



## The Small UWB Monopole Antenna with Stable Omnidirectional Radiation Pattern

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**Abstract**—Ultra Wideband (UWB) technology is an unmodulated wireless digital communication system that uses an extremely short duration pulse to transmit information bit. Because of this pulse, the UWB system needs a very wide bandwidth. Federal Communication Commission (FCC) has regulated the 3.1 – 10.6 GHz frequency spectrum for UWB. Since FCC released this frequency, many research in telecommunication have been done on UWB systems. One of them is a development of an Antenna that is suitable for UWB devices. UWB antenna characteristics require FCC band, omnidirectional radiation pattern, and compact size. In order to meet these needs, an antenna with a simple structure in the form of a monopole patch antenna with a similar patch size and ground width has been designed. The antenna is built on an FR4 – epoxy substrate material, with 4.4 dielectric constant and 1.6 mm thickness. The antenna feeding structure consists of two 100  $\Omega$  and 50  $\Omega$  lines with a wideband impedance matching scheme using tapered side and tapered transformers. The antenna design and optimization processes are conducted using electromagnetic simulation software, and measurements are carried out in an anechoic chamber. Simulation and measurement results show good agreement, and the antenna can work at frequencies 3.5 - 11.3 GHz with a gain of 1.5 – 3.25 dBi and stable omnidirectional radiation patterns. The antenna has dimensions of 27 × 8 × 1.6 mm, which are smaller than the antenna reported in the last research and suitable to be applied on various UWB devices.

**Keywords**— UWB antenna; tapered side; tapered transformer; omnidirectional.

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### I. INTRODUCTION

The development of wireless communication technology has a huge impact on our daily lives. It can be seen in the increasing interest in and use of wireless technology. The high demand for high capacity, fast service, and secure connections result in a scarcity of radio frequency spectrum [1]. This is because every radio technology occupies a portion of the band on the frequency spectrum and does not interfere with the others. The Internet of things, one of the current development issues, requires wireless technology that can overcome the constraints of the scarcity of frequency and large data capacity. Ultra-wideband (UWB) technology offers a solution for frequency spectrum scarcity and enables coexistence with current radio systems with minimal or no interference[2].

The UWB technology is wireless without a carrier that uses very narrow pulses to communicate between the transmitter and receiver. This system requires exceptionally low power;

meanwhile, applying the pulses with very narrow duration results in the need for very wide bandwidth. Therefore the Federal Communication Commission in America regulates the use of UWB frequencies which eventually are used as global standards in the 3.1 - 10.6 GHz band [3]. Low power allows this system to work without interfering with other communication systems in the 3.1 - 10.6 GHz band.

Since the FCC regulates bands for UWB applications, few research have been done on the design and implementation of UWB. The antenna is one of the important devices in this technology. The antenna designs vary depending on the needs and applications, especially for mobile handheld devices, which need an antenna with a small size and omnidirectional pattern. Three antennas often used in commercial devices are microstrip, slot, and dielectric resonator antennas [1]. An antenna usually develops an antenna design with a small size and an omnidirectional radiation pattern in the form of a printed monopole structure. The configurable antenna is also required for the UWB antenna design [4], [5].

In recent literature, many antennas have been made for UWB applications. For example, the antenna design with Tilted Annular-shaped Printed Line (TAPL) structure, magnetic transfer (TM<sub>11</sub>, TM<sub>12</sub>, and half wave dipole mode), and proposed cylindrical Dielectric Resonator Antenna (DRA) [1]. Pentagon-shaped planar monopole antenna with a pyramid-shaped reflector [6]. The circular monopole antenna, which adds a split ring resonator (SRR) [7], [8] and a biconical antenna [9] Wrapped bowtie [10], array structure [11], adding frequency selective surface [12], metamaterial loaded [13], and Magneto Electric Monopole (MEM)[14]. Previous studies produce antennas with UWB characteristics, but the antenna becomes thicker due to dielectrics, pyramid reflectors, SRR, Array Structure, FSS, metamaterial loaded MEM, and biconical forms.

