A New High Performance Hibiscus Petal Pattern Monopole Antenna for UWB Applications

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Abstract **─** A new ultra wideband (UWB) antenna is proposed that can be efficiently used for different wireless UWB applications. The antenna structure has a very simple patch with Hibiscus petal pattern. The antenna is designed on a 31×31 mm^2 Rogers RT/duroid 5870 substrate with permittivity 2.33, loss tangent 0.0012, 1.57 mm thickness and a 50 ohm impedance microstrip fed line. Different parts of antenna are analyzed to optimize the antenna properties. The novel patch of the antenna is modified to achieve the desired wide bandwidth behavior. The simulation results show that the antenna has an impedance bandwidth of 145% from 3.2 to 20 GHz with VSWR<2, a stable omnidirectional radiation pattern, an average gain of 5.1 dBi and the average radiation efficiency is 85%, which is ideal for use in UWB applications. The proposed antenna was successfully prototyped and the measured results are consistent with simulation.

Index Terms **─** Hibiscus petal pattern, monopole antenna, UWB, VSWR.

I. INTRODUCTION

In order to cope with rapid development of wireless communication technology, the demand of high performance antennas, which capable of operating at an extremely wider frequency band like ultra-wideband (UWB), are urgently needed. UWB communication technology has been regarded as one of the most promising technologies in the wireless communication industry because of their attractive features like high speed data rate, extremely low spectral power density, high precision ranging, simple and low cost designs, robustness to multi-path fading and very low interference, since the Federal Communications Commission (FCC) has allocated 7.5 GHz of the spectrum from 3.1 GHz to 10.6 GHz for UWB radio applications from February 2002 [1]. UWB also have wide applications in short range and high speed wireless systems, such as ground penetrating radars, medical imaging system, high data rate wireless local area networks (WLAN), communication systems for military and short pulse radars for automotive even or robotics [2-5].

Some of these UWB antennas can improve the properties by changing the shape of the radiator to circular, rectangular, elliptical, heart shape etc. Furthermore, reducing the ground plane dimensions can achieve wider bandwidth [6-9]. In the study by Gokmen et al. [10], a compact size UWB antenna with heart shape using triangular patches is proposed operating from 4 GHz to 19.1 GHz with dimensions of 25×26×0.5 mm^3. Liu and Yang [11] presented a hook-shaped UWB antenna operating from 3 GHz to 10.7 GHz with a dimension of 10×10×1.6 mm^3. Furthermore, Ojaroudi et al. [12] proposed an ultra-wideband monopole antenna with inverted T-shaped notch in the ground plane, operating from 3.12 GHz to 12.73 GHz, is presented with a compact size of 12×18 mm^2. A tapered slot antenna [13] with area of 22×24 mm^2 with operating frequencies from 3 GHz to 11.2 GHz is also presented in literature. In another study [14], a heart shaped monopole antenna over a defected ground plane was proposed and optimized for ultra-wide band applications. To improve the impedance bandwidth and reduce the return losses, three semi-circular slots in the ground plane were proposed. A heart-shaped monopole patch and two rectangular ground plane on the same side of a substrate can also achieve wide bandwidth [15]. The impedance bandwidth can be achieved from 2.1 to 11.5 GHz. Most antennas presented in literature suffer from low fractional bandwidth or large size.

In this paper, a new UWB Hibiscus Petal Pattern monopole antenna with enhanced impedance bandwidth is offered. This antenna consists of a trapezoidal shape partial ground plane on the opposite side of a patch with hibiscus petal shape. The outer edge of patch is partially etched away to increase the bandwidth. Simulation and measured results shows that the proposed antenna can

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obtain the bandwidth from 3.2 to 20 GHz with evenly distributed current distribution and relatively stable omnidirectional radiation pattern and high radiation efficiency. It has a significant average peak gain. Simulated results for VSWR, gain, efficiency, radiation pattern, surface current distribution of different frequencies are presented along with the measured results. The simulation is carried out by using HFSS and CST software package.

