A Circularly Polarized UWB Antenna for Improved Positioning Accuracy

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***Abstract*—This paper presents a compact low-cost circularly polarized UWB antenna covering both UWB channels 5 and 9. The antenna is based on a capacitively fed patch element excited through a quadrature hybrid coupler. The reported field tests demonstrate that the circular polarization provided by the proposed antenna allows the anchor-tag communication to be improved and made independent of the relative orientation between the two devices.**

***Index Terms*—UWB, printed antenna, circular polarization, positioning, ranging.**

I. Introduction

When it comes to locating objects or tracking assets or any type of targets, especially those in complex indoor environments, ultra-wideband (UWB) is nowadays the most reliable and accurate technology [1]. UWB is widely used in time-based ranging and localization methods, such as one-way or two-way ranging with Time-of-Flight (ToF) and Time-Difference of Arrival (TDoA) [2]. Its ability to transmit ranging data over a broad frequency bandwidth of 500 MHz or more enables highly accurate distance and position estimations between an anchor and a tag.

In a typical UWB-based localization infrastructure, both the anchor and the tag antennas display omnidirectional, dipole-like linearly-polarized radiation patterns. This characteristic is crucial for providing extensive coverage, as it allows both nodes to detect each other regardless of their relative position. The linear polarization of the antenna, however, makes the localization system sensitive to the orientation of the tag with respect the anchor [3].

In this paper, a low-cost compact circularly polarized UWB antenna is proposed. The circular polarization exhibited by the antenna allows improved positioning and ranging accuracy [4]. The antenna covers the 499.2 MHz wide UWB channels 5 and 9, centered at 6489.6 and 7987.2 GHz, respectively.

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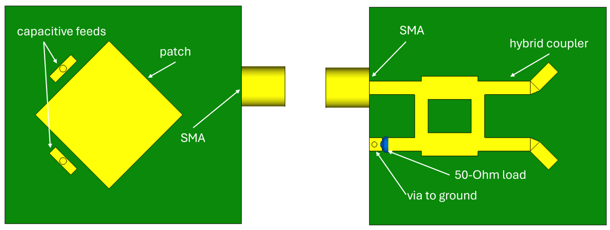


(a) (b)

Fig. 1: Antenna structure. (a) Front view with the radiating element, and (b) back view with the hybrid coupler.

II. Antenna Structure

The structure of the proposed antenna is constituted of two 0.8 mm thick printed circuit boards (PCBs) made of low-cost FR4 substrate ($\epsilon_r = 4.3$). The PCBs are located one above the other at a distance of 4 mm. The antenna radiating element is a 12×12 mm^2 patch printed on the top PCB (shown in Fig. 1(a)), which is capacitively fed through two metallic pads shown in Fig. 1. These pads are connected through metallic pins to the a quadrature hybrid coupler printed on the bottom face of the lower PCB (shown in Fig. 1(b)). The role of the coupler is to split the input signal (coming from the SMA connector) into two output signals, of equal magnitude, with a 90 degree phase difference. The simultaneous excitation of the patch antenna by these signals allows the radiation of a circularly polarized electromagnetic field. The top face of the lower PCB is completely covered with metal and acts as ground plane for both the patch antenna and the coupler.

III. Simulated and Measured Antenna Results

Fig. 2 shows the simulated behavior of the proposed antenna in terms of impedance matching and total efficiency. Simulations have been performed using the CST

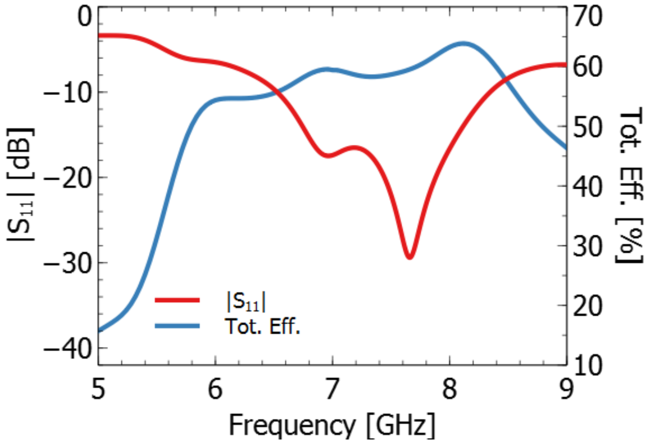
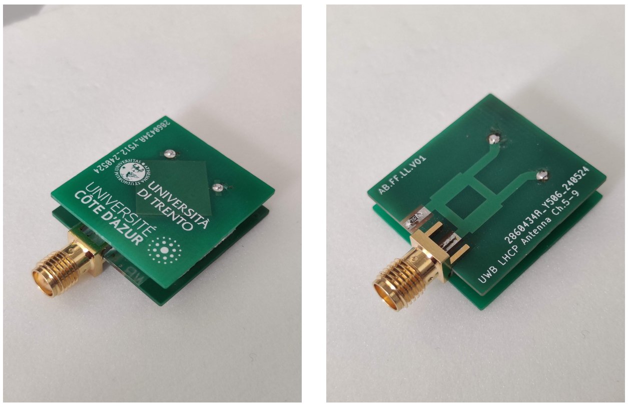


Fig. 2: Simulated impedance matching and total efficiency.



