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Novel Microstrip Slot Antenna for MIMO Systems and Super-Wideband Applications

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Abstract

A novel planar microstrip slot antenna for multiple-input-multiple-output (MIMO) systems and Ultra-wideband (UWB) and Super-wideband (SWB) applications is presented. The proposed antenna is compact with a size of $40\times40\times1$ mm^3 which is printed on a cheap substrate of FR-4. Measurement and simulation results show that presented antenna has 2:1 VSWR bandwidth from 2.53 GHz to 25.5 GHz, giving a ratio impedance bandwidth of more than 10:1. Simulation and measurement results are compared and discussed. Moreover different configurations of array of the antenna for MIMO application are studied.

Keywords: Microstrip Antenna, Multiple-Input-Multiple-Output (MIMO), Super Wideband(UWB), wireless communications.

INTRODUCTION

After allocation of the frequency band of 3.1-10.6 GHz (UWB) for commercial use by the FCC (Federal Communication Commission) [1], Ultra wideband systems have received wonderful attraction in wireless communication. Microstrip antennas are popular because of offering antennas with low cost, low profile, light weight and ease of fabrication.

In the recent years, wireless communication systems have increased rapidly. In high-bit-rate wireless communication for reduced multipath fading and increased capacity, multiple-input-multiple-output (MIMO) systems are suitable. The MIMO antenna array should have compact structure and high isolation between the signal ports [2]. To achieve maximum channel capacity the array is also required to have high gain [3].

Moreover, it is worthy noting that the maximum operating frequency range of an indoor UWB antenna in the provision of FCC-sanctioned UWB technology is from 3.1 to 10.6 GHz with a ratio bandwidth of 3.4:1, while an antenna with a ratio bandwidth greater than or equal to 10:1 is generally called a super-wideband (SWB) antenna in the antenna literature.

In this paper, the main target is to present a novel lunate-shape slot (LSS) structure with a step-by-step design procedure. The main radiator of the proposed antenna is a simple elliptical-shaped patch and impedance bandwidth is enhanced by using slotted patch. In the proposed antenna, by using two pairs lunate-shape slot (LSS) and a rectangle slot with rounded upper side in the patch, a proper control on the upper and lower frequencies of the band can be achieved. Using LSS forms in the patch, simultaneously causes the bandwidth to increase and therefore -10 dB S11 requirement is satisfied. Simulated and measured results are presented to validate the usefulness of this proposed small antenna structure for the aforementioned applications.

ANTENNA STRUCTURE AND DESIGN

The presented monopole antenna is fed by a microstrip line, whose geometry and photography of the fabricated antenna are shown in Figure 1. The compact antenna is symmetrical with respect to the longitudinal direction (X-axis), the antenna basically consists of an ellipse-shaped patch as the main radiator in which some part of the patch is etched by slots and a half-ellipse-shaped ground plane with rectangle-shaped that has been etched from the ground plane as shown in Figure 1.

As mentioned earlier, the main shape of the antenna's patch is ellipse. The first pair of lunate-shape slot (LSS) is subtracted from the patch as depicted in Figure 1. The second pair of LSS is formed by subtraction of 2 ellipse from each other with their radius equal to 10 mm in X direction and their radii equal to 6 and 4 mm along Y-axis. Then dichotomize in X direction afterward each part is rotated 15° as shown in Figure 1. The third slot is rectangle with rounded upper side. The dimension of the main rectangle is 17.93×1 mm2, meanwhile a circle with radius of 1 mm at the center of the upper side of the rectangle has been added to the third slot.

As alluded, the ground plane's shape is half-ellipse from which the rectangle cutting is subtracted.