II. ANTENNA DESIGN

The proposed Hibiscus Petal Pattern Monopole UWB antenna geometry layout is shown in Fig. 1, which is printed on a Rogers RT/duiroid 5870 substrate of thickness 1.57 mm, permittivity 2.33 and loss tangent 0.0012. The proposed antenna consists of a partial radiating patch on one side and ground plane on the other side of the substrate. Figure 1 (a) shows the front end of antenna where a hibiscus petal pattern patch is developed on the substrate. To achieve Hibiscus Petal Pattern, some parts of radiator has been etched away and a microstrip feed line printed on the same side of the substrate. The ground plane of the antenna is a trapezoidal shape as shown in Fig. 1 (b). The width of the microstrip feed line is tapered with base width of W_{f1} and upper edge width of W_{f2} with length L_f, as shown in Fig. 1. An SMA connector is soldered to the bottom of the microstrip feed line. The overall size of the antenna is W×L mm^2 and the ground plan has an area of $(W+W_g)/2 \times L_1$ mm^2. The details of the optimized design parameter are summarized in Table 1.

Figure 2 shows the effect of ground plane length on the reflection coefficient of the proposed antenna. It is clearly seen that the proposed ground plane provides wider bandwidth than full ground plane (31 mm), half ground plane (16.5 mm) and a ground plane with 5 mm. For full ground plane, the reflection coefficient is much higher than that of operating bandwidth (-10 dB) and no resonant frequency is found over the entire bandwidth. For 16.5 mm a small bandwidth 9.4-9.7 GHz) is found where S11<-10 dB and first resonant frequency is found at 9.5 GHz. For 5 mm ground plane the first resonant is found at 2.7 GHz and its starting bandwidth is remarkable. But after 3 GHz reflection coefficient is starting to rise and no other band is found where S11<-10 dB. In Fig. 3, the reflection coefficient of the proposed antenna for different values of the gap between ground and the patch is shown. For the gap 0.78 mm, 0.53 mm, 0.72 mm and 0.42 mm, the starting bandwidth is higher than that of proposed bandwidth (1.58 mm). The lower frequency bandwidth is significantly affected when the gap is altered.

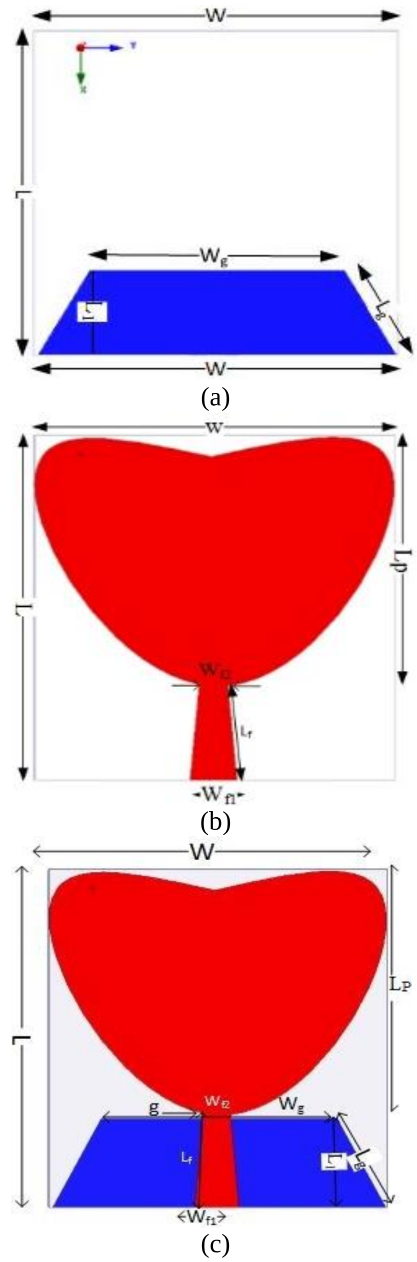


Fig. 1. The proposed antenna: (a) top layer, (b) bottom layer, and (c) both (all dimension are in mm).

