A compact UWB elliptic antenna for indoor localization system

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Abstract In this letter, a compact low cost ultra-wideband elliptic antenna was presented and discussed. The proposed antenna is printed on a 1.6 mm thick FR4 with a size of 21 × 27 × 1.6 mm. It was composed of a 4 ellipses radiating patch and a reduced ground plane with three rectangular slots. The measurement shows that the considered antenna operates over a wide impedance bandwidth of 16.26 GHz (3.12 GHz to 19.38 GHz) with a maximum Gain of 6 dBi with an omni-directional radiation pattern. Details of simulation and experimental results are presented and discussed.

Keywords: UWB, monopole antenna, slotted ground, elliptic antenna, omni-directional, high gain

Classification: Microwave and millimeter-wave devices, circuits, and modules

1. Introduction

Since the ruling of Ultra-wideband (UWB) technology by the Federal Communication Commission’s (FCC) in February 2002 [1], the UWB antenna has generated a great deal of interest for use in many applications such as indoor localization systems [2, 3, 4, 5, 6, 7]. Therefore, in this system, types and requirements of UWB antennas are different according to the used localization technique. The main desired characteristics of UWB antennas for localization systems based on RF Time of Arrival are: wide bandwidth, Omni-directional and stable radiation pattern, constant gain, high radiation efficiency, constant group delay, small and compact size and low cost [8, 9, 10, 11]. But there are many challenges in the design of such antennas, especially the contradiction between the size reduction, the bandwidth enhancement and the fabrication cost which remains unsatisfactory in many published works like in [12] were a planner printed monopole antenna with a dimension of 44 × 42 mm² is presented and it exhibit a bandwidth of 8.7 GHz (2.5 GHz to 11.2 GHz), but unlike in [13] were a compact geometry of 25 × 25 mm² is used but the antenna reveal an impedance bandwidth of 2.3 GHz (3.9 GHz to 6.2 GHz) and the antenna is designed on a laminated Rogers substrate RO4003C which is more expensive than the traditional FR4 substrate.

Since last few decades, diverse techniques have been examined to improve the antenna bandwidth and to miniaturize the overall size of the antenna in the same time, such as the use of tapered impedance transformer [14, 15], the insertion of diverse slots with different sizes in the reduced ground plane [10, 16], notching the radiating patch and adding slot on the patch [17], the use of special shape for the radiating patch [18, 19], the use of slot antennas [20], curving and defecting the ground plane [21], adding an extended ground stub to further enhance the bandwidth [21], using a liquid crystal polymer (LCP) in the fabrication of the antenna [22], the use of meta-materials transmission line as feeders for the antenna to reveal an infinite-wavelength [23, 24, 25], loading small shunt capacitance and large shunt inductance into the symmetric and asymmetric zeroth-order resonator (ZOR) antennas [26], the combination of zeroth-order resonator (ZOR) and λ/2 resonance frequencies together in a single pass-band of the resonant ring loaded composite right/left-handed transmission line (CRLH-TL) antenna [27] and the use of a thick substrate or a multilayer structure with low permittivity [28].

However, all of these approaches have omnipresent trade-off between bandwidth, size, cost and design complication.

In this work, a new low cost compact antenna structure is proposed that exhibits ultra-wideband response from 3.12 GHz to 19.38 GHz with an impedance bandwidth of 16.26 GHz (144.53%) with a reflection coefficient better than −10 dB. The enhancement of the impedance matching was achieved by using multi-resonant elements as radiating patch, eventually four ellipses with different radii and by optimizing the size, number and position for the inserted slot in the partial ground plane.

2. Antenna design

The UWB patch antenna is printed on a standard FR-4 substrate of thickness h = 1.6 mm, dielectric constant εr = 4.4 and loss tangent tan δ = 0.02. This structure was inspired from the Bell-Shaped Ultra Wideband Antenna published in our previous work [18, 19].

The challenge in this work is how to increase the bandwidth of this antenna without increasing its occupied area and its cost of fabrication. As first step in the design, the Bell-Shaped Patch which is printed on the top side of the substrate in [18, 19] replaced by four ellipses with different radii as demonstrated in Fig. 1.
The reduced ground plane with dimensions \( W_g \times W_{sub} \) covers most of the 50 \( \Omega \) microstrip feed line leaving only a gap distance \( d \) between the upper edge of the ground plane and the lower edge of the radiating patch.

In the second step, three slots were added to the reduced ground plane to enhance the impedance bandwidth of the proposed antenna.

