Low Sidelobe Tapered Printed Wide-Slot Antenna Array

R. Bayderkhani and H.R. Hassani

Electrical & Electronic Eng. Dept., Shahed University
Persian Gulf Highway, Tehran, Iran
bayderkhani@shahed.ac.ir, hassani@shahed.ac.ir

***Abstract*— A unique technique to increase the impedance bandwidth and reduce sidelobe level of printed antenna array is proposed. To do so, a printed tapered wide-slot antenna array fed by an array of printed patch elements placed above a metal reflector is introduced. The impedance bandwidth of the antenna array is 10.3-23.1 GHz. By tapering the length of each of the slot elements, a very low sidelobe level of -33.5 dB is obtained. The proposed antenna has a stable radiation pattern over the 14.7-17 GHz, i.e. the 3 dB gain bandwidth is 15.2% and has a 40 dB of front-to-back ratio level and a low cross-polar component <-45 dB at broadside and < -35 dB off broadside direction. The simulated and measured results are presented and discussed.**

I. Introduction

Printed antenna arrays are usually used in telecommunication systems such as point to point and point to multipoint and in radar microwave and millimeter systems [1]. They have numerous attractive features in terms of light weight, small size, low cost, high efficiency, and ease of fabrication and installation, and in array designs the microstrip feed network can be placed on the same substrate as the microstrip patches [1, 2]. In radar systems parameters such as sidelobe level (SLL), front-to-back ratio (F/B), [1, 2], and bandwidth, [3], are of high importance. Depending on the radar system SLL between -20 and -50 dB is usually required [2].

With printed antenna, the realization of arrays with SLL lower than -25 dB becomes increasingly difficult mainly due to: mutual coupling between radiating elements, surface wave effect, parasitic radiation from a feeding network, and tolerances in fabrication [1-2]. There are usually two types of arrays in microstrip structures, namely, the corporate-fed and the series-fed patch antenna arrays, both of which are inherently narrow in bandwidth. The discontinuities, bends, power dividers, and other components in the corporate-fed array cause spurious radiation that limits the minimum SLL achievable [2]. The structure of a series-fed array is such that it uses shorter line length in comparison with corporate-fed arrays, and this leads to an antenna with less space on substrate, lower attenuation loss, and spurious radiation from feed lines [4]. However, for large series-fed arrays, amplitude and phase tracking with frequency can be problematic [5].

To reduce the sidelobe level in printed antenna arrays several approaches have been proposed, such as the use of the following: a corner reflector (i.e. a non-planar structure) to shield the feed network from the main radiating elements leading to -32 dB in SLL [1]; coaxial probes along with phase shifters to reduce SLL to almost -35dB [2]; feed network behind the ground and connected to the antenna via pins [6]; aperture coupled patch antennas [7, 8]; and a waveguide-fed microstrip patch array at 76 GHz [9, 10]. By extending the finite ground plane in between the Yagi-like antenna elements, [16], and the double dipole antenna elements, [17], low sidelobe linear series-fed endfire arrays were proposed. It is worth mentioning that in these two papers no attempt was made to increase the impedance bandwidth of the antenna array structures.

Bandwidth enhancement in patch antenna array is mostly based on stacking patches on top of each other [11] or placing parasitic elements beside the patch antenna [12]. There is, however, no mention of the SLL performance in those papers dealing with such array structures.

Based on the literature review done by the present authors, it seems that most of the works published are either on increasing the bandwidth or improving the SLL of the array, but not both together. The improved SLL structures published are either very complex or are non-planar in structure.

In this paper a unique technique is introduced to overcome the impedance bandwidth and sidelobe limitation associated with printed antenna array. To do so, a printed tapered wide-slot antenna array fed by an array of printed patch elements placed above a metal reflector is introduced leading to wide impedance bandwidth along with low SLL. The tapering of the slot elements is carried out by changing the length of each element. The simulated and measured results are presented and discussed. The proposed printed tapered wide slot antenna array was analyzed with a commercially available full-wave finite element electromagnetic (EM) simulator, Ansoft's HFSS. The simulated and measured results are presented and discussed.

