Progress In Electromagnetics Research Letters, Vol. 35, 165–179, 2012

A NEW ULTRA-WIDEBAND ANTENNA WITH UNIQUE GROUND PLANE SHAPE

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Abstract—A new shape of ultra-wideband antenna with a measured bandwidth of 122.67% is presented in this paper. The proposed antenna has fabricated on Duriod $22 \times 41\,\mathrm{mm}^2$ substrate and tested. The simulated and measured return loss results which have been presented in this paper indicate the antenna operates between 2.9 to 12.1 GHz frequency bands. In order to increase the bandwidth of aforementioned antenna, a unique shape of the ground plane has been proposed. This shape of ground plane has a very important role not only on increasing the bandwidth but also for removing some unwanted ripples from the return loss results.

1. INTRODUCTION

Ultra wideband systems or signals are the ones which either have a large relative or large absolute bandwidth. Ultra wideband has a strong effect in respect of information content, implementations' simplicity and signal [1].

A system with more than 500 MHz and 20% of bandwidth refer to large absolute and large relative bandwidth, respectively. The first one enables the possibility of large spreading factor, which means the ratio of signal bandwidth to the symbol bandwidth rate is very sizeable. On the other hand, the large relative bandwidth approach can improve signal robustness of data transmitting and has very important benefits for radar and ranging [1–3].

The Federal Communication Commission (FCC) in the USA has considered 3.1 to 10.6 GHz bandwidth with an effective isotropic

Received 22 May 2012, Accepted 24 July 2012, Scheduled 29 October 2012
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radiated power (EIRP) of below -10 dB/GHz for Ultra Wideband (UWB). It has been agreed for the UWB antennas that they must have the minimum fractional bandwidth of at least 20% or 500 MHz or more [2].

In addition to impedance bandwidth, the radiation pattern should be constant over the bandwidth, so an antenna qualifies to be classified in UWB category. Minimized distortion, signal transmission and reception, ringing and spreading are necessary in UWB antennas since they transmit narrow pulses instead of continuous wave in information sending [4, 5].

There has been offered many kinds of UWB antennas such as horn and parabolic antennas [6–17]. Although they have an ultra-impedance bandwidth, they suffer from some limitation specially their size, which deprives them to use in small commercial units [1, 2].

Microstrip printed patch antennas have been studied due to their unique specifications such as compact size, low profile, low fabrication cost, low weight, wide impedance bandwidth, semi omnidirectional and simple feed ability, which enable them easy to integrate with microwave integrated [5, 18–22].

Microstrip patch antennas with a finite ground plane which can operate as a monopole antennas are a good candidates for commercial units in terms of their size, but they have a narrow impedance bandwidth, usually less than 5%. Nowadays, various bandwidth widening techniques are presented. Probe compensation, coplanar parasitic patches, stacked parasitic patches, the U-slot patch antenna, the L-probe coupled patch, the M endering-probe fed patch, aperture coupled patches and ground plane modification are such techniques, which are totally investigated in many research projects [2, 5, 18–20, 23–26].

It has been proven that slots on patch or ground plane can increase the bandwidth of planar antennas as they make an irregular current surface [27]. By selecting an appropriate ground plane shape, better bandwidth and improved antenna gain will be achieved.

In this paper, an Ultra wideband monopole antenna with a Wing-Shaped ground plane is presented and discussed. This antenna operates from 2.9 GHz up to 12.1 GHz (122.67% of the impedance bandwidth). The design of the antenna was simulated using the CST Microwave Studio. Good agreement achieved between simulation and measured results.

2. CIRCULAR RING PATCH ANTENNA'S PARAMETER CALCULATIONS

2.1. Fields and Current

Considering the coordinate system as shown in Figure 4 and the cavity model analysis, it is obvious the modes are determined as TM_{nm} as they do not vary along the z direction for very thin substrates ($h \ll \lambda_0$, where h is the thickness of the substrate). It is proved in [28, 29] that substrate is a good radiator for TM_{1m} modes where m is an even number and good resonator with very little radiation for TM_{1m} modes where m is an odd number [30].

