Design of Microstrip Patch Antenna Using Slotted Partial Ground And Addition Of Stairs And Stubs For UWB Application

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***Abstract*—This paper presents the design with optimum geometry of a novel UWB rectangular patch antenna. A simple narrowband patch antenna is designed before proceeding to the geometry of UWB antenna. A special configuration of patch antenna with slotted partial ground and addition of stairs and stubs was designed and optimized using CST Microwave Studio (CSTMWS). The designed antenna was fabricated, tested and compared with the simulation results. The proposed antenna's characteristics were investigated with various options and found to operate satisfactorily. A remarkable improvement has been noticed in this design. Moreover, the antennas structure offers great advantages due to its simple designs and small dimensions.**

***Index Terms*— ultra wideband antenna, microstrip patch antenna**

I. Introduction

THE development of ultra wideband antennas in the recent years has played an essential role to justify the needs of high bandwidth and capacity demands over a wide frequency spectrum in the current wireless communication system structure. Ultra wideband can be used in the wireless communication as a solution for current higher bandwidth demand amongst the users. In specific, by producing ultra wideband antenna, it will produce a high bandwidth, and correspondingly will have the higher data rate for short distance application.

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The word 'ultra-wideband' (UWB) commonly refers to signals or systems that either have a large relative or a large absolute bandwidth [1]. The ultra wideband system covers the frequency range from 3.1 to 10.6 GHz, which based on narrow pulses to transmit data at extremely low power [2]. With such large bandwidth, it offers specific advantages to the communication technologies especially in term capacity of channels, data transfer rate and so on.

Fundamentally, from the Shannon-Hartley theorem, the ultra wideband provides high data rates using very low power at very limited range, which will lead to the applications well suited for wireless personal area network (WPAN). These advantages provide the high data rate for short distance electronic devices. For example; electronics consumers like digital cameras, video cameras, MP3 players, televisions, personal video recorders, automobiles and DVD players will experience high data rate in home and for their personal entertainment.

Secondly, sensors of all types also offer an opportunity for ultra wideband to flourish [3]. The key requirements for sensor networks include low cost, low power and multi-functionality which can be well met by using ultra wideband technology. High data rate ultra wideband systems are capable of gathering and disseminating or exchanging a vast quantity of sensory data in a timely manner. The cost of installation and maintenance can drop significantly by using ultra wideband sensor networks due to being free from wires. This advantage is especially attractive in medical applications because ultra wideband sensor network frees the patient from wires and cables when extensive medical monitoring is required. In addition, with a wireless solution, the coverage can be expanded more easily and made more reliable.

Positioning and tracking is another unique property of ultra wideband. Since ultra wideband has the high data rate characteristic in short range, ultra wideband provides an excellent solution for indoor location with a much higher degree of accuracy than a Global Positioning Systems (GPS). In addition, with advanced tracking mechanism, the precise determination of the tracking of moving objects within an indoor environment can be achieved with an accuracy of several centimeters [3]. Ultra wideband systems can operate in complex situations to yield faster and more effective communication between people. It can be used to find people or objects in a case of calamities, such as casualties in children lost in the mall, lost people in natural disaster such as earthquake, fire fighters in a burning building and so on.

Lastly, ultra wideband can also be applied to radar and imaging applications. It has been used in military applications to locate enemy objects behind walls and around corners in the battlefield. It has also found value in commercial use, such as rescue work where ultra wideband radar could detect a person's breath beneath rubble, or medical diagnostics where X-ray systems may be less desirable.

There are many types of antenna that can be applied in order to achieve the ultra wideband, however in this project, we focusing on the microstrip patch antenna. Microstrip patch antenna becomes very popular in any antenna design nowadays since its ease of fabrication, planar design, mechanical reliability and mass production [4, 5,10]. The advantages of microstrip antennas are that they are low-cost, conformable, lightweight and low profile, while both linear and circular polarization is easily achieved. These attributes are desirable when considering antennas for wireless system. [5]

Several techniques have been proposed in past few years. The increment of the bandwidth can be achieved by using the partial grounding and adding stairs in the microstrip patch antenna. All the researchers have come out with their proposal that by using the partial grounding, the bandwidth increased in certain amounts which is average of 3-4GHz. In this paper, an additional technique was introduced as slotted partial grond and addition of stairs and stubs. New approach has been analyzed, design and simulated. Fabrication and test was also done to validate the design.

