High Gain Printed Monopole Arrays for Wireless Applications

M. Farran[1], **S. Boscolo**[2], **D. Modotto**[1], **A. Locatelli**[1],
A. D. Capobianco[3], **M. Midrio**[2], **and V. Ferrari**[1]

[1]Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Italy
[2]Dipartimento di Ingegneria Elettrica, Gestionale e Meccanica, Università degli Studi di Udine, Italy
[3]Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Padova, Italy

Abstract— In this work we discuss the design of planar arrays in which $N + 1$ parasitic monopoles, properly placed in a linear array of N active elements, allow a broadside radiation and a gain value close to that of a standard $2N + 1$ active element array. Parasitic metallic strips are placed symmetrically on both sides of each microstrip monopole and, in order to achieve the correct phase lag for a broadside pattern, meandered lines are inserted between the feeding microstrips and the active monopoles.

Linear arrays working in the wireless local area network (WLAN) band around 2.4 GHz and composed of 5×1 and 9×1 microstrip monopoles with their feeding network have been designed and fabricated on FR4 substrates. In order to obtain a unidirectional pattern, a metallic plane reflector is placed at a distance of about $\lambda/4$ from the array board: predicted gain (11 dB for 5×1 array and 15 dB for 9×1 array) and bandwidth (around 600 MHz) are larger than for conventional microstrip patch arrays having similar board dimensions.

1. INTRODUCTION

Antenna arrays are commonly used in wireless communication base stations which are nowadays facing the challenges of wider bandwidths and higher gains for an increased channel capacity. Compact arrays can be composed of printed antennas offering a large variety of designs, for instance: patch antennas [1], printed dipole antennas [2], printed monopole antennas and their variants (e.g., the inverted-F) [3, 4]. The disadvantage of patch antennas is their narrow bandwidth, which prevents their use in many applications. On the contrary, the design of printed monopoles is flexible and moderate to wide bandwidth (300 MHz to 1 GHz) impedance matching can be achieved [3, 4], therefore, microstrip monopoles have been widely adopted in wireless communication systems [5, 6]. According to the principles of Image Theory, the monopole and its mirror image with respect to the ground plane will form a dipole antenna [7]. However, the antenna is installed on a finite ground plane, whose size and shape can affect both the resonance frequency and the radiation pattern.

In this paper, we present two printed planar arrays of monopoles with their feeding networks; as can be seen in the drawings of Figure 1, these arrays are formed of N (= 2 and 4) active monopoles and $N + 1$ (= 3 and 5) parasitic monopoles. Only the active monopoles are fed directly, whereas the parasitic radiators are fed through the currents induced by the active monopoles and by the current passing across the ground plane, as there is no balun at the input port. To obtain a broadside pattern and maximize directivity it is necessary to properly choose magnitude and phase of the currents exciting each isotropic microstrip radiator. We numerically demonstrate that, by using meandered lines capable of delaying the currents feeding the active monopoles, a broadside radiation pattern can be obtained with a gain value close to that of a standard $2N + 1$ (= 5 and 9) active element array. The details of the antenna design and its radiation performance are described in the following sections.

2. ANTENNA ARRAY DESIGN

The array radiating elements are present on both faces of a standard FR4 substrate: the active elements are fabricated on the front of the substrate, whereas the parasitic elements are fabricated on the back of the same substrate. The proposed arrays are illustrated in Figure 1. The expected monopoles length is a quarter-wavelength, but this value must be tuned by numerical simulations since the resonance condition is influenced by the finite size of the ground plane (i.e., the large rectangular plane on the substrate back). As shown in Figure 1(a), the key concept of our design is to place symmetrically on both sides of each active monopole (at a distance of about $\lambda/4$) two parasitic metallic strips which are protrusions of the ground plane. The meandered lines are inserted between the feeding microstrip lines and the active monopoles and act as phase-delay lines for the current feeding the active monopoles. The microstrip network between the input

