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# Bidirectional Monopole Antenna Array with Minimized Ground Plane for WLAN Applications

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**Abstract**—This paper proposes a new design of printed monopole antenna array for WLAN applications. In order to get rid of the parasitic effects of a uniform ground plane on the array feeding network, the metal shape is specifically cut out to minimize its interaction with the monopole while ensuring the proper operation of the array feeding network. Simulations of a 2-by-2, monopole antenna array with the optimized ground plane shape shows that the array performance is significantly improved with miniaturization of ground structure. These results are validated by the measurements showing that the unique shape of the ground structure increases the antenna gain by 1.75 dB and decreases the side lobe level by 5.30 dB with respect to a standard uniform ground.

**Index Terms**—antenna array, bidirectional antenna, ground plane, monopole antenna, WLAN.

## I. INTRODUCTION

Printed monopole antennas have received great attention especially in Wireless Local Area Network (WLAN) applications [1] due to their advantages in terms of low profile, compact size, larger bandwidth, quasi-omnidirectional radiation properties, and easy integration with other microstrip circuits. Although the omnidirectional behaviour of monopole antennas has been exploited extensively [2], bidirectional antennas are more attractive in longer and narrower application scenarios [3], such as indoor corridors, tunnels, and subways. A single-element monopole antenna performs well in a confined space or towards limited directions but only in a short range because of its low power gain. In order to increase the operating range, the most suitable solution would be the use of antenna array composed of multiple single-element antennas to reduce complexity and size.

In the literature, solutions involving monopole antenna array have not been studied extensively also because of its strong dependence on the ground plane [4]. The ground plane size can have a strong negative impact on the overall radiation performance of the array, in particular it can alter drastically both the impedance bandwidth and the radiation pattern. To solve this problem, operative steps [5] have been investigated to minimize ground plane effects and impact. Similarly, various type of approaches [6] have been adopted in order to enhance the gain of the monopole antenna arrays.

In this work, a printed monopole antenna array, operating at 2.45 GHz, equipped with a novel shape of a minimized

ground plane, is presented and focus is given to the procedure adopted to investigate and minimize the effects of the ground plane size of the microstrip feeding network on the array performance. The resulting optimum ground plane shape allows for decreasing the side lobes level significantly while increasing the array gain and its bandwidth. Moreover, given that a tightly-shaped ground plane is necessary to improve the array performance, it is noteworthy that such minimization cannot be pushed further but optimal dimensions must be searched. Hence, a delicate trade-off is needed, as is described in the next sections.

The article is organized as follows: Section II explains the design and full-wave characterization of the presented monopole antenna array and Section III shows the simulated and measured results and discusses the comparison of the array performance obtained by various ground plane sizes.

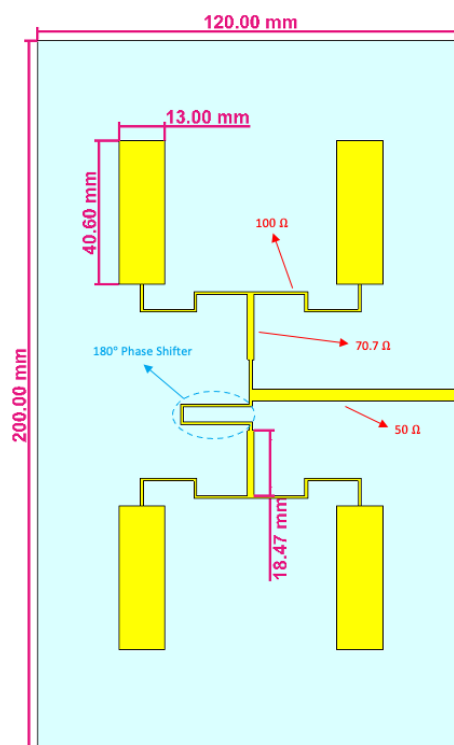


Fig. 1. Top view of a 2-by-2 array of monopoles: the array feeding network is realized in microstrip technologies with a bottom ground plane.

## II. ANTENNA DESIGN

The antenna is designed on a low-cost, durable FR4 substrate with  $\epsilon_r=3.68$ ,  $\tan(\delta)=0.0035$ , thickness=1.5 mm tuned to operate at 2.45 GHz for WLAN communication systems. The array is composed of four printed monopoles, operating as a broadside antenna.

### A. Antenna and Feeding Network Configuration

The radiating part and the feeding network of the proposed four monopole antennas design is shown in Fig. 1 and it is hosted on the top layer. The length of each monopole has been selected according to the general guideline such that the element length is about  $\lambda/4$ , where  $\lambda$  is the resonance wavelength.