II. Rectangular Microstrip Patch Antenna

The rectangular and circular patches are the basic and most commonly used microstrip antennas. Moreover, Patch antenna are popular for their well known attractive features, such as low profile, light weight and compatibility with Microwave Integrated Circuit (MIC) and Monolithic Microwave Integrated Circuit (MMIC) [6]. A microstrip patch antenna consists of a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on other side.

Before designing a rectangular microstrip patch antenna, there are several parameters need to be considered which will affect the antenna bandwidth as well as the resonant frequency.

A. Patch Length & Width

The shape of the patch is its main parameter and naturally affects most of the antenna characteristics. However, the patch width has a minor effect on the resonant frequency and radiation pattern of the antenna. So a larger patch width increases the power radiated and thus gives decreased resonant resistance, increased bandwidth, and increased radiation efficiency. The patch width should be selected to obtain good radiation efficiency if real state requirements or grating lobe are not overriding factors. It has been suggested for patch dimension that 1 < W/L < 2. [7]. The patch length determines the resonant frequency, and it is critical parameter in the design, however the patch length L for TM10 mode is given by:

$$L = \frac{C}{2 f_r \sqrt{\varepsilon_r}} \quad \text{.................................(1)}$$

Where; f_r is the resonant frequency.

B. Directivity & Gain

The directivity is a measure of the directional property of an antenna compared to those of an isotropic antenna. The directivity is defined as the ratio of the maximum power density in the main beam to the average radiated power density [4]. A simple approximation for the directivity of a rectangular patch is given as:

$$D \approx \frac{4(k_0 W)^2}{\pi \eta_0 G_r} \quad \text{..................................(2)}$$

where: Gr is the radiation conductance of the patch and η_0 is the instintic constant of the space.

The directive gain of the antenna is defined as :

$$G = kD \quad \text{...(3)}$$

where; k is the radiation efficiency of the antenna.
Gain is always less than directivity because k lies in the range $0 < k < 1$.

C. Feed point location

After the patch dimension L and W for a given substrate, the next task is to determine the feed point (x_0, y_0) so as to obtain a good impedance match between the generator impedance and input impedance of the patch element. However, the feed point can be selected anywhere along the patch width but it better to choose y_0 = W/2 if W > L. Moreover, an expression for x_f which is (4):

$$x_f = \frac{L}{2\sqrt{\varepsilon_{re}(L)}} \quad \text{..(4)}$$

where; $\varepsilon_{re}(L) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\left(\frac{W}{L}\right)$ .... (5)

D. Effect of finite size ground plane

It has been assumed in the previous analysis of the microstip patch antenna that the size of ground plane is infinite. In actual usage only a finite size ground plane can be implemented. However, finite ground plane resulting in changes in radiation pattern, radiation conductance, and resonant frequency. Experimentally it was found that for a patch antenna with the ground plane size equal to the patch metallization , the resonant frequency is higher compared to that of an infinitely sized ground plane antenna. [4][5][8]

E. Fringing Effect

For a moderate permittivity substrate such as ε_r=2.2 the directivity is about 6.1(7.8dB) when the substrate is thin. For high permittivity substrate such as ε_r = 10.8 the directivity is about 3.5 (5.4 dB) when the substrate is thin [9].

Fringing effect as shown in Figure 1(b) occurs at the edges of the patch as the length and width of the patch are finite. It is a function of the dimensions of the patch and the height of the substrate. For microstrip antennas, this happens to be so but fringing effects must still take into account as it affects the resonant frequency of the antenna. The transmission line model introduces the effective dielectric constant, ε_{reff}, which consider the fringing and the wave propagation in the line which occurs due to the propagation of some of the waves in the substrate and some in air (as shown in Figure 1 b). Generally, the effective dielectric constant has the range between 1 and εr.

