

Wide-Angle Impedance Matching of Phased-Array Antenna Using Overlapped Subarrays

Run-Liang Xia, Shi-Wei Qu, Ming-Yao Xia, and Zai-Ping Nie

Department of Microwave Engineering, University of Electronic Science and Technology of China (UESTC)
Chengdu, 611731, China
rlxia2012@gmail.com

Abstract—For phased array antennas, the active impedance of the radiating elements changes considerably with scan angle. Therefore it is ordinarily possible to match the active impedance at only one scan angle. In this paper, a microstrip patch phased array using overlapped subarrays is designed and simulated. It is found that by using overlapped subarrays good impedance matching over a wide range of scan angle can be achieved. Simulated results show that the investigated phased array has much better scan performance compared with conventional microstrip patch phased arrays.

I. INTRODUCTION

One of the most challenging design aspects of phased array is the wide impedance matching technique. An unusual issue exists in phased array design is the active impedance of element varies considerably with scan angle. The inherent mutual coupling among the elements is the main cause that leads to the impedance of each element in a way changes with the scan angle [1]. Consequently, the elements can be impedance matched at only one scan angle by ordinary matching techniques. The mismatch at other scan angles may seriously reduces the gain realized by the antenna and deteriorates other specifications e.g. radiation pattern, polarization purity, and amplifier stability [2], [3].

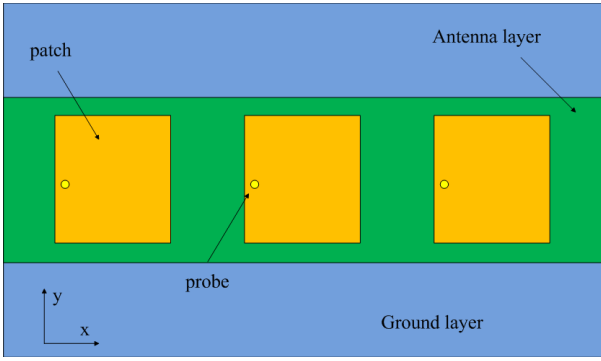
Wide-angle impedance matching (WAIM) technique is used to compensate for the change of reflection coefficient with scan angle [4]. There have been various studies on the WAIM technique by a number of researchers. In [5], Hannan *et al.* put a connecting circuit between neighboring elements which introduces a signal, variable with generator phasing, i.e., with scan angle, into each array element. This approach can effectively compensate the variation of element active scan impedance. In [4], Magill and Wheeler employed a planar thin sheet with high dielectric constant located in front of, and parallel to the array aperture to compensate the varied reactance due to the array scan so that wide-angle impedance matching can be realized. In [6], Sajuyigbe *et al.* investigated the use of metamaterials in achieving wide angle impedance matching. The anisotropic properties of a metamaterial layer could provide more degrees of freedom than an isotropic dielectric layer, thus a wider range of scan angle can be achieved. Recently Awida *et al.* proposed a class of microstrip patch phased arrays backed by substrate-integrated cavities which perform wider scan angle than that of conventional counterpart [7].

According to previous studies, overlapped subarrays are often employed to reduce the side lobe level in a large array. For moderate scan angles, overlapped subarrays allow for the side lobe levels of down to -20dB [8]. Recently Bhattacharyya studied the wide-angle performance of phased arrays with overlapped subarrays and numerical results prove that overlapped subarrays have wider scan performance than conventional subarrays with and without WAIM layer [9]. His research provides a new approach to wide-angle impedance matching in phased arrays.

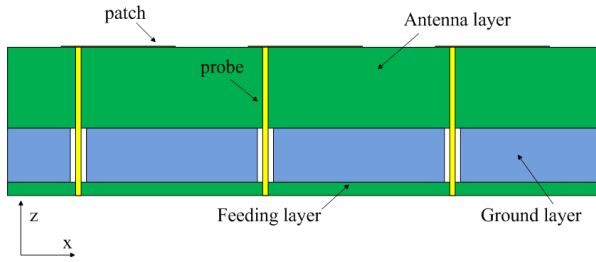
In this paper, an E-plane microstrip patch phased array using overlapped subarrays is developed. In Section II, the phased array configuration with overlapped subarrays is illustrated. In Section III, a unit cell of the investigated array is first designed utilizing the periodic boundary condition. A simple feeding networks for the best impedance matching performance over a wide range of scan angle in the E plane is simulated, following the results in [9]. In Section IV, a 16 patch elements array is built by assembling 16 well designed unit cell elements mentioned above. Simulated results show that the designed phased array has a wide scan performance of better than 60°. Finally, Section V concludes the paper.

