A Novel 2-D Multi-Beam Antenna without Beam Forming Network

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***Abstract*— A novel design of multi-beam array antenna without feeding network is presented in this communication. This array antenna consists of 3×3 microstrip patches as radiators. In this design, feeding network is avoided where each patch is fed by a probe. Furthermore, whatever patch is excited, input power can be coupled to all patches through four microstrip lines located between the radiating elements. In addition, nine radiation beams can be implemented depending on different field distributions which are generated by exciting each patch individually. The proposed antenna has a simple single-layered structure, and does not suffer from complex feeding network compared with traditional multi-beam antennas. Experimental results demonstrate that the scanning ranges of the nine beams are ±24° and ±45° in the vertical and horizontal directions, respectively. Moreover, measured gain for the nine beams of the implemented antenna varies from 9.06 dBi to 10.45 dBi.**

***Index Terms*—Antenna, compact structure, multi-beam antennas, beam forming network.**

I. INTRODUCTION

Multi-beam antennas are widely used in modern wireless communication systems, due to their ability to generate different beams pointing in different directions with the same radiating aperture. Beam forming network (BFN) is widely used to realize multiple beams [1-2]. A BFN is usually composed of power dividers, directional couplers, and phase shifters to generate output signals with controllable magnitude and phase distributions. Therefore, array radiating elements are excited properly to obtain expected far-field radiation patterns.

Different types of transmission lines including microstrip lines, and substrate integrated waveguides (SIWs) have been used for BFNs [3-11]. Various BFNs such as Butler, Blass, Nolen matrixes, and the Rotman lens were employed to feed one-dimensional (1-D) linear arrays [3-6]. Compared with 1-D multi-beam arrays, two-dimensional (2-D) multi-beam antenna arrays can usually provide higher beam steering resolution [7-11]. In [7], a 2-D multi-beam antenna was proposed. Leaky-wave was excited to realize beam scanning in the elevation plane while a BFN was introduced to realize beam scanning in the orthogonal plane. A simple 2-D multi-beam antenna based on an eight-port SIW hybrid was proposed in [8], which generated 2×2 beams in two orthogonal planes. In [10], sixteen beams were produced by a 4×4 multi-beam antenna array fed by two sets of 4-way Butler matrices, where one set controlled the beam-scanning in the vertical plane and the other one controlled in the horizontal plane. However, these multi-beam antennas usually suffer from BFNs with complicated configurations which inevitably occupied large areas.

A novel 2-D multi-beam antenna is proposed in this paper. The proposed 3×3 planar array antenna is composed of nine microstrip patches as radiators, and each patch is fed by a probe. Four microstrip lines are employed between antenna elements as a mutual coupling feeding network. The power from one input port can be coupled to the other eight patches. Different field distributions over the radiating aperture resulting from the excitation at different input ports produce switchable beams. Compared with conventional multi-beam antennas with BFNs, the proposed antenna can obtain nine beams in two-dimensional planes without the need of BFN.

II. ANTENNA DESIGN

The geometry of the multi-beam antenna is shown in Fig. 1. The antenna is designed on a single-layered Rogers-Duroid 5880 with thickness h = 1.5mm (ε_r = 2.2 and $tan\delta$ = 0.0009). As exhibited in Fig. 1, the array is composed of nine microstrip patches. Four narrow microstrip lines are employed between the patches as a feeding network. Each patch element is fed by a probe, so there are nine input ports. In practical application, the patch with excitation from the input port can be seen as a driven element while the other eight elements are parasitic elements. The input power can be coupled from the driven patch to all parasitic patches.

The length and width (p_x, p_y) of radiating patches are main parameters that determine the antenna resonant frequency. The proposed antenna is designed at the center operating frequency of 12 GHz. As shown in Fig. 1, three patches located in the same row are close to each other. Besides, a narrow microstrip line is placed between two neighboring patches. The gap between the patch and the microstrip line is d_x and the width of the microstrip line is s_x. For the patches in the same row, energy can be coupled from each other through capacitive gaps.

Because a microstrip patch antenna radiates from the top and bottom edges, elements arranged in different rows cannot be directly fed through coupling. Hence, the microstrip line is employed to transmit power between different rows. Length of microstrip line s_y is initially set to $\lambda_g/2$ to make an additional phase shift of 180°.