Given an array feeding network input impedance of  $50 \Omega$  the array elements are fed by a  $100 \Omega$  microstrip line and a quarter-wave transformer connects the upper and lower branches to ensure the appropriate transition to the  $50 \Omega$  input impedance. Furthermore, upper and lower element pairs are fed from different directions, therefore a  $180^\circ$ -phase shift between those pairs is required.

Although the horizontal distance between the elements is  $\lambda/2$ , to guarantee the lowest side lobe level (SLL) possible, while preventing the coupling effect between the element pairs, the presence of a quarter-wave transformer and the meandered line of phase shifter do not allow the structure to have the same vertical distance.

However, the  $100 \Omega$  lines feeding the monopoles have been meandered in order to shorten the vertical distance between the antenna elements as much as possible, as can be inferred by the schematic representation in Fig. 1.

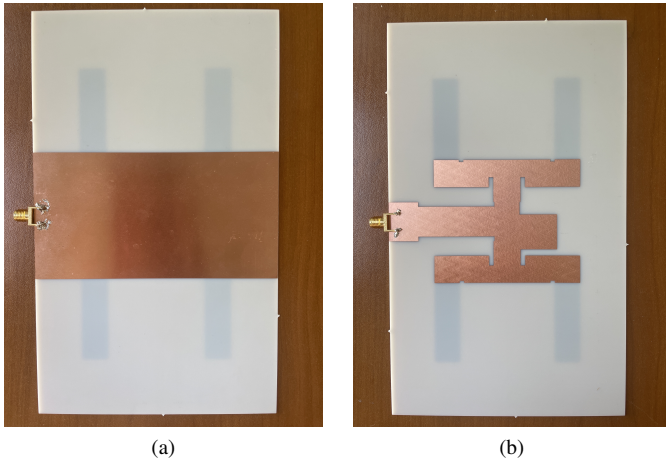


Fig. 2. Ground structures: (a) standard (reference); (b) optimized.

### B. Reference Monopole Antenna

A reference 4-elements monopole antenna has been initially designed with a standard full ground plane as shown in Fig. 2a and its performance is preliminarily evaluated, representing the starting point for further optimization that will be explained in the following. The optimal dimensions of the standard

ground plane has been set in such a way that it covers the entire horizontal dimensions, whereas for the vertical one, it is truncated right below the monopole, as needed for the standard design procedures for these types of antennas.

Preliminary full-wave simulation of the above-mentioned structure have been conducted and the results show a SLL of  $-5.9$  dB where SLL defined as the ratio of the amplitude at the peak of the main lobe to the amplitude at the peak of a side lobe. This drawback is due to the parasitic radiation effects of such large ground plane.

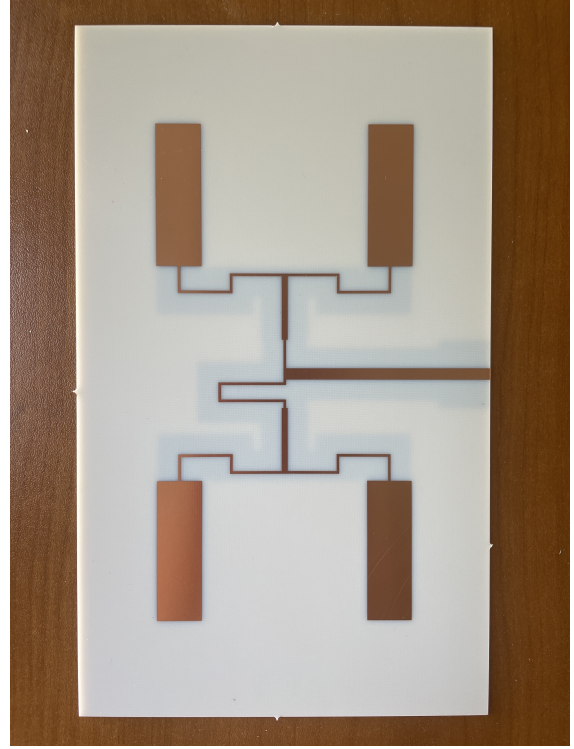


Fig. 3. The manufactured prototype top view.

### C. Minimized Ground Structure

To optimize the monopole array performance, the ground plane must be modified without negatively affecting the feeding network. Different shapes and sizes of the ground plane have been studied to understand their effects on the antenna radiation performance. The optimized shape of the ground plane is shown in Fig. 2b. Such layout has been firstly delineated by simply mimicking and randomly enlarging the exact layout of the feeding network hosted on the top layer, which is shown in Fig. 3. Subsequently, the structure has been enlarged on its perimeter by adding a certain margin  $M$ , as displayed on the left side of Fig. 4. This parameter  $M$  has been optimized in order to observe the effect on the array radiation properties and to find the best trade-off between ground plane dimensions and effects on the array radiation properties and feeding network.