Table 1: Optimized dimension of the prototype

Parameter	Value (mm)	Parameter	Value (mm)
W	31	L	31
Wf1	4	Lp	22.98
Wf2	2.43	L1	8
Lg	9.42	Lf	8.515
Wg	21.6		

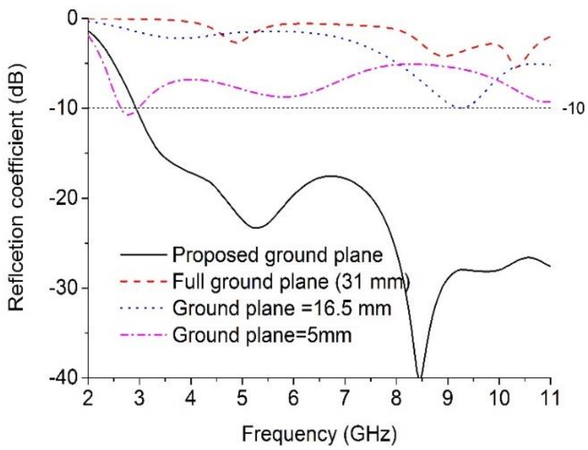


Fig. 2. Effect of ground plane length on S11 of the proposed antenna.

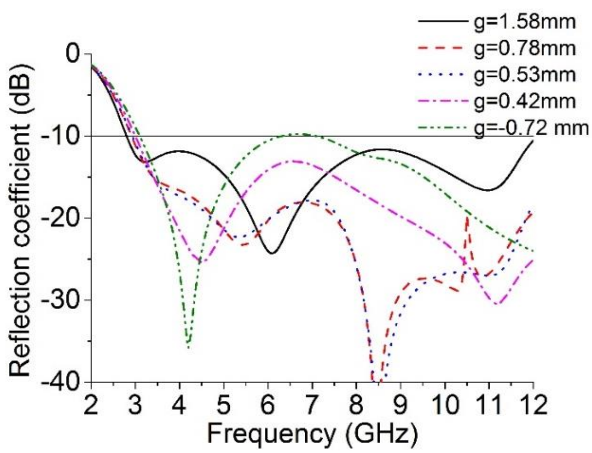
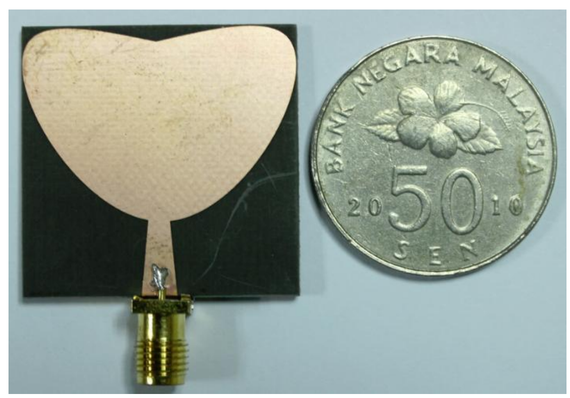


Fig. 3. Effect of gap between ground and patch on reflection coefficient.