The association of ellipses with different radii for the patch, the use of partial ground plane, the control of the gap distance \( d \) between the radiating element and ground plane and the insertion of slots at the ground plane, have an effect on impedance matching and lead to the diminution of the physical size of the proposed antenna.

The width of the micro-strip feed line is fixed at 3 mm to achieve 50\( \Omega \)-characteristics impedance.

The antenna has a very compact size (27 \( \times \) 21 mm\(^2\)) compared to the structures published in [11, 12, 29, 30, 31]. The geometry of the proposed antenna is shown in Fig. 1.

All performances of the proposed antenna were analyzed using the Finite Element Method (FEM) on Ansoft high-frequency structure simulator (HFSS) v.13. A parametric study on the ellipses’ radii, the number and position for the inserted slot in the ground plane and the gap distance were conducted to obtain a better impedance bandwidth. The optimal parameters that were found are summarized in Table I. During simulations, an SMA coaxial connector has been connected to the feed line to obtain more realistic results as revealed in Fig. 2.

3. Result and discussion

Fig. 3 shows the effect of the adding of slots in the ground plane.

It is clear that the antenna bandwidth was enlarged and a new band of frequencies was introduced (10 GHz to 16 GHz).

After that, the antenna was fabricated for experimental verification. The photograph of the realized antenna is shown in Fig. 4.

| Parameter   | Quantity | Value (mm) |
|-------------|----------|------------|
| \( W_{sub} \) | Substrate width | 21 |
| \( L_{sub} \) | Substrate length | 27 |
| \( W_f \) | Feed line width | 3 |
| \( L_f \) | Feed line length | 10 |
| \( W_g \) | Ground plane width | 8 |
| \( R_{e1} \) | Ellipse 1 radius | 10 |
| \( R_{e2} \) | Ellipse 2 radius | 8 |
| \( R_{e3} \) | Ellipse 3 radius | 6 |
| \( R_{e4} \) | Ellipse 4 radius | 4 |
| \( e_1, e_2, e_3, e_4 \) | Ellipses eccentricity | 0.5 |
| \( W_s \) | Slot width | 3 |
| \( W_{s1} \) | Slot width | 4 |
| \( L_s \) | Slot length | 3 |
| \( d \) | Gap Distance | 2 |
The measurements were monitored using the microwave network analyzer ANRITSU 37369A.

The variations of the measured and the simulated reflection coefficient of the proposed antenna in dB are shown in Fig. 5.

Simulation results show that the impedance bandwidth for the proposed antenna is about 16.1 GHz (143.11%) starting from 3.2 GHz to 19.3 GHz for \( S_{11} < -10 \) dB.

The measured impedance bandwidth is 16.26 GHz (144.53%) starting from 3.12 GHz to 19.38 GHz for \( S_{11} < -10 \) dB.

There is a minor discrepancy between simulation and measurement results. These disparities are mostly due to the inaccuracies in the fabrication and due to the effect of the feeding cable used in the measurements. This can also be explained by the intrinsic properties of FR4 substrate which has an unstable dielectric constant and dissipation factor with increasing frequency.

The simulated group delay and the peak gain of this antenna were reported to Fig. 6 and Fig. 7.

As it can be observed, the group delay is less than 0.5 ns over the operating bandwidth then it proves that the antenna introduce a low distortion on the transmitted UWB signal.

Also, our antenna can reach a maximum Gain of 6 dBi which is a high value compared to other published structures like in [29, 30].

The simulated and measured radiation patterns for the proposed antenna at 4 GHz, 7 GHz, 10.2 GHz, 13 GHz and 16 GHz are shown in Fig. 8. The results show that the radiation pattern is quite stable over the entire UWB frequency band.

The antenna provides a nearly Omni-directional radiation pattern in both the H-plane and the E-plane.

4. Conclusion

A novel very compact and low cost UWB antenna which exhibit nearly omni-directional radiation patterns in both planes and a maximum Gain of 6 dBi for indoor localization has been presented. The impedance bandwidth of this antenna was enhanced by the insertion of rectangular slots on the upper edge of the ground plane and the use of 4 ellipses with controlled radii as resonator. The obtained results favorite this antenna to be a potential candidate for the indoor localization systems regarding to its low profile and price, its very wide impedance bandwidth, its stable radiation pattern and its high gain.
Fig. 8. Simulated and measured radiation patterns at 4 GHz, 7 GHz, 10.2 GHz, 13 GHz and 16 GHz.

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