Superdirective Wideband Array of Planar Monopole Antenna With Loading Plates

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***Abstract*—A wideband superdirective array of a two-element planar plate monopole antenna is presented. Initially, a two-element, closely spaced array of a simple rectangular planar monopole antennas is considered. Based on a relative phase shift of 100° between the two elements, over the 3–6-GHz bandwidth this antenna array provides directivity of 3.5–6.9 dB. In order to achieve a higher directivity over a wider frequency bandwidth, a pair of small parallel plates is attached to the radiating edges of the rectangular planar monopole antenna. It is shown that this antenna array with element spacing of 2 cm and a relative phase shift of 135° between the elements produces 3.1–7.5 GHz impedance bandwidth with 7.7–10.1 dB of directivity. This antenna has an efficiency of 60%–91% over the bandwidth. Simulation and experimental results are provided and discussed.**

***Index Terms*—Antenna arrays, planar monopole antenna, superdirectivity, wideband.**

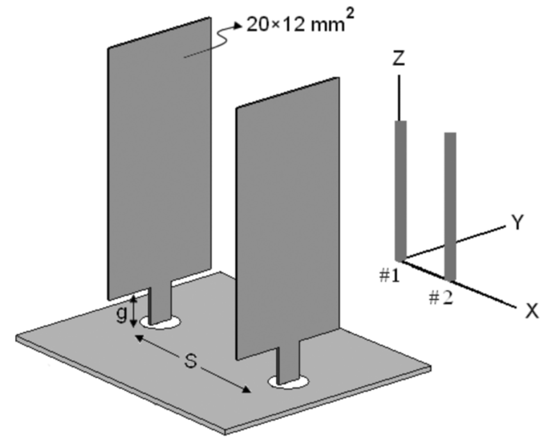

Fig. 1. Simple planar monopole antenna array.

I. Introduction

SUPERDIRECTIVE antenna arrays are a class of arrays that can be designed to achieve higher directivity than those obtained from the uniformly excited, equally spaced equivalent array. To increase the directivity of a uniformly excited array, a large number of elements N is required. Directivity approaches N as N becomes large [1]. Uzkov [2] has shown that with the proper choice of magnitude and phase of the N collinear isotropic elements, the endfire directivity of the array approaches a value of N^2 as the separation distance of the radiating elements approaches zero. A directivity of N^2 represents an extraordinary "superdirectivity" compared to the maximum attainable directivity N for isotropic elements spaced a half-wavelength apart.

Superdirectivity applies in principle to electrically small antennas [3], to arrays of isotropic elements [4], and to non-isotropic elements such as dipoles [5] or monopoles [6], slots [7], and patches [8]. Most of the works published on the superdirective arrays are related to thin monopole wire antennas.

Two undesirable features of superdirective arrays that have been reported so far are related to their narrow bandwidth and their low efficiency. For monopole wire arrays, bandwidth rapidly becomes a problem as the element spacing decreases below $\lambda/4$. Low efficiency is mainly due to matching network losses and losses in the antenna elements [9].

The planar plate monopole (PM) antenna has been shown to provide wideband impedance characteristics [10]. These antennas also have the attractive feature of low profile, low cost, and ease of fabrication. However, the radiation patterns of the PM antennas are usually omnidirectional with low directivity.

In this letter, a two-element simple rectangular planar monopole antenna array is described that gives 3.5–6.9 dB of directivity over the 3–6-GHz bandwidth. In order to achieve higher superdirectivity over a wider bandwidth, a pair of small parallel plates is attached to the radiating edge of the simple rectangular monopole antenna. The addition of the plates improves the directivity over the lower frequency range. This array structure gives 7.7–10.1 dB of superdirectivity over the 3.1–7.5-GHz bandwidth. Simulation based on CST software as well as experimental results are provided and discussed.

