ELectronics EXpress



# Aperture-coupled multi-layer broadband ring-patch antenna array

**Mohammad Mahdi Honari**[a], **Abdolali Abdipour, and Gholamreza Moradi**

*Microwave/mm-wave and wireless communication research Lab*

*Department of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran*

a) *mahdi_honari@aut.ac.ir*

**Abstract:** An aperture-coupled multi-layer broadband microstrip array antenna with coupling ring slots and modified ring patches is presented. The structure of the array consists of a 3-dB 180°-phase shifter, two 1-port's and two 2-port's aperture-coupled microstrip antennas. All parts of the array antenna are designed for broadband operation. The array antenna works based on the back coupling to the microstrip line of 2-port aperture-coupled antenna. Simulation results of the array display encouraging properties, such as wide impedance bandwidth of 77% for $|S_{11}| < -10\,dB$ and nearly stable gain. The maximum gain of the array antenna is almost 12.65 dBi at 5 GHz. The radiation efficiency, radiation pattern, side-lobe level and cross-polarization are also adequate within the impedance bandwidth between of 3.34 and 7.53 GHz.

**Keywords:** aperture-coupled antenna (ACA), array antenna, broadband array

**Classification:** Wireless communication hardware

## References

[1] T. Yuan, N. Yuan, and L. W. Li, "A novel series-fed taper antenna array design," *IEEE Antenna Wireless Propag. Lett.*, vol. 7, pp. 362–365, 2008.

[2] Y. Qin, S. Gao, A. Sambell, E. Korolkiewicz, and M. Elsdon, "Broadband patch antenna with ring slot coupling," *Electron. Lett.*, vol. 40, no. 1, pp. 5–6, 2004.

[3] W. J. Tseng and S. J. Chung, "Analysis and application of a two-port aperture-coupled microstrip antenna," *IEEE Trans. Microw. Theory Tech.*, vol. 46, no. 5, pp. 530–535, 1998.

[4] D. M. Pozar and D. H. Schaubert, "Comparison of three series-fed microstrip array geometries," *IEEE AP-S Int. Symp.*, pp. 728–731, 1993.

[5] K. Wincza and S. Gruszczynski, "Four-element series-fed antenna sub-array for high-frequency antenna applications," *Asia-Pacific Microwave Conference, APMC 2007*, pp. 1–4, 2007.

[6] B. Zivanovic, J. Mcknight, T. Weller, and C. Costas, "A dual-fed array series microstrip patch array," *IEEE AP-S Int. Symp.*, p. 1, 2008.



DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012

EL*ectronics*
EX*press*

IEICE Electronics Express, Vol.9, No.4, 250–255

[7] B. M. Schiffman, "A new class of broad-band microwave 90-degree phase shifters," *IRE Trans. Microw. Tech.*, vol. 6, no. 2, pp. 232–237, 1958.
[8] K. Wincza, S. Gruszczynski, and J. Borgosz, "Microstrip antenna array with series-fed 'through-element' coupled patches," *Electron. Lett.*, vol. 43, no. 9, pp. 487–489, 2007.

## 1 Introduction

Microstrip antenna arrays are being widely used in many wireless applications, such as satellite communication systems but an efficient design along with the fabrication of planar array antenna with the suitable side-lobe levels and wide impedance bandwidth are challenging tasks [1]. In recent years, many efforts have been devoted to the bandwidth enhancement of microstrip antennas [2]. In [3], it has been shown that a 2-port aperture-coupled antenna can increase the bandwidth by coupling mechanism. Compared with corporate-fed arrays, the series-fed array structures employ shorter lines which leads to a simpler and more compact feed network and lower insertion loss [1, 4, 5]. The natural tendency of a series-fed array and similar structures is beam tilting and radiation pattern shifting over frequency range [6]. Using the dual-feed forces excitation symmetry about the centre of the array, the elevation beam is fixed at the broadside independent of the frequency [6, 8].