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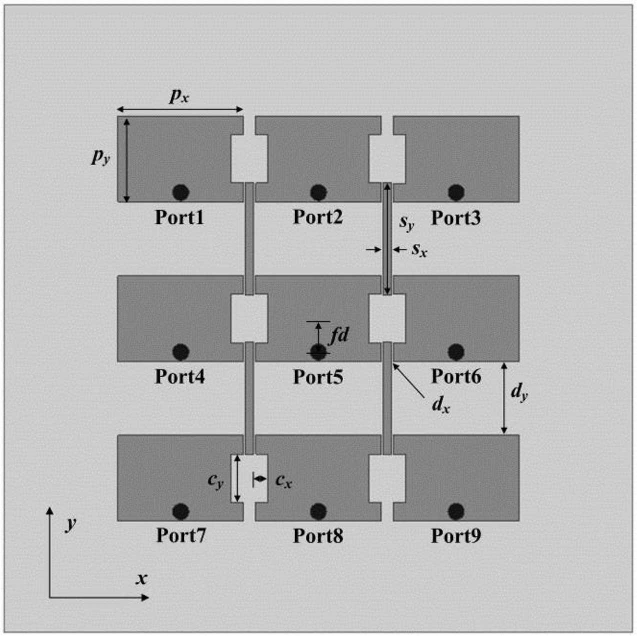
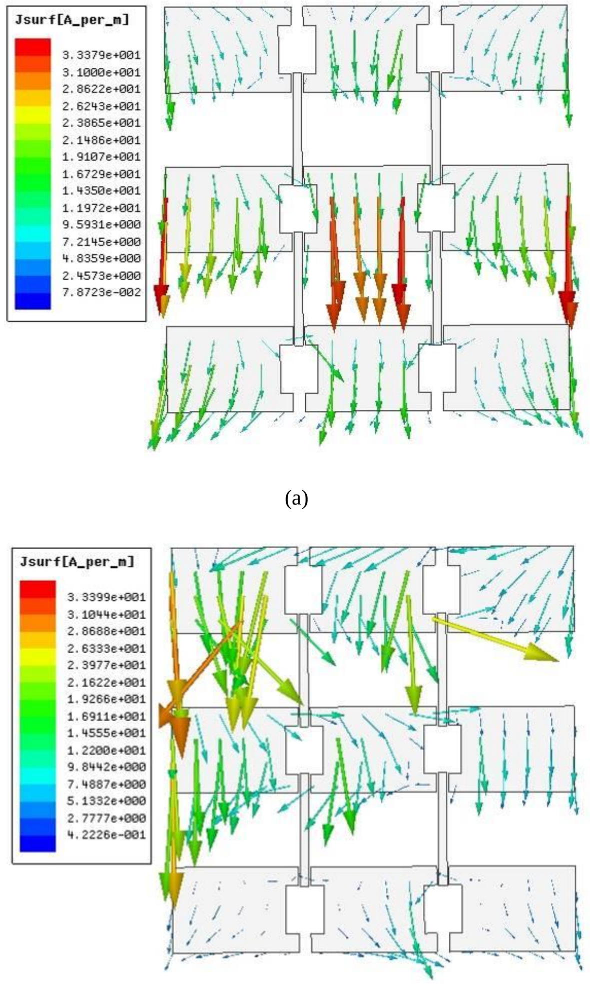


Fig. 1. Geometry of the multi-beam antenna. Parameters of the antenna are fixed as p_x=10 mm, p_y=6.8 mm, s_x=0.67 mm, s_y=9 mm, d_x=0.15 mm, d_y=5.9 mm, c_x=1 mm, c_y=3.84 mm, and fd=2.67 mm.

Therefore, the phase difference between patches in two adjacent rows is 2π.

The offset of the probe fd is used to adjust the input impedance of the antenna. Besides, additional slots with dimensions of c_x and c_y are cut at two non-radiative edges of the patches to further improve the impedance matching of the array. The dimensions of the array are optimized with the assistance of a full wave electromagnetic simulator HFSS. Final values are presented in the caption of Fig. 1.

In the proposed array antenna, the field distribution on the patches generated through the mutual coupling is not uniform. Therefore, the field distribution is not the same for the excitation from different input ports, which results in multiple radiation beams. Fig. 2 shows the current distributions when Port 5 and Port 1 are excited, respectively. It can be seen that the current distribution on the patches is symmetrical about the center of the array when Port 5 is fed. Thus the main beam of the array is at the boresight direction. However, when the antenna is excited by Port 1 as shown in Fig. 2 (b), the current on the driven patch is stronger than the counterpart on the parasitical patches. Moreover, the magnitude of the current gradually decreases while the distance to the driven patch increases. Due to the unsymmetrical field distribution, the main beam is tilted from the z-axis. Similar results can be expected when the other seven ports are excited respectively. The simulated far field distributions for the excitation from Ports 1–9 are plotted in Fig. 3, which demonstrates that the array can generate nine radiating beams when different input ports are fed respectively.



(a)

(b)

Fig. 2. Current distributions of the antenna when (a) Port 5, (b) Port 1 is excited.