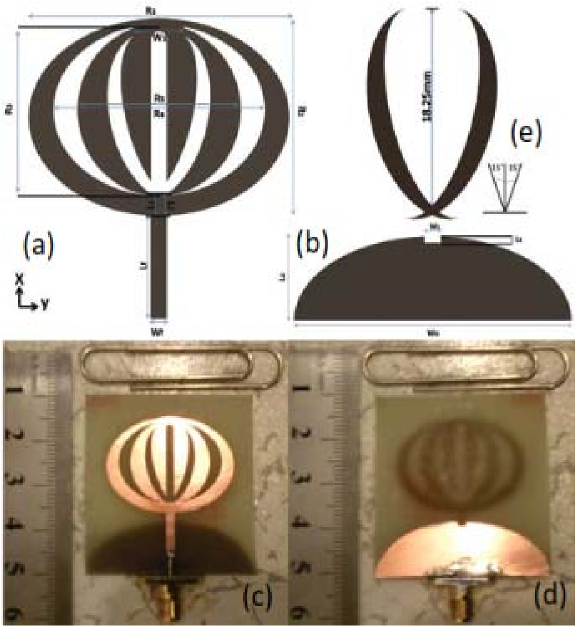


Figure 1. Geometry of the proposed antenna, (a) front view, and (b) back view (W_f= 1.99, L_f = 12,W_G = 40, L_G = 11.48, R_1 = 32, R_2 = 23, R_3 = 19.74, R_4 = 26, R_5 = 20, L_1 = 2.33, L_2 = 2.52, L_3 = 0.88, W_1= 6, W_2 = 2.4) (unit: milimeters), and Photograph of the proposed realized antenna, (c) front view, and (d) back view and (e) formation of the second pair of lunate-shape slot(LSS)

RESULTS AND DISCUSSIONS

UWBAntenna

In this section, simulated and measured results of the proposed monopole antenna are presented. The prototype antenna was fabricated on FR4 substrate with permittivity of 4.4, thickness of 1 mm and loss tangent of 0.024 using conventional printed circuit board (PCB) technique. 50Ω SMA connector was used to feed the antenna. The width and height of the microstrip feed-line are 1.99 and 12 mm, respectively, to achieve 50Ω characteristic impedance. The performance of the proposed antenna at different iteration has been investigated using a commercially available finite element software, Ansoft HFSS (ver. 13). The impedance bandwidth of the antenna was measured using the Agilent 8722ES Vector Network Analyzer.

The rectangle cutting in the upper and middle face of the ground plane which is subtracted causes the current path to increase under antenna's patch and it is shown in Figure 2.

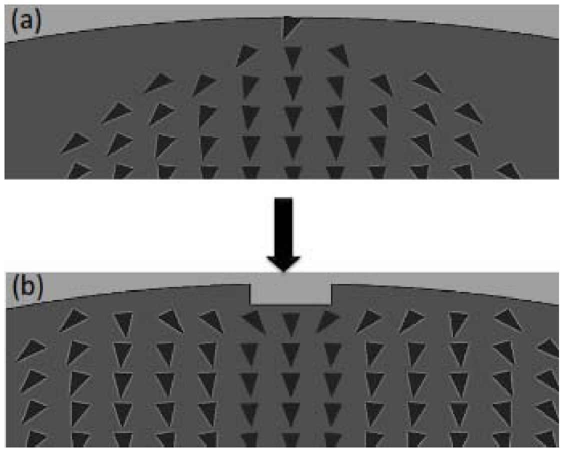


Figure 2. Simulated surface current distribution over the ground-plane at 7 GHz, (a) without modification, and (b) modified.

The simulated return-loss performance for each slot is shown in Figure 3.

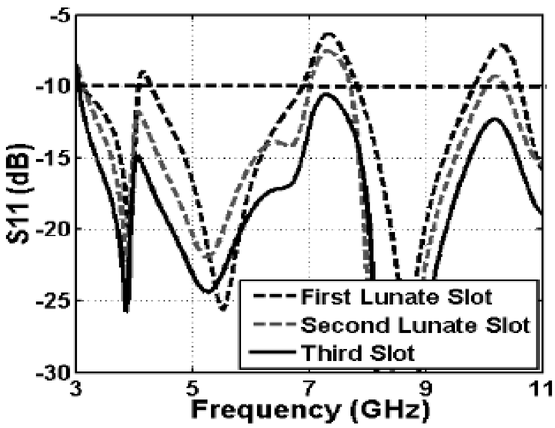


Figure 3. Effect of each slot on the antenna's return-loss response.

