Highly Directional Planar Ultra Wide Band Antenna for Radar Applications

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***Abstract*— We describe a novel planar highly directive Ultra Wide Band (UWB) antenna based on a disc monopole fed by a 50-Ohm microstrip line. The key feature of the proposed antenna is a careful engineering of the ground plane that permits to increase directionality for radar applications. We demonstrate through numerical simulations and measurements in anechoic chamber that the designed antenna exhibits low return loss, high directivity and good time-domain properties in the band of interest between 6 and 8 GHz.**

I. Introduction

Since the acceptance of unlicensed use of the UWB technology in the range between 3.1 and 10.6 GHz in the USA [1] the realization of low cost UWB wireless systems is considered a fundamental research goal both for military and commercial applications. In this context design, fabrication and characterization of effective antennas to be employed in UWB devices are challenging tasks with respect to the case of narrowband systems [2]. A suitable UWB antenna should be capable of operating over an ultra wide band. Therefore, it is necessary to guarantee a good behavior of the antenna in the whole band of interest in terms of radiation properties, transfer function (in order to get constant group delay and thus to avoid distortions of the transmitted short pulses), and impedance matching with the transceiver.

Recent UWB antenna research tends to focus on ultra compact planar antennas as they are more practical in terms of manufacturing, integration with the system electronic board and form factor. Typical configurations exhibit radiation patterns similar to the traditional monopole antennas and behave as quasi-omnidirectional radiators. This feature is desirable for UWB communication systems, whereas it is a strong limitation in the case of radar applications [3]. In the past few years, several planar broadband monopole-like configurations have been reported for UWB applications [4]-[7]. Nevertheless, very few efforts have been made to increase directionality of printed UWB antennas to be employed, for example, in radar applications [8].

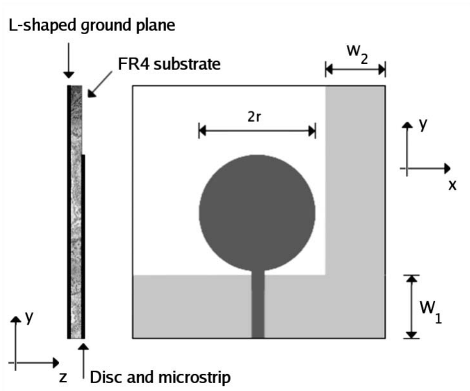

Fig. 1. Schematic view of the printed disc monopole with L-shaped ground plane. On the left (right) you can see a side (front) view of the designed antenna.

In this work we describe a novel planar UWB antenna composed of a disc monopole fed by a 50-Ohm microstrip line printed on a FR4 substrate. The ground plane of the system is carefully structured in order to increase the directionality of the radiator for employment in combination with a single-chip UWB radar transceiver operating at a central frequency of 7 GHz with a resolution of 75 millimeters (corresponding to a 2 GHz bandwidth). Both numerical simulations and measurements performed in anechoic chamber confirm the good behavior of the antenna in the band of interest between 6 and 8 GHz and a strong improvement of directivity with respect to conventional printed monopoles.

II. Description of the antenna structure

The antennas were designed to be fabricated on a low-cost FR4 substrate. The thickness of the dielectric and the conductor layers are 1.6 mm and 35 μm, respectively, and we

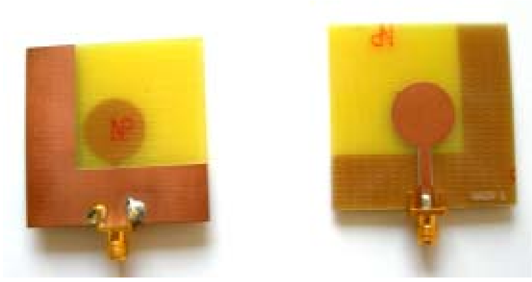

Fig. 2. Photograph of the fabricated prototypes with identical geometric parameters. Left: side of the board with the L-shaped ground plane. Right: side of the board with the disc and the microstrip.

have chosen to use a value of 4.5 for the relative permittivity of the dielectric in the whole analysis. In Fig. 1 we report a schematic view of the printed antenna. The substrate is a square dielectric FR4 board with dimensions 5 cm $\times$ 5 cm. On one side of the board we have a 50-Ohm microstrip feeding line (width 3 mm), and a disc with radius r centered in the middle of the board. On the other side of the substrate we have an L-shaped ground plane. The part of the conductor plane with the long side parallel to x-axis (width W_1) forms the microstrip line, whereas the conductor strip with the long side parallel to y-axis (width W_2) acts as a reflector, and this is the key element which is introduced to improve directionality.

III. Antenna design and characterization

The final goal of the work is to get a planar antenna with low return loss, near constant group delay and radiation patterns, and increased directivity in the band between 6 and 8 GHz. We performed massive numerical simulation using the CST Microwave Studio package [9], which utilizes the finite integration technique for electromagnetic computation, in order to find a good tradeoff between these requirements. We varied the radius of the disc and the width of the two strips that compose the ground plane and we have identified an optimum set of geometric parameters: r = 9.1 mm, W_1 = 1.49 cm, and W_2 = 1.39 cm.