The circular monopole antenna as on [5], [15]–[18] can produce the Antenna with UWB characteristics, but by adding the SRR, L-shape stub, and annular ring, the antenna structure will contribute to the design complexity of the antenna. Meanwhile, the antenna with a rectangular patch structure [5], [19]–[24], which is designed to have UWB characteristic, generally still have an antenna structure with that relatively large dimension.

In this research, we propose the monopole antenna design consisting of a basic rectangular shape and a smaller antenna structure size than the previous works. The characteristics of UWB are obtained using a combination of tapered side connection [25], [26] and linear tapered side transformer [27], so the antenna design is simpler than the antennas that have been reported in the literature. The antenna design process is carried out using electromagnetic simulation software, where the antenna structure can be designed, simulated, and optimized by conducting a parametric study of the antenna structure.

## II. MATERIAL AND METHOD

In this section, we present the design methodology of the UWB antenna. The antenna is designed using a conventional patch antenna design, and the feed line is a microstrip line which is then designed to be an antenna with UWB characteristics. There are some basic formulas for designing patch antennas with microstrip lines, and particular antenna design steps are needed to obtain the UWB characteristics.

### A. Patch Antenna Design

A patch antenna has a substrate, the thickness  $h$ , and a certain dielectric constant  $\epsilon_r$ . The antenna can be designed using the formula and procedures [28]. For the dielectric constant of the substrate  $\epsilon_r$ , the thickness ( $h$ ), and the resonance frequency ( $f_r$ ), then the patch width  $W$  and patch length  $L$  can be calculated as follows [28].

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}\epsilon_r} \sqrt{\frac{2}{\epsilon_r+1}} = \frac{v_0}{2f_r} \sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}\mu_0\epsilon_0}} - 2\Delta L \quad (2)$$

where:

$$\epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{W}\right]^{-1/2} \quad (3)$$

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{\text{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{\text{reff}}+0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

### B. Microstrip Line Design

The most common ways to feed the patch antenna use a microstrip line, coaxial probe, aperture coupling, and proximity coupling [28]. In this work, the microstrip line is chosen because the design is simple and does not change the thickness of the antenna. Furthermore, for designing a microstrip line with conductor width  $W$ , substrate thickness  $d$ , and relative permittivity  $\epsilon_r$ , use the following formulas [29]:

$$\epsilon_e = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \frac{1}{\sqrt{1+12d/W}} \quad (5)$$

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) & \text{for } \frac{W}{d} \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_e}\left[W/d + 1.393 + 0.667\ln\left(\frac{W}{d} + 1.444\right)\right]} & \text{for } \frac{W}{d} \geq 1 \end{cases} \quad (6)$$

$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A-2}} & \text{for } \frac{W}{d} < 1 \\ \frac{2}{\pi} \left[ B - 1 - \ln(2B-1) + \frac{\epsilon_r-1}{2\epsilon_r} \left\{ \ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] & \text{for } \frac{W}{d} > 1 \end{cases} \quad (7)$$

and:

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1} \left(0.23 + \frac{0.11}{\epsilon_r}\right) \quad (8)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

Where  $\epsilon_e$  = effective dielectric is constant,  $Z_0$  = characteristic impedance.

### C. UWB Antenna Design

The antenna design uses electromagnetic simulator software. FR4 was chosen as the substrate with consideration due to the low price having a thickness 1.6mm and a dielectric constant ( $\epsilon_r$ ) 4.4. The antenna geometry is shown in Fig. 1, which consists of a patch with the length  $L$  and the width  $W$ . Two microstrip lines feed the antenna with the impedance of 50  $\Omega$  and 100  $\Omega$  as on [27]. Both lines are connected by the linear tapered transformer  $T$ . The 100  $\Omega$  line is connected to the patch using the tapered side. The ground part of the antenna utilizes the partial ground plane structure.