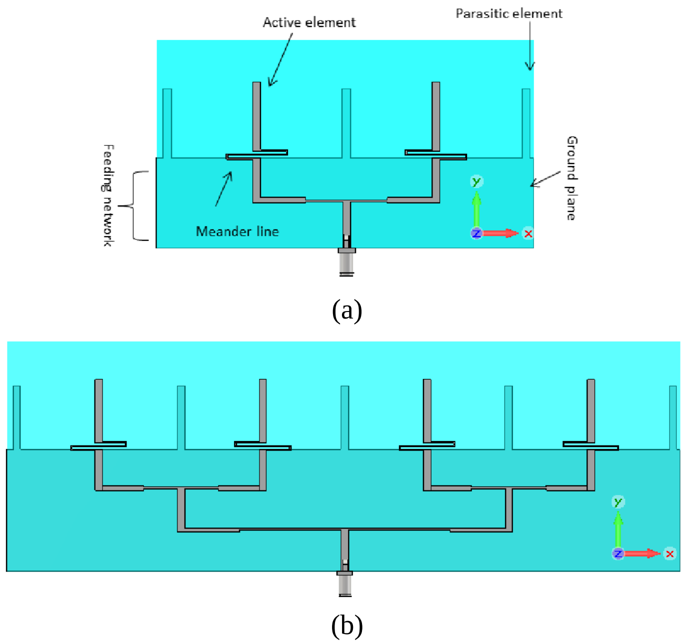


Figure 1: Drawing of the microstrip monopole arrays: (a) 5×1 array, (b) 9×1 array. The feeding network, the meanders and the active monopoles are on the substrate front face, whereas the ground plane and the parasitic elements are on the substrate back face.

port and the active elements allows for a wide bandwidth impedance matching. In the case of the 5×1 array (Figure 1(a)), the input 50-Ohm microstrip is split into two 100-Ohm lines, which are followed by 70-Ohm quarter wave transformers connected to the 50-Ohm microstrips feeding the meanders. Numerical simulations performed by means of CST Microwave Studio show that the current densities on the parasitic strips are mainly induced by the driven monopoles. In our design only an unbalanced waveguide like the microstrip is requested; this choice implies that some current passes across the ground plane and reaches the parasitic elements, but the same current is useful to achieve impedance matching on a wider band.

Each meandered delay line is composed of 5 segments with a width of 0.5 mm and a total length l that must compensate for the phase delay among the active monopoles and the parasitic ones; a long optimization procedure gave the value $l = 2.86$ cm.

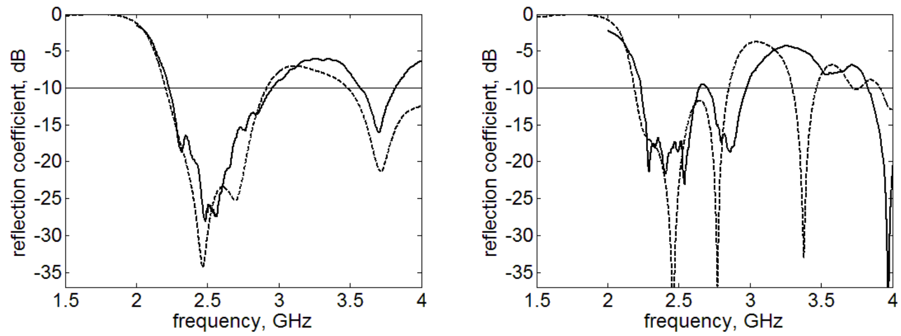
CST simulations confirm that the $2N+1$ radiators are fed in phase and it must be underlined that the currents flowing in the parasitic elements are less intense than the ones in the active monopoles. Without the presence of the meanders the relevant gain enhancement due to the array factor of $2N+1$ isotropic elements cannot be observed, even by significantly changing the radiating elements separation or optimizing the feeding network.

A thorough numerical optimization has led to the geometrical dimensions of the final designs displayed in Figure 1: the substrate total area is $13.9 \times 7.6\,\text{cm}^2$ for the 5×1 array and $27.1 \times 9.2\,\text{cm}^2$ for the 9×1 array, the area occupied by each meander is $2.25 \times 0.35\,\text{cm}^2$ and the driven and parasitic microstrips have a width of 2.9 mm.

