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FR-4 Substrate Based Modified Ultawideband Antenna with Gain Enhancement for Wireless Applications

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Abstract

A new circular shape patch ultrawideband (UWB) single feed microstrip antenna is described in this paper. The radiated patch of the proposed UWB antenna is embedded with slots to improve the radiation characteristics ensuring a wide impedance bandwidth. In the ground plane, two rectangular rings slots are etched to provide proper impedance matching over a wide frequency range. The proposed single layer UWB with overall dimensions of 55 mm by 56 mm is fabricated using low cost 4.3 relative permittivity FR-4 substrate. From results obtained, the antenna can provide an impedance bandwidth ranging from 2.2 GHz to more than 12 GHz (138%) that is wider than the standard UWB band. In addition, the modified UWB antenna can enhance the gain to more than 6.6 dB, which is higher than that achieved by the ordinary UWB antenna by more than 16%. Comparison of the modified UWB antenna simulated and measured results shows a close agreement, which enable it to be a promising solution for many wireless applications such as UWB applications, X-band (8-12GHz) satellite communication, portable wireless devices, medical applications, positioning systems cognitive radio and WiMAX 5.4 GHz band application.

Keywords: Antenna, Enhanced gain, FR-4, UWB applications.

1. Introduction

Nowadays, with the rapid development in wireless communication systems, large bandwidth (in few GHz) with higher data rates is required. Microstrip antennas have the advantages of easy integration with microwave circuits, low cost, small size, and easy fabrication process [1]-[2]. Many microstrip antennas with various patch shape such as square, rectangular, triangular and circular have been proposed to improve the bandwidth into few GHz for UWB applications. Despite the abovementioned advantages of microstrip antennas, they suffer from short range bandwidth. Thus, many techniques have been applied to enhance the operating bandwidth. These techniques are meandered slots [3], defected ground structure (DGS) [4], excitation with coplanar waveguide technology [5, 6], elliptical patch [7], octagonal patch [8], circular [9] and modification in the ground plane shape [10].

Another technique applied to cope UWB applications is the design of monopole antennas with wide bandwidth as proposed in [11-15]. However, their gain is low. Many research works have been carried out on the ultrawideband (UWB) antennas since it was introduced by Federal Communication Commission which considers UWB band to have fractional bandwidth of 109.5% (from 3.1 to 10.6 GHz) [16]. Due to the advantages of planar UWB antennas such simpler structure, low cost and low profile [17], they were the most studied by researchers. However, these antennas suffer from poor radiation characteristics that limit use in many practical applications such as cognitive radios [18]-[19], portable wireless devices and positioning systems. Such wireless systems required a UWB antenna with high realized gain.

To overcome this above-mentioned issue, some methods to enhance the UWB antenna radiation characteristics have been reported. Electromagnetic band gap (EBG) loaded with UWB antennas [20] dielectric resonator [21] and stacked patches [22] techniques have been applied for UWB antenna gain enhancement. However, the adoption of parasitic elements into UWB antenna enlarges the physical size. Some designers have applied cavity-backed technique to increase the gain of UWB antenna as presented in [23-28]. Although the gain is enhanced, the antenna structure is quite bulky. In [29], modification to the patch and ground plane of UWB antenna is adopted to improve its impedance bandwidth. The antenna is fabricated using cost effective 4.4 permittivity FR-4 substrate. This antenna can cover frequency range from 2.66 GHz to 11 GHz. However, it’s peak gain is limited to 3.157dB.

In this paper, a modified UWB antenna with wide range impedance bandwidth and high realized gain is proposed. This antenna uses circular patch with single microstrip feedline. The antenna is simulated and fabricated using low-cost FR-4 board. Slotting technique is adopted to modify the patch and ground plane of the proposed UWB antenna to enhance its realized gain to more than 6.5 dB maintaining a wide operating frequency ranging from 2.2 to more than 12

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GHz (138%). With this improvement, the proposed modified UWB antenna can be applied for many wireless applications, such as UWB applications, X-band (8-12GHz) satellite communication, portable wireless devices, medical applications WiMAX 5.4 GHz band application, cognitive radios, portable wireless devices and positioning systems, efficiently.