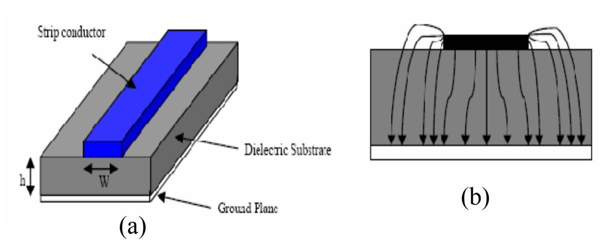

Figure 1: (a) Microstrip line and (b) Electric field lines[9].

To account for the fringing effect, an effective dielectric constant εerff is used. The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that;

For $\frac{W}{h} \geq 1$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \quad \text{............(6)}$$

For $\frac{W}{h} \leq 1$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} + 0.041\left[1 - \sqrt{\frac{W}{h}}\right] \quad \text{................(7)}$$

The electric field line has exact electrical characteristics, particularly propagation constant, as the actual electric field line [2]. The equation for ε_{reff} is given as (7)

F. Effective Length and Width

Due to fringing effect, electrically the patch dimensions will be bigger than its physical dimensions. A practical approximate formula to calculate the width and length is shown below. The following equation is used to calculate the width, W:

$$W = \frac{c}{2f_0\sqrt{(\varepsilon_r + 1)/2}} \quad \text{...................(8)}$$

where f_r is the resonant frequency, Co is the free-space velocity of light (Co = 3×10^8 m/s) and ε_r is the dielectric constant of substrate.

To determine the length, L, of the patch, the following equation is used:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad \text{........................(9)}$$

Normalized extension of the length ΔL is :

$$\Delta L \; 0.412\, h \frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.364\right)}{(\varepsilon_{\text{reff}} + 0.258)\left(\frac{W}{h} + 0.8\right)} \quad \text{..................... (10)}$$

III. UWB ANTENNA DESIGNS SIMULATIONS.

A. Antenna with Partial Ground & Addition of Stair

A rectangular patch antenna was designed and optimized with full partial ground. After full partial grounding, stairs have been introduced in order to achieve ultra wideband. The steps are added in lower end of the patch antenna. It can be observed that adding one or more steps with certain dimension in the patch antenna, there has been a sudden increment in the bandwidth of the antenna. This configuration was done based on the research works done previously.

To determine the dimensions of stairs, it has been added one stair only with length 1mm, and then the width of stair was optimized. The additional second stair yeilded very small increment in the bandwidth as well as shifting the the frequency to the rigths. The optimization was done to have better retun loss compared to width dimensions. The simulation results of designed and optimized antennas for patch with full ground and partial ground, partial ground without stair and with single stair and partial ground with single stair and double stairs are shown in Fig. 2.

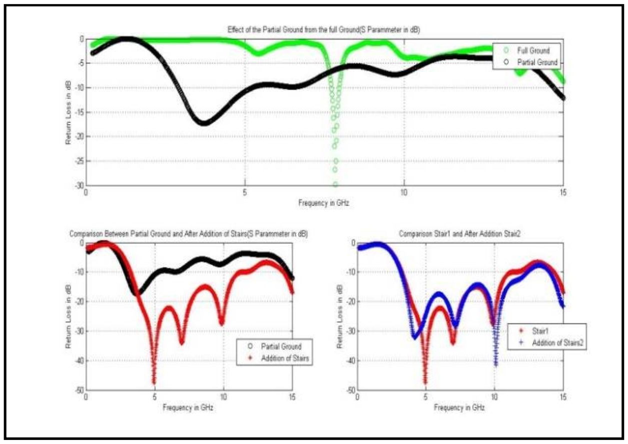

Figure 2: Simulated results of antennas with (a) full and partial ground, (b) partial ground without stair and with single stair, (c) partial ground with single and double stairs.

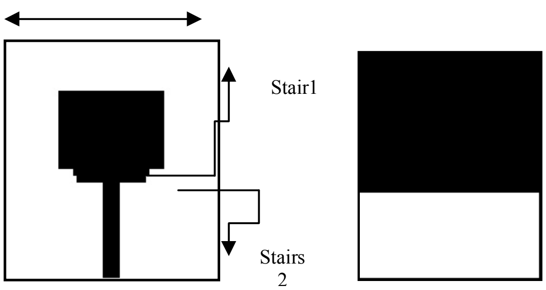

Figure 3: Structure of designed antenna with partial ground and stairs.

