Two Element Wideband Planar Plate Monopole Superdirective Array

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***Abstract*— A two element, closely spaced array of wideband planar monopole antennas to achieve superdirectivity is presented. In this study, three rectangular plate monopole structures, the simple Planar Monopole element (PM), the Planar Monopole element with Bevel (PMB), and the Planar Monopole element Loaded in its radiating edges with small rectangular Plates (PMLP) are considered as the array elements. In each case, the spacing and phase of excitation between the two elements is adjusted to achieve the highest directivity over the widest frequency band. It is shown that the PMLP antenna with element spacing of 2 cm can produce 7.6-10.1 dB of directivity over the 3-8 GHz band. This antenna has an efficiency of 60-91% over the bandwidth. Simulation and experimental results are provided and discussed.**

Keywords- Antenna Arrays; planar monopole antenna; superdirectivity; wideband

I. INTRODUCTION

Array antennas are highly used in applications where directive beam antennas are required. 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. It was shown in [1] that the endfire directivity of collinear isotropic radiators, each excited with the proper magnitude and phase, approaches a value of N^2 as the separation distance of the radiating elements approaches zero. This is also desirable in some applications, where physically compact size arrays are required.

Most of the works published on the superdirective array are related to monopole wire antennas. In [2] a two element superdirective array of resonant monopoles is investigated. These two elements are both fed with equal magnitude but different phases. It is shown theoretically that for a 0.05λ element separation some 10.5 dB endfire directivity is possible. Design of a closely spaced folded monopole Yagi antenna to achieve high gain in a compact size is reported in [3]. The antenna has 3-elements, one is driven and the other two elements are parasitic. The spacing between elements is set at 0.02λ. It is shown that the array produces some 10 dB directivity over 1.7 % bandwidth at 1 GHz.

A multiple arm folded element was used in [4] to impedance match a dipole closely spaced to a conducting ground plane. The antenna gives 8.5 dBi gain with 90% efficiency while the dipole is 0.25λ above ground. It was also shown that if wire dipole is replaced by a conducting plate, the achievable gain does not change much. In [5] a simulation study on a two element impedance matched multiple folded monopole array is given. The spacing between elements is 0.1λ and each element is fed by equal magnitude and phased 163^o relative to each other. The bandwidth achieved is 4.9% and the simulated peak directivity is 10.18 dB. Apart from monopole wire super-directive arrays reported above, a 2-element low profile microstrip-based folded monopole endfire array with high-μ metamaterial matching network on each element is reported in [6]. At 2.45 GHz the maximum directivity and efficiency of the proposed antenna array is 5.8 dB and 40%, respectively. In [7] a physically small 5element patch array, $1.18\lambda_o$ long, employing metamaterial insula-tors between the elements to reduce mutual coupling, exhibits superdirectivity over 6% bandwidth at 2 GHz.

A two undesirable feature of superdirective arrays reported so far are narrow bandwidth and low efficiency. For monopole wire end-fire 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 [8].

The Planar Plate Monopole (PM) antenna is shown to provide extremely wideband impedance characteristics. These antennas also have the attractive feature of low profiles, low cost, and easy fabrications. But the radiation patterns of PM antenna are usually omnidirectional.

In this paper, a study is given on wideband 2-elements planar monopole antenna to obtain the highest directivity possible. Three different planar monopole antenna structures are considered and for each, based on bandwidth, efficiency, radiation pattern and highest possible directivity the phase of excitation and separation between elements is provided. It will be shown that the spacing between elements greatly affects the bandwidth and relative phase of excitation affects the highest directivity possible. Simulation based on CST software package as well as experimental results are provided and discussed.