TM_{11} is known as the *dominant mode* since it has the minimum mean radius of ring for any given frequency. Also the TM_{0m} modes just vary along the width of microstrip where m is even (no field variation in the ϕ direction) [27, 30].

2.2. Resonance Frequency

There are several numerical methods used to calculate the resonant frequencies of ring patch antenna [29, 31]. An approximate value that has been offered for resonant frequencies of ring patch antenna is:

$$f_{mn} = \frac{\chi_{nm} c}{2\pi r \sqrt{\varepsilon_r}} \tag{1}$$

where c is the velocity of light in free space and $\chi_{nm} = k_{nm} r$.

By solving Eq. (1) for first TM_{nm} modes of ring antenna, a good approximation of frequency can be obtained:

$$f_r = \frac{87.94}{r\sqrt{\varepsilon_r}} \tag{2}$$

where r is the radius of ring in m and ε_r is dielectric permittivity.

3. ANTENNA STRUCTURE

Figure 1 shows the evolution of circular semi-ring monopole antenna with a novel wing-shaped ground plane be fed by microstrip line which has been studied in this paper. A basic circular ring monopole with a radius of r_1, r_2 and a $50\,\Omega$ microstrip feed line are printed on the same side of 22×41 mm dielectric substrates. Duroid was used as a dielectric substrate with a thickness of $h = 0.87$ mm and a relative permittivity of $\varepsilon_r = 3.8$. w_f, h_f and h_2 were chosen at 2.6, 20.4 and 3 mm in order to achieve $50\,\Omega$ impedance.

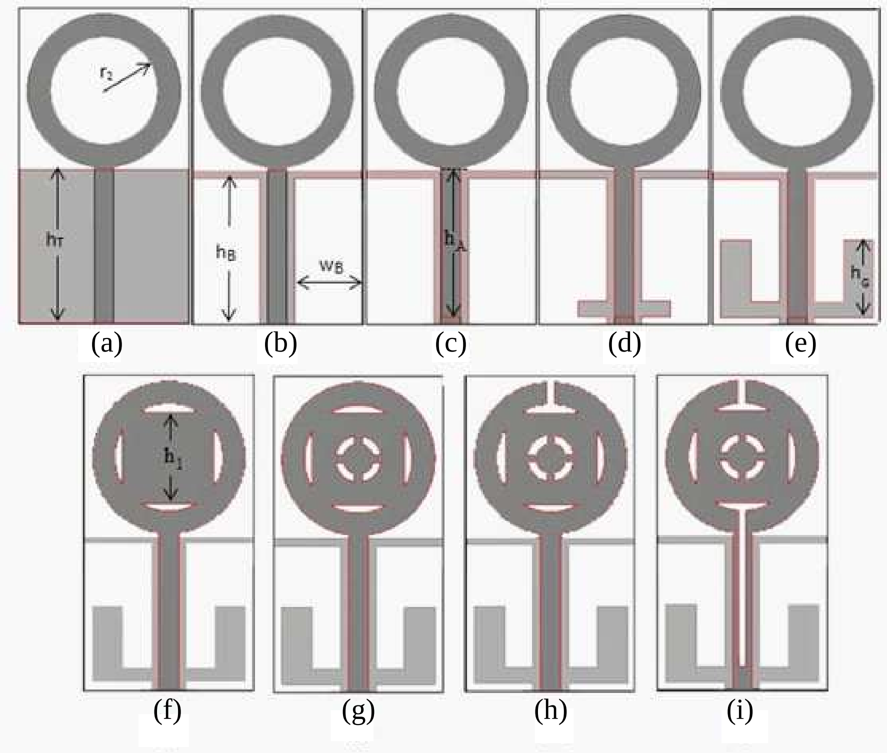


Figure 1. Proposed antenna's evolution.