Table 1: The Dimension of Designed Antenna with partial ground and stairs.

Parameter Used	Value
Height of Substrate, h	1.6 mm
Length of the whole geometry, L	35 mm
Width of the whole geometry, W	31 mm
Length of the Ground, LG	14.75 mm
Physical Width of Patch Antenna, WP	15.5 mm
Effective Width of Patch Antenna	12.9 mm
Length of Patch Antenna, LP	11.4 mm
Length of Stair 1, ST1	1 mm
Length of Stair 2, ST2	1 mm
Width of Stair 1, WST1	11.2 mm
Width of Stair 2, WST2	10 mm
Width of the Feed, WF	1.249 mm
Length of the Feed, WP	16.3 mm

The result indicates very clearly the effects of partial grounding and stairs on increasing bandwidth. It is also obvious that the 2nd stair does not have impact on bandwidth. The designed structure of antenna is shown in Fig. 3 and all designed parameters are tabulated in Table 1.

B. Antenna with Partial Slotted Ground & Addition of Stair

This configuration is an attempt to improve with slotted partial ground. Since, double stairs in previous design is not improved much from single stair, hence only one stair and

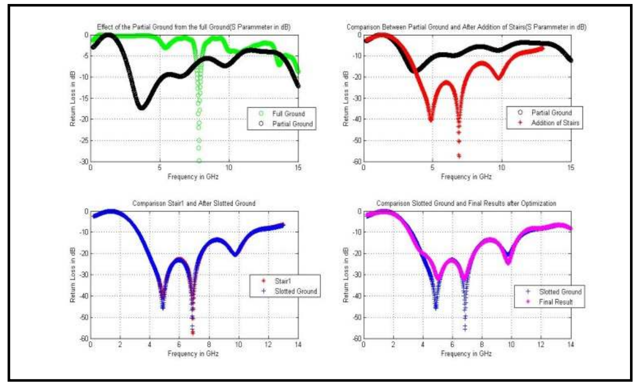

Figure 4: Simulated results of antenna with partial ground, partial ground with stair, slotted partial ground and optimized structure.

slotted partial ground have been introduced. A slot with rectangle shape is added to the ground. The slotted rectangle shape is very small in width and length, yet small changes slotted ground will lead to shifting the frequecy and increment of the bandwidth. The simulation results of optimized antenna and it's structure are shown in Fig 4 and Fig 5. All designed parameters are given in Table 2. It is clear from Fig. 4, the slot has no effect on bandwidth but it increases the return loss.

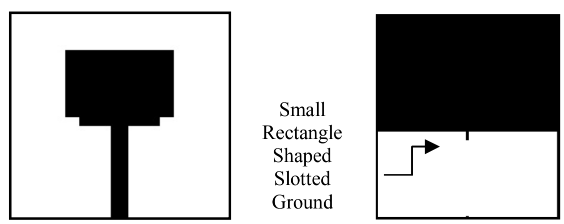

Figure 5: Structure of slotted partial ground antenna with stair.

The simualted gain of antennas with partial ground and stair with slotted partial ground and stair are compared in Fig. 6. From the figure, the gain achieved for both configurations almost similar to each other. As for configuration 1 (partial ground and stair), the maximum gain is 6.662 dB at frequency of 13 GHz. While for ccnfiguration 2 (slotted partial ground and stair), the maximum gain is 6.664 dB at 12 GHz. Both gain curves are also increasing uniformly and it has the maximum of 6 dB approximately for both configurations. The gain of microstrip patch antenna usually approximately 6dB, yet when the frequency increases, the gain increases up to 9 dB.

Table 2: The Dimension of Designed Antenna with slotted partial ground and stairs.