II. Antenna Design and Structure

The aim of this work is to design a uni-directional low SLL, wide bandwidth printed wide-slot antenna array. As is well documented in the literature, a slot antenna if appropriately fed, i.e. has a tapered aperture field distribution, would have a

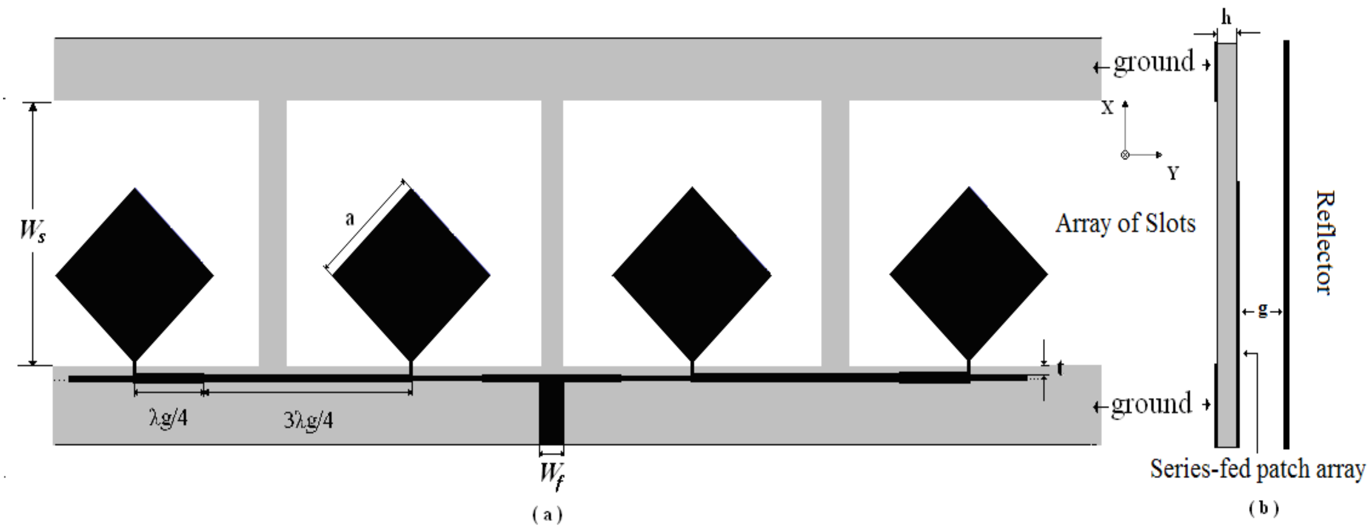

Fig.1. The structure of the proposed antenna showing array of tapered slots fed by array of series fed patch elements. (a) Top view, (b) Side view

low SLL, and a wide printed slot antenna can provide a large impedance bandwidth. A series-fed printed antenna array with proper Chebyschev distribution can produce a suitable tapered field distribution. Thus, one can use such series-fed printed antenna array as the feed system for a linear wide slot printed antenna array. Such a structure can provide a low SLL and wide band impedance bandwidth antenna array.

Since tapering an array of antenna elements results in lowering of SLL, this idea can be applied to the slot array of the above structure, i.e. the length of the slots in the linear direction can be tapered to further improve the SLL of the array.

The proposed structure is shown in Fig. 1. The array contains 22 equal square patch elements of side 5.6 mm each, placed on a grounded substrate of $\varepsilon_r = 2.2$ and thickness of 0.508 mm. The size of the substrate is L = 310 mm and W = 20 mm. The corner-fed square patches were chosen because they provide high input impedance, making them well suited for series-fed patch array.

The array is of resonant type and is designed for radiation in the broadside direction. The design center frequency is 16.26 GHz. The antenna array is split into two linear sub arrays and fed in the middle. This symmetric arrangement further improves the cross-polarization level of the array and prevents the beam-pointing direction from varying with frequency [13]. As such, the cross-polar component generated in one side of the patch/array is cancelled by the cross-polar component generated in opposite side of the patch/array at broadside direction. To get a broadside pattern, the spacing between the feed points of the array elements must be set at one guided wavelength λ_g, to ensure an equal phase between the elements. The antenna array has been designed for a -40 dB SLL through appropriate Chebychev taper distribution. A tapered distribution is readily obtained using quarter-wavelength transformers along the line. Two quarter-wave transformers along with a half-wave transformer are used throughout the first seven elements on each side of the main feed source (one quarter-wave transformer has the same characteristic impedance as the half-wavelength line, which results in less spurious radiation from such discontinuities). Between elements 7 and 11 four quarter-wavelength transformers are used (in this way for the last array elements the size of the feed lines would be physically large enough to be constructed). The characteristic impedance of the half-wave lines are set at 115 ohm while those of the quarter-wave Transformers are between 80 and 125 ohms. The detailed design considerations for series-fed patch array are discussed in [14-15].