(a) (b)

Fig. 3: Antenna prototype. (a) Front view with the radiating element, and (b) back view with the hybrid coupler.

Microwave Studio electromagnetic simulator. Concerning impedance matching, the $|S_{11}|$ value exhibited by the antenna is always lower than -7.5 dB all over the UWB channel 5, while it becomes better than -10 dB in the entire channel 9. Concerning total efficiency, the simulated values increase from about 55% in the lower frequency band to about 65% in the high frequency band.

A prototype of the antenna (Fig. 3) has been realized using a photolitographic printing process. The prototype has been equipped with an SMA connector to realize the antenna impedance measurements using a Vector Network Analyzer (VNA) as well as to be integrated with the UWB boards for the field tests.

Fig. 4 shows the measured impedance matching and total efficiency of the realized prototype. Compared to the simulated results, the experimental data are shifted towards the lower frequencies. This can be ascribed to the PCB substrate, which probably has a dielectric permittivity value higher than the nominal one. Despite this difference, and thanks to its wideband matching characteristics, the proposed antenna can

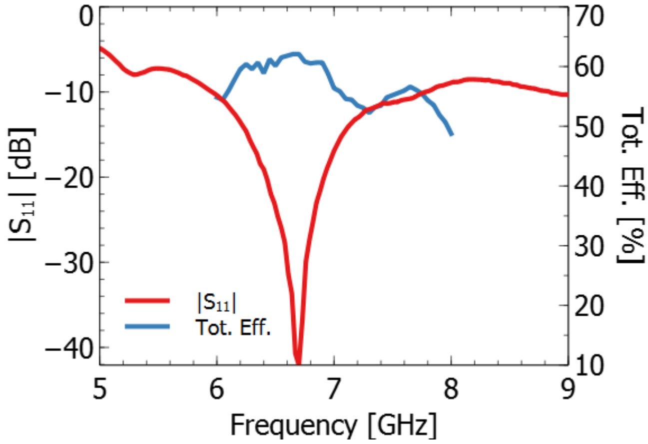


Fig. 4: Measured impedance matching and total efficiency.

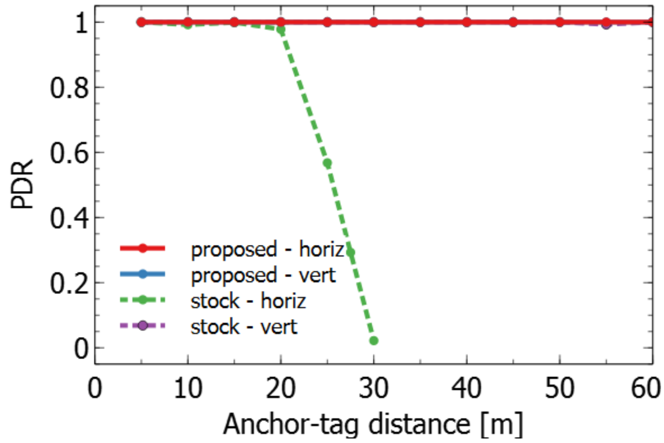


Fig. 5: Measured packet delivery ratio (PDR).

still efficiently operate in the targeted UWB channels.

IV. Field Test

To assess the effect of using the proposed antenna in a real UWB localization scenario, the field test described in the following has been set up. Two EVB1000 evaluation boards based on the DW1000 UWB transceiver IC by Qorvo [5] have been configured to mimick a packet exchange for UWB localization purposes. Both boards, one acting as an anchor and one acting as a tag, are controlled by a RaspberryPi 3B+ via serial commands. Each exchange consists in the transmission of 500 packets divided in 10 rounds (50 packets per round). This round robin strategy was used to prevent any adverse conditions (e.g. interference, passage of people, etc.) that could affect only one transmission. The transmitted power has been set to 10 dBm.