II. Two-Element Simple PM Antenna Array

A two-element simple PM antenna over an infinite ground plane is shown in Fig. 1. Each element consists of a planar rectangular plate with dimension 20×12 mm^2, excited at the middle of its base by a narrow metal strip connected to a 50-Ω coaxial feed. The feed gap parameter, g, is set at 1 mm.

The spacing and the relative phase between the elements needs to be correctly chosen to provide the widest bandwidth and highest directivity from this antenna structure. Fig. 2 shows the return loss of the two-element simple PM antenna array for various element spacing S with both elements being fed. From this figure, it is seen that $S = 25$ mm provides the widest

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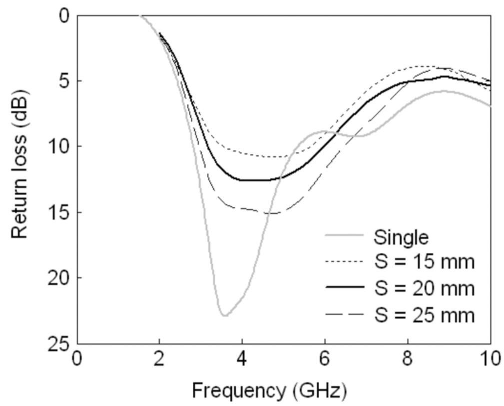


Fig. 2. Return loss of the simple PM antenna array for various element spacing S.

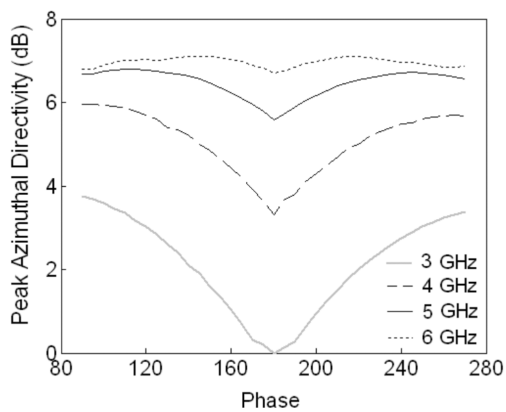


Fig. 3. Peak azimuthal directivity of the simple PM antenna with element spacing $S = 20$ mm at different frequencies for various phasing of element #2.

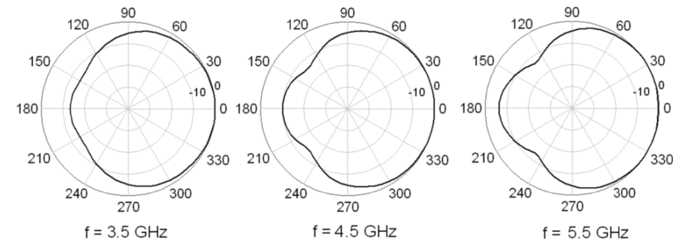


Fig. 4. Normalized H-plane (xy) pattern of the simple PM antenna over an infinite ground plane for 100° phase shift between the elements.

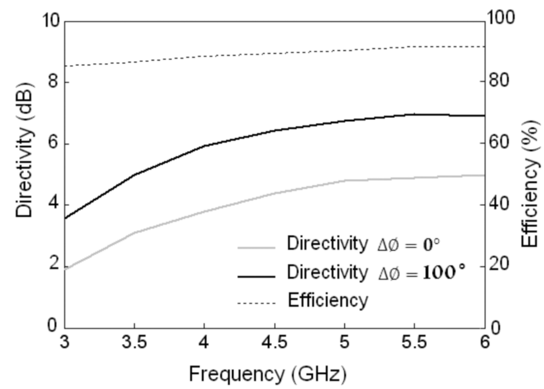


Fig. 5. Directivity and efficiency of the simple PM antenna array.

impedance bandwidth, but for having the highest directivity, we chose $S = 20$ mm.