The enlargement procedure is kept the same as above-mentioned with the exception of the termination

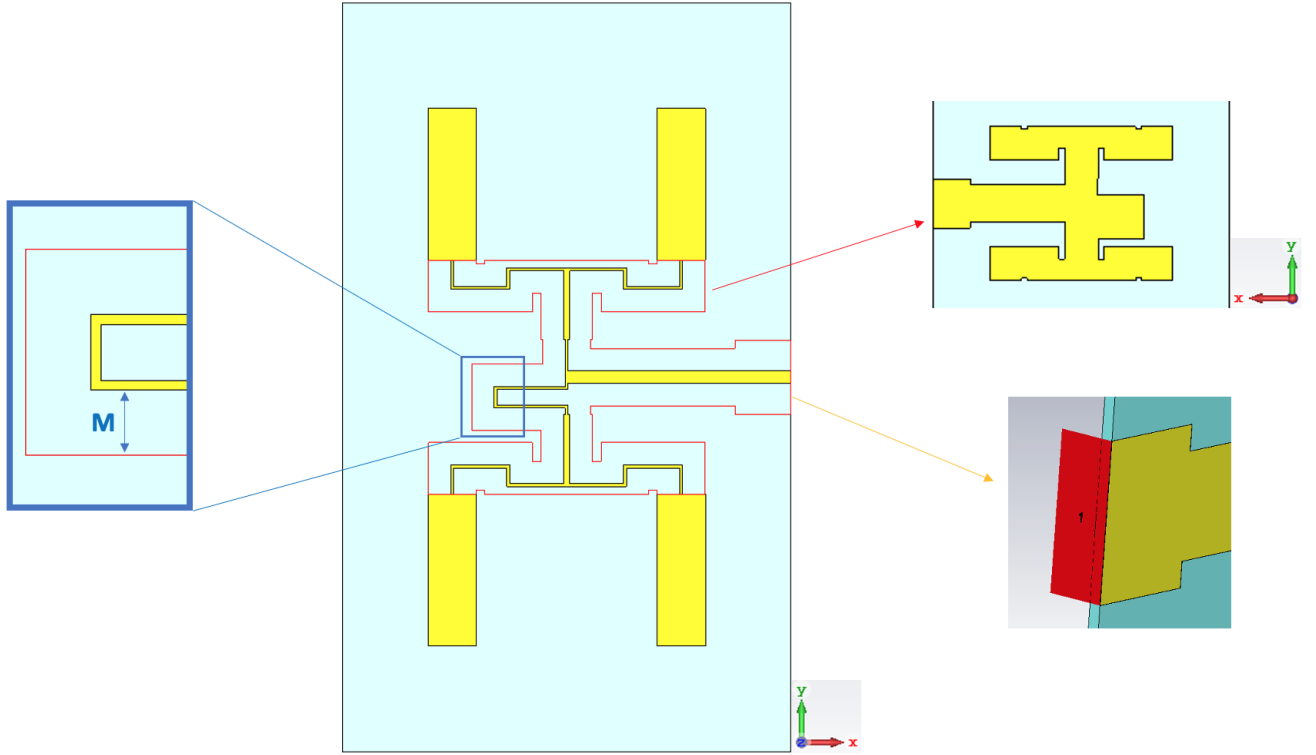


Fig. 4. The ground plane visualization with respect to the top layer. The feeding network has been expanded with the variable  $M$  to obtain the unique shape of the ground structure. The dimension of the ground near the simulation port is adjusted according to the port size for coherent results.

of the  $50 \Omega$  feeding line, hosting the waveguide port for numerical simulation purposes, that has to exhibit at least the same dimensions of the that port to prevent inaccurate simulation results. Furthermore, also the portion of the ground plane close to the monopole radiating element must be excluded from this tuning process, since it would significantly affect the tuning of the monopole itself. In fact, it is part of the antenna itself and its tuning would have a strong impact on the overall array performance, including the operating frequency.

### III. RESULTS AND COMPARISON

To understand the effects of the ground plane size on the antenna performance, the full-wave simulations of the overall structure with progressively enlarged ground plane are compared to the one related to the standard structure shown in Fig. 2a. The obtained results are listed in Table I. Apart from the reference structure, the smallest and largest meandered ground plane are obtained for  $M = 3 \text{ mm}$  and  $M = 7 \text{ mm}$  respectively.

TABLE I  
ANTENNA RADIATION CHARACTERISTICS FOR DIFFERENT DIMENSIONS AND SHAPES OF THE GROUND PLANE.