It is observed that by adding slot in each iteration, a wider bandwidth and satisfying -10 dB edge can be achieved. The measured return-loss and Standing Wave Ratio (SWR) are shown in Figure 4.

The measured gain of the antenna is exhibited in Figure 5. The minimum gain is appeared at the initial frequencies due to compact size of the antenna,but the maximum gain is at frequency 10.14 GHz which is equal to 5.1dB.

Figure 6 shows the measured radiation pattern at frequencies 4.5, 6.8 and 8.7GHz, in the E-plane (y-z) and H-planes (x-z). From an overall view of these radiation patterns, the proposed antenna behaves quite similarly to the typical printed monopoles in the whole frequency bands. The H-plane patterns are omnidirectional, as well.

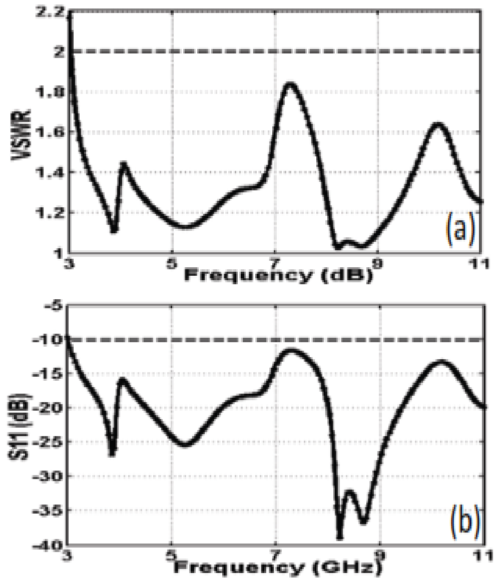


Figure 4. The measured (a) Standing Wave Ratio (SWR)and (b) return-loss

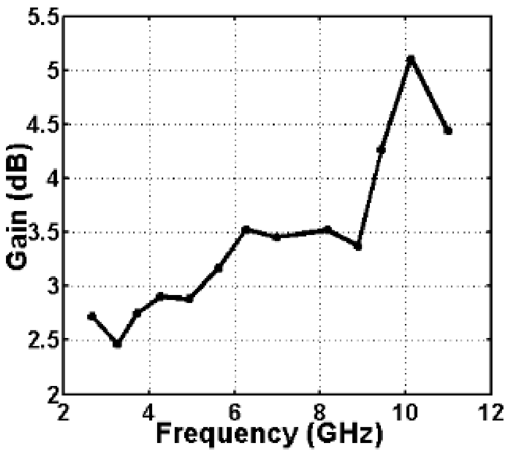
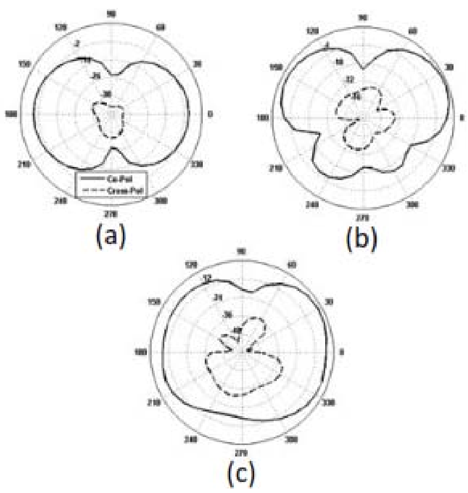