II. PHASED ARRAY CONFIGURATION

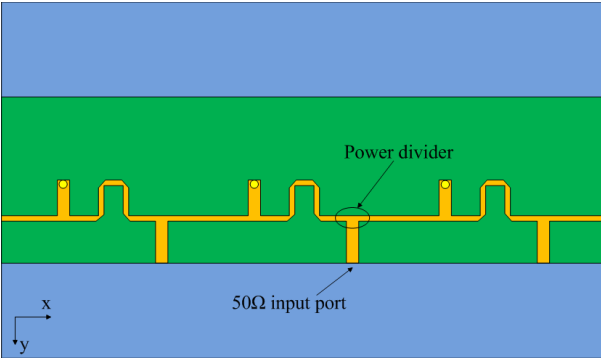
Geometry of the designed phased array is shown in Fig. 1, including top view, side view, and feeding network. Patch elements are etched on the top side of a substrate layer (antenna layer) with a relative permittivity of 2.2 and thickness $h_1 = 3$ mm. The patch element spacing is 20 mm, i.e., $0.5\lambda_0$ at the operating frequency 7.5 GHz. The feeding network in Fig. 1(c) is printed on the other substrate (feeding layer) with a relative permittivity of 2.2 and thickness $h_2 = 0.5$ mm, which is isolated from the antenna layer by a common aluminum ground plane of thickness 2 mm. A simple two-way power divider is adopted as the feeding network and the characteristic impedances of the input and output ports are 50 and 100 Ω , respectively. Each radiating element is shared by two adjacent power dividers as depicted in Fig. 1(c). By adjusting the length of the 100- Ω transmission line at the output ports, a good impedance matching can be obtained. The two-way power divider has two arms of different lengths thus can provide branch currents with phase difference which is the main cause leads to the improvement according to [9].



(a)



(b)

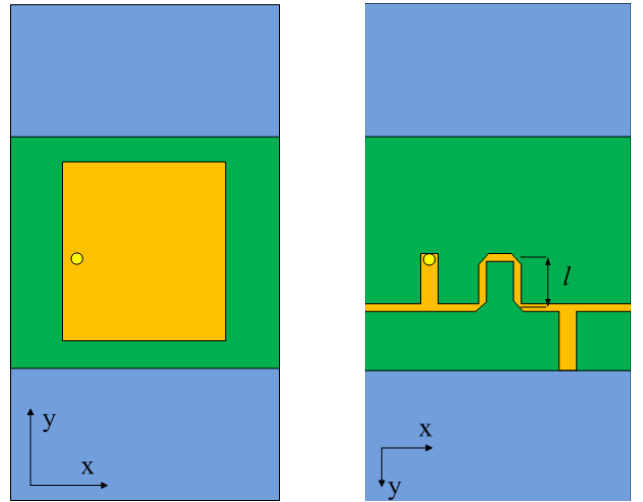


(c)

Figure 1. Geometry of the E-plane overlapped array. (a) Top view (b) Side view (c) Feeding network.

III. ARRAY ELEMENT DESIGN

Impedance matching performance of the investigated phased array has been investigated using HFSS, commercial software based on the finite element method (FEM). First in our numerical study that the phased array is assumed to be infinite and in order to simulate an array unit cell the periodic boundary condition is utilized in HFSS. The geometry of one unit cell is shown in Fig. 2. Then the active reflection coefficients of the investigated phased array are calculated versus the scan angles. The length l of the transmission line at the output port of the divider is adjusted to obtain the best active reflection coefficients as the array is scanned from 0° to



(a)

(b)

Figure 2. (a) Top view. Cell size= $40.4\text{mm} \times 20\text{mm}$. patch size= $12.2\text{mm} \times 13\text{mm}$. probe location = 5 mm from patch center. probe diameter= 0.84mm . (b) Feeding layer.

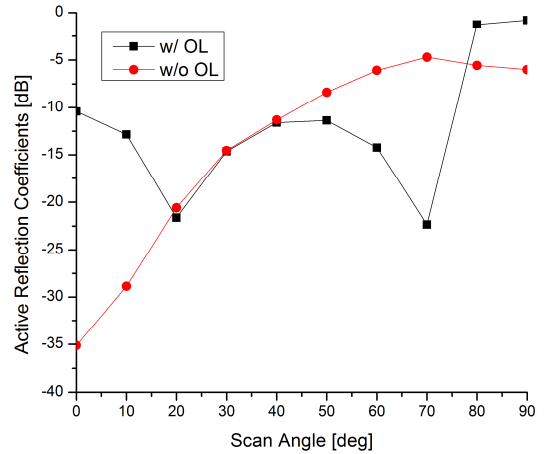


Figure 3. Simulated active reflection coefficient of a unit cell

60° . The scan range is defined in this work by a value in which the reflection coefficient is below -10dB . Fig. 3 shows the simulated active reflection coefficients versus scan angles as l varies. For comparison, that of the conventional microstrip array is also shown in Fig. 3, as a reference.