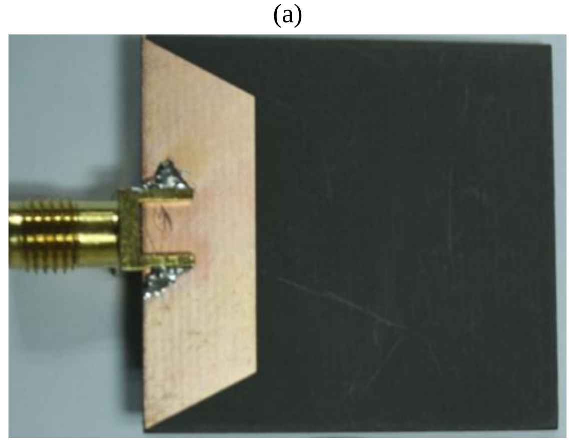
III. RESULTS AND DISCUSSION

The photographs of the proposed antenna prototype (top and bottom view) are shown in Fig. 4. The performance of the proposed antenna has been analysed and optimized using the finite element method based high frequency 3D full-wave electromagnetic simulator Ansoft's HFSS and efficient computational 3D simulation software CST for electromagnetic design and analysis. The measured results were obtained using the Agilent E8362C vector network analyzer and Satimo near field anechoic chamber (UKM StarLab). Figure 5 illustrates the simulated and experimental voltage standing wave ratio (VSWR) of the antenna. The measured bandwidth for VSWR less than 2 ranges from 3.2 GHz to 20 GHz and in simulation using CST from 2.8 GHz to 20 GHz, whereas in HFSS from 3.2 to 20 GHz. The measured and simulated results show a good agreement. The minor discrepancies between simulated and measured results can be attributed to imperfect fabrication and the coaxial cable used during measurement. The cable is not considered in simulation. Although the size of proposed antenna is small, it achieves a much wider bandwidth compared with the designs published in literature. The proposed antenna easily covers the UWB band (3.1-10.6). The gain across the operational band, simulated (HFSS) and measured, are presented in Fig. 6. The gain varies between 1 to 8.3 dBi from 2 to 20 GHz. The peak is recoded at 6.4 GHz the average gain across the operational band is 5.1 dBi. In Fig. 7, the simulation (HFSS) and measured efficiencies of proposed antenna are presented. The average radiation efficiency is 85% over the bandwidth.

The surface current distribution on the antenna at 4, 8, 12 and 18 GHz are shown in Fig. 8 and the measured radiation pattern including the cross-polarization and co-polarization of the fabricated antenna for same frequency in three principle planes *xz-plane(φ=0)*, *yz-plane(φ=90)* and *xy-plane(φ=180)* are shown in Fig. 9. At the low frequency of 4 GHz, Fig. 6 (a) shows that the current is distributed evenly. With increasing frequency, the proposed design shows that the higher order current modes are starting to develop and current density is less evenly distributed on the radiator.



(a)



(b)

Fig. 4. Photographs of the fabricated antenna: (a) top layer and (b) bottom layer.

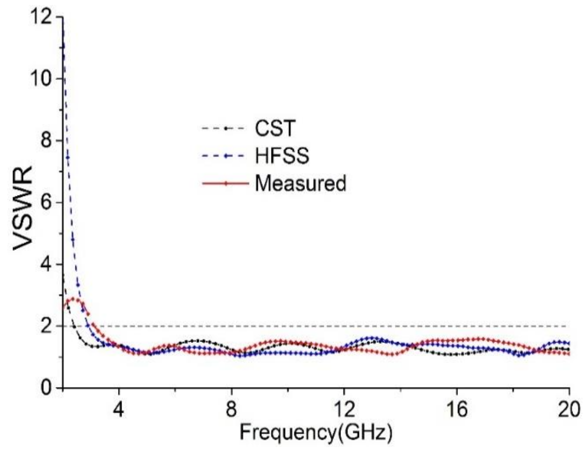


Fig. 5. Simulated and measured VSWR of the proposed antenna.

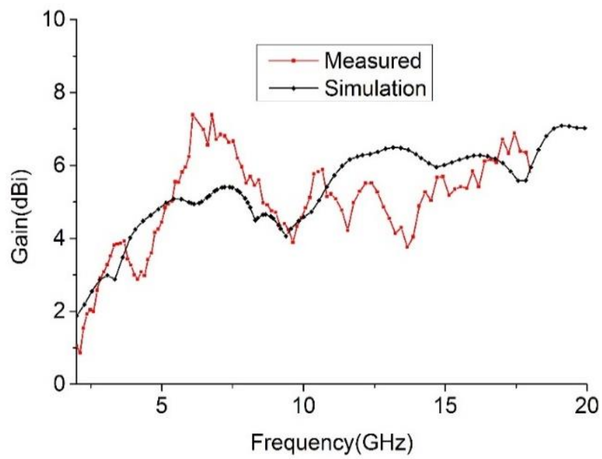


Fig. 6. Simulated and measured gain of the proposed antenna.