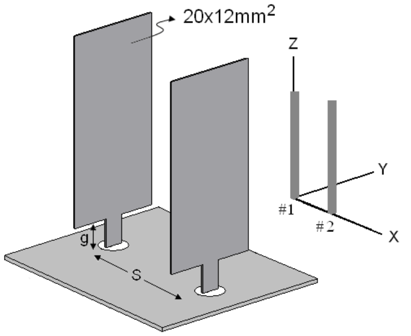


Figure 1. Simple planar monopole antenna array placed along x-axis

II. THE 2-ELEMENT WIDEBAND SUPERDIRECTIVE

In this section, design and analysis of three planar rectangular plate monopole structures as the array elements are considered. This includes: a simple Planar Monopole element (PM); Planar Monopole element with Bevel (PMB); and a Planar Monopole element Loaded in its radiating edge with small rectangular Plates (PMLP). In each case, the spacing and phase of excitation between the two elements is adjusted to achieve the highest directivity over the widest frequency band.

A. Simple Planar Monopole (PM)

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

As mentioned in the previous section, when two antenna elements are very closely spaced and fed with equal amplitude but with appropriate phase, the resulting radiation pattern becomes directional. Thus, the spacing and relative phase of the elements needs to be optimized to provide the widest bandwidth and highest directivity from this antenna structure. Fig. 2 shows the return loss of the simple 2 element PM antenna array for various element spacing, *S.* Also shown in this figure is the return loss of the single element. From this figure it is seen that S = 5 mm provides the widest impedance bandwidth. It should be stated that these results are obtained by feeding one of the elements while the other element is terminated in a matched load.

The relative phase of excitation between the two elements is then adjusted while amplitude of the excitations is kept constant at 1 volt. Fig. 3 shows the endfire directivity of this array structure versus relative phase of excitations at three different frequencies 4, 5.5, 7 GHz. The phase of excitation for element #1 is set at 0^o while phase of excitation for element #2 is varied between 90^o to 270^o (for relative phase of less than 90^o or larger than 270^o the radiation pattern tends towards an omnidirectional pattern). It can be seen from the results that 180^o out-of-phase excitation gives the minimum directivity while 90^o or 270^o phase excitation gives maximum directivity. Although the 2-element monopole array can be made superdirective using a 90^o or 270^o phase shift between the elements the radiation patterns may not have good directional behaviour over the entire bandwidth. It can be shown that if element #2 is fed at 120^o a compromise between high directivity and good radiation pattern can be obtained. Fig. 4 shows the directivity pattern of the simple PM antenna array at 90^o and 120^o relative phase shifts at three different frequencies 4, 5.5 and 7 GHz over the band. Although not shown, for a phase shift of 180^o to 270^o the pattern would be mirror image of that at 90^o to 180^o. Fig. 5 shows the relevant E-plane pattern at 120^o relative phase shifts. It is noted that if the ground plane of the structure becomes finite, with change in frequency, the location of the peak radiation pattern changes and no longer is located at $\varphi = 0^o$ and $\theta = 90^o$.

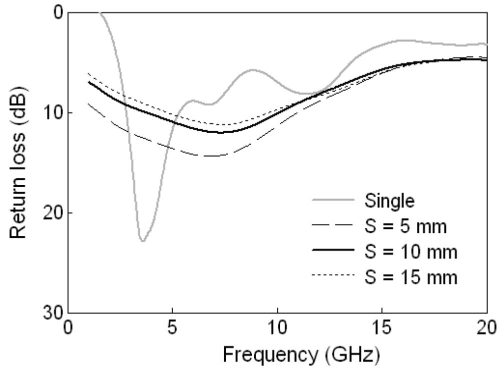


Figure 2. Return loss of the simple planar monopole antenna array for various element spacing S