The UWB boards have been equipped with the proposed antennas and, for the sake of comparison, with the stock antennas available with the evaluation boards. These have dimensions similar to the proposed antenna and are also printed on a low-cost PCB. The main differences are in terms of antenna type and polarization. The proposed antenna is

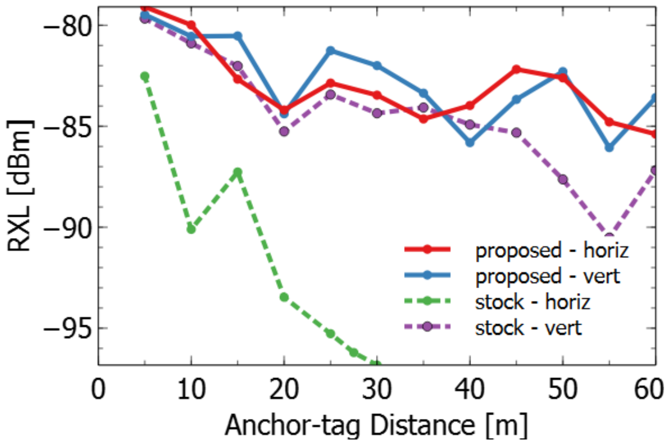


Fig. 6: Measured received signal power level (RXL).

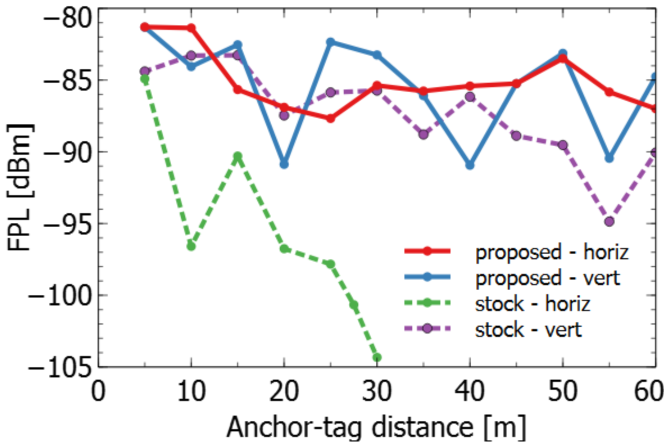


Fig. 7: Measured first path power level (FPL).

a patch-based antenna exhibiting circular polarization, while the stock one is a classical dipole-like linearly (vertically) polarized antenna.

The field test was conducted considering four different configurations, which vary based on 1) the type of antenna connected to the UWB transceivers, either the proposed antenna or the stock one, and 2) the tag orientation, either vertical (ideal) or horizontal (worst-case); the anchor is always positioned vertically. The test has been performed in an indoor environment (university corridor). For each configuration, the distance between the anchor and the tag has been varied from 5 to 60 m, while the distance from the ground was fixed to 1.4 m (simulating a board placed on a user's chest).

Fig. 5 shows the packet delivery ratio (PDR), calculated as the number of received packets divided by the number of transmitted ones, for the four considered configurations. Each curve name indicates the antenna being connected to UWB transceivers and the orientation of the tag. As it can be noticed, when the tag is vertically oriented, thus parallel to the anchor, the PDR is 100% using both the proposed and the stock antennas over the considered distance range (solid blue and dashed purple curves). However, when the tag is horizontally oriented (perpendicular to the anchor), the PDR starts decreasing drastically at 20 m, with zero packets received at 30 m (dashed green curve). Conversely, thanks to circular polarization exhibited by the proposed antenna, the packet exchange is not affected at all by the tag orientation, with the PDR remaining 100% even at 60 m (solid red curve).

These results are confirmed by the average (over 500 packets) received signal power level (RXL) shown in Fig. 6. As it can be observed, when the proposed antennas are used, the RXL is varying almost identically over the distance, whatever the tag orientation (solid red and blue curves). On the other hand, when the stock antennas are used, the RXL rapidly decreases below the sensitivity threshold of the receiver if the tag is not oriented as the anchor (dashed green curve). Moreover, it is also worth noting that, even when both the tag and the anchor are parallel to each other (dashed purple curve), the RXL level decreases faster at larger distances (starting from 40 m) with respect to the configuration using the proposed antennas. This trend could be ascribed to the signal reflections occurring in an indoor environment, which increase with the distance between the devices, and that can cause variations in the polarization of the propagated electromagnetic field. As a result, the use of the proposed antennas could increase the maximum communication range (to be confirmed with measurements beyond 60 m).

Finally, very similar considerations can be made by looking at the first path power level (FPL) shown in Fig. 7.

V. Conclusion

In this paper, an UWB circularly polarized antenna is proposed. The antenna small dimensions and the low-cost and easy-to-manufacture structure make it a good candidate for integration in compact UWB devices for localization applications. The effectiveness of the proposed solution has been numerically and experimentally validated. Moreover, preliminary field tests using UWB localization boards indicate that the UWB communication between an anchor and a tag can be improved and make it independent on the tag orientation.

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