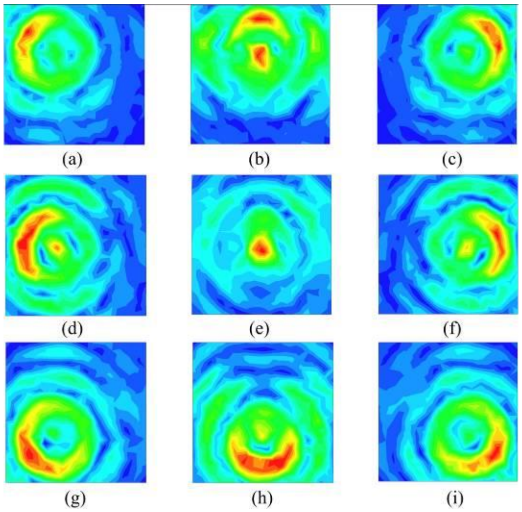


Fig. 3. Simulated far field distributions at 12 GHz for excitation from (a) Port 1, (b) Port 2, (c) Port 3, (d) Port 4, (e) Port 5, (f) Port 6, (g) Port 7, (h) Port 8, and (i) Port 9.

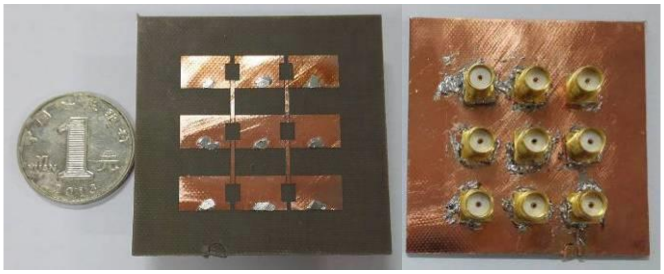


Fig. 4. Photographs of the fabricated antenna.

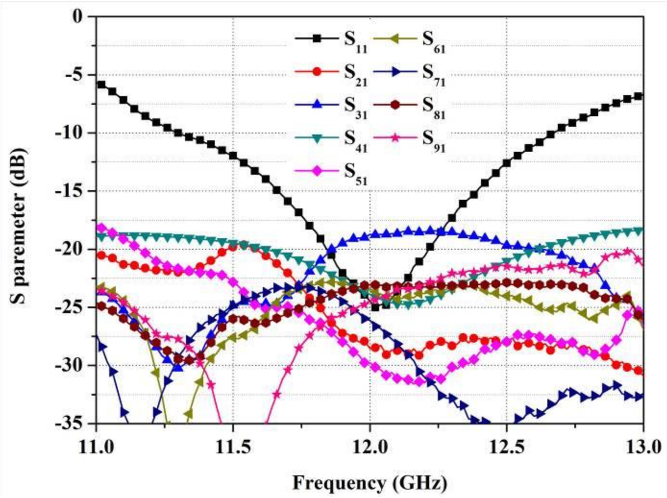


Fig. 5. Measured S-parameters of the proposed antenna.

III. RESULTS

The 3×3 array antenna shown in Fig. 4 is fabricated and tested to demonstrate the correctness of the design. It has a compact size of 50×50 mm^2. Fig. 5 presents the measured S-parameters when Port 1 is excited. The other ports that are not excited are connected to 50 Ω loads. The measured -10 dB impedance bandwidth is 11.3% from 11.3 GHz to 12.65 GHz. The isolations between each two ports are greater than 18 dB over the operating band.

Fig. 6 and Fig. 7 show the simulated and measured radiation patterns at 12 GHz when different input ports are excited respectively. The maximum radiation of the eight tilted beams in the horizontal plane are at phi=0°, 45°, 90°, 135°. To illuminate the beams changing in elevation direction, radiation patterns in four cut-planes are plotted. As shown in Figs. 6 and 7, measured and simulated radiation patterns are in good agreement.