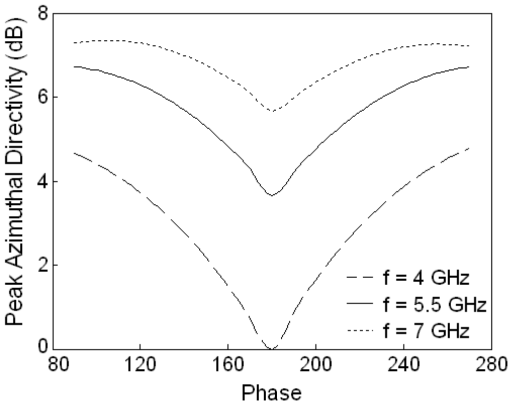
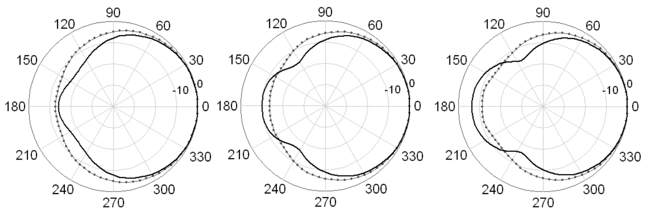
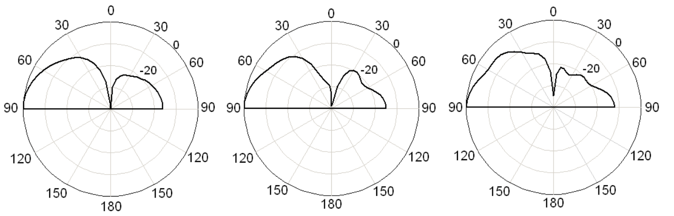


Figure 3. Peak azimuthal directivity of the simple PM antenna versus relative phase of excitations at three frequencies, with S = 5 mm



f = 4 GHz f = 5.5 GHz f = 7 GHz

Figure 4. Normalized radiation pattern of simple planar monopole antenna in the H-plane (xy), for 90^o (dash) and 120^o (solid) phase shift between the elements at various frequencies



f = 4 GHz f = 5.5 GHz f = 7 GHz

Figure 5. Normalized radiation pattern of simple planar monopole antenna in the E-plane (xz), for 120^o phase shift between the elements

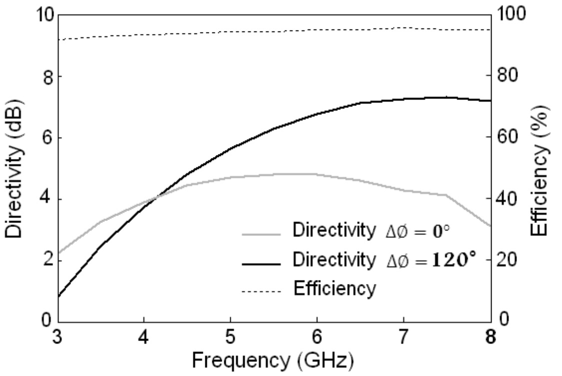


Figure 6. Directivity and efficiency of the simple PM antenna array

B. *Planar Monopole with Bevel (PMB)*

In rectangular planar monopole antenna, increase in impedance bandwidth can be achieved by beveling the radiating element edge near the ground plane on both sides of the feed probe, as shown in Fig. 7. In PMB antenna, fine control of the impedance bandwidth can be achieved by varying the bevel angle, α. The optimum value of α is found to be 40^o for the widest impedance bandwidth [10]. Fig. 8 shows the return loss of the 2-elements PMB antenna array for various element spacing, *S*, along with that of the single antenna element. Similar to the previous section, the lower the S the wider would be the impedance bandwidth, but based on obtaining the highest directivity, S = 10 mm is chosen. This spacing provides 2.6-15.7 GHz bandwidth. After choosing the element spacing, the relative phase of excitation between 2-elements is adjusted. As before, the excitation voltage amplitude of monopole #1 and #2 is set at 1 v.