Figure 5. Measurment gain response of the proposed antenna



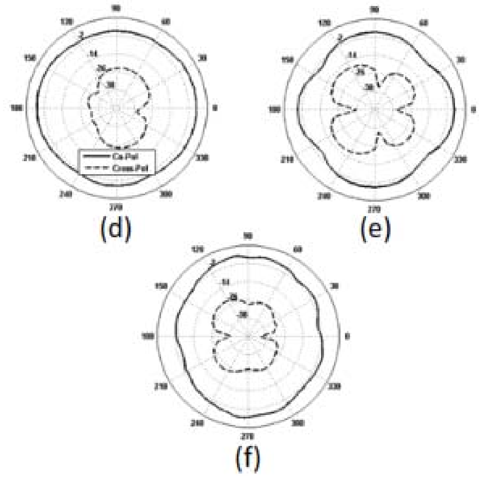


Figure 6. Measured E-plane radiation patterns for the proposed antenna at: (a) 4.5 GHz, and (b) 6.8 GHz, and (c) 8.7 GHz and H-plane radiation patterns for the proposed antenna at: (d) 4.5 GHz, and (e) 6.8 GHz, and (f) 8.7 GHz.

The key in the UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should have the capability of transmiting the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant (2).

$$\text{group delay} = \frac{-d\theta(\omega)}{d\omega} \qquad (2)$$

Measurement of group delay was performed by exciting two identical prototype antennas, which were located in their far field, in two orientations: side-by-side and face-to-face. The system's transfer function was measured in an anechoic chamber. The separation between the identical monopole antenna pair was 0.5 m.

As depicted from the Figure 7, the group delay variation of the proposed antennas at the resonant frequencies with respect to other frequencies is more. In spite of this, the group delay variation is less than 10 ns over the frequency band from 2 up to 12 GHz which ensures us that transmitted or received pulse by the antenna will not distort seriously and will retain its shape. Therefore, the proposed antenna is suitable for modern UWB communication systems.

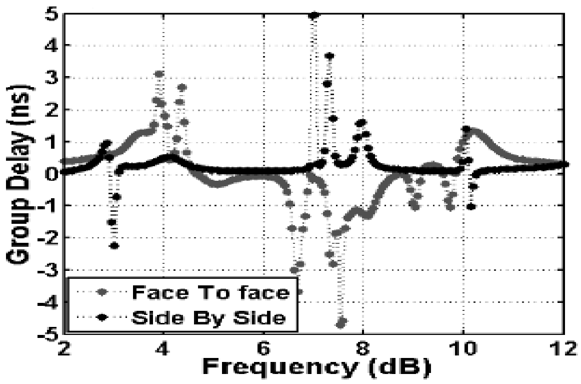
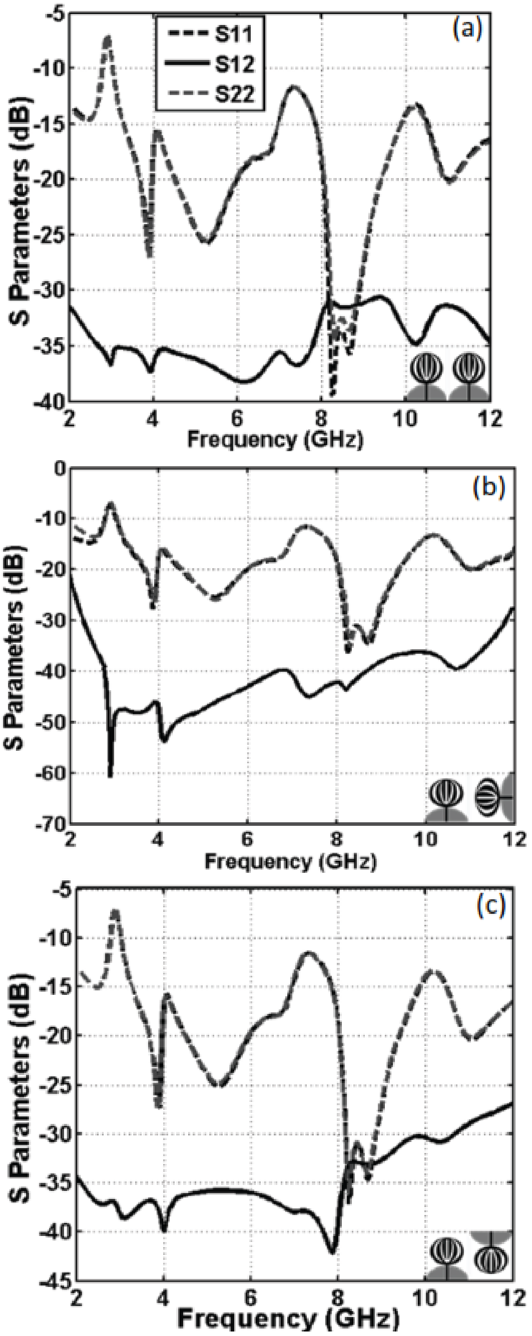