2. Geometry Design of UWB Antenna

The modified UWB antenna proposed here consists of circular patch and single microstrip feedline as in the antenna front side in Fig. 1 (a). The slots etched in the radiated circular patch are designed to enhance the electric field radiation. Thus, realized gain is improved. Fig.1 (b) shows the UWB antenna backside where partial ground plane is designed. Two rectangular rings slots are designed in the ground plane, side to the feedline to improve the impedance matching. Calculation of UWB antenna dimensions is first conduced. The following are the formulas for circular patch microstrip antenna design. Then, the parameters are optimized using CST software. The optimized dimensions of modified UWB antenna are listed in Table 1. Circular patch radius is calculated using equation (1)-(2) [30].

$$a = \frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon_r F}[\ln\left(\frac{\pi F}{2h}\right)+1.77296]}} \quad (1)$$

Where, a = Patch radius

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

f_r = Resonant frequency
h = Height of the dielectric substrate
ε_r = Antenna substrate dielectric constant

Based on 50 Ω Characteristic impedance, Wf and Lf of the microstrip feedline can be calculated using equations (3)-(5) [30].

$$Z_o = \frac{60}{\sqrt{\varepsilon_{reff}}}\ln\left(\frac{8h}{W}+\frac{W}{4h}\right) for \frac{W}{h}<1 \quad (3)$$

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{W}{h}+1.393+0.667\ln\left(\frac{W}{h}+1.444\right)\right]} \quad (4)$$

$$for \frac{W}{h}>1$$

Where,
W = Feedline width
Effective dielectric constant, ε_{reff}

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{3}+\frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{(1+12\frac{h}{W})}} \quad (5)$$

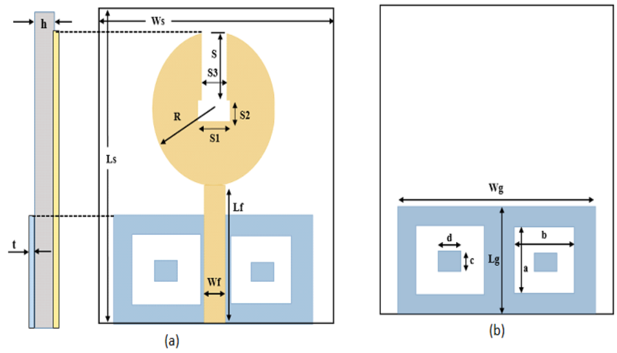

Fig. 1. Modified UWB antenna geometry. (a) Antenna front and side views, (b) Antenna back view.

Table 1. Modified UWB optimized parameters.

Parameter	Value [mm]	Parameter	Value [mm]
Ws	55	b	15
Ls	56	c	4
R	14.5	d	5
Lf	20.6	S	11.8
Wf	3	S1	7
Wg	50	S2	5
Lg	20	S3	5
a	10	Null	

The antenna performance is influenced by the type of the substrate used. Substrate design parameters, such as loss tangent, substrate thickness and dielectric constant, effect the antenna characteristics. Substrate with low loss tangent and low dielectric constant values will have better performance as compared to those having higher values. In this work, FR-4 substrate is used. FR-4 is known as the glass reinforced epoxy laminated sheets. FR-4 is a good choice as a substrate due to its low cost and its availability. Table 2 shows FR-4 board specifications.

Table 2. FR-4 substrate parameters

Substrate Parameters	Value
Dielectric constant, ε_r	4.3
Loss Tangent, δ	0.019
Conductor (copper) thickness, t	0.035 mm
Substrate thickness, h	1.6 mm

3. Results and Discussion

Modified UWB antenna simulated and measured results are illustrated in this section. Prior to fabrication process the antenna is simulated and optimized using simulation computer technology (CST).