The antenna design is initiated by using the equation (1) – (4) to calculate  $W$  and  $L$ ; meanwhile, calculating the length and the width of the microstrip line uses the equation (5) – (8). Furthermore, all the results of the length and width for the patch and the microstrip line are simulated and optimized to have the UWB antenna characteristic have the minimum size. The substrate width and length of the antenna is chosen on a similar size to the patch width and length to have minimum antenna dimension.

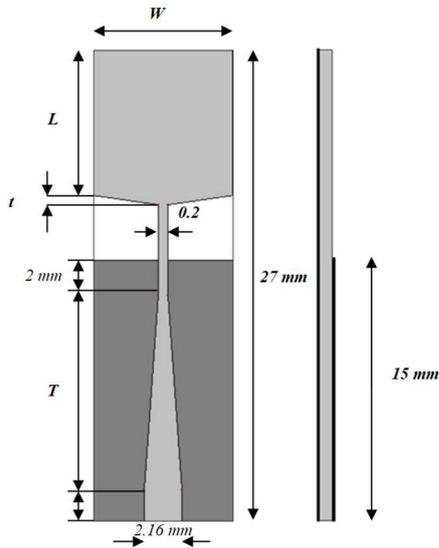


Fig. 1 The geometry of the antenna structure

The antenna design uses a conventional patch structure [28], which produces a narrow band frequency response. The patch antenna is then modified to a monopole patch structure for a broadband response by cutting the ground part and obtaining the partial ground plane. The broadband impedance matching can be achieved by adjusting the partial ground plane, the linear transformer  $T$ , and the tapered side connection. The antenna design's optimum dimension is shown in Fig. 1. The figure shows the patch part of the antenna with the length  $L$  and width  $W$ . Meanwhile,  $t$  is the length of the tapered transformer. The patch is connected by a tapered feed line which has a width 0.2 mm on the top and gradually widened to 2.16 mm on the bottom. In total, the patch and feed line have a length of 27 mm. The antenna's ground plane is the dark grey part on the back of the feed line. The side view of the design is on the right part of the figure. The patch dimension after optimization is  $27 \times 8 \times 1.6$  mm. Meanwhile, the ground plane dimension is  $15 \times 8 \times 1.6$  mm. The structure uses the same width of patch and ground plane.

### III. RESULT AND DISCUSSION

#### A. Parametric Study

The parametric study is carried out by adjusting one of the Antenna dimensions in Fig. 1 while keeping other dimensions constant and then simulating it to have the optimal design. Some antenna characteristics are observed continuously, i.e., return loss, radiation pattern, gain, and VSWR (*Voltage Standing Wave Ratio*). As explained in the previous section, the antenna design is initiated using equations (1) – (4) to have the conventional patch antenna with a unidirectional radiation pattern. The FR4 substrate with a thickness 1.6 mm and dielectric constant 4.4 is applied to these equations to have  $L = 11$  mm and  $W = 8$  mm. Fig. 2 shows the antenna return loss ( $S_{11}$ ) when using this size. This initial result has a narrow-band response.

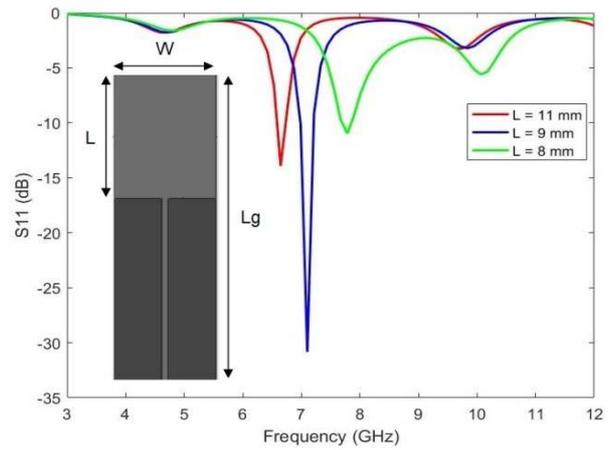


Fig. 2 The return loss of the initial design of the antenna for different lengths of  $L$