Parameter Used	Value
Height of Substrate, h	1.6 mm
Length of the whole geometry, L	35 mm
Width of the whole geometry, W	31 mm
Length of the Ground, LG	14.75 mm
Physical Width of Patch Antenna, WP	15.5 mm
Effective Width of Patch Antenna	12.9 mm
Length of Patch Antenna, LP	11.4 mm
Length of Stair 1, ST1	1.5 mm
Width of Stair 1, WST1	5.8 mm
Slotted Ground Length, SLGL	1 mm
Slotted Ground Width, SLGW	0.6 mm
Width of the Feed, WF	1.249 mm
Length of the Feed, WP	15.8 mm

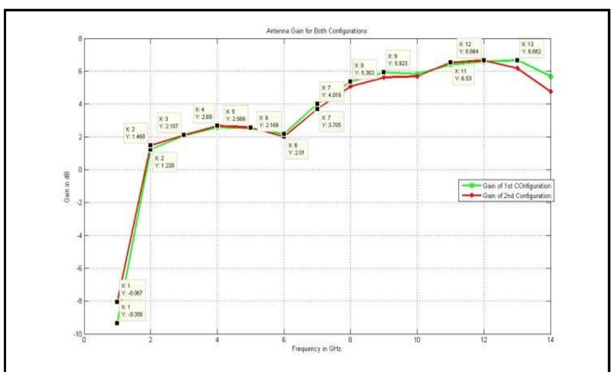

Figure 6: Comparison of simulated gains between antennas with partial ground and stair with slotted partial ground and stair.

C. *Antenna with Partial Slotted Ground with Addition of Stair & Stub*

It has been found that the addition of tuning stub enhance the the S_{11} curve charecteristics and the antenna gain by almost 0.7dB over the the UWB range of frequencies . The optimized 1mm length and 1.25mm wide stub is palced on the left side of the patch as shown in Fig. 8. The simulated return loss vurve is shown in Fig. 7. The dimensions of slotted partial ground with addition of stair and stub are given in Table 3.

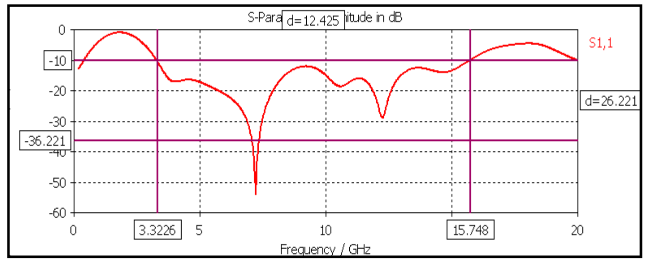

Figure 7: Simulated results of optimized antenna with tunning stub.

Table 3: The Dimension of Designed Antenna with Slotted partial ground with addition of stair and stub.

Parameter	Value(mm)
Dielectric Constant	5.2
Substrate Thickness, h	1.6
Substrate Length, L	35
Substrate Width, W	30
Ground Length, GL	11
Patch Antenna Width of, PW	16
Patch Antenna Length, PL	12
Step's Length , ST1	2
Step's Width , ST1	10
Ground Width, GW	14
Feed Width, FW	3.04
Feed Length, FL	11.5
Stub width SW	1.25
Stub length SL	1.6
A	6

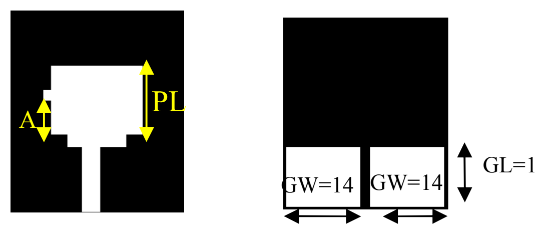

Figure 8: Structure of partial slotted ground antenna with addition of stair and stub.

IV. Fabrication and Test Results

In order to validate the simulated results, all three designs were fabricated, where each prototype is connected to SMA-Female (Gold Type) connector. All fabricated antennas are tested using VNA-Network Analyzer (N52330A 100MHz – 50 GHz) at RF design Lab in Faculty of Engineering, IIUM. We have tested the antennas, and the output of the designs as follows.

A. *Antenna with Partial Ground & Addition of Stair*

The antenna designed with partial ground and stair was fabricated and upper and lower parts of it's photo are shown in Fig. 10. The simulated and test results are plotted and shown in Fig. 9 for comparisons. It can be obeserved that the fabricated result is shifted to the right from the simulated result.