3.1 UWB Antenna Reflection Coefficient and Bandwidth

The proposed ultrawideband antenna is designed with micostrip feed line. The feed line width of the antenna is studied to have 50 Ω characteristics impedance so that antenna can match with the coaxial cable during measurement process. The characteristic impedance is 49.43 Ω which is closed to 50 Ω. The ultrawideband antenna reflection coefficient is presented in Fig. 2. It can be noted that the modified UWB antenna achieves -10 dB impedance bandwidth from 1.8412 GHz to more than 12 GHz, that is wider than the standard ultawideband antenna bandwidth that is between 3.1GHz to 10.6 GHz. The impedance bandwidth percentage can be calculated using equation (6) [30]. Based on this calculation, the proposed modified UWB antenna achieved an impedance bandwidth percentage of 138%, which is wider than the standard UWB Band [16].

$$BW = \frac{F_H - F_L}{(F_H + F_L)/2} \qquad (6)$$

Where, F_H represents the upper frequency and F_L is the lower frquency.

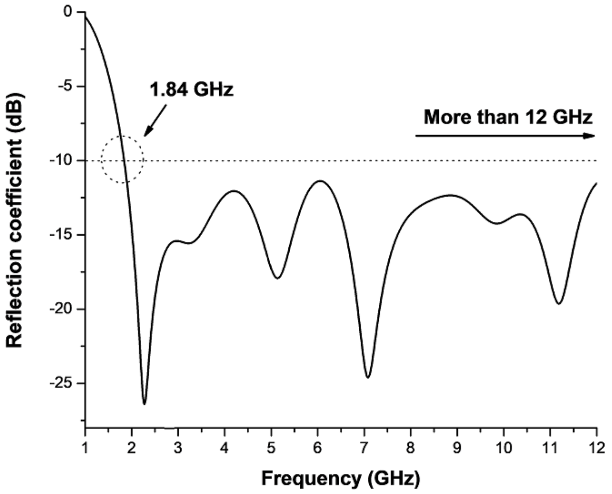

Fig. 2. Proposed ultrawideband antenna simulated reflection coefficient and bandwith.

3.2 Ultrawideband Antenna Gain

The antenna gains of the proposed modified UWB and ordinary UWB antenna are compared over a wide frequency range as shown in Fig. 3. The antenna with modified shape can achieve maximum gain of more than 6.5 dB at 8 GHz, whereas the maximum gain of the ordinary UWB antenna is limited to 5.5 dB at the same frequency. Thus, the embedded slots into the patch and ground plane has enhanced the UWB antenna gain. Gain of more than 3 dB is achieved at Wi MAX operating frequency (5.4 GHz).

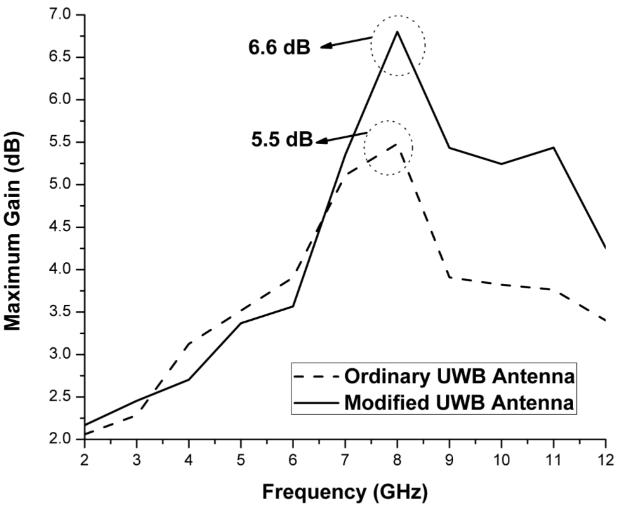

Fig. 3. Gains comparison of the modified UWB antenna and ordinary UWB antenna.