Fig. 9 shows the endfire directivity of the PMB antenna array against phase of element #2 at three frequencies, 4, 5.5, and 7 GHz. The phase of element #1 is kept constant (reference 0^o). Similar to simple PM antenna array, it can be seen from the results that at 180^o out-of-phase excitation, minimum directivity occurs. When phase shift decreases from 180^o or increases from it, directivity increases and for 90^o or 270^o, maximum directivity occurs. But at either of these two phases, the radiation patterns of the array in the H-plane would not be directional over the entire bandwidth. The appropriate phase shift for element #2 is found to be 125^o. The radiation pattern of the PMB antenna can be shown to be very similar to that of the simple PM antenna of the previous section, thus, to save on space it is not shown here. At the higher frequencies the dimensions of this antenna array are no longer small compared to a wave-length and the radiation pattern suffers some degradation.

The directivity of the PMB antenna array with and without the relative phase shift of 125^0 along with the efficiency is shown in Fig. 10. The antenna shows more than 93% efficiency while the directivity ranges between 0.6 to 7.4 dB over the 3-8 GHz bandwidth. It is noted that over the 6.5-8 GHz bandwidth this antenna provides more than 7dB of directivity. It can be concluded that although, beveling has increased the antenna bandwidth, but it has not changed the superdirectivity level as compared to the simple PM antenna.

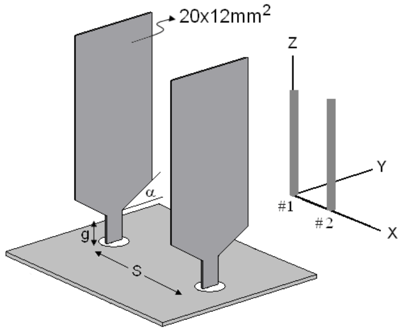


Figure 7. Planar monopole antenna array with beveling over infinite ground

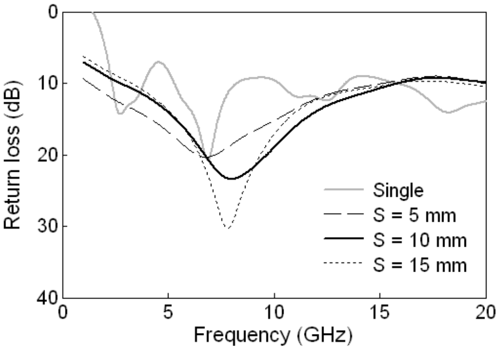


Figure 8. Return loss of the planar monopole antenna array with bevelling for various element spacing S

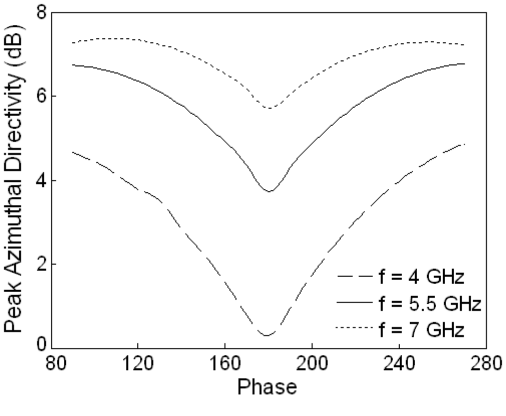


Figure 9. Peak azimuthal directivity of the PMB antenna array at three different frequencies for various phasing of element #2