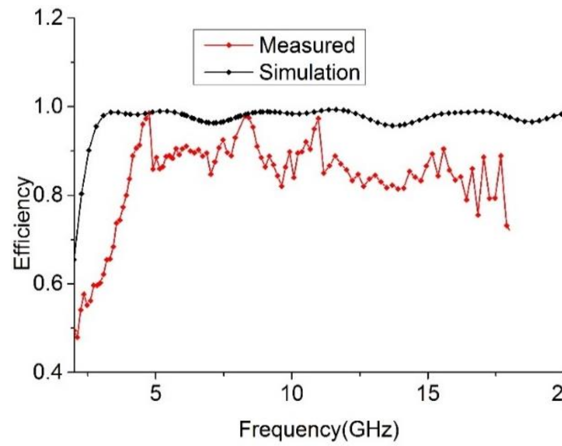
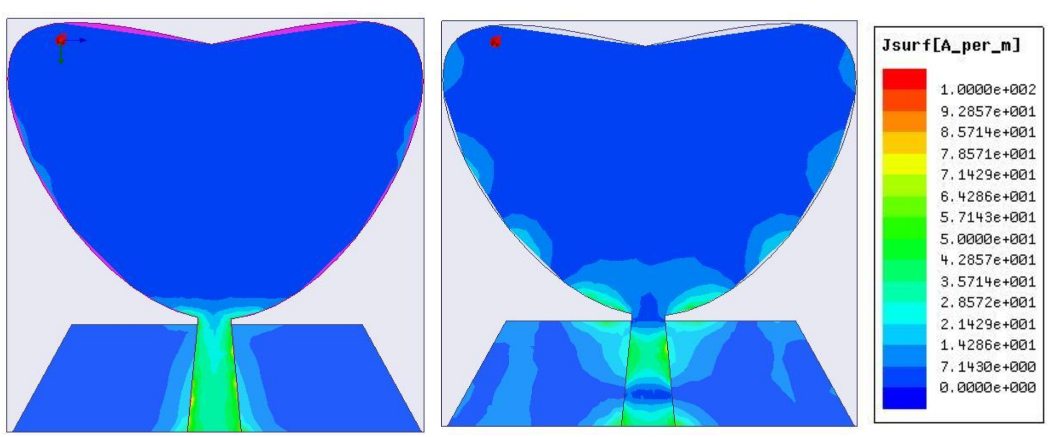
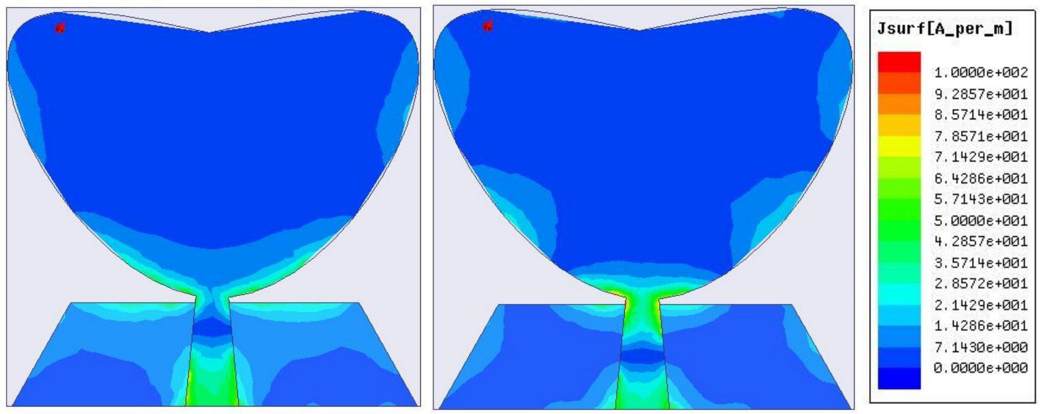


Fig. 7. Simulated and measured efficiency of the proposed antenna.