This antenna is based on the circular ring antenna which has been described in the previous section. [1] indicates the fact that overlapping of close resonant frequencies can create impedance bandwidth. Since, some frequencies inside the range of 3.1 and 10.6 GHz were chosen firstly which were almost close together such as 4.5, 6.5 and 8.5 GHz. The inner and outer radiuses of proposed ring antenna were calculated so that the antenna is able to resonate at 4.5 and 6.5 GHz. So overlapping of these two resonances can provide the first stage of our desired bandwidth. Equation (3a) is obtained by rewriting Equation (2):

$$r = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \tag{3a}$$

where f_r is resonance frequency in GHz and ε_r is dielectric permittivity. At a design frequency of 4.5 and 6.5 GHz, the calculated radius for the circular patch is:

$$r_1 \approx 10 \tag{3b}$$

$$r_2 \approx 7 \tag{3c}$$

The outer and inner radiuses in ring patch are very important since the ratio of outer to inner radius can control the separation of resonant modes [30]. Figure 3(a) shows the bandwidth variations for various number of r_2.

It is proven in [28] that replacing an infinite ground plane with a finite ground plane will increase the microstrip antenna bandwidth. Since for the basic shape as it is shown in Figure 1(a) we chose a finite ground plane. Figure 3(b) demonstrates how we chose the best value as the size of ground plane, h_T.

Also two symmetrical and big rectangular slots in the ground plane shown in Figure 1(b), were created to increase the bandwidth of the proposed antenna. They have a good e?ect on the range of 4.1 to 4.9 GHz. Figure 3(c) shows the effect of different sizes of rectangular slot on the antenna bandwidth. The next step was adding another rectangular slot on the ground plane behind the feeder line as it is illustrated in Figure 1(c). This slot pushes the return loss curve down under -10 dB by creating some extra resonances as they are depicted in Figure 3(d). In order to have another resonance at 8.5 GHz to increase the bandwidth up to at least 10.6 GHz (UWB requirements) two rectangular slots on the ground plane were added which are demonstrated in Figure 1(e). Using Eq. (4) we can determine the length of these slots:

$$h_G = \frac{C}{2f_r\sqrt{\varepsilon_r}} \tag{4a}$$

where C (Velocity of light) equals to 3×10^8 m/s, and h_G is the length of patch in m. The slots are symmetrical and will be achieved by Eq. (4), so:

$$h_G = 0.0096\,\mathrm{m} \approx 10\,\mathrm{mm} \tag{4b}$$

They were connected to the ground plane by two small rectangular slots which are shown in Figure 1(d). On the other hand, Figures 1(f) to (i) represent the evolution of patch from ring to proposed shape. A square and discrete small ring slots are added to create some extra resonant frequencies inside the antenna bandwidth to support our ultra-bandwidth specification. The antenna will resonate on 6.8 GHz caused by square patch using Eq. (5):

$$f_r = \frac{C}{2h_1\sqrt{\varepsilon_r}} \tag{5a}$$

$$f_2 = 6.8\,\mathrm{GHz} \tag{5b}$$

where h_1 is square's side and it equals to 12 mm.

Figure 3(f) shows the variations of return loss with various number of h_1. Also if we consider the patch as a normal disk patch with a diameter of $2r_1$, we can note that the first resonant frequency should be around 4 GHz. In fact, the quarter-wavelength at the first resonance (20 mm) just equals to $2r_1$. So the first resonance occurs when the disk behaves like a quarter-wave monopole [1].

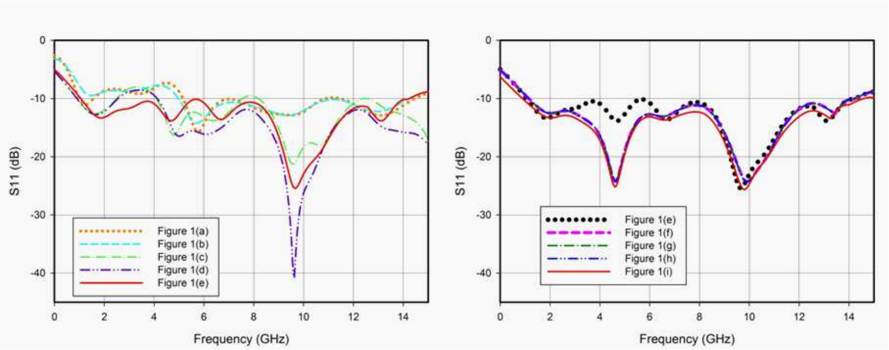
Figure 2 shows the return loss results for each step of proposed antenna design.

