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A Compact Multi-Beam Antenna Without Beam Forming Network

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***Abstract* - A novel approach to design a multi-beam array antenna without a beam forming network (BFN) is presented. The proposed antenna consists of 3×3 microstrip patches that are tightly coupled through microstrip lines. By exciting any one of these patches, the energy can be coupled to all the patches. Nine beams towards different directions are obtained by selecting different feeding ports. The resultant gain varies from 10 dBi to 11 dBi. The scanning ranges of the beams are ±24° and ±45° in the elevation and horizontal directions, respectively. The proposed antenna has a single-layered structure without complex feeding network, which significantly lowers its cost.**

***Index Terms* — Multi-beam antenna, compact structure, beam forming network.**

1. 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 networks (BFN) consisting of power dividers, directional couplers, and phase shifters are required in multi-beam antennas. The most popular BFNs employed in multi-beam antennas are constructed using microstrip lines or substrate integrated waveguides (SIW) [1-7]. Conventional BFNs such as Butler, Blass, and Nolen matrixes, and Rotman lens are promising solutions to feed one-dimensional (1-D) linear arrays [1-3]. However, to feed two-dimensional (2-D) multi-beam antenna arrays for higher beam steering resolution, the conventional BFNs suffer from high complexity and occupy a large area [4-7].

In this paper, a novel 2-D multi-beam antenna is proposed without BFN. The proposed planar array is composed of 3×3 microstrip patches as radiators. Each microstrip patch is connected to a feed probe. By exciting any one of the feed probes, the energy can be coupled to all the patches through four microstrip lines placed between the patches. Nine different radiation beams are realized by exciting different probes. Compared with conventional multi-beam antennas with BFNs, the proposed antenna is far more compact and cost-effective.

2. Antenna Design

The geometry of the proposed multi-beam antenna is shown in Fig. 1. The antenna is based on a single-layered Rogers-Duroid 5880 substrate with a thickness of h =1.5 mm, a dielectric constant of ε_r = 2.2, and a loss tangent of $tan\delta$= 0.0009. As shown in Fig. 1, the array consists of three rows of microstrip patches. The patches in each row are placed closely together to obtain strong couplings between them. Four narrow microstrip lines are employed to enhance the coupling between the patches in different rows. Each patch is fed by a probe and there are nine input ports in total. By exciting any one of the patches, the input power can be coupled to the other eight patches due to the strong mutual couplings. Here we define the excited patch as driven patch and the other patches as parasitic patches. We remark that the induced current on a parasitic patch has an attenuated magnitude and a phase delay, compared to the current on the driven element. A proper phase delay is required to tilt the radiation beam towards other directions.

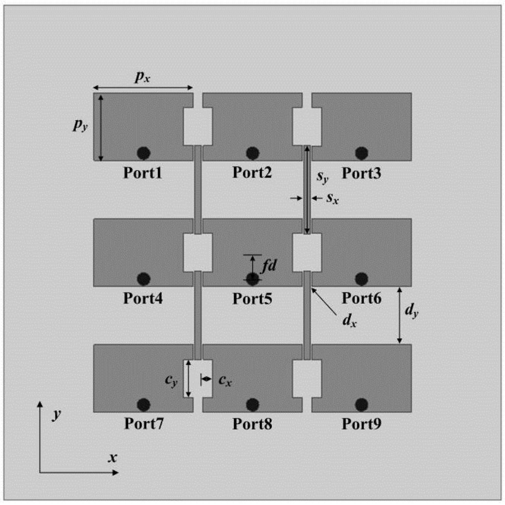

Fig. 1. Geometry of the multi-beam antenna.

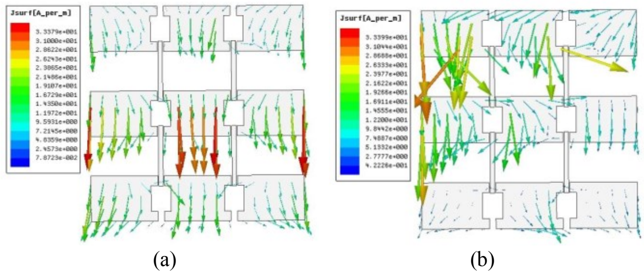

Fig. 2. Current distributions of the antenna when (a) Port 5, (b) Port 1 is excited.

Optimized values of the dimensions are obtained with the assistance of Ansys HFSS. The design and optimization procedures are as follows. The length of the patches p_y is the

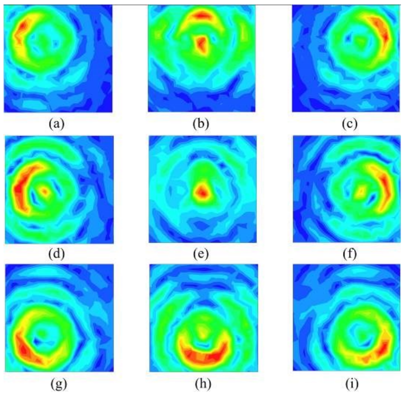

Fig. 3. Simulated far field distributions at 12 GHz for excitation from (a) Port 1, (b) Port 2, (c) Port 3, (d) Port 4, (e) Port 5, (f) Port 6, (g) Port 7, (h) Port 8, and (i) Port 9.