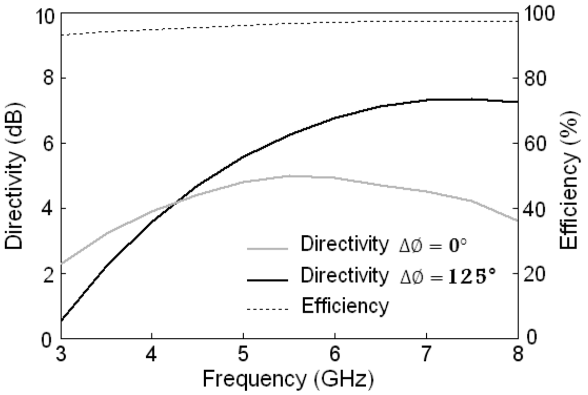


Figure 10. Directivity and efficiency of the PMB antenna array

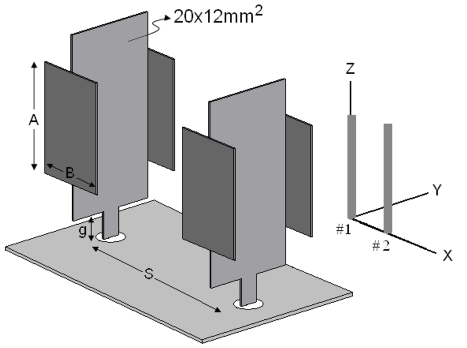


Figure 11. Planar monopole antenna array with loading plates

C. Planar Monopole Antenna with Loading Plate (PMLP)

PMLP antenna consists of a rectangular planar metal monopole antenna loaded at its two radiating edges by small rectangular plates and excited at the middle of its base by a narrow metal strip. The pair of plates placed on the two sides of the radiating element is determined by two parameters A and B, Fig. 11. In [11] in order to provide wider impedance bandwidth, the A and B parameters are selected to be 12 mm and 6 mm, respectively. It assumed that the ground of the structure is also infinite.

Unlike the two structures of previous sections reduction of spacing between array elements does not lead to higher impedance bandwidth. From Fig. 12, the optimum value of element spacing, *S,* is 20 mm. The relative phase of excitation between the two elements is adjusted while amplitude of the excitations is kept constant at 1 volt. Fig. 13 shows the endfire directivity of the PMLP antenna array versus relative phase of excitation at three different frequencies, 4, 5.5, 7 GHz. It can be seen from the results that the 180° out-of-phase excitation gives the minimum directivity at lower frequencies and maximum directivity at higher frequencies. In the present antenna structure, contrary to the two previous structures, relative phase shifts of 90° or 270° give minimum directivity. The optimum relative phase shift for maximum directivity over the bandwidth is 135°. The directivity patterns of the endfire array in the H-plane at three frequencies, 4, 5.5, and 7GHz are shown in Fig. 14. At frequencies higher than 8 GHz, pattern suffers some degradation. Fig. 15 shows the relevant E-plane pattern at 135° relative phase shifts.

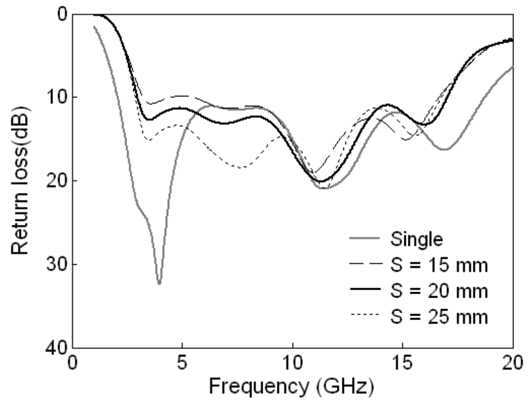


Figure 12. Return loss of planar monopole antenna array with loading plates for various elements spacing S

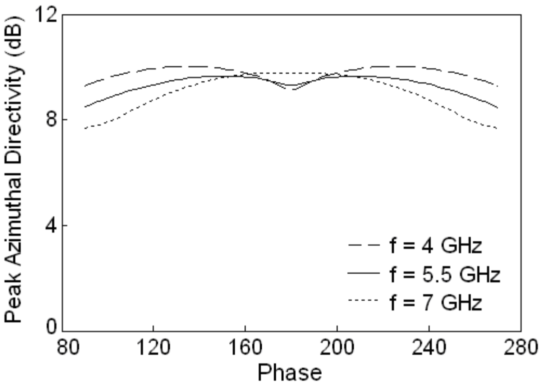


Figure 13. Peak azimuthal directivity of planar monopole antenna array with loading plates at three different frequencies for various phasing of element #2

