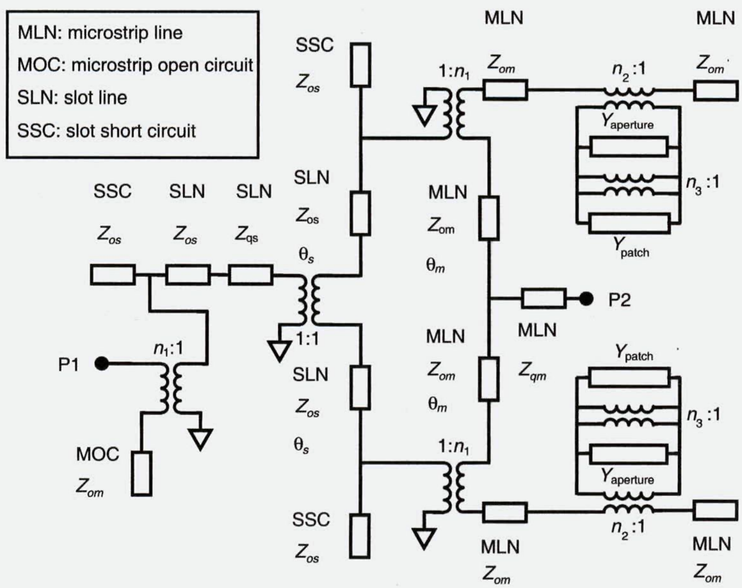


Figure 2. Equivalent circuit of the proposed ACMPA array.

Table 1. Structure parameters.

parameter	Value (mm)
θ_m	π
θ_s	$\pi/2$
Z_{qm}	$Z_{om}/\sqrt{2}$
Z_{qs}	$\sqrt{2}Z_{os}$
n_1	$\sqrt{Z_{om}/Z_{os}}$

The feed network which may be considered as a printed magic-T using microstrip-slot transition [16]. The equivalent circuit of the proposed ACMPA array is shown in Figure 2. Table 1 shows the values of the structure parameters for the equivalent circuit. The transformation ratios n_2 and n_3 can be efficiently calculated by the method described by Himdi [17]. The electric field and current distributions of the proposed ACMPA array are shown in Figures 3(a) and (b), respectively, which enable us to have a conceptual understanding of the in-phase and out-of-phase feeding mechanism. Meanwhile, Figure 4 shows the simulated electric filed and current distributions using CST-MWS. As shown, when the sum port (port 1) is excited, the line A-B which is in the ground plane becomes virtual short. The equivalent circuit can, therefore, be further simplified as shown in Figure 5(a). The input signal at port 1, is equally split into two components to excite the two elliptical patches with a phase difference of 180°, and port 2 becomes isolated. As a result, the two elliptical patches are in-phase radiation, so the sum beam is generated. On the other hand, when the difference port (port 2) is excited, A-B becomes virtual open, and the equivalent circuit is simplified as shown in Figure 5(b). It should be noted that the input signal is evenly split into two in-phase components to excite the two elliptical patches, and port 1 is isolated. In this case, the two elliptical patches are out-of-phase radiation, and the difference beam is launched. Then, a metallic cavity is used at the back of the antenna array to minimize the back radiation. The values of the design parameters are listed in Table 2. The distance d between the two elliptical patches is optimized to avoid grating lobes (sum beam) and minimize the effects

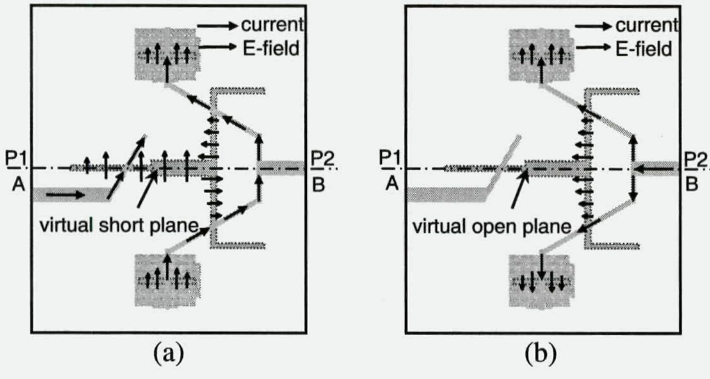


Figure 3. Electric field and current distributions. (a) In-phase radiation. (b) Out-of-phase radiation.