$$f_r = \frac{C}{\lambda} \tag{6a}$$

$$\frac{\lambda}{4} = 2r_1 = 20\,\text{mm} \Rightarrow \lambda = 80\,\text{mm} \tag{6b}$$

$$f_1 = 3.75\,\text{GHz} \tag{6c}$$

Figure 4 shows the geometry of front and back view of designed antenna. In Figure 4(b), the novel ground plane is depicted. As we discussed, by selecting the right changes, we can achieve wider bandwidth because of scrambling in the current surface. It is proved that any intended changes in the ground plane and the surface current distribution has a direct effect on the antenna's parameter, especially on bandwidth [5, 18, 27]. According to this fact, this



(a) (b)

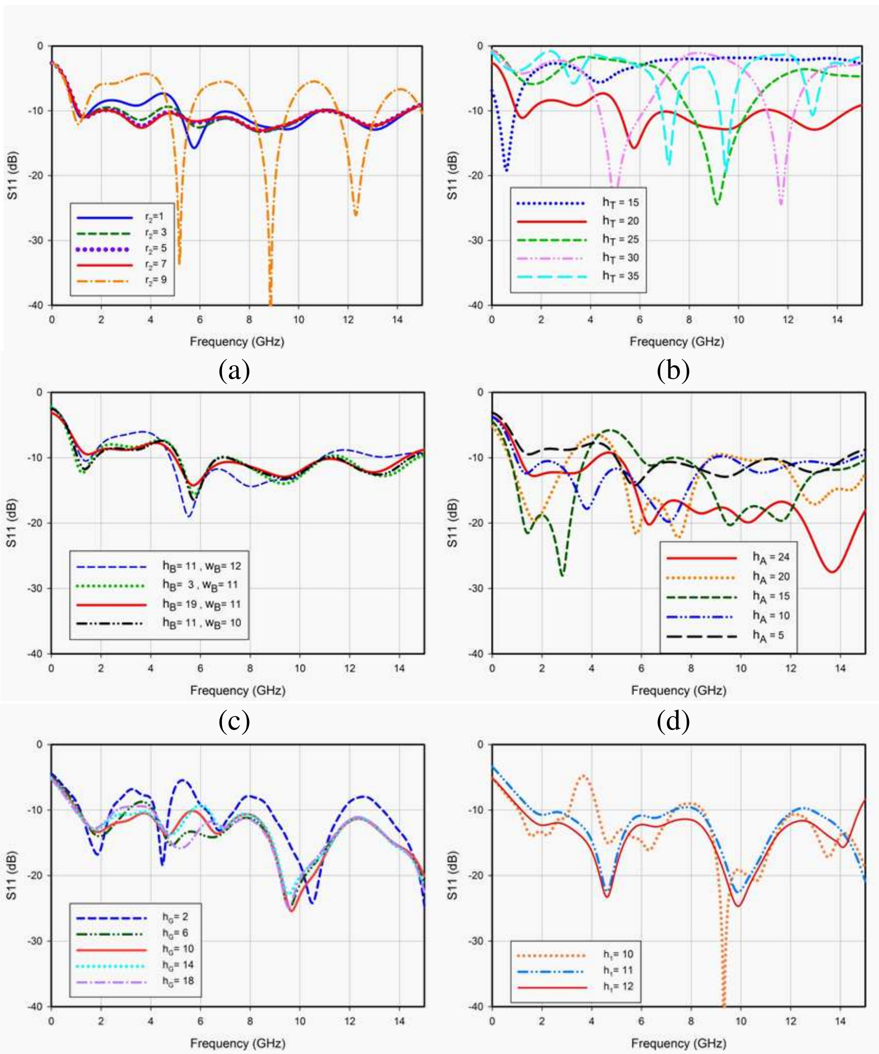
Figure 2. Comparison return loss for various shapes of proposed antenna.