To investigate the effects of embedded slots into UWB antenna, surface current at 5 GHz and 10 GHz is studied. Fig. 4 (a) shows the surface current distribution density of the modified UWB antenna at 5 GHz, while Fig. 4 (b) shows the surface current distribution density at 10 GHz. Similarly, the surface current distribution density of the ordinary UWB antenna is simulated at 5 GHz and 10 GHz as presented in Fig. 5 (a) and Fig. 5 (b), respectively. From the current surface distribution view, it can be found that the current flow of the modified UWB antenna at 5 GHz and 10 GHz is stronger in comparison to the current flow of the ordinary UWB. This increases the antenna capacity and gain as well.

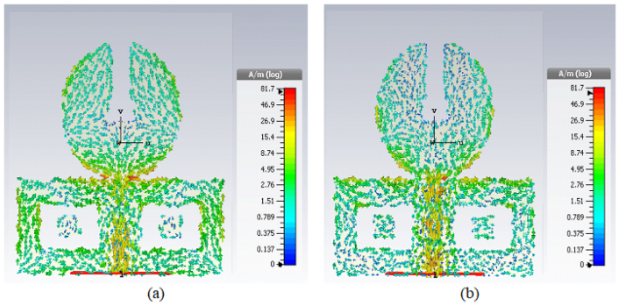

Fig. 4. Distributions of surface current of modified UWB antenna (a) at 5 GHz and (b) at 10 GHz.

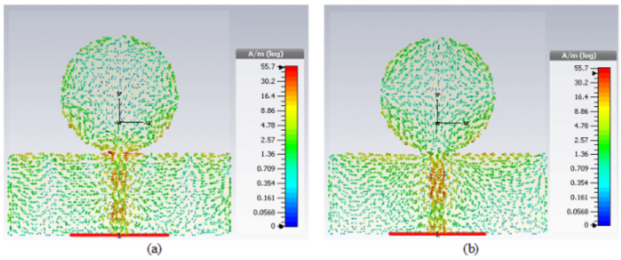

Fig. 5. Distributions of surface current of the ordinary UWB antenna (a) at 5 GHz and (b) at 10 GHz.

3.3 Fabricated Modified UWB Antenna

Once the ultawideband antenna design characteristics are satisfactory, fabrication process took place in the laboratory. FR-4 substrate with 4.3 relative permittivity was used. The prototype of ultrawideband antenna is shown in Fig. 6. Fig. 6 (a) illustrates the ultrawideband antenna font view, while Fig. 6 (b) illustrates the back view of the modified ultawideband antenna. Small difference between simulated and measured results is due to manufacturing tolerance and soldering effects.

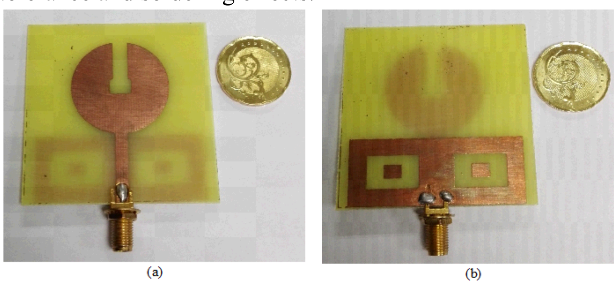

Fig. 6. Fabricated modified UWB antenna. (a) Prototype front view, (b) Protype back view

The measurement of modified UWB antenna is conducted in laboratory using Vector Network Analyzer (VNA). From the experimental results of the antenna, it is found that the -10 dB operating bandwidth starts from 2.2 GHz to more than 12 GHz as shown in Fig. 7.

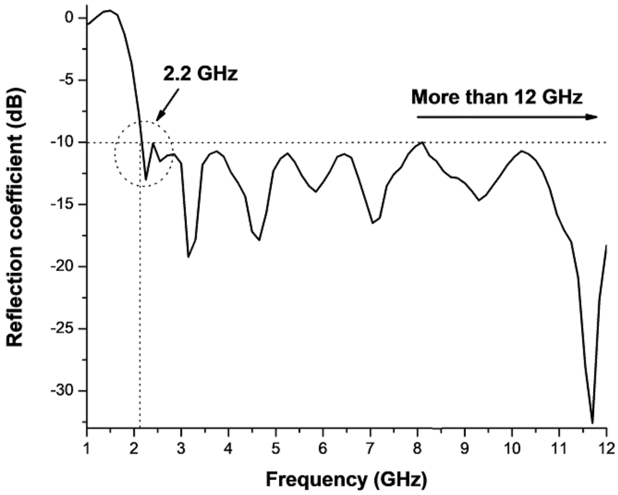

Fig. 7. Proposed ultrawideband antenna measured reflection coefficient and bandwidth