There are three antenna lengths ( $L$ ) have been studied in this design, i.e., 8, 9, and 11 mm. The length of  $L = 8$  mm is chosen to have a smaller size antenna, and then the frequency response with the center frequency between 3 – 12 GHz. The next target is adjusting the antenna frequency response according to the need of UWB, i.e., in the range of 3.1 – 10.6 GHz.

After this initial design, a parametric study is conducted on the ground plane area by adjusting the length of a ground plane while keeping the substrate width constant. The simulation result for this setting is shown in Fig. 3. The wider bandwidth can be obtained by adjusting the length of the antenna ground plane from 30 mm to 15 mm, even though the return loss is not so good (below 10 dB). Meanwhile, the figure also shows that reducing the length of the antenna ground plane below 15 mm will result in a narrow bandwidth frequency response and shift the resonance frequency.

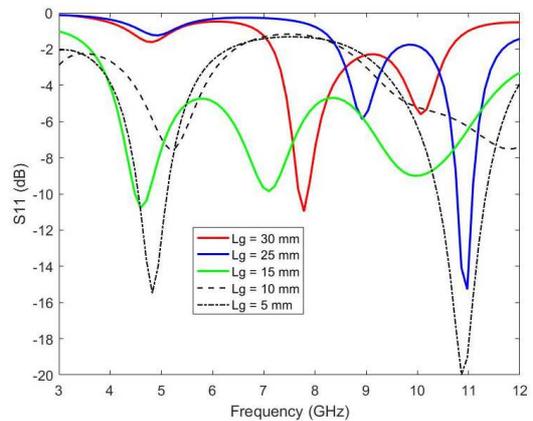


Fig. 3 The return loss of the initial design of the antenna for different lengths of  $L_g$

The ground plane size reduction also affects the antenna radiation pattern as Fig. 4 shows the three-dimensional pattern toward some changes in ground plane size, i.e., for  $L_g$  is equal to 30 mm, 25 mm, 20 mm, 15 mm, and 10 mm. The red patterns indicate the maximum radiation of the antenna. The figure shows that increasing the patch area will enlarge the size of the minor antenna lobe. The simulations also denote that reducing the patch area, which is covered by the ground plane, will transform the antenna radiation pattern from unidirectional to omnidirectional. Fig. 4 also shows that the

ground plane length at 15 mm yields the maximum radiation and omnidirectional radiation pattern, meeting the need for a UWB antenna. Therefore, using this length of ground plane size ( $L_g = 15$  mm), the impedance matching will be carried out between the antenna and the feed line to have broadband impedance matching. The main part of the impedance matching procedure is adding the tapered side and tapered transformer on the feed line.

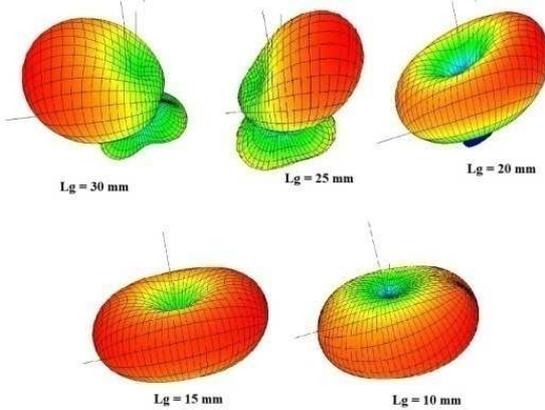


Fig.4 The antenna radiation pattern for different lengths of  $L_g$

The simulation result after adding the tapered side and transformer is shown in Fig.5, where there are three conditions of the antenna feed line, i.e., without tapered, with tapered side, and using both tapered side and transformer.