Two prototypes with the same optimum geometric parameters have been fabricated. In Fig. 2 we show a photograph of the two antennas. On the left it is possible to see the side of the board with the L-shaped ground plane, whereas on the right we have the other side with the disc and the microstrip line. The fabricated prototypes have been fully characterized through measurements in anechoic chamber. In the following we report the properties of the proposed antenna by comparing numerical and experimental results.

A. Return loss

Return loss of one prototype was measured through a vectorial network analyzer in anechoic chamber. In Fig. 3 we report a comparison between these measurements and the numerical results. Simulations predict a 10-dB bandwidth extending from 5.76 to over 10 GHz, with a good uniformity of the response in the band of interest between 6 and 8 GHz.

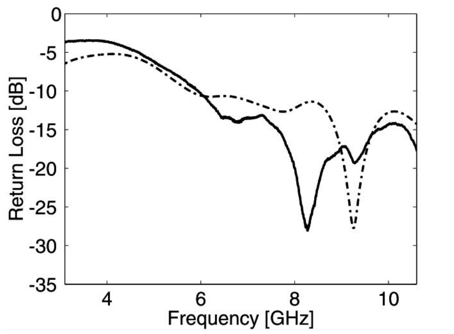

Fig. 3. Measured (solid line) and simulated (dash-dotted line) return loss curves in the full UWB window.

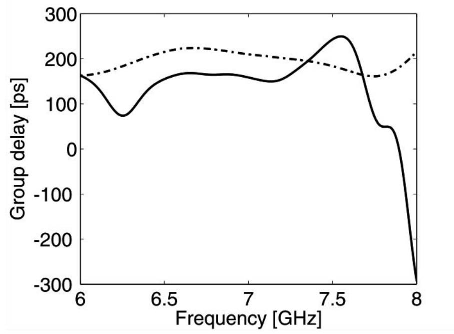

Fig. 4. Measured (solid line) and simulated (dash-dotted line) group delay curves in the frequency range between 6 and 8 GHz.

The reported experimental results confirm with reasonable accuracy the theoretical 10-dB antenna bandwidth, even though it is possible to note a shift of the return loss curve towards lower frequencies due to the high uncertainty on the FR4 permittivity.

B. Group delay

We have simulated the variation in frequency of the group delay, which is related to the first-derivative of the phase of the S-parameter. This is a key point, in fact UWB applications require a good linearity of the phase of the radiated field (and then small variation in frequency of the group delay) in order to minimize pulse distortions. In Fig. 4 we report the numerical results in the band of interest. Simulations demonstrate that group delay variation in bandwidth is less than 100 ps, which is negligible if compared with the duration of the transmitted pulses (about 1 ns). We also measured the phase of the S-parameter through the vectorial network analyzer, and we got the measured group delay, which is reported in Fig. 4. A good agreement between experiments and numerical results is visible, except for a strong variation around 8 GHz.

C. Directivity and radiation pattern

The radiation patterns of the proposed antenna have been calculated through CST Microwave Studio simulations and the radiative properties of the fabricated prototypes have been

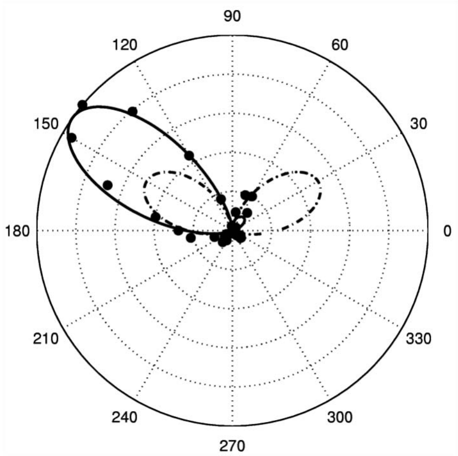

Fig. 5. Radiation pattern of the disc monopole with L-shaped ground plane (solid line) and of the conventional disc monopole (dash-dotted line) in the x-y plane at 6 GHz. Black circles represent measurements on a prototype in anechoic chamber. Results are reported in linear scale.

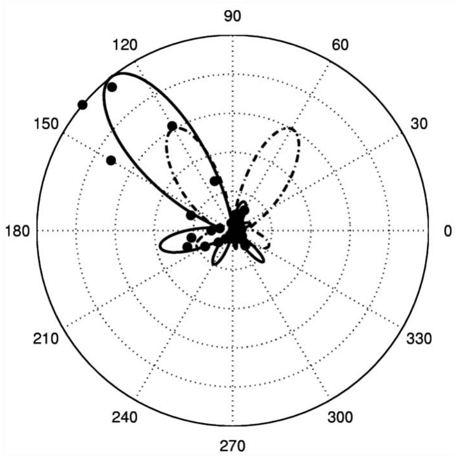

Fig. 7. Radiation pattern of the disc monopole with L-shaped ground plane (solid line) and of the conventional disc monopole (dash-dotted line) in the x-y plane at 8 GHz. Black circles represent measurements on a prototype in anechoic chamber. Results are reported in linear scale.