It can be seen that over the desired frequency band proposed antenna has stable radiation pattern characteristics. Based on these results of the radiation patterns of proposed antenna, it is evident that the proposed design is nearly omnidirectional for at lower frequencies. It is observed that with the increase of frequency produces undesirable cross-polarization due to the changing of surface current distribution. At higher frequency the radiation pattern become slightly directional. At the highest observed frequency in Fig. 8 (d) the higher order current modes are excited and current density is no longer distributed evenly. This results in the directional pattern seen in Fig. 9 (d). Furthermore, at higher frequencies, multiple nulls can be observed in the current distribution. This indicates that the radiating element is excited with higher order modes, which typically results in the directional radiation patterns.

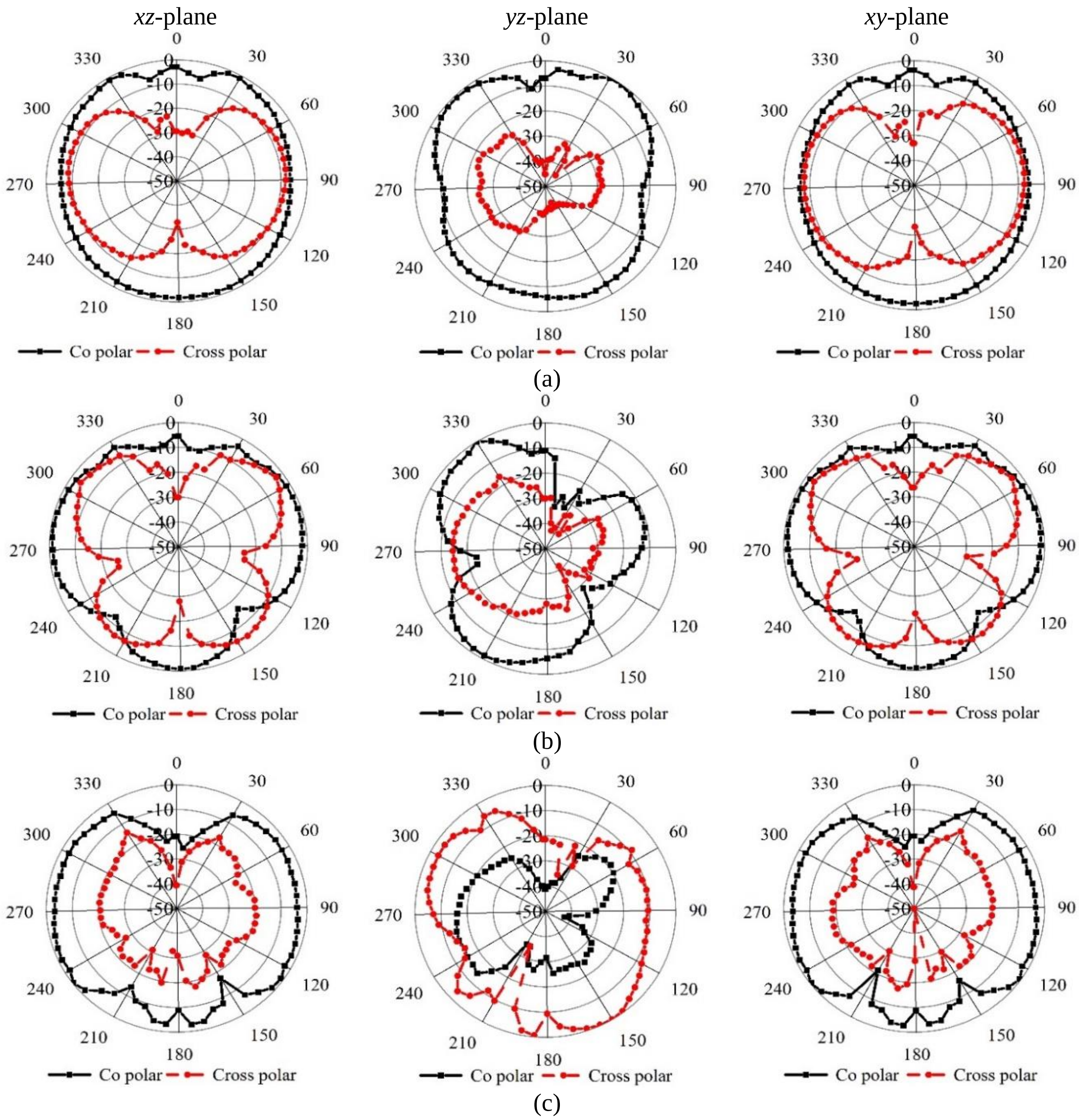


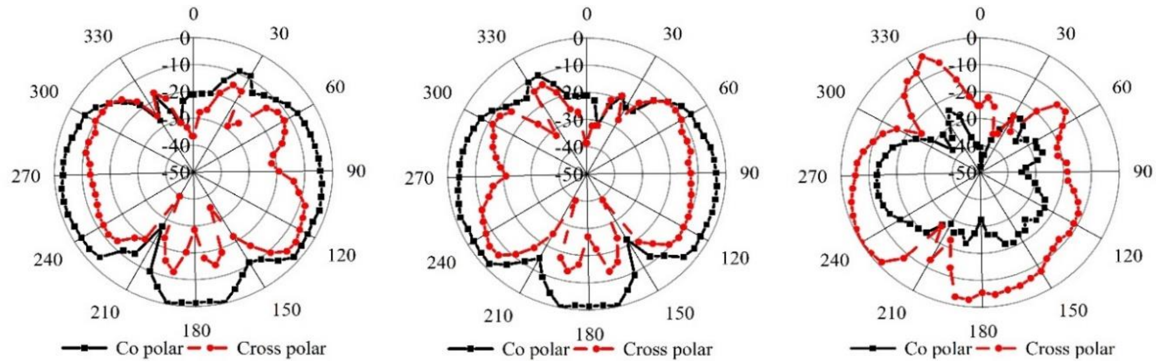
(a) (b)



(c) (d)

Fig. 8. Surface current distribution of proposed antenna at: (a) 4, (b) 8, (c) 12, and (d) 18 GHz.





(d)

Fig. 9. Measured radiation pattern of cross-polarization and co-polarization of the proposed antenna at: (a) 4 GHz, (b) 8 GHz, (c) 12 GHz, and (d) 18 GHz.

Table 2 compares the proposed UWB antenna and existing antennas. The proposed antenna and the existing antennas (literature review) were also studied to conduct an impartial comparison where all reference antennas cover ultra-wideband spectrum. The performances