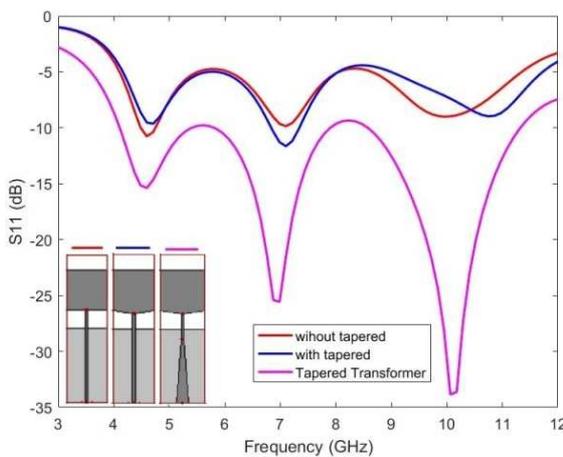


Fig. 5 The antenna return loss for different tapered techniques

The design with a tapered side and tapered transformer contribute more to impedance matching of the antenna, which gives good return loss with wider bandwidth and maximum level at -34 dB. Furthermore, smooth impedance matching can be made by adjusting the tapered side and tapered transformers where the target matches the impedance of the patch antenna to the  $100 \Omega$  and  $50 \Omega$  lines. The simulation results are shown in Fig.6, which give good return loss with wide bandwidth and maximum level at -40 dB.

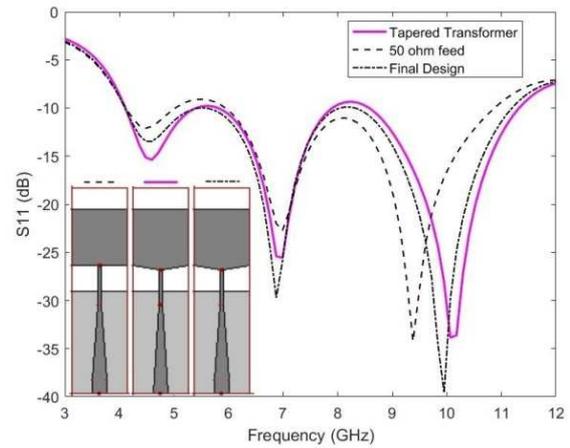


Fig. 6 Tuning the impedance matching of the antenna

In order to reduce the antenna dimensions, the antenna substrate is cut at the top of the patch, as shown in Fig.7. According to the figure, this cut does not affect the antenna frequency response significantly. Thus, the result of this parametric study is the antenna structure with the optimum design and best dimension with the geometry, as shown in Fig.1.

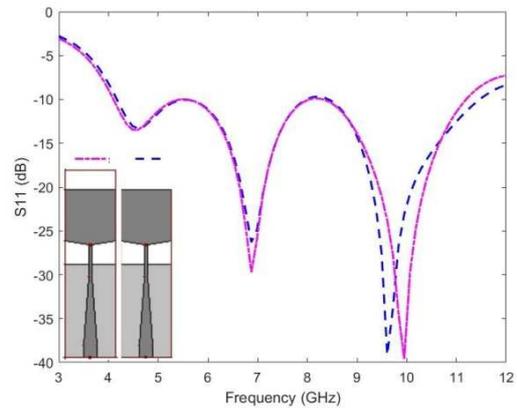


Fig. 7 Antenna substrate cutting

### B. Antenna Measurement

The antenna design process through parametric studies has obtained an antenna with optimal dimensions for UWB operating frequency. The next step is validating the simulation result by measuring the fabricated antenna in the laboratory. The antenna is fabricated on the substrate material FR4 with a thickness 1.6 mm and a dielectric constant 4.4 using the dimension which is based on the optimization results. The physical realization of the antenna after fabrication is shown in Fig. 8, which has the dimension of  $27 \times 8 \times 1.6$  mm.