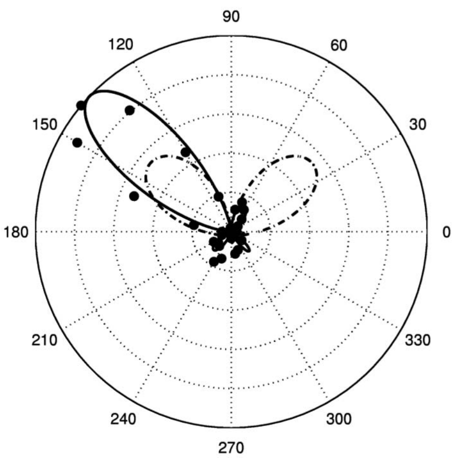

Fig. 6. Radiation pattern of the disc monopole with L-shaped ground plane (solid line) and of the conventional disc monopole (dash-dotted line) in the x-y plane at 7 GHz. Black circles represent measurements on a prototype in anechoic chamber. Results are reported in linear scale.

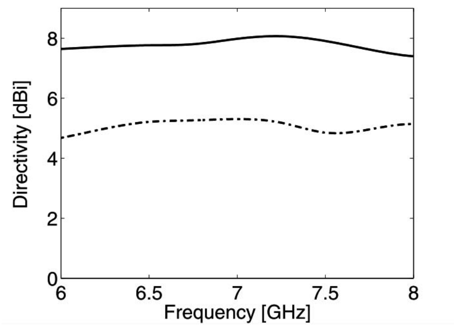

Fig. 8. Maximum antenna directivity in the case of conventional disc monopole (dash-dotted line) and with an L-shaped ground plane (solid line).

fully characterized in anechoic chamber. This is an important issue, since UWB applications require a good stability in frequency of radiation patterns and directivity over the whole bandwidth. Moreover, we must demonstrate that the structured ground plane permits the tremendous increase of directionality required for radar applications.

We have numerically analyzed the effect of the introduction of the L-shaped ground plane on the radiation patterns by comparing the proposed antenna, characterized by the geometric parameters listed in Section 3, with a similar structure with a simple ground plane (a conventional disc monopole). We have plotted the simulated radiation patterns in the x-y plane, where we expect to find a strong influence of the added conductor strip. In Figs. 5-7 we report the numerical results at 6, 7 and 8 GHz. It is straightforward to note that the conventional disc monopole has two radiation lobes around 30 and 150 degrees from the x-axis, whereas in the case of disc monopole with L-shaped ground plane the lobe at 30 degrees (which points in the direction of the added conductor plane) is suppressed, and the magnitude of the other lobe is increased. This is a clear signature of the increased directivity of the antenna with structured ground plane. Indeed, we calculated the maximum value of the directivity in the whole 3D space with varying frequency (see Fig. 8). In the case of the conventional disc monopole directivity is slightly oscillating around 5 dBi, whereas the introduction of an L-shaped ground plane nearly permits to double the directivity, with small variation around the value of 7.5 dBi in the band of interest.

Figs. 5-7 demonstrate the good stability in frequency of the radiation patterns, either. In fact, simulations predict that the direction of maximum radiation moves (in the bandwidth 6-8 GHz) between 130 and 145 degrees from the x-axis in presence of the L-shaped ground plane, whereas the radiation peak is between 120 and 150 degrees in the case of the conventional disc monopole. Moreover, the 3-dB angular bandwidth of the main lobe of radiation varies between 37 and 47 degrees in the first case, and between 40 and 57 degrees in the second one.

In Figs. 5-7 we also report a preliminary characterization in anechoic chamber of the radiation pattern of a prototype with structured ground plane. It is possible to note a good agreement between simulations and measurements, in particular we can identify only one lobe of radiation and the direction of maximum radiation is around 140 degrees from the x-axis, as expected.

We have verified that further optimization of the antenna can be obtained through a more complex structuring of the ground plane and of the substrate. In particular, preliminary results demonstrate that smoothing the sharp corners of the L-shaped ground plane can raise directivity and permits to get a larger bandwidth. Moreover, the dimensions of the substrate seem to have an impressive influence on the shape of the radiation lobes, and then on directivity. All these issues will be addressed in a future work.

IV. Conclusions

We have investigated the properties of a low-cost printed UWB antenna based on a disc monopole fed by a 50-Ohm microstrip line with an L-shaped ground plane designed to be employed in combination with a single-chip UWB radar. The reported numerical results and measurements in anechoic chamber demonstrate that the proposed antenna permits to achieve a tremendous increase of directionality with respect to conventional printed monopoles and retains their simple and compact structure. Moreover, the printed monopole with structured ground plane exhibits good properties in terms of bandwidth, small variation of group delay and radiation patterns in the band of interest between 6 and 8 GHz. The idea of shaping the radiation patterns of planar antennas through the employment of structured ground planes can be further developed for design of ultra compact, efficient and highly directional antennas for radar applications.

Acknowledgment

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