Next, the relative phase of excitation between the two elements is adjusted while the amplitude of the excitations is kept constant over the impedance bandwidth. Fig. 3 shows the peak azimuthal directivity of this array structure versus relative phase of excitations at different frequencies (3, 4, 5, and 6 GHz). The phase of excitation for element #1 is set at 0°, while phase of excitation for element #2 is varied between 90° to 270° (for relative phase of less than 90° or larger than 270°, the radiation pattern tends toward an omnidirectional pattern). From the results, it can be seen that 180° out-of-phase excitation gives the minimum directivity over most of the bandwidth. The optimum relative phase shift for maximum directivity over the bandwidth is 100°.

Fig. 4 shows the radiation pattern of the simple PM antenna array at 100° relative phase shifts at three different frequencies (3.5, 4.5, and 5.5 GHz) over the band. For a phase shift of 180° to 270° the pattern would be mirrored image of that of 90° to 180°.

The directivity of the simple PM antenna array with and without the relative phase shift of 100° along with the efficiency is shown in Fig. 5. The antenna shows 85%–93% radiation efficiency while the directivity ranges between 3.5 to 6.9 dB over the 3–6-GHz bandwidth. The directivity of a single simple PM antenna is less than 3 dB over 3–5-GHz bandwidth [11].

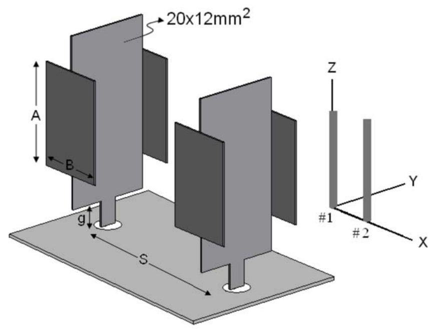
III. Two-Element Planar Monopole Antenna Array With Loading Plate (PMLP)

It is known in a wire monopole antenna that by adding multiple arms to the antenna improves radiation properties and increases the effective surface area, leading to increased directivity over a wide impedance bandwidth [12]. Similarly, to increase the effective surface area of the planar monopole antenna, one can add loading plates to the vertical radiating edges of the PM antenna, leading to a planar monopole antenna with loading plates, PMLP.

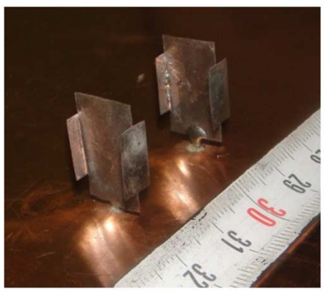
As shown in [13], through application of the transmission line modeling (TLM), the dimensions of the loading plates can also be chosen appropriately to provide a very wide impedance bandwidth.

The pair of loading plates is determined by two parameters A and B. In [13], in order to provide the widest impedance bandwidth, the A and B parameters for the specified planar monopole antenna are selected to be 12 and 6 mm, respectively. Fig. 6 shows the array of two PMLP antenna elements placed over an infinite ground plane. The simulated return loss of the single-element and the two-element PMLP antenna arrays (with both elements being fed) for various element spacing (S) are shown in Fig. 7. From this figure, it is clear that the optimum value of S is 20 mm.

To obtain superdirectivity, a suitable relative phase shift between the two elements is required. The relative phase of excitation between the two elements is adjusted while amplitude of the excitations is kept constant at 1 V. Fig. 8 shows the endfire directivity of the PMLP antenna array versus relative phase of excitation at three different frequencies (4, 5.5, and 7 GHz). It can be seen from the results that the 180° out-of-phase excitation gives



(a)



(b)

Fig. 6. (a) Two-element planar monopole antenna array with loading plate. (b) Fabricated antenna array.