In this Letter, a broadband array antenna is presented. Here, a dual excitation from both sides of the array is employed which helps to prevent of radiation pattern shifting and tilting beam and reduces the distribution network complexity. It utilizes 2-port aperture-coupled structure to increase the impedance bandwidth by coupling mechanism. The impedance bandwidth lower than $-10$ dB and gain bandwidth better than 10 dB are 77% and 38%, respectively. High radiation efficiency, low cross polarization and stable radiation pattern are achieved.

## 2 Antenna design and configuration

A multi-layer microstrip ACA array is designed with a wide bandwidth, illustrated in Fig. 1 (a) and (b). The overall specifications of the proposed array are similar to those of [8]. The differences between them are in the type of the employed antenna and phase shifter. Due to broadband operation, we use aperture-coupled antenna and Schiffman phase shifter which are inherently broadband structures. The feed substrate is Rogers 5880 with relative permittivity of 2.2 and thickness of 1.57 mm. It is well known that a broadband antenna uses a thick substrate with low permittivity. So a 7-mm air-filled substrate is employed which separates ring slots on the ground plane from the modified ring patches, as shown in Fig. 1 (a). The proposed array antenna comprises three parts: a 3-dB 180°-phase shifter, two 1-port's and two 2-port's microstrip ACAs. A 3-dB 180°-phase shifter is applied to excite two 2-ports ACAs in-phase together [8]. Since we are going to design a wideband array antenna, all parts of the array should be wideband. The


DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012

ELectronics EXpress
IEICE Electronics Express, Vol.9, No.4, 250–255

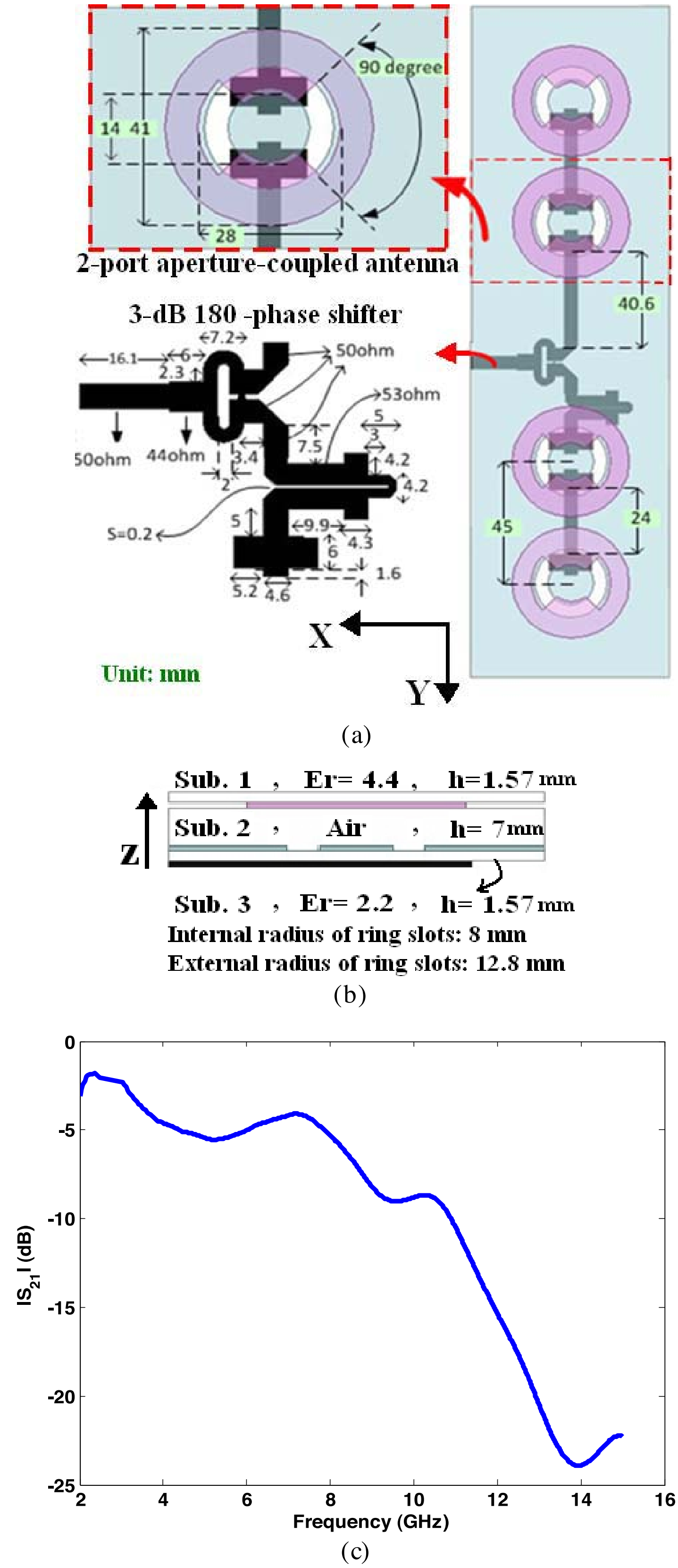



**Fig. 1.** (a) Geometry of the proposed aperture-coupled microstrip array antenna (top view), (b) Side view of the array antenna, and (c) Simulated transmission power ratio of 2-ports ACA ($S_{21}$ from first port to the second port in 2-ports antenna).


DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012

IEICE Electronics Express, Vol.9, No.4, 250–255

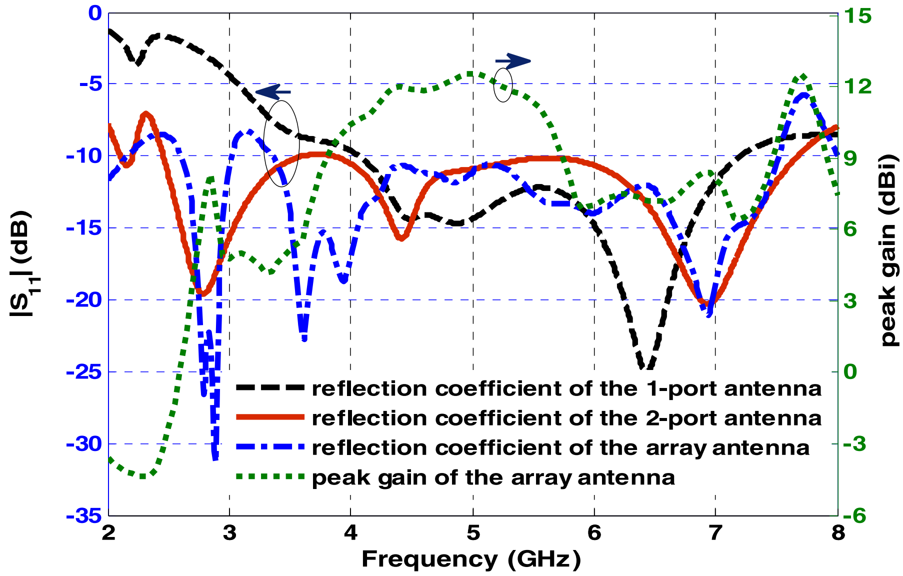



**Fig. 2.** Simulated reflection coefficients and peak gain of the antennas.

geometry of the 3-dB 180°-phase shifter is also illustrated in Fig. 1 (a) which contains a Wilkinson power divider and an 180°-broadband Schiffman phase shifter [7]. Both parts of the 3-dB 180°-phase shifter should be designed for wideband operation.