Through optimization, the width of the slot elements is W_s = 13 mm ($\approx\lambda_g$) and its length, L_s changes according to a linear tapering format from the size of 11 mm at the ends of the array to 13 mm at the center of it. Table I summarizes the lengths of each of the slot array elements. The slot is positioned t = 0.2 mm from the main feed line, and a 50-ohm microstrip line with W_f = 1.53 mm is used to feed the array, as shown in Fig. 2. As this structure is a bi-directional radiator, one can place a reflector of same dimension as that of the substrate above the printed patch elements to make the radiation uni-directional. The reflector-to-patch spacing is set at g = 1.5 mm.

In the following section the simulation, via software package HFSS, and measured results are presented.

III. Results and Discussion

In this section, detailed simulation and experimental results of the proposed antenna array are presented. Figure 2 shows the simulated as well as the measured reflection coefficient of this antenna. The results show that the proposed antenna has a wide impedance bandwidth, ranging from 10.3-23.1 GHz. In comparison with the antenna investigated in [4], the

TABLE I
LENGTH OF THE SLOT ARRAY ELEMENTS

Slot's number (from center to end of the array)	Lengths (mm)
1	13
2	12.8
3	12.6
4	12.4
5	12.2
6	12
7	11.8
8	11.6
9	11.4
10	11.2
11	11

impedance bandwidth of the proposed antenna has increased almost 26 times. Through simulations it is seen that the proposed antenna has a stable radiation pattern over the 14.7-17 GHz, i.e. the 3 dB gain bandwidth is 15.2%. In this range, the radiation pattern has a pencil beam shape, but out of this range the pattern splits, similar to that of the previous section.

Figure 3 shows the simulated and measured E- and H-plane radiation patterns of this antenna array. From this figure it can be seen that the proposed antenna has a good directional pattern with -33.5 dB SLL and 4.5 degree half-power beam width (HPBW) at center frequency. It needs to be said that if equal size slot array elements are used, the SLL would be -32.5 dB, thus, some 2 dB improvement has been achieved through tapering the slot array elements lengths. Moreover, the proposed antenna has 40 dB of F/B level and a low cross-polar component <-45 dB at broadside and < -35 dB off broadside direction. At the beam peak, the proposed antenna has maximum co-polarization gain of 18.1 dBi at broadside direction.

Through simulations it is seen that the proposed antenna has a stable radiation pattern over the 14.3-16.8 GHz, i.e. the 3 dB gain bandwidth is 16% and the frequency range over which SLL < -20 dB is found to be 15.5-16.5 GHz which is 6.2%.

IV. CONCLUSION

In this paper a simple method (which is also easy to construct) to provide a wideband, very low SLL and high F/B printed antenna array is reported. The proposed antenna array has: an impedance bandwidth of 10.3-23.1 GHz; a very low SLL of -33.5 dB; a 3 dB gain bandwidth of 15.2%; a F/B of 40 dB and a low cross-polarization level of <-45 dB at broadside and <-35 dB off broadside direction. The array antenna introduced is useful for many low sidelobe level radar applications.

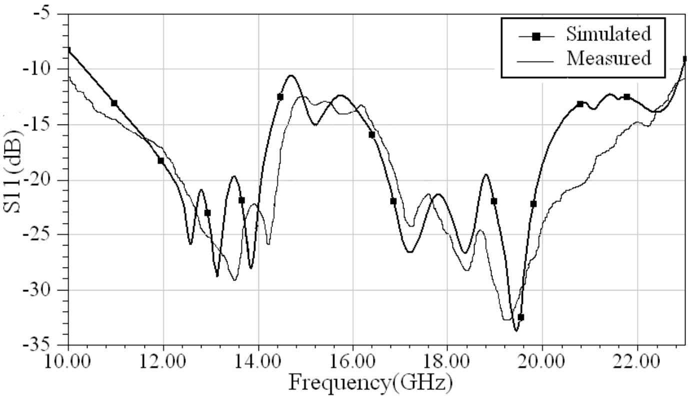

Fig. 2. The simulated and measured reflection coefficient of the proposed antenna