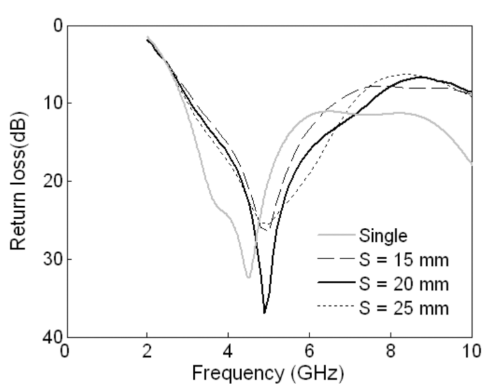


Fig. 7. Return loss of the PMLP antenna array for various element spacing S.

the minimum directivity at lower frequencies and maximum directivity at higher frequencies. In the present antenna structure, relative phase shifts of 90° or 270° give minimum directivity. The optimum relative phase shift for maximum directivity over the bandwidth is 135°. The H-plane radiation patterns of the endfire array at three frequencies (4, 5.5, and 7 GHz) are shown in Fig. 9. It is noted that if the ground plane of the structure becomes finite, square-shaped with 600 mm side length, the location of the peak radiation pattern changes with frequency around $\varphi = 0°$, as shown in Fig. 9.

The directivity of the PMLP antenna array with and without the relative phase shift of 135° along with the efficiency is shown in Fig. 10. The antenna shows between 60%–91% efficiency while the directivity ranges between 7.7 to 10.1 dB over the 3.1–7.5-GHz bandwidth. The maximum directivity of the single-element planar monopole antenna with loading plates is 4.5 dB over the bandwidth [13].

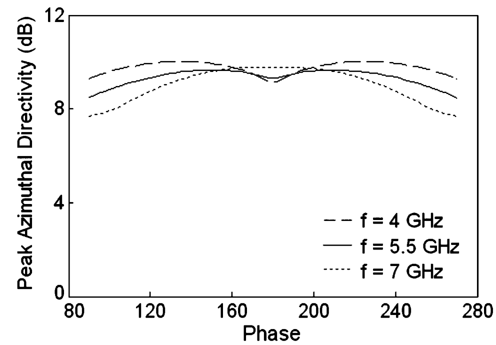


Fig. 8. Peak azimuthal directivity of the PMLP antenna array at three different frequencies for various phasing of element #2.

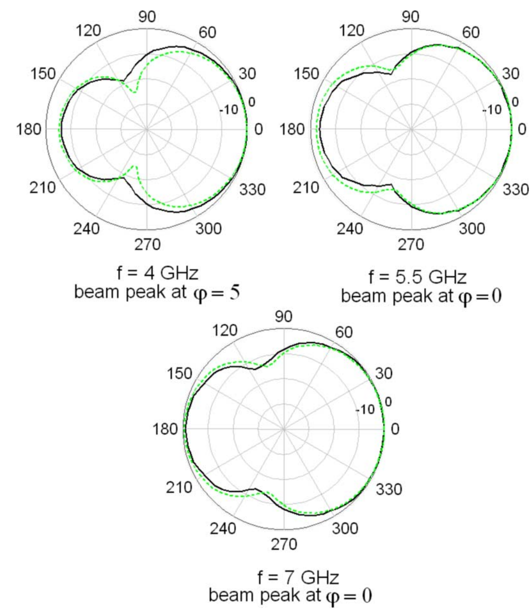


Fig. 9. Normalized H-plane (xy) pattern of the PMLP antenna array over an infinite ground plane (dashed line), a finite ground plane (solid line) at 135° phase shift between the elements.

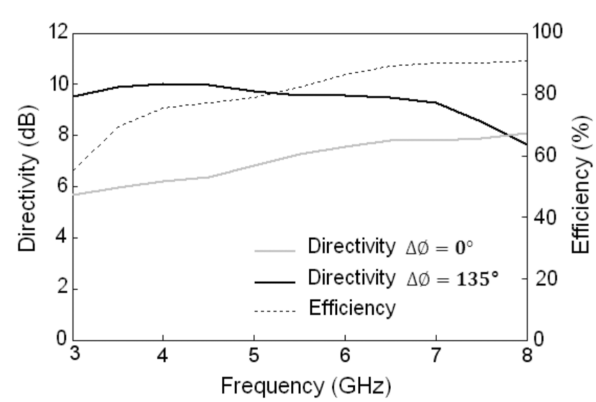


Fig. 10. Directivity and efficiency of the PMLP antenna array.