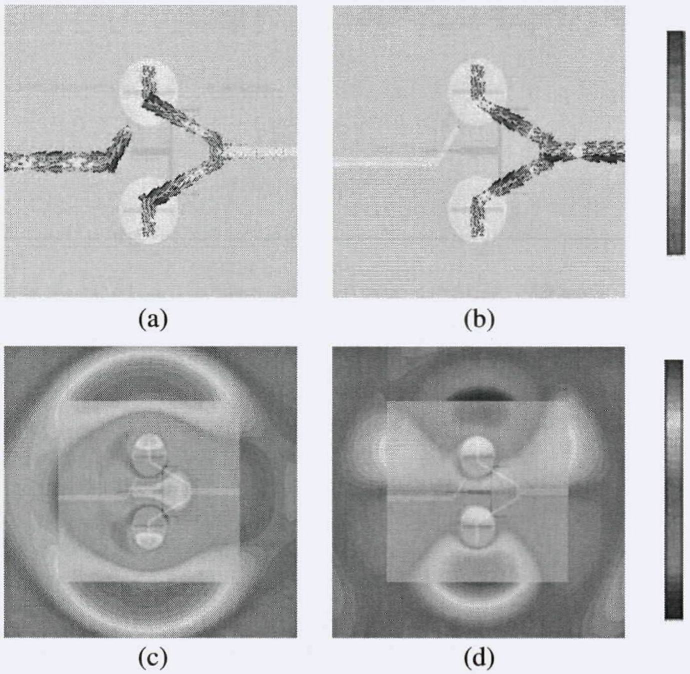


Figure 4. Simulated electric field and current distributions using CST-MWS. (a), (c) In-phase radiation. (b), (d) Out-of-phase radiation.

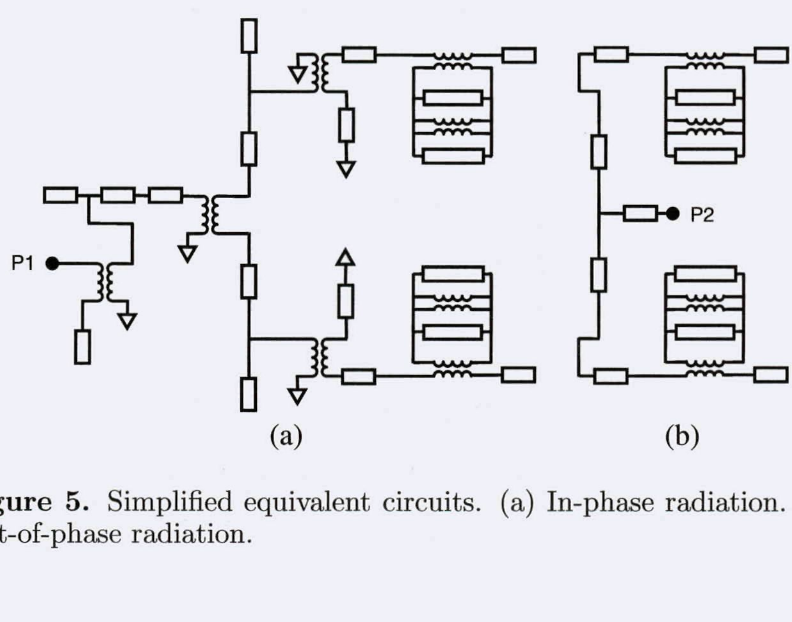
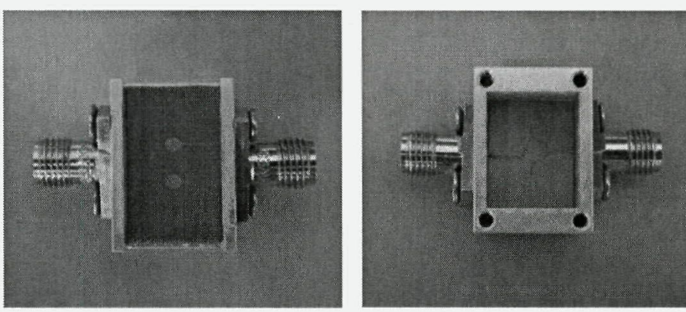


Figure 5. Simplified equivalent circuits. (a) In-phase radiation. (b) Out-of-phase radiation.

Table 2. Design parameters.

parameter	Value (mm)	parameter	Value (mm)
W_{m1}	0.39	L_{m4}	0.94
W_{m2}	0.19	L_{s1}	1.38
W_{s1}	0.10	L_{s2}	1.40
W_{s2}	0.29	L_{s3}	1.20
W_{s3}	0.10	L_{s4}	1.90
L_{f1}	3.66	r_a	1.1
L_{f2}	4.22	r_b	1.26
L_{m1}	2.37	h_1	0.508
L_{m2}	1.24	h_2	0.254
L_{m3}	1.05	h_3	10.0



(a) (b)

Figure 6. Photograph of the fabricated ACMPA array. (a) Top view. (b) Bottom view.

of mutual coupling (difference beam). It can be found that the best compromise between the sum and the difference beam is achieved when $d = 4.4\,\text{mm}$. The main advantage of the elliptical patch array is that it can generate a wider illumination beamwidth in E-plane than the traditional rectangular one.