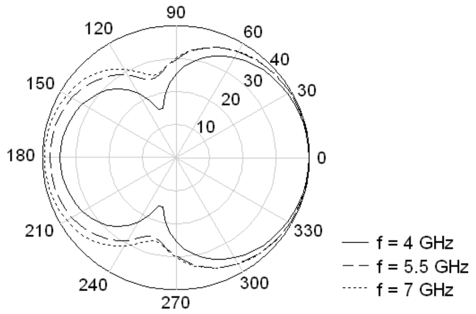


Figure 14. Normalized radiation pattern of the PMLP antenna array in the H-plane (xy), at 135° relative phase shift for three frequencies

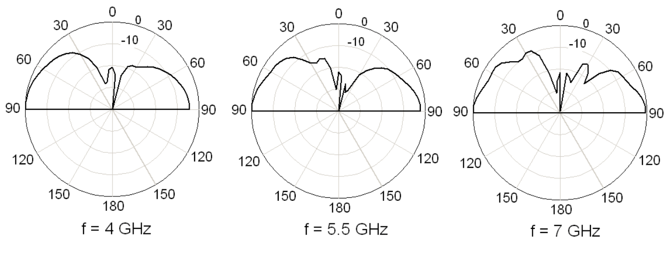
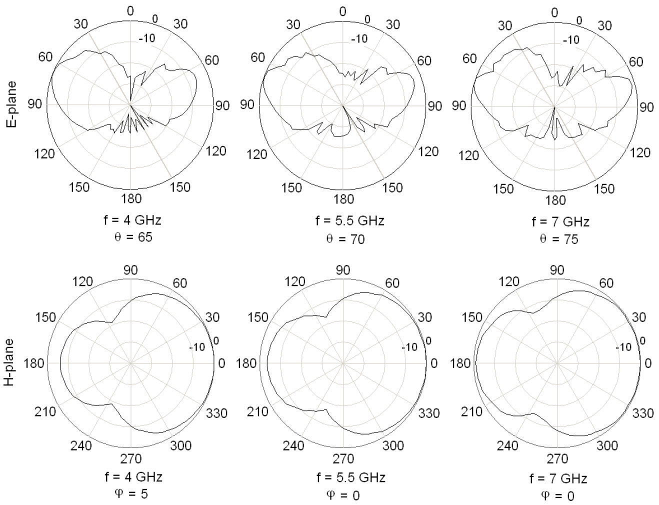


Figure 15. Normalized radiation pattern of the PMLP antenna array in the E-plane (xz), for 135° phase shift between the elements



f = 4 GHz
θ = 65

f = 5.5 GHz
θ = 70

f = 7 GHz
θ = 75

f = 4 GHz
φ = 5

f = 5.5 GHz
φ = 0

f = 7 GHz
φ = 0

Figure 16. Normalized radiation pattern of PMLP antenna array over finite ground plane with 135° relative phase shift

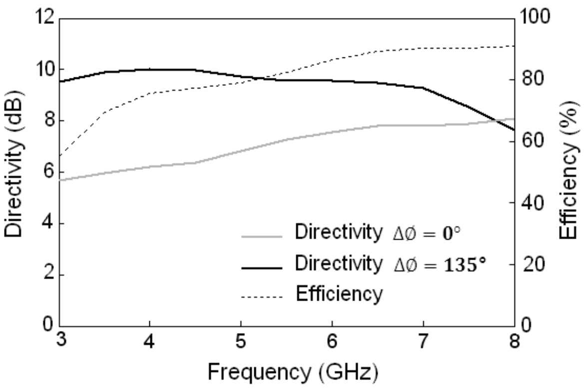


Figure 17. Directivity and efficiency of the planar monopole antenna array with loading plates

The pattern of Fig. 14 and 15 is for an infinite ground plane, thus, pointing at endfire for all frequencies. Fig. 16 shows the radiation patterns of the PMLP antenna array over a finite square 600 × 600 mm^2 ground plane. As such, the peak of the pattern moves off from endfire direction ($\varphi = 0^o$ and $\theta = 90^o$). The position of the peak at each frequency is shown in Fig. 16.