parameters, such as applications, 10-dB bandwidth, dielectric constant, fractional bandwidth and gain are presented in Table 2. The proposed antenna's fractional bandwidth (FBW, 145%) is better than antennas presented in literature. Therefore, the proposed UWB metamaterial antenna can offer good compact characteristics while maintaining wide operational bandwidth.

Table 2: Bandwidth, dielectric constant, fractional bandwidth and gain comparison

Reference	Application	BW (S_{11}<-10dB)	Dielectric Constant	FBW (%)	Gain (dBi)
[4]	Near field imaging	3.4-9.9	4.8	97	Not reported
[5]	Breast cancer imaging	4.4-7.7	10.2	77	Not reported
[7]	UWB application	4-14	2.2	111	2.32-4.4
[8]	UWB application	3.1-15.2	4.4	132	2.5
[9]	UWB application	3.7-18	-	132	3.97
[10]	UWB application	4-19.1	3.50	130	>1
Proposed prototype	UWB application	3.2-20	2.33	145	5.1

VI. CONCLUSION

The design of a hibiscus petal pattern monopole antenna for UWB Applications with a size of 31×31 mm^2 has been presented in this paper. Measurement result shows that the antenna has an impedance bandwidth of about 145% from 3.2 to 20 GHz with VSWR<2, a stable omnidirectional radiation pattern, an average peak gain 5.1 dBi and the radiation efficiency is about 85% over the bandwidth. The design of the proposed antenna is very simple and can be used in microwave circuitry with low manufacturing cost, easy to integrate with portable devices. Experimental results show that the proposed antenna could be good candidate for various UWB applications.

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