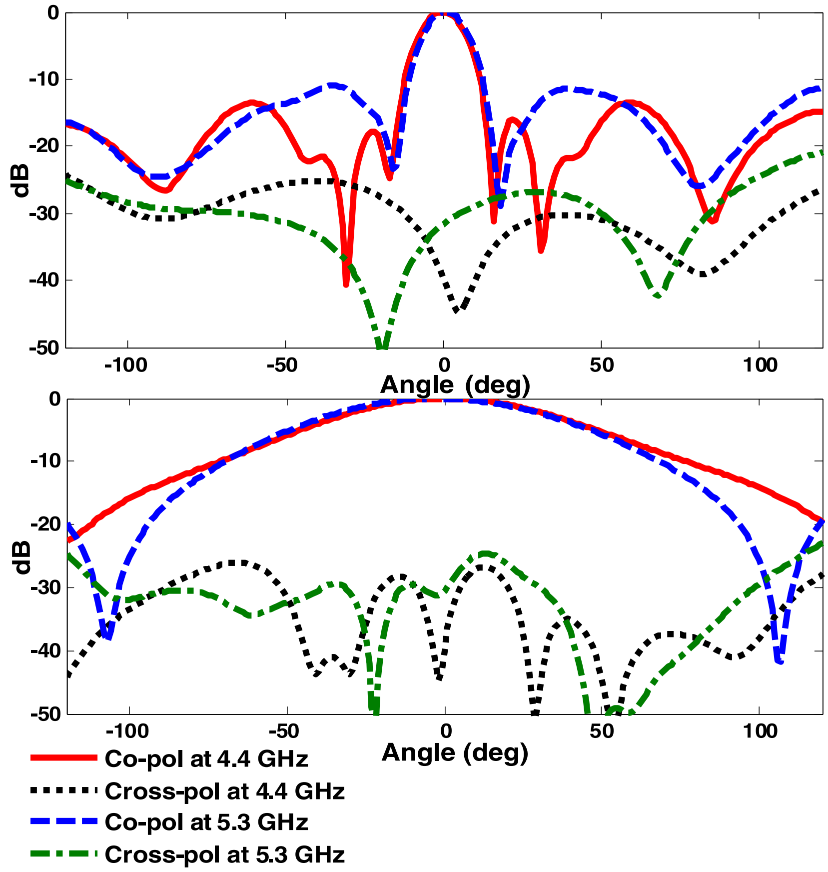
The geometries of 1-port and 2-port microstrip ACAs are shown in Fig. 1 (a). The main idea of designing this antenna array is the generating the wide impedance bandwidth of the 2-port ACAs by coupling mechanism [3]. The 2-port antenna includes two microstrip lines, the first is feeding port and the other is coupling port. When power enters to feeding port, a part of it is coupled to the patch through the ring aperture on the ground plane and radiated into the free space, and the other part of it is then coupled back to coupling port radiated by 1-port ACAs [3]. Fig. 1 (c) shows the transmission power ratio of 2-port microstrip ACA (*i.e.* the coupled power of the feeding port to that of the coupling port). It is seen that the proposed coupling structure can be used in ACA array over the frequency range from 3 to 8 GHz, because in this range of the frequency the suitable power for $1 \times 4$ double sided array (the configuration of this paper) is coupled to the second port (coupling port) [5, 8]. Impedance matching of 1-port and 2-port microstrip ACAs is done by changing the shape of microstrip lines and adjusting the modified patches. Finally, distance between 1-port and 2-port ACAs should nearly be a multiple of wave-length to excite in-phase. All parts of the array are separately designed for 50-ohm matched for broadband operation.