Figure 7. Measured group delay of the antenna

Array Structures of UWB antenna forMIMO Applications

This antenna can be arrayed to be used in MIMO applications. The performance of an appropriate antenna array for MIMO applications is based on various parameters such as mutual coupling and radiation pattern. Based on the four possible configurations, any two such monopole antennas can be arranged beside each other. Figure 8 illustrates the relevant simulated S-parameters. In each case, the spacing between array elements is set at 15 mm (λ/10 of the lowest frequency band) [4, 5].

As can be seen from Figure 6, reflection coefficient (S11) of the all array structures are nearly similar. It is also obvious that S21 or mutual coupling in Figure 6(d) is little more than three other figures in some frequencies.



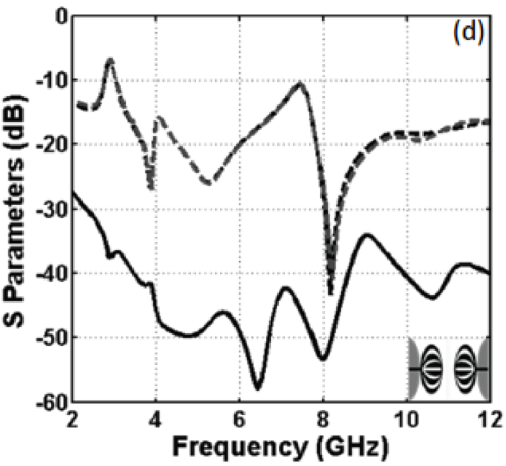


Figure 6. (a)–(d) Simulated S-parameters of the MIMO configured proposed antenna for different arrangement of two elements beside

SWBAntenna

The proposed antenna is applicable in SWB applications, meanwhile the measured return-loss authenticate the aforesaid statement.

Figure 7 depicts the measured return-loss of presented antenna from 2.53 GHz to 25.5 GHz.

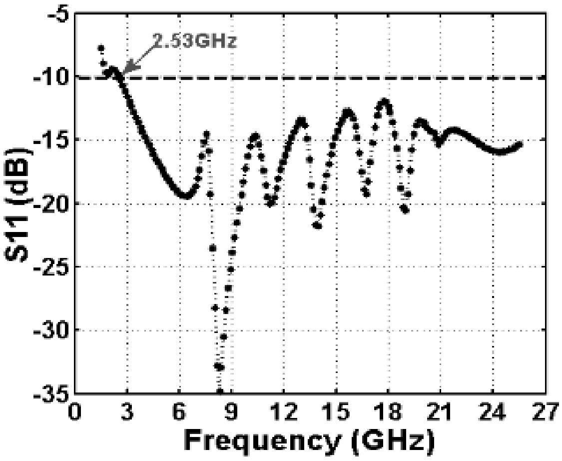


Figure 7. Measured return-loss of the proposed antenna

CONCLUSIONS

In this paper, unique microstrip monopole antennas with compact size for UWB and SWB applications were presented. By using a lunate-shaped slot (LSS), the bandwidth of this antenna has grown from 2.53 GHz to 25.5 GHz which out numbers the defined UWB band, by the way it is proved, the antenna is appropriate for SWB communication systems with ratio impedance bandwidth of more than 10:1. Also two element arrays of such antennas in four different configurations for MIMO applications were analyzed. Measured Patterns of the antenna at three frequencies of 4.5, 6.8 and 8.7 GHz were presented then the results show that the proposed antenna could be an appropriate candidate for MIMO applications.

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