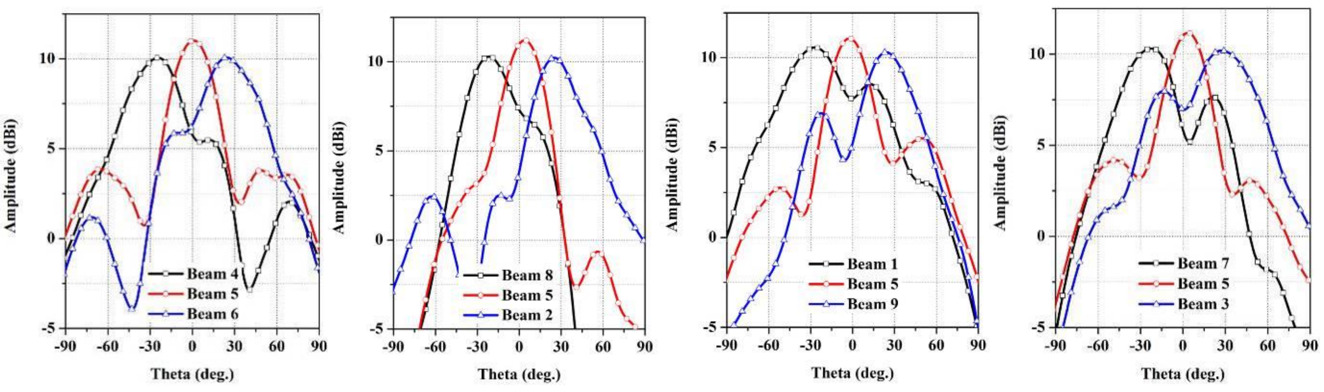
More details of the radiation performance are listed in Table I. The angle between the main direction of the eight tilted beams and the *z*-direction is 24°±3°. There also exists slight distinction in beam direction between the simulated and measured results, which is mainly due to the fabrication tolerance. The measured gain has a discrepancy of around 1 dB compared with the simulated one because of the losses of antenna and connectors. Moreover, when the antenna is excited at Port 5, the measured gain is 10.45 dBi. However, the gain is lower when the antenna is excited at the other eight ports. The measured gain varies from 9.06 dBi to 10.45 dBi. The cross-polarization levels are also measured and plotted in Fig. 7, which are -14 dB less than the co-polarization levels.

TABLE I
SIMULATED AND MEASURED RESULTS OF THE 2-D MULTIBEAM ANTENNA

Beam	Beam Direction (degree)				Gain (dBi)	
	ϕ	Simulated θ	Measured	Error θ (%)	Simulated	Measured
Port 1	-45	-27	-22	18.5	10.57	9.16
Port 2	90	25	24	4	10.23	9.06
Port 3	45	27	22	18.5	10.19	9.16
Port 4	0	-24	-24	0	10.05	9.62
Port 5	0	0	0	0	11.06	10.45
Port 6	0	24	22	8.3	10.07	9.27
Port 7	45	-22	-26	18.2	10.3	9.28
Port 8	90	-22	-24	9.1	10.28	9.36
Port 9	-45	24	26	8.3	10.3	9.68

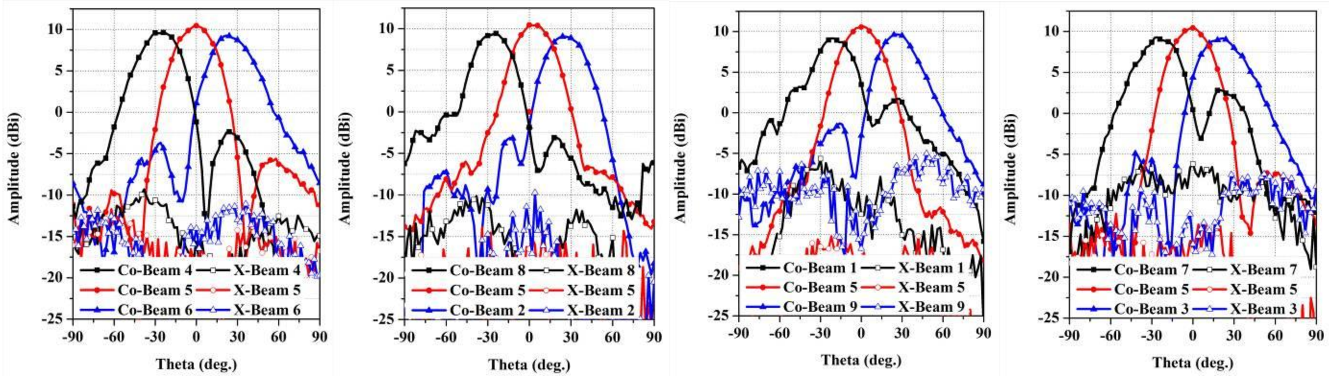
IV. CONCLUSION

In this paper, a novel 2-D multi-beam array antenna is proposed. The antenna consists of nine microstrip patches with probe feeds. All patches can radiate effectively due to the mutual coupling when one input port is excited. Furthermore, the proposed antenna can produce nine beams in two dimensions as a result of exciting different ports respectively. The measured gain of the antenna varies from 9.06 dBi to 10.45 dBi. With the advantages of the simple structure and good multi-beam radiation performance, the proposed antenna can be an alternative design for applications of wireless communications.



(a) (b) (c) (d)

Fig. 6. Simulated radiation patterns excited at different ports at 12 GHz: (a) ϕ =0°, (b) ϕ =90°, (c) ϕ =135°, (d) ϕ =45°.



(a) (b) (c) (d)

Fig. 7. Measured radiation patterns excited at different ports at 12 GHz: (a) ϕ =0°, (b) ϕ =90°, (c) ϕ =135°, (d) ϕ =45°.

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