TABLE I: Beam Directions with Different Excitations

Beam Direction	ϕ (degree)	θ (degree)
Port 1	-45	-27
Port 2	90	25
Port 3	45	27
Port 4	0	-24
Port 5	0	0
Port 6	0	24
Port 7	45	-22
Port 8	90	-22
Port 9	-45	24

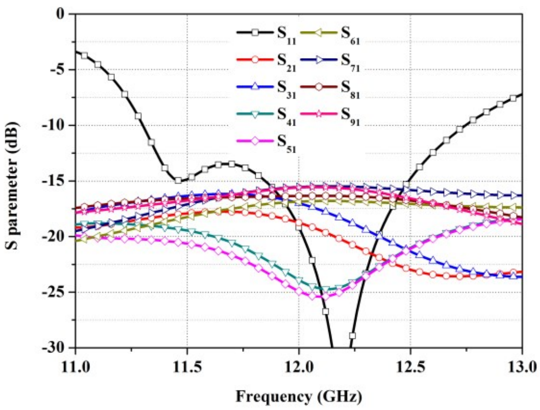

Fig. 4. Simulated S parameters of the proposed antenna.

first parameters to be tuned. It is the dominant parameter determining the antenna's resonant frequency. Then, the width of the microstrip lines d_x and the separation distance s_x between a patch and a microstrip line were tuned to obtain a proper coupling ratio between patches in a row. The patch width p_x and the length of the microstrip line s_y determine the phase delay values between patches. Subsequently, the offset value *fd* of a feed probe from the horizontal axis of the patch was optimized for impedance matching. Finally, additional slots with dimensions of c_x and c_y were etched at the non-radiate edges to widen the bandwidth.

3. Results

Fig. 2(a) and 2(b) illustrates the current distributions on the array with optimized dimension values when ports 5 and 1 are excited, respectively. As observed from the figure, the magnitude of the current has the highest level on the driven patch. The currents on the parasitic patches have lower magnitudes, and the further the parasitic patch is placed away from the driven patch, the lower the current magnitude it has. Moreover, there are phase delays as the energy coupled from the driven element to the parasitic elements. Those progressive phase delays generate beam tilt.

Nine different beams are obtained by feeding the nine ports. Simulated E-field distributions of the array when ports 1-9 are excited are plotted in Fig. 3(a) to 3(i), respectively. The main lobe directions are summarized in Table I. Fig. 4 shows the simulated S parameters when Port 1 is excited and other ports are connected to identical 50-Ω loads. The simulated10 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 across the entire operating band.

4. Conclusion

In this paper, a novel 2-D multi-beam array antenna was proposed. The antenna consists of nine microstrip patches in one layer without a feed network. The patches are linked by strong mutual coupling. By manipulating the coupling, the power can be distributed on the patches in a specifically designed way. The working mechanism and design procedure of the array antenna was presented. The antenna can have nine beams by exciting different ports, covering a range from ±24° and ±45° in the elevation and horizontal planes.

References

[1] P. Chen, W. Hong, Z. Q. Kuai, and H. M. Wang, "A mul-tibeam antenna based on substrate integrated waveguide technology for MIMO wireless communications," *IEEE Trans. Antennas Propag*., vol. 57, no. 6, pp. 1813–1821, Jun. 2009.

[2] Y. J. Cheng, W. Hong, and K. Wu, "Millimeter-wave substrate integrated waveguide multibeam antenna based on the parabolic reflector principle," *IEEE Trans. Antennas Propag*., vol. 56, no. 9, pp. 3055–3058, Sep. 2008.

[3] T. Djerafi, N. Fonseca, and K. Wu, "Planar 4x4 Ku-band Nolen matrix in SIW technology," *IEEE Trans on Microwave Theory and Technique,* vol. 58, no.2, pp. 259-266, Feb. 2010.

[4] Y. J. Cheng, W. Hong, K. Wu, and Y. Fan, "Millimeter-wave substrateintegrated waveguide long slot leaky-wave antennas and two-dimensional multibeam applications," *IEEE Trans. Antennas Propag.,* vol. 59, no. 1, pp. 40–47, Jan. 2011.

[5] Y. J. Cheng, W. Hong, and K. Wu, "Millimeter-wave multibeam antenna based on eight-port hybrid," *IEEE Microw. WirelessCompon. Lett.,* vol. 19, no. 4, pp. 212–214, Apr. 2009.

[6] W. F. Moulder, W. Khalil, and J. L. Volakis, "60-GHz two-dimensionally scanning array employing wideband planar switched beam network," *IEEE Antennas Wirel. Propag. Lett.,* vol. 9, pp. 818-821, 2010.

[7] Y. J. Li and K. M. Luk, "60-GHz Dual-Polarized Two-Dimensional Switch- Beam Wideband Antenna Array of Aperture- Coupled Magneto-Electric Dipoles," *IEEE Trans. Antennas Propag*.,Accpeted for publication.