As seen from the figure, the conventional microstrip phased array presents a scan range of 44° and a weak scan blindness at about 70° . Unlike the referenced microstrip arrays, the E-plane scan performance of the investigated phased array gets much broader, and its scan range in the case of $l=4.05\text{mm}$ is about 75° . At boresight, overlapped subarrays technique slightly worsens the active reflection coefficient but it is still less than -10dB . This is a tolerable sacrifice for applications.

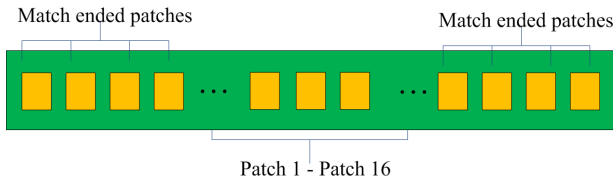
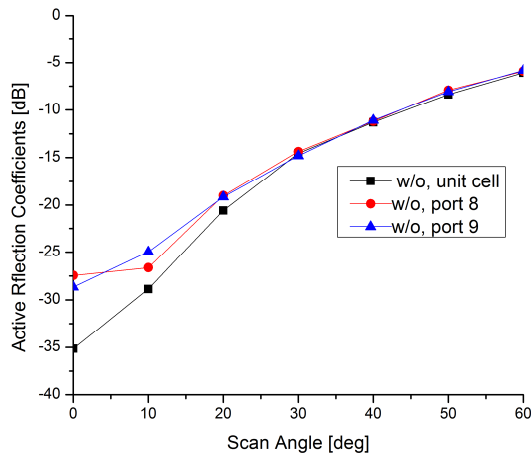
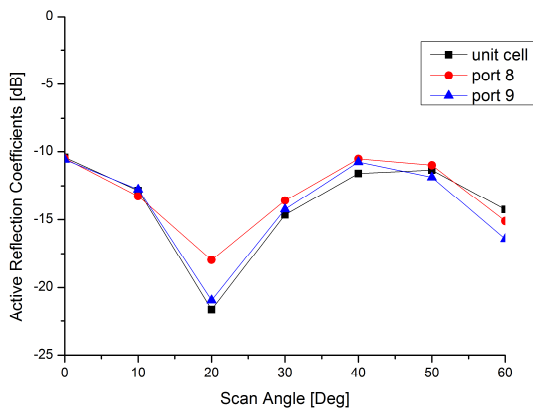


Figure 4. A 16 patch elements array



(a)



(b)

Figure 5. Simulated active reflection coefficients of the 16 elements array in case of (a) the conventional microstrip phased array (b) the investigated phased array with overlapped subarrays.

IV. SCAN PERFORMANCE OF THE 16 ELEMENTS ARRAY

In Section III, the unit cell has been well designed in an infinite phased array environment. In this section a finite microstrip phased array is built by assembling 16 unit cell elements and another 4 elements match-ended in each side of the array (see Fig. 4). The simulated active reflection coefficients versus scan angles from Port 8 and Port 9

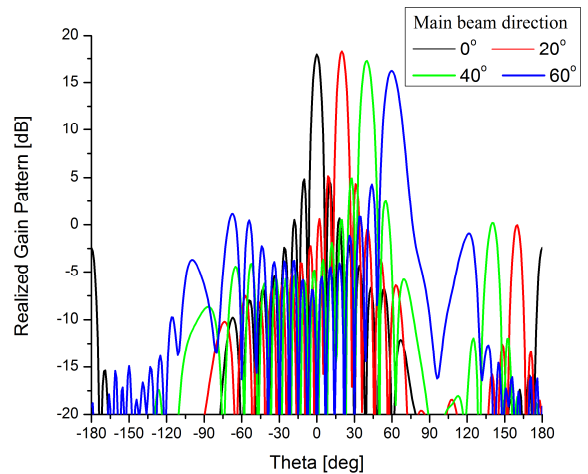


Figure 6. Pattern scanning of the investigated phased array.