IV. Measurement

The PMLP antenna array elements are mounted on a $600 \times 600\ \mathrm{mm}^2$ copper ground plane. Fig. 6(b) shows the fabricated antenna array. To obtain the measurement results, the setup shown in Fig. 11 is required. The measured return

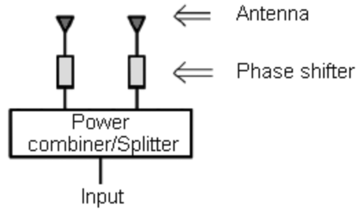


Fig. 11. Measurement setup.

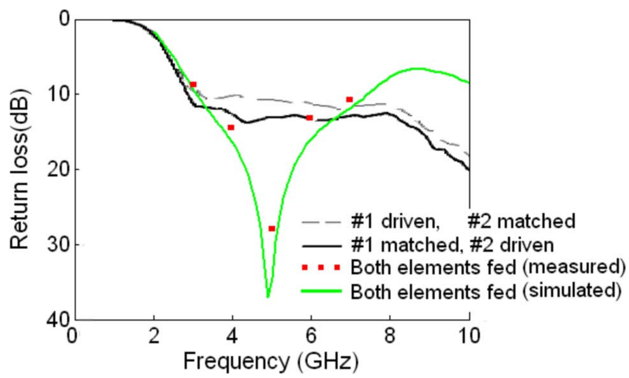


Fig. 12. Measured return loss of the PMLP antenna with $S = 20$ mm for two cases, one element driven and the other match terminated, and measured and simulated result for both elements fed with relative phase shift of 135°.

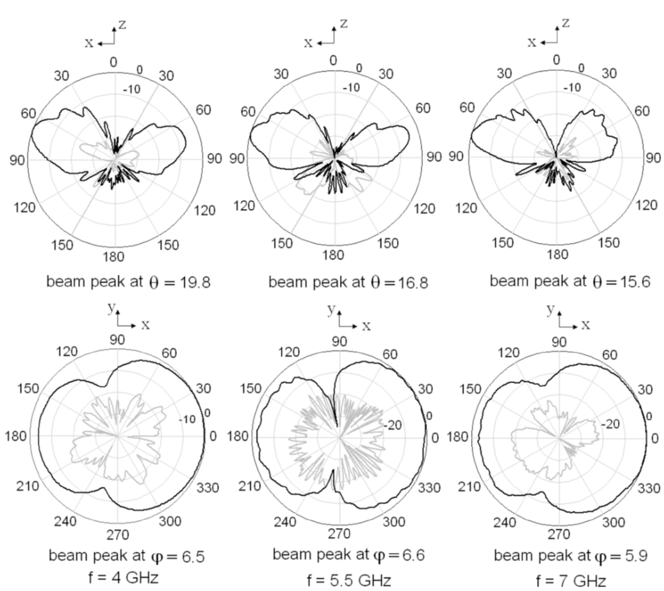


Fig. 13. Measured normalized E-plane (xz) and H-plane (xy) copolar (black) and cross-polar (gray) radiation pattern of PMLP antenna array at 135° relative phase.

loss of the array antenna is shown in Fig. 12 for two cases. In the first case, one monopole is driven and the other one is match terminated, and in the second case, both elements are fed with 135° relative phase shift. Because of the finite ground plane, edge reflections change the measured return loss results compared to the simulation in which infinite ground plane is assumed.