Table 1. Dimensions of the proposed antenna.

Parameter	W_1	W_2	W_f	W_s	W_B	W_G	h_g	h_f	h_s
Size (mm)	1	2	2.6	22	11	5	19	20.4	41

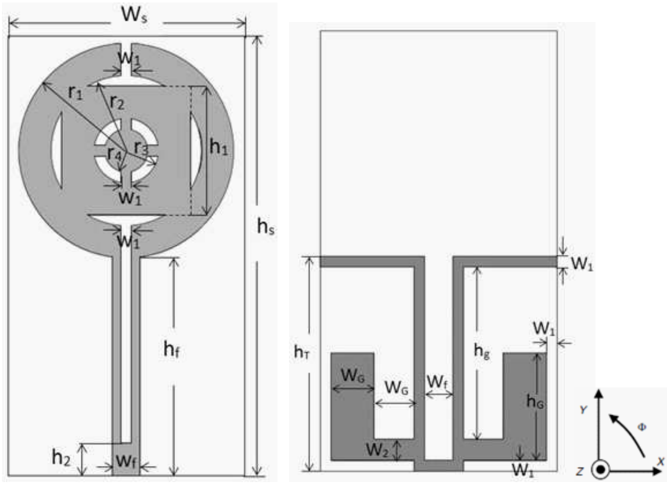
Parameter	h_A	h_B	h_G	h_T	h_1	h_2	r_1	r_2	r_3	r_4
Size (mm)	24	19	10	20	12	3	10	7	3	2

shape of the ground plane has been chosen. Using this shape not only increases impedance bandwidth to more than 122.67% but also enhances radiation pattern of the antenna. The dimensions of the antenna after optimization are tabulated in Table 1. Also the prototype of proposed antenna has been shown in Figure 5.



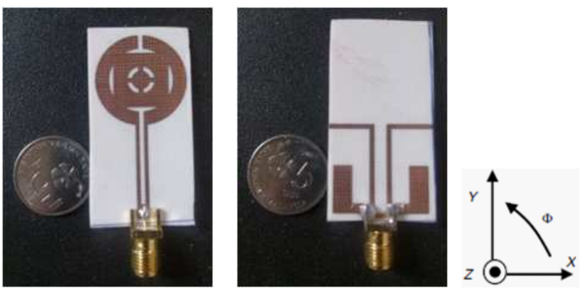
(e) (f)

Figure 3. Simulated S_{11}-parameters of proposed antenna with various numbers of (a) r_2, (b) h_T, (c) h_B, w_B, (d) h_A, (e) h_G and (f) h_1 (the solid lines show the selected value for the desired parameters).



(a) (b)

Figure 4. The geometry of the proposed antenna. (a) Front view. (b) Back view.



(a) (b)

Figure 5. Prototype of the proposed antenna: (a) Front view and (b) back view.

4. RESULTS AND DISCUSSION

The prototype of proposed antenna in Figure 5 shows satisfactory performance after measurement. Although usually one mode appears in printed antenna, in higher frequency higher order of modes will be appearing, too. It is too difficult to determine the resonance modes of the antenna using traditional ways such as impedance or Smith charts. However, the return loss curve indicates good impedance matching in some frequencies, which are regarded as the resonances of the antenna [1].

Figure 6 shows simulated and measured return loss results for proposed antenna. The results prove the Ultra-Wideband characteristics of proposed antenna. As it can be seen from the measured result, the antenna is excited between 2.9 to 12.1 GHz, and good agreement also can be noticed between simulation and measurement.

The first resonance occurs at 4 GHz, the second one at 7.5 GHz and the third one at 10.2 GHz. It has been proven that the overlapping of these resonance modes which are closely distributed across the spectrum results in an ultra-wide −10 dB bandwidth [1].