Fig. 8 Manufactured Antenna

The antenna return loss measurement is performed using the devices shown in Fig. 9. The Vector Network Analyzer (VNA) Keysight E5071C is shown at the bottom left of the figure. Meanwhile, radiation pattern, gain, and VSWR measurement is carried on the anechoic chamber where the transmitting antenna is shown at the upper right and the receiving antenna (this work) at the bottom left of the figure.

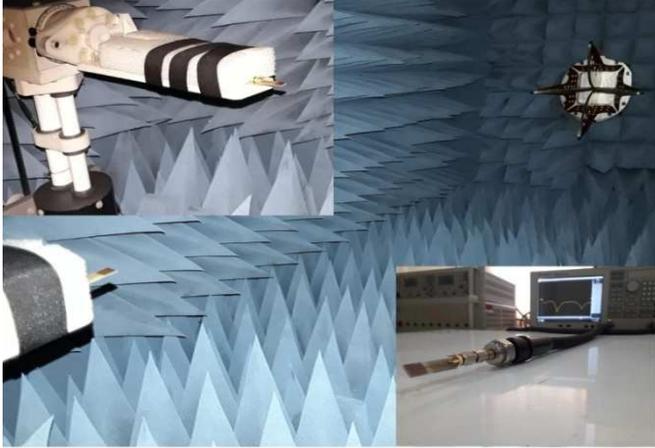


Fig. 9 Measurement devices

Fig. 10 shows the return loss of the antenna for both simulation and measurement results. According to this measurement result, the antenna bandwidth is obtained in the 3.5 – 10.8 GHz range. The figure shows good agreement between the measurement result and simulation results. The discrepancy occurs possibly because of the presence of a soldering part to join the SMA connector and the antenna. The fabrication inaccuracy in transferring antenna size from the simulation process is another possibility of causing the discrepancy.

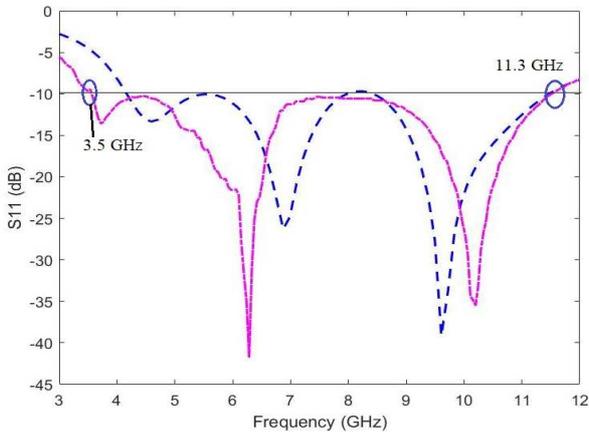


Fig. 10 Return loss of the antenna for simulation and measurement

The measurement result of the antenna radiation pattern is shown in Fig. 11. The pattern is measured for the frequencies of 4 (Fig.11a), 6 (Fig.11b), 8 (Fig.11c) dan 10 GHz (Fig.11d), which represents the UWB operating frequencies. The figures also show the antenna's horizontal radiation pattern, which has an omnidirectional radiation pattern at an average level of -5 dBm for all of the measurement frequencies. The cross-polarization is mainly on a quite low level except for some increments at higher frequencies. The vertical radiation

pattern of the antenna indicated that the antenna is identical to the monopole antenna radiation pattern. Furthermore, antenna gain is 1.2 - 4.5 dBi on the antenna working frequency band. This low gain is due to the very small antenna size.