Ground Structure	GAIN [dBi]	SLL [dB]	DIRECTIVITY [dBi]
Standard (Reference)	7.30	-5.9	7.89
$M = 3 \text{ mm}$	8.92	-9.9	9.63
$M = 4 \text{ mm}$	9.02	-10.4	9.64
$M = 5 \text{ mm}$	9.04	-10.6	9.59
$M = 6 \text{ mm}$	9.05	-11.2	9.64
$M = 7 \text{ mm}$	9.07	-11.2	9.66

As it can be clearly seen from Table I, having a minimized and meandered ground plane allows for increasing the antenna radiation performance with respect to the reference case. Nevertheless, tuning the parameter  $M$ , which results in an enlargement of the ground plane, leads to further improvement on antenna gain and SLL. The design with  $M = 6 \text{ mm}$  is selected as the optimum case since a further increase does not change the outcomes significantly.

#### IV. CONCLUSION

A novel bidirectional monopole antenna array with minimized ground structure for WLAN application has been designed, simulated, and measured. The antenna structure consists of four monopole elements and it operates at 2.45 GHz. Various sizes of the ground structures have been investigated and a comprehensive analysis has been made between different designs. The configuration that results in the best trade-off between antenna performance and size has a peak gain of 9 dBi on broadside and opposite directions. The proposed design is also superior in terms of the resulting lower side lobe level. The comparison among different shaped and sized of ground planes leads to a conclusion that the relationship between the array performance and the size of ground structure is not straightforward (the smallest ground plane does not result the best outcome), but a suitable optimization must be carried out. The procedure adopted for a 2-by-2 array has been validated by measurements and can be straightforwardly scaled for a large-element monopole array.

#### ACKNOWLEDGMENT

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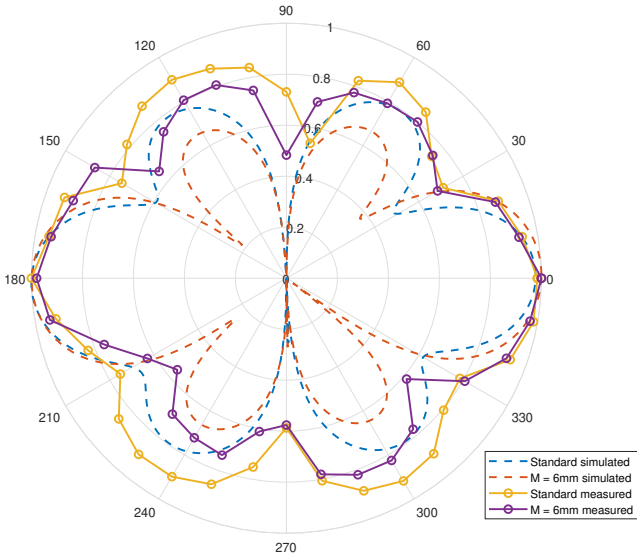


Fig. 5. Normalized simulated and measured radiation diagrams of the monopole array: with the standard the meandered ( $M = 6 \text{ mm}$ ) ground planes.

Fig. 5 displays the normalized antenna radiation diagrams by comparing the standard and minimized ground plane shapes with both simulation and measurement results. The polar plots clearly illustrate the improvements in the antenna gain and SLL, validated by measurements. Furthermore, the bidirectional radiation pattern of the optimized layout, exhibiting a directivity of around 9.6 dBi, can be observed in the same plots.

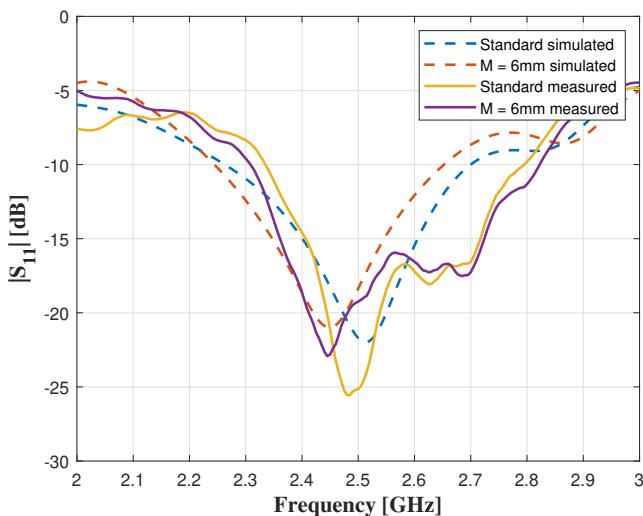


Fig. 6. Simulated and measured reflection coefficient plots at the array input port of the standard antenna and the proposed antenna with the minimized ground plane ( $M = 6 \text{ mm}$ ).

Fig. 6 shows the reflection coefficient plots at the array input port in the frequency range of 2 – 3 GHz. The measurement results of the optimized structure shows the impedance bandwidth ( $|S_{11}| < -10 \text{ dB}$ ) as 510 MHz (2.32–2.83 GHz), which is larger than the reference design, and also  $|S_{11}|$  as low as -23 dB at the operating frequency, 2.45 GHz.