Comparison of the simulation and measurement results of modified UWB antenna is illustrated in Fig. 8. It can be realized that the fabricated antenna maintains wide bandwidth excepts that the bandwidth starts at higher frequency compared to the simulated results. This shift is due to the permittivity tolerance variation of FR-4 board.

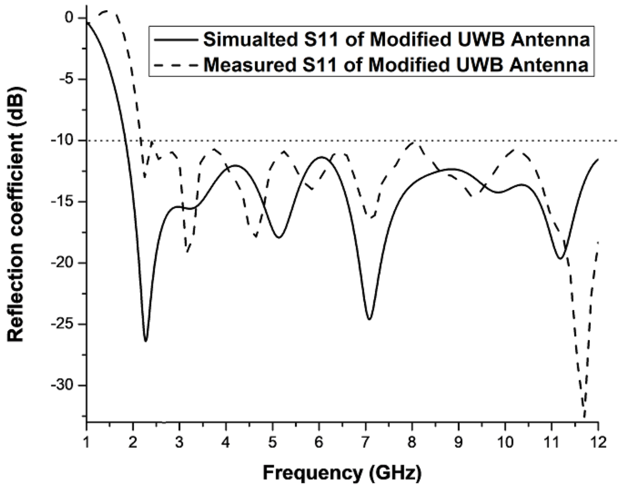

Fig 8. Simulated and measured reflection coefficient and bandwidth of modified UWB antenna.

Table 3 shows a comparison between past studies on UWB antennas and the proposed UWB antenna related to impedance bandwidth, peak gain achieved and type of substrate used.

Table 3. Comparison between the past studies and proposed UWB antenna

Past studies on UWB antenna	Impedance bandwidth range (GHz)	Bandwidth (%)	Bandwidth (GHz) at VSWR < 2	Peak gain (dB)	Type of substrate used
[29]	2.66 to 11	122.1	8.34	3.157	FR-4
[31]	3.1 to 13	122.9	9.9	~6	Rogers RT/duroid 5880
[32]	2.5 to 10.8	124.81	8.3	~ 3.8	FR-4
[33]	3.1 to10.6	109.48	7.5	5.7	FR-4
[34]	3.1 to more than 11	112.05	7.9	~ 4	Taconic
[35].	3.1 to 10.6	109.48	7.5	~4.5	FR-4
[36]	2.6 to more than 15	< 141	12.4	~ 4	FR-4
[37]	3.0 to 14	129.4	11	5.3	Rogers RT/duroid 5880
[38]	2.78 to 12.8	128.6	10.02	~3.92	FR-4
This work	2.2 to more than 12	< 138	< 9.8	6.5	FR-4

4. Conclusion

A new modified circular shape UWB antenna has been reported. The modification of the radiated patch and the partial ground plane has achieved wide impedance bandwidth as well as high realized gain. This UWB antenna can provide -10 dB bandwidth ranging from 2.2 to more than 12 GHz, that is equal to 138% fractional bandwidth. In addition to that, the modified UWB antenna has a maximum gain of more than 6.5 dB. The high performance of the modified UWB antenna with the close similarity between simulation and measurement results enable it to be a good choice for wireless application such as UWB applications, cognitive radio, WiMAX 5.4 GHz band application, positioning systems MVDDS (12.2–12.7GHz) band application, and X-band (8-12GHz) satellite communication and portable wireless devices and medical applications. As this work focus on single element of UWB antenna, array of UWB antennas can be considered for future work. Besides that, more efficient substrate such Roger boards can be used to further enhance the performance of UWB antennas.

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