The directivity of the PMLP antenna array with and without the relative phase shift of 135^0 along with the efficiency is shown in Fig. 17. The antenna shows between 60 to 91% efficiency while the directivity ranges between 7.6 to 10.1 dB over the 3-8 GHz bandwidth. The maximum directivity of the single element planar monopole antenna with loading plates is 4.5 dB over the bandwidth.

III. MEASUREMENT

The configuration of the measurement setup is shown in Fig.18. The monopole plate antenna elements are mounted on a 600×600 mm^2 copper ground plane. The measured return loss of the antenna is shown in Fig. 19 in which one monopole is driven and the other one is match loaded. Because of the finite ground plane, edge reflections change the return loss results compared to the simulation in which infinite ground plane is assumed. Fig. 20 shows the measured and the simulated H-plane radiation pattern of the antenna at three different frequencies. The simulated pattern is for an infinite ground plane, thus, pointing at endfire for all frequencies. The measured pattern is for the finite ground plane. Although, not clearly seen, the peak of the measured pattern moves between +5^o to -10^o around the endfire for various frequencies. Similar situation occurs in the E-plane pattern for the finite size ground plane as frequency changes. It can be shown that the beam moves away from horizon and rotates between 15^o to 25^o.

The measured directivity for various frequencies, with the relative phase between the two elements being 135^o, is shown in Table I. The radiation pattern in H-plane is measured at zero elevation angle, thus the maximum measured directivity is less than the simulated one.

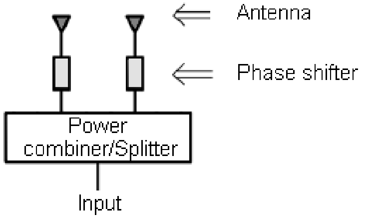


Figure 18. The measurement setup

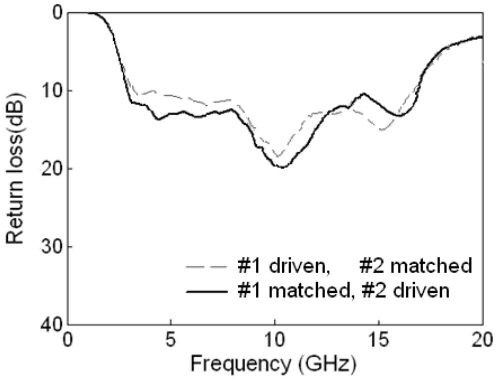
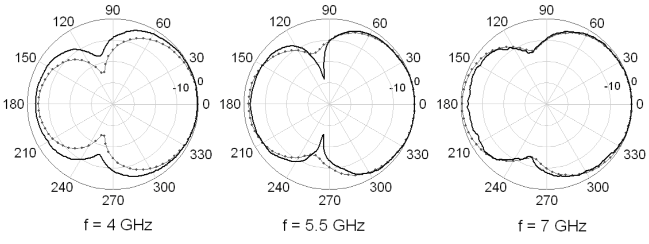


Figure 19. Measured return loss of planar monopole antenna array with loading plates with S = 20 mm



f = 4 GHz

f = 5.5 GHz

f = 7 GHz

Figure 20. Measured (solid) and simulated (dash) normalized directivity of planar monopole antenna array with loading plates in the H-plane (xy), at 135^o relative phase

TABLE I. MEASURED DIRECTIVITY

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

IV. CONCLUSION

The structure of a 2-element planar plate monopole antenna for superdirectivity has been analyzed. Three different antenna elements are considered. The first two structures cover the 6.5-8 GHz bandwidth with good directivity, while the third structure, the planar monopole antenna with loading plates provides the highest bandwidth, 3-8 GHz, and highest directivity of 7.6-10.1 dB. This antenna provides 60-91% of efficiency.

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