3. RESULTS

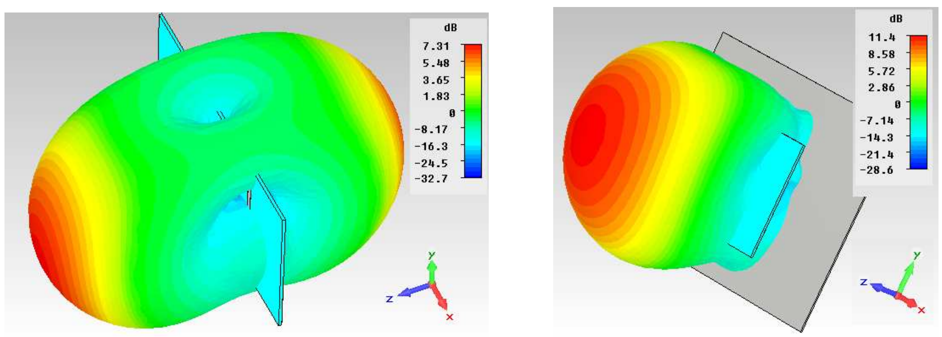
Prototypes were milled on FR4 substrates (with thickness 1.58 mm, $\varepsilon_r = 4.5$, $\tan\delta = 0.025$) and measured in anechoic chamber by using a two port Agilent N5230 PNA-L network analyzer. The simulated and measured reflection coefficients of the 5×1 and 9×1 arrays are shown in Figure 2(a) and 2(b), respectively. The 10 dB impedance matching bandwidth ranges from 2.2 GHz to 2.91 GHz for the 5×1 linear array, with a fractional bandwidth (FBW) of 0.28, and ranges from 2.2 GHz to 2.65 GHz (FBW $= 0.17$) for the 9×1 linear array. The simulated and measured return losses are in good agreement for the 5×1 linear array; considering the 9×1 linear array, we have almost the same -10 dB bandwidth, but the minima predicted by the numerical simulation are 15 dB smaller than the measured ones.

Figure 3(a) shows the calculated 3D radiation pattern of the 5×1 array; as expected from basic array theory, there are two main lobes (tilted by 10° with respect to the normal to the



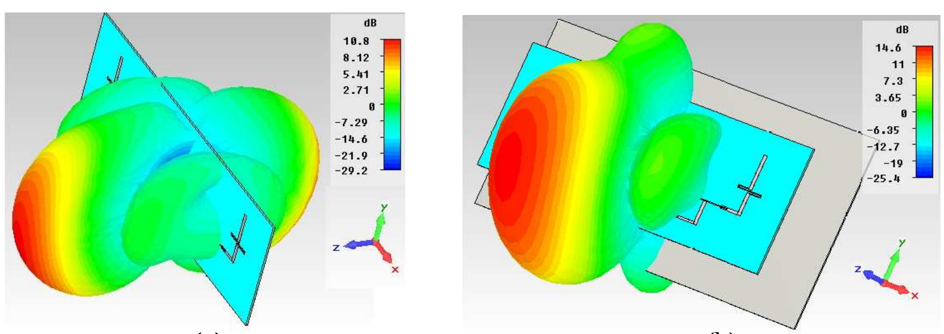
(a) (b)

Figure 2: Computed (dashed lines) and measured (solid lines) reflection coefficients: (a) 5×1 array, (b) 9×1 array.



(a) (b)

Figure 3: Radiation patterns of the 5×1 array at the frequency of 2.4 GHz: (a) plain array, (b) array with metallic plane reflector.



(a) (b)

Figure 4: Radiation patterns of the 9×1 array at the frequency of 2.4 GHz: (a) plain array, (b) array with metallic plane reflector.

board) and the gain is 7.3 dB. In order to obtain a unidirectional pattern, a metallic plane reflector ($18 \times 12\,\text{cm}^2$) is placed at a distance of 3 cm from the array board and the resulting 3D pattern is shown in Figure 3(b); the main lobe is almost perpendicular to the board (the tilt is only 5° and the corresponding gain is 11.4 dB (the increase in gain is even larger than the 3 dB predicted by theory). The 3D radiation pattern of the 9×1 array exhibits a gain of 10.8 dB (see Figure 4(a)), which can be augmented up to 14.6 dB when a metallic plane reflector ($31 \times 12\,\text{cm}^2$) is placed at a distance of 3 cm (see Figure 4(b)). In the case of the 9×1 array, secondary lobes are present (with a side lobe level of -10 dB) and the main lobe is tilted of 20° irrespectively of the presence of the metal reflecting plane.

4. CONCLUSION

Two printed arrays with N active microstrip-fed element and $N + 1$ parasitic strips have been designed and characterized at 2.4 GHz: meanders are used to enforce a phase lag to the currents flowing in N of the radiating metallic strips and determine a broadside radiation. Simple fabrication techniques that are inexpensive can be employed to realize these structures and the feeding network is much more simple than those required by monopole arrays already reported in the literature [6]. The results of this study have shown that by adding $N + 1$ parasitic elements, we can obtain a broadside radiation gain value close to that one of a standard $2N + 1$ isotropic element array and the bandwidth is significantly larger (> 600 MHz) than the one of conventional microstrip patch arrays [8]. In spite of the compact board areas, gains of 11 dB and 15 dB are achieved with a metallic plane reflector placed at a distance of about $\lambda/4$. In order to verify the array performance, prototypes have been fabricated and are currently under test. The proposed antennas may be suitable candidates for WLAN point to point operations.

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