The negligible inconsistency that observes between calculated and measured resonances may have many reasons. One possible reason refers to Eq. (1), where we have to use effective dielectric constant, $\varepsilon_{\rm re}$, instead of dielectric constant ε_r.

$$f_{nm} = \frac{\chi_{nm} C}{2\pi r \sqrt{\varepsilon_{\rm re}}} \tag{7}$$

To find value of ε_{re}, we need modified outer and inner radius, r_{1e} and r_{2e}. An empirical formula for r_{1e} and r_{2e}, are:

$$r_{1e} = r_1 + \frac{3h}{4} \tag{8a}$$

$$r_{2e} = r_2 - \frac{3h}{4} \tag{8b}$$

Figure 7 shows the radiation pattern of proposed antenna. It can be observed that Fairfield is omnidirectional for H-plane like conventional monopole antennas. There are some ripples on the results that they may occur due to the alignment factor between the test and reference antennas while doing the measurement. Nevertheless, the

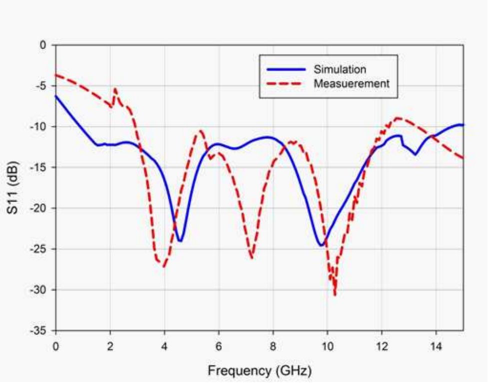
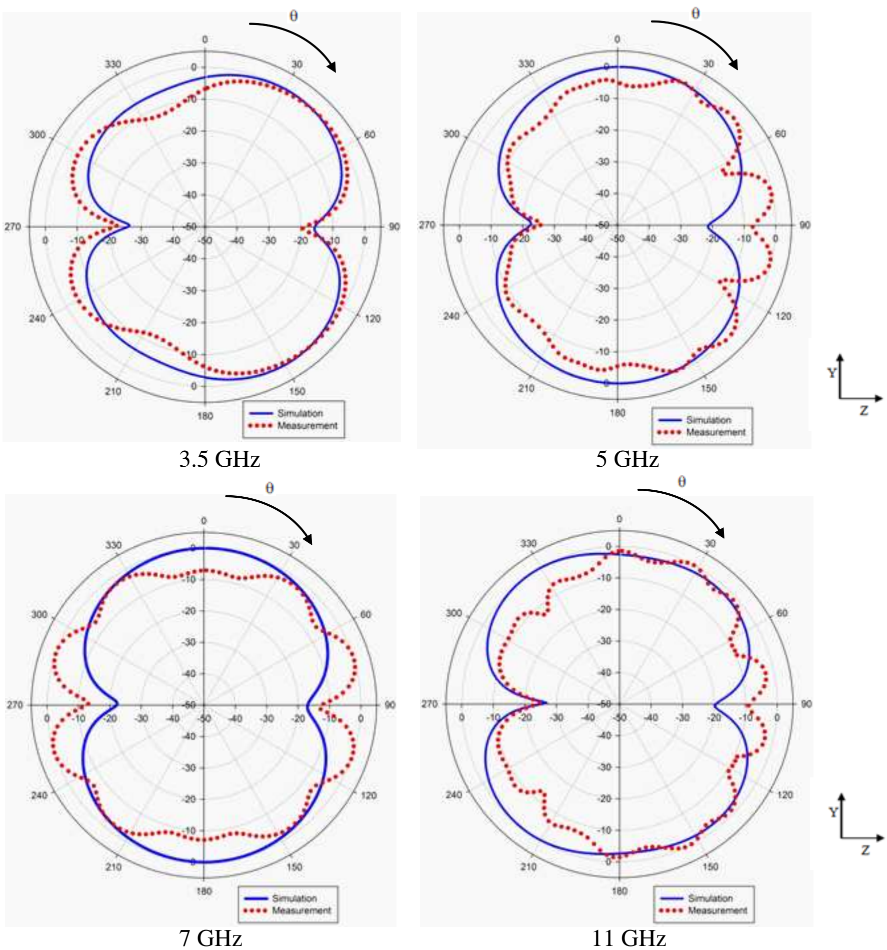


Figure 6. Simulated and measured return loss for proposed antenna.