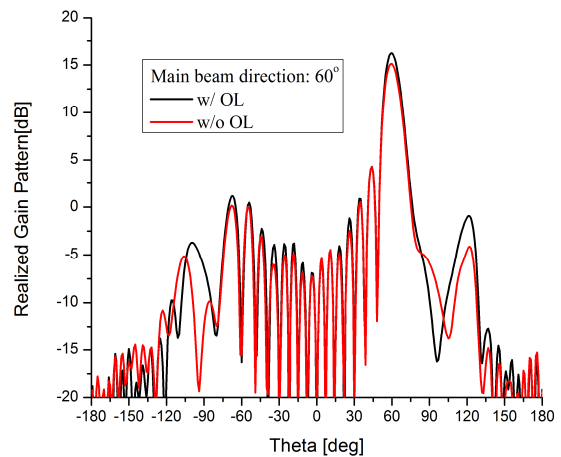


Figure 7. Antenna pattern when scanning to 60°

TABLE I
REALIZED GAIN COMPARISON OF THE TWO KIND OF PHASED ARRAY

Scan angle		0	20	40	60
Realized Gain[dB]	w/ OL	17.94	18.27	17.27	16.22
	w/o OL	18.34	18.39	17.52	15.11

corresponding to Patch 8 and Patch 9 in the middle of the array is presented in Fig. 5. The reason of choosing Ports 8 and 9 is that the electromagnetic environment in the middle of the array is the most similar to an infinite array. A conventional array without overlapped subarrays, as a reference, is also built for comparison.

The active reflection coefficients versus scan angles of the referenced array is shown in Fig. 5(a) which agrees well with the simulated result in Fig. 3 and the scan range is still about

44°. In Fig. 5(b), the impedance matching performance of the 16 patch elements array using overlapped subarray is given. A good impedance matching is obtained as the array is scanned from the boresight to 60°. The realized gain pattern of the investigated array is also shown in Fig. 6. As seen from the figure, the investigated array can scan its main beam from 0° to 60° with a gain fluctuation less than 2.1 dB and the maximum gain of 18.27 dB occurs at the scanning angle of 20°. The overlapping results in about 1 dB gain improvement at 60° scan angle, as shown in Table I compared to the referenced array at 60°.

V. CONCLUSION

This paper addressed the use of overlapped subarrays to improve the impedance matching performance over wide scan angle. Simulated results show that the scan range of the investigated E-plane arrays is much wider than the conventional microstrip phased arrays with equal dimensions.

REFERENCES

- [1] H. A. Wheeler, "Simple relations derived from a phased-array antenna made of an infinite current sheet," *IEEE Trans. Antennas Propag.*, vol. 13, pp. 506-514, Jul. 1965.
- [2] P. W. Hannan, "The element-gain paradox for a phased-array antenna," *IEEE Trans. Antennas Propag.*, vol. 12, pp. 423-433, Jul. 1964.
- [3] J. Blass and S. J. Rabinowitz, "Mutual coupling in two-dimensional arrays," *1957 IRE WECON Conv. Rev.*, pt. 1, pp. 134-150, 1957.
- [4] E.G. Magill and H. A. Wheeler, "Wide-angle impedance matching of a planar array antenna by a dielectric sheet," *IEEE Trans. Antennas Propag.*, vol. 14, pp. 49-53, Jan. 1966.
- [5] P. W. Hannan, D. S. Lerner and G. H. Knittel, "Impedance matching a phased-array antenna by a connecting circuits," *IEEE Trans. Antennas Propag.*, vol. 13, pp. 28-34, Jan. 1965.
- [6] S. Sajuyigbe, M. Ross, P. Geren, S. A. Cummer, M. H. Tanielian and D.R. Smith, "Wide angle impedance metamaterials for waveguide-fed phased-array antennas," *IET Microw, Antennas Propag.*, vol. 4, pp. 1063-1072, 2010.
- [7] M. H. Awida, Aladin. H. Kamel, and A. E. Fathy, "Analysis and design of wide-scan angle aide-band phased arrays of substrate-integrated cavity-backed patches," *IEEE Trans. Antennas Propag.*, vol. 61, pp. 3034-3041, Jun. 2013.
- [8] R. J. Mailoux, "A low sidelobe partially overlapped constrained feed network for time delayed subarrays," *IEEE Trans. Antennas Propag.*, vol. 49, pp. 39-40, Feb. 2001.
- [9] A. K. Bhattacharyya, "Floquet modal based analysis of overlapped and interlaced subarrays," *IEEE Trans. Antennas Propag.*, vol. 60, pp. 1814-1820, Apr. 2012.