## 3 Results and discussions

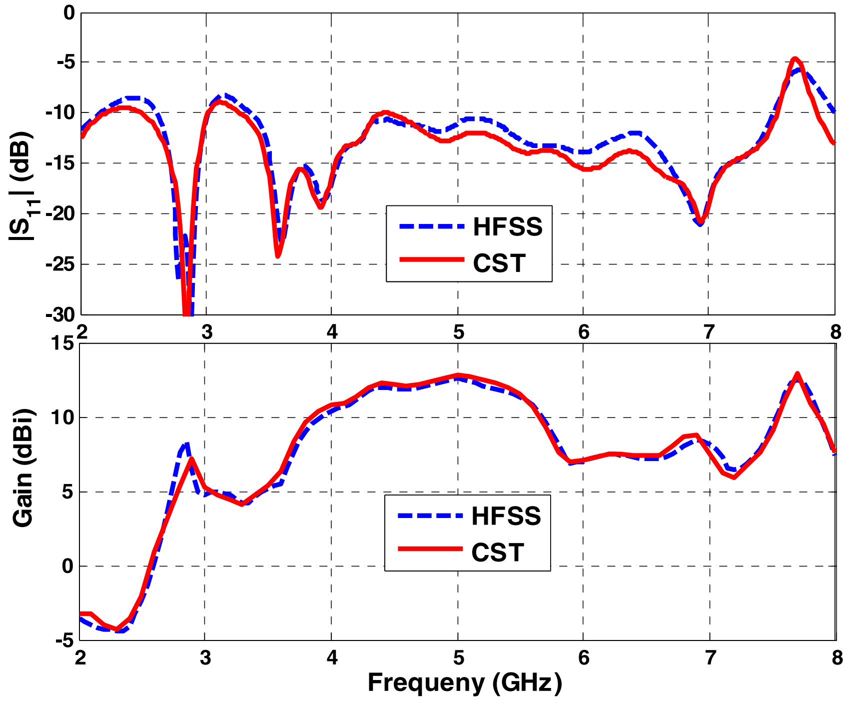
The simulations have been done with a frequency domain simulator (HFSS) and a time domain simulator (CST) to be sure about the results. Fig. 2 shows the simulated reflection coefficients and peak gain of various antennas as functions of the frequency. It is seen that the reflection coefficient bandwidth


DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012

ELectronics EXpress
IEICE Electronics Express, Vol.9, No.4, 250–255




(a)




(b)

**Fig. 3.** (a) Simulated E-plane and H-plane radiation patterns of the array antenna at the frequency of 4.4 and 5.3 GHz, (Top graph) E-plane, (bottom graph) H-plane, and (b) (Top graph) Reflection coefficient and (Bottom graph) Gain of the array antenna calculated by HFSS and CST simulator.


DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012

IEICE Electronics Express, Vol.9, No.4, 250–255

of the 2-port and array antenna are 105% and 77%, respectively. As it is evident, both of the bandwidth of 1-port antenna and 3-dB 180°-phase shifter (as shown in Fig. 1 (a)) limit the bandwidth of array antenna. The simulated radiation efficiency is better than 94% throughout the impedance bandwidth. The gain bandwidth greater than 10 dBi is 38% with a centre frequency at 4.75 GHz as shown in Fig. 2. The peak gain is almost 12.65 dBi at 5 GHz.

Fig. 3 (a) depicts the simulated E-plane and H-plane radiation patterns of the array antenna at the frequency of 4.4 and 5.3 GHz. It is seen that the beamwidth of H-plane is greater than E- plane beamwidth, because the patchesare sorted sequentially. Good radiation patterns are obtained in both E- and H-planes. Cross-polarizations of E- and H-planes of the antenna are negligible. Cross-polarizations in the 3-dB beamwidth are at least 26 dB below the co-polarizations in the E-plane and at least 25 dB below the co-polarizations in the H-plane for the array antenna. These results show good linearity of the polarization of the antenna array. Also, the side-lobe level is $-10$ dB in the E-plane which is acceptable for $1 \times 4$ array.

Finally as shown in Fig. 3 (b), the reflection coefficient and gain of array antenna calculated by HFSS and CST simulator are in a good agreement. The desired applications for this type of the antenna are various indoor and outdoor systems and the other systems with multiple frequency bands (multi-standard). This antenna can be also used in RADAR, satellite and multi-standard mobile communications.

## 4 Conclusion

A wideband microstrip ACA array has been proposed. The broadband operation has been obtained, due to using the broadband 2-port ACA. The elevation beam-angle is fixed at broadside due to the use of a dual-feed from both sides of the array antenna. A wide bandwidth of 77% is obtained. The peak gain and the minimum 10 dB gain bandwidth are nearly 12.65 dBi and 38%, respectively. A stable radiation pattern, good radiation efficiency and low cross- polarization are obtained. This design is a proper candidate for satellite or multi-standard mobile communication systems and wideband applications over frequency range of 5 GHz.


DOI: 10.1587/elex.9.250
Received December 20, 2011
Accepted January 16, 2012
Published February 25, 2012