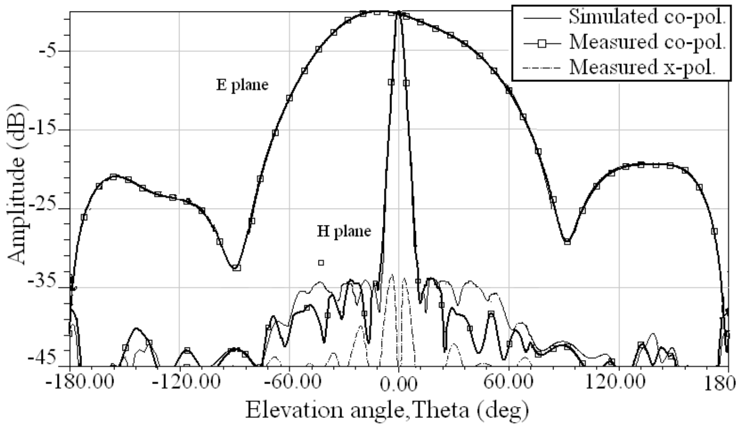

Fig. 3. The simulated and measured radiation pattern (E and H-plane) of the proposed antenna

REFERENCES

[1] A. Nesic, Z. Micic, S. Jovanovic and I. Randonvic "Millimeter wave printed antenna array with high side lobe suppression," in Proc. IEEE AP-S Int. Symp, pp. 3051-3054, 2006.
[2] D. M. Pozar and B. Kaufman,"Design considerations for low sidelobe microstrip arrays," IEEE Trans. Antennas & Propag., vol. 38, no. 8, pp.1176-1185, Aug. 1990.
[3] M. I. Skolnik, *Radar Handbook*, 3rd ed., McGraw Hill Press, 2008, Ch. 1, p. 8.
[4] D. M Pozar, and D. H. Schaubert, "Comparison of three series-fed microstrip array geometries," Proc. IEEE AP-S Int. Symp, vol. 2, pp. 728 – 731, 1993.
[5] D. M Pozar, "A review of bandwidth enhancement techniques for microstrip antennas," in Microstrip Antennas: Analysis and Design of Microstrip Antennas and Arrays, IEEE Press, pp. 157-166, 1995.
[6] G. Gronau, H. Moschuring, and I. Wolff, "Microstrip antenna arrays fed from the backside of the substrate,"Proc. Int. Symp, Antennas Propagat., Kyoto, Japan, 1985.
[7] D.M. Pozar, "A microstrip antenna aperture coupled to a microstrip line," Electronics Letters, vol 21, pp 49-50, Junuary1985.

[8] D.M. Pozar and R. W. Jackson, "An aperture coupled microstrip antenna with a proximity feed on a perpendicular substrate," IEEE Trans. Antennas & Propag. , vol. 35, pp.728-731, June 1987.

[9] J. Hirokawa and M. Ando, "Sidelobe suppression in 76 GHz post-wall waveguide-fed parallel plate slot arrays," IEEE Trans. Antennas & Propag., vol 48, no. 11, pp.1727–1732, Nov. 2000.

[10] Y. Kimura et. al., "76 GHz alternating-phase fed single –layer slotted waveguide arrays with suppressed sidelobes in the E-plane," IEEE Trans. AP-S, Dig. Vol.41, pp.1042-1045, June 2003.

[11] S. D. Targonski, R. B. Waterhouse, and D. M. Pozar, "Wideband aperture coupled stacked patch antenna using thick substrates," Electronics Letters, vol. 32, pp. 1941-1942, Oct. 1996.

[12] S. Oh, S. Seo, M. Yoon, C. Oh, E. Kim, and Y. Kim, "A broadband microstrip antenna array for LMDS applications," Microwave and Opt. Lett., vol. 32, no. 1, pp. 35-37 , Jan. 2002.

[13] A. Vallencchi, and G.B. Gentili, "Design of dual-polarized series-fed microstip arrays with low losses and high polarization purity," IEEE Trans. Antennas & Propag., vol 53, pp.1791–1798, May 2005.

[14] J. R. James and P. S. Hall, *Handbook of microstrip antennas*, Peter Peregrinus Ltd., London, United Kingdom, 1989, pp. 645–665.

[15] R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, *Microstrip Antenna Design Handbook.* Norwood, MA, Artech House, 2001

[16] R. Bayderkhani and H. R. Hassani, "Wideband and low sidelobe linear series fed Yagi-like antenna array", Progress In Electromagnetics Research B, Vol. 17, pp. 153–167, 2009

[17] R. Bayderkhani and H. R. Hassani, "Low sidelobe wideband series fed double dipole microstrip antenna array", *IEICE Electron. Express*, Vol. 6, No. 20, pp.1462-1468, 2009.