Fig. 13 shows the measured E-plane and H-plane radiation pattern of the antenna at three different frequencies. Although, not clearly seen, the peak of the measured pattern moves between +5.9° to +6.6° around the endfire for various frequencies. A similar situation occurs in the E-plane pattern. The beam moves away from horizon and rotates between 15.6° to 19.8°.

The directivity at various frequencies is measured according to the procedure given in [14], with the relative phase between the two elements being 135°. The results are shown in Table I. For the measured directivity, the measured radiation pattern at azimuth plane is used.

TABLE I
MEASURED DIRECTIVITY

Frequency (GHz)	4	5.5	7
Directivity (dB)	8.83	8.34	8.05

V. CONCLUSION

The structure of a two-element planar plate monopole antenna array for superdirectivity has been analyzed. Two different antenna elements are considered. In the first structure, an array of simple planar monopole antennas covers the 3–6-GHz bandwidth with 3.5 to 6.9 dB directivity, while in the second structure, an array of planar monopole antennas with loading plates provides 3.1–7.5 GHz bandwidth with a directivity of 7.7–10.1 dB. The latter array structure provides 60%–91% of efficiency.

REFERENCES

[1] W. L. Stutzman and G. A. Thiele, *Antenna Theory and Design*. New York: Wiley, 1981, pt. 3, p. 142.
[2] A. I. Uzkov, "An approach to the problem of optimum directive antennae design," *Comptes Rendus (Doklady) de l'Academie des Sciences de l'URSS*, vol. 53, pp. 35–38, 1946.
[3] A. D. Yaghjian, T. H. O'Donnell, E. E. Altshuler, and S. R. Best, "Electrically small supergain end-fire arrays," *Radio Sci.*, vol. 43, no. RS3002, May 2008.
[4] O. Ishii, K. Itoh, Y. Nagai, and K. Kagoshima, "Miniaturization of array antennas with superdirective excitation," in *Proc. Antennas Propag. Soc. Int. Symp.*, 1993, vol. 3, pp. 1850–1853.
[5] S. R. Best, "Improving the performance properties of a dipole element closely spaced to a PEC ground plane," *IEEE Antennas Wireless Propag. Lett.*, vol. 3, pp. 359–363, 2004.
[6] E. E. Altshuler, T. H. O'Donnell, A. D. Yaghjian, and S. R. Best, "A monopole superdirective array," *IEEE Trans. Antennas Propag.*, vol. 53, no. 8, pp. 2653–2661, Aug. 2005.
[7] S. A. Bokhari, H. K. Smith, and J. R. Mosig, "Line source radiation in the presence of slotted cylinders," in *Proc. Antennas Propag. Soc. Int. Symp.*, Jul. 1992, vol. 3, pp. 1583–1586.
[8] K. Buell, H. Mosallaei, and K. Sarabandi, "Metamaterial insulator enabled superdirective array," *IEEE Trans. Antennas Propag.*, vol. 55, no. 4, pp. 1074–1085, Apr. 2007.
[9] R. C. Hansen, *Electrically Small, Superdirective, and Superconducting Antennas*. Hoboken, NJ: Wiley, 2006.
[10] N. P. Agrawall, G. Kumar, and K. P. Ray, "Wide-band planar monopole antennas," *IEEE Trans. Antennas Propag.*, vol. 46, no. 2, pp. 294–295, Feb. 1998.
[11] M. J. Ammann, "Square planar monopole antenna," in *Proc. IEE Nat. Conf. Antennas Propag.*, 1999, pp. 37–40.
[12] S. R. Best, "The performance properties of electrically small resonant multiple-arm folded wire antennas," *IEEE Antennas Propag. Mag.*, vol. 47, no. 4, pp. 13–27, Aug. 2005.
[13] S. M. Mazinani and H. R. Hassani, "A novel broadband plate loaded planar monopole antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 1123–1126, 2009.
[14] C. A. Balanis, *Antenna Theory*. Hoboken, NJ: Wiley, 2005, ch. 17.