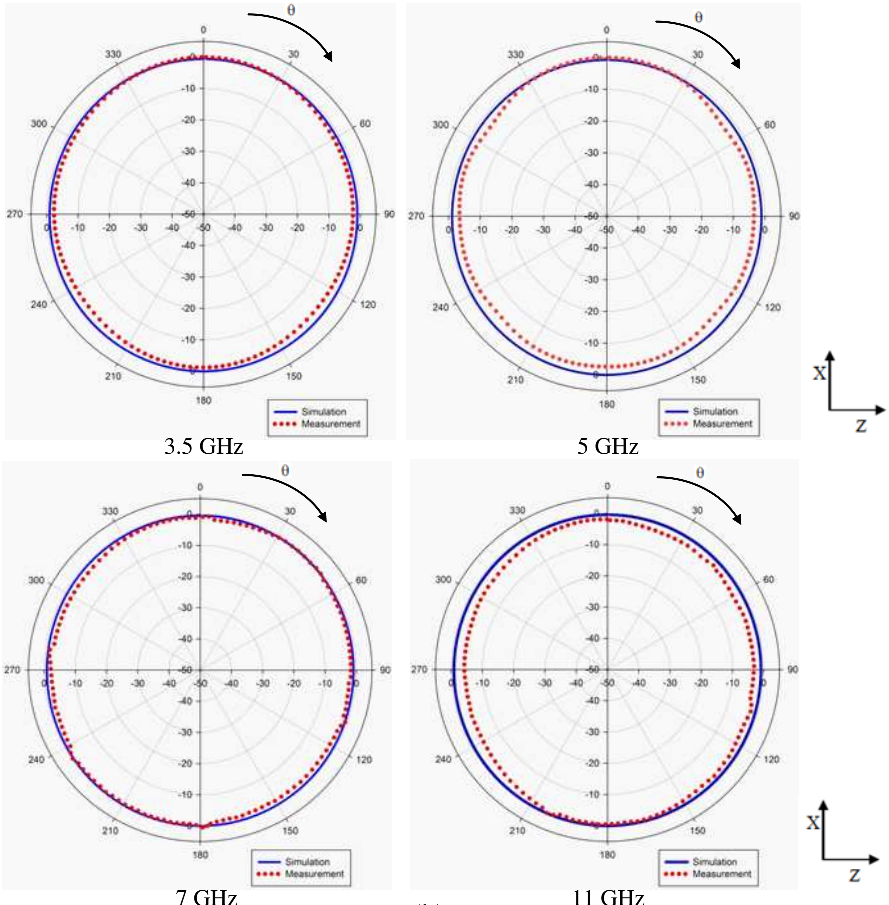
antenna main radiation (E-plane) can be said to be normal to the radiating patch.

The simulated antenna gain within the operating band has been plotted in Figure 8. It demonstrates the antenna gain ranges between 1.8 to 5.4 dBi within 2.9 to 12.1 GHz. The measured gain of the antenna is also depicted in Figure 8. The maximum gain variation is about 3.6 dBi. Also the maximum gain peak obtained from measurement is around 4.8 dBi. Figure 9 shows the group delay of proposed antenna. As it can be seen group delay is almost flat in desired bandwidth.

Since the return loss or the input impedance describes the behavior of the antenna as a lumped load at the end of feeding line, examining the field and current distributions of antenna are necessary to identify



(a)



(b)

Figure 7. Simulated and Measured radiation pattern for proposed antenna for (a) E-plane and (b) H-plane at 3.5, 5, 7 and 11 GHz.

the detailed EM behavior of the antenna. Figure 10 depicts the current distribution of proposed antenna. These current distributions confirm the fact that UWB characteristics of the antenna are achieved by overlapping of a sequence of closely spaced resonance mode.