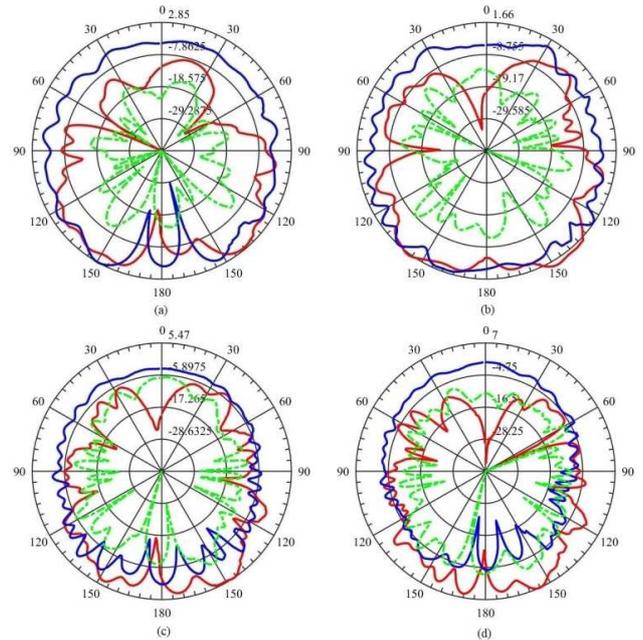


Fig. 11 Antenna radiation pattern measurement results. (a) 4 GHz, (b) 6 GHz, (c) 8 GHz, (d). 10 GHz. ( Blue = x - y plane, red = x - z pattern, green = cross polar)

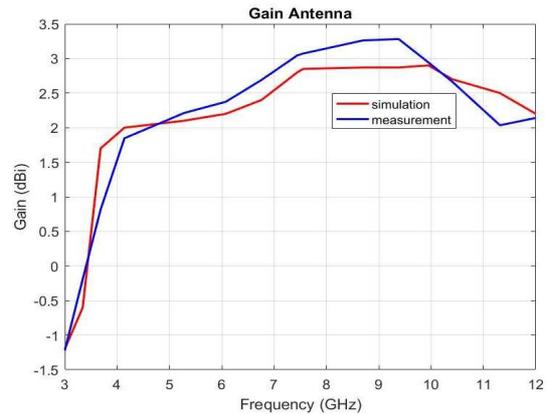


Fig. 12 Gain of proposed Antenna

TABLE I  
COMPARISON OF THIS ANTENNA WITH OTHER DESIGNS

Ref.	Dimension (mm)	Footprint (mm <sup>2</sup> )	Freq. Range (GHz)
[9]	40 × 40 × 12	1600	3 – 11.8
[30]	45 × 54 × 1.52	2430	3.1 – 10.6
[7]	50 × 50 × 1.575	2500	2.6 – 10.8
[17]	24 × 28 × 1.6	672	2.1 – 11.4
[31]	15.8 × 22 × 0.78	348	3.1 – 10.6
[16]	35 × 35 × 0.65	864	3.1 – 11.5
[21]	12 × 22 × 1.6	264	3.1 – 10.6
This work	8 × 27 × 1.6	216	3.5 – 10.6

Table I compares the antenna size in this study with some antennas in previous studies. The maximum footprint area is 2500 mm<sup>2</sup> [7]. The table also shows that the antenna of this

design has the smallest size with a footprint area of 216 mm<sup>2</sup> which is suitable for various UWB devices application.

#### IV. CONCLUSIONS

The UWB antenna design, which has a simple design and small size, has been presented. The small antenna with a dimension of 27×8×1.6 mm is suitable for various UWB communication devices. The antenna with tapered transformer and tapered side feeding point has been studied and discussed where it can improve the antenna bandwidth proper for the UWB system. The antenna has a bandwidth of 4.4–10.8 GHz and radiates the stable omnidirectional radiation pattern on UWB band. The research has met the main target where the antenna size is smaller than the latest literature, meets the UWB bandwidth, and has a stable radiation pattern. This antenna design can be developed in the future to get the lowest bandwidth according to FCC requirements on 3.1–10.8 GHz.

#### ACKNOWLEDGMENT

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