3. RESULTS AND DISCUSSION

A photograph of the fabricated ACMPA array is shown in Figure 6. The simulated and measured S-parameters are given in Figure 7. As shown, the return losses for both the sum and difference ports are

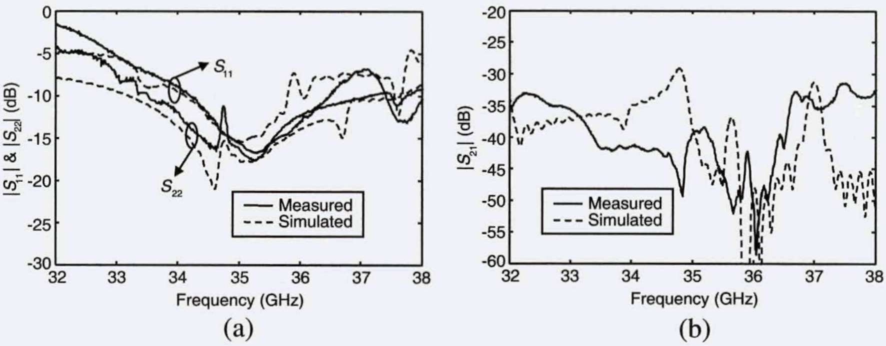


Figure 7. Simulated and measured S-parameters.

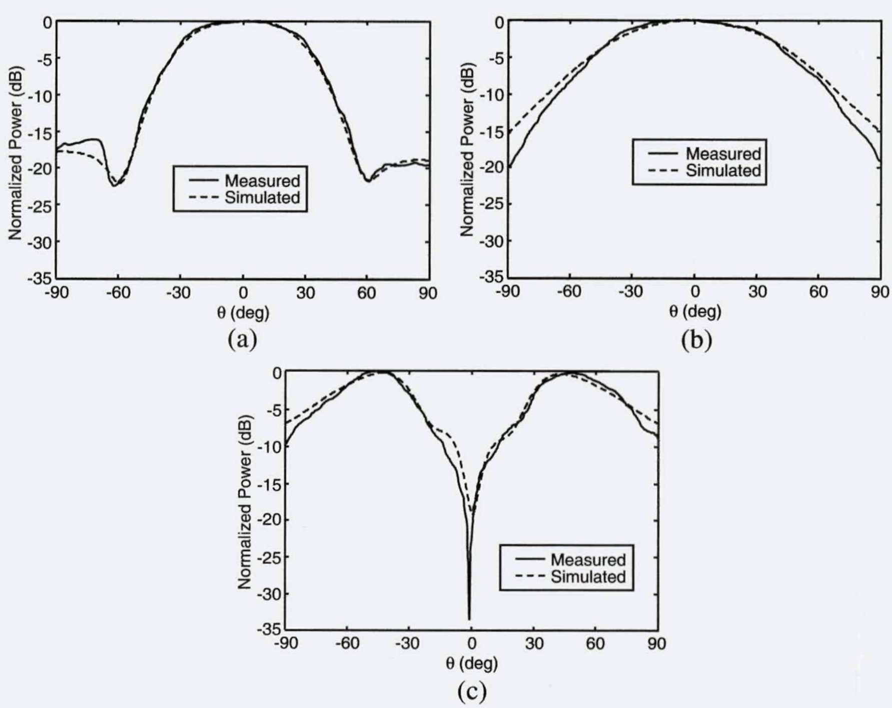


Figure 8. Simulated and measured radiation patterns at 35 GHz. (a) Sum E-plane (y-z plane). (b) Sum H-plane (x-z plane). (c) Difference E-plane (y-z plane).

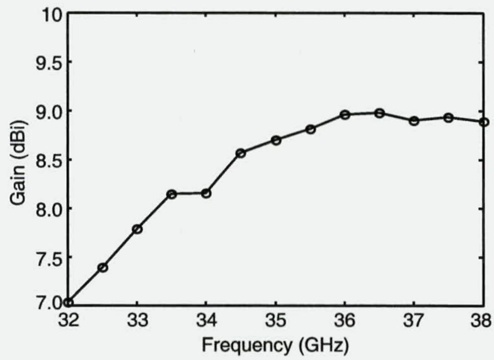


Figure 9. Measured gain of the sum beam.

less than 10 dB from 34.2–36.6 GHz, corresponding to a bandwidth of 6.8%. Within this bandwidth, the isolation between the sum and the difference ports is better than 38 dB. Figure 8 shows the measured sum and difference patterns at 35 GHz. As shown, clean and symmetrical patterns are realized for both the sum and the difference beams. The measured −3-dB *E*- and *H*-plane beamwidths of the sum pattern are 55.8° and 77.6°, respectively. And the measured −10-dB *E*- and *H*-plane beamwidths of the sum pattern are 84.6° and 137.7°, respectively. The measured null depth in the difference pattern is −32.4 dB. The gain of the sum beam is 8.7 dBi and the sidelobe level in the sum *E*-plane pattern is −16 dB. Figure 9 shows the measured gain of sum beam over the frequency band of 32–38 GHz. The measured cross-polarization levels for both the sum and the difference patterns are at least 30 dB below peak.

4. CONCLUSION

This paper presents a new cavity-backed ACMPA array with sum/difference beams at the center frequency of 35 GHz. Experimental results presented in this work have demonstrated that this ACMPA array has good radiation-pattern characteristics and keeps high isolation between the sum and difference ports. A deep null is achieved in the difference radiation pattern due to the circuit symmetry. This cavity-backed ACMPA array is well suitable for two-dimensional monopulse applications because of its compact structure, light weight, low cost, and high performance.

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