Also regarding to the current distribution pattern in Figure 10, we can clearly perceive any intentional changes in the current path has a direct effect on the bandwidth. Selecting a logical shape on the current path (either feeder, patch or ground plane) causes to increase the antenna impedance bandwidth. The current density increases from gray to black color in Figure 10. It can be observed that the majority of current is distributed on the lower part of antenna especially in feeder

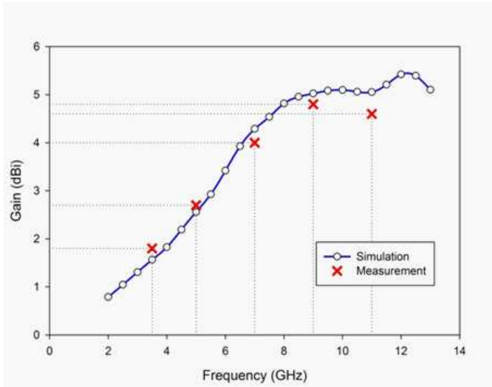


Figure 8. Simulated and measured gain of proposed antenna.

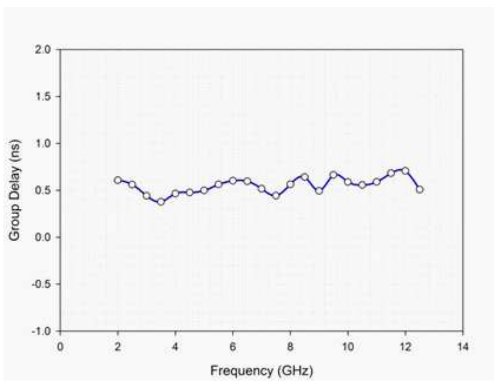


Figure 9. Measured group delay of proposed antenna.

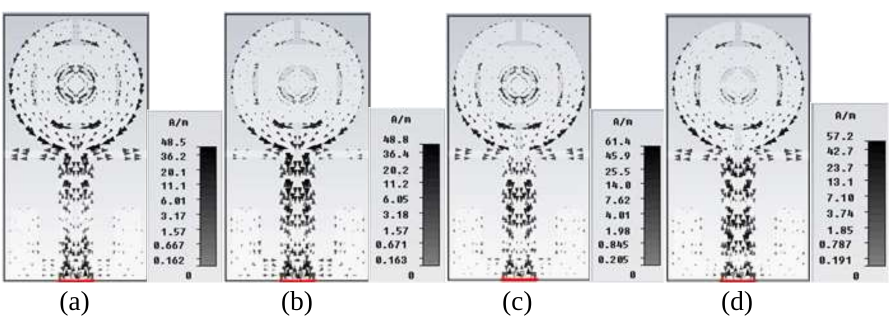


Figure 10. Current distribution of proposed antenna at (a) 3.5 GHz, (b) 5 GHz, (c) 7 GHz, and (d) 11 GHz.

line. Also we can clearly see that the slots direct current distribution to the edges of the patch.

5. CONCLUSION

A novel shape of patch antenna fed by microstrip line is presented in this paper. The proposed antenna will operate between 2.9 to 12.1 GHz frequency bands for ultra-wideband applications. The measured bandwidth is about 122.67%. A good agreement is achievedcompared with expected and measured results. Small size and low profile are two important characteristics of proposed antenna that enable the antenna to be used in devices that have space restrictions.

ACKNOWLEDGMENT

The authors wish to acknowledge the Universiti Sains Malaysia (USM) for the funding under fellowship scheme and also grant (Electroceramic for Microwave Applications, 1001/PELECT/854004, USM RUT) that enable this work to be accomplished. Furthermore especial thanks to school of Electrical and Electronics Engineering, Universiti Sains Malaysia for their helps and kindness.

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