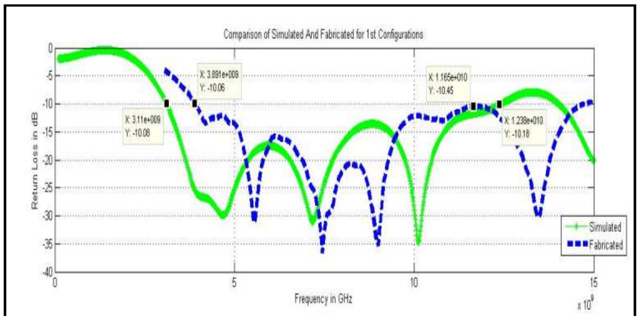

Figure 9: Comparison between Simulated and test results of antenna with partial ground and stair.

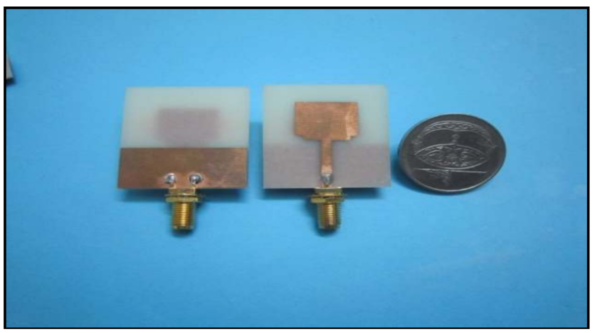

Figure 10: Fabricated antenna with partial ground and stair.

The shifting of the fabrication might be due to the fabrication error such as inaccuracy of fabrication design, connector type and so on. The test result indicates four resonants clearly with lower bandwidth from simulated results. The simulated and test results of designed and fabricated antennas are summarized in Table 4.

Table 4: Summary of bandwidth achieved by simulated and fabricated results from antenna with partial ground and stair.

	Simulated Result	Test Result	Differences
Operational Frequency	3.105 - 12.43 GHz	3.88 – 11.724 GHz	Shifted to right (600MHz) & Left by (500MHz)
Bandwidth Achieved	9.325 GHz	7.844 GHz	1.4 GHz

B. Antenna with Slotted Partial Ground & Addition of Stair

The antenna designed with slotted partial ground and stair was fabricated and upper and lower parts of it's picture are shown in Fig. 12. The simulated and test results are plotted and shown in Fig. 11 for comparisons. It can be obeserved that the fabricated result is shifted to the right from the simulated result same as shown in Fig. 9. The test result indicates four resonants clearly with higher bandwidth from simulated results. The simulated and test results of designed and fabricated antennas are summarized in Table 5.

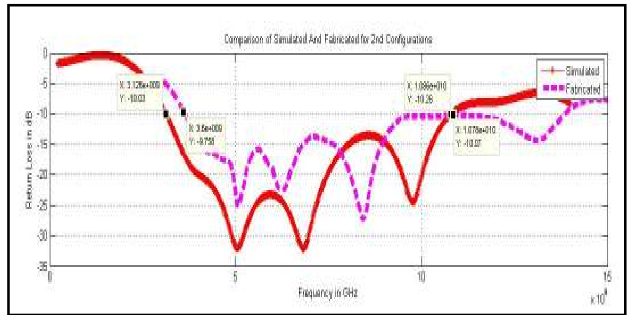

Figure 11: Comparison between Simulated and test results of antenna with slotted partial ground and stair.

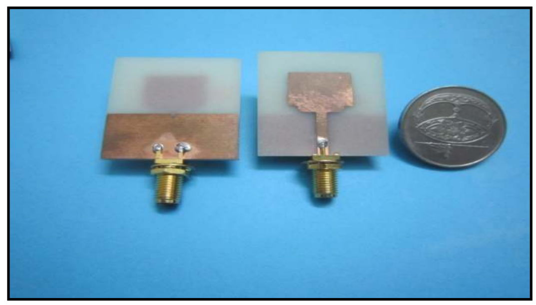

Figure 12: Fabricated antenna with slotted partial ground and stair.

Table 5: Summary of bandwidth achieved by simulated and fabricated results from antenna with slotted partial ground and stair.

	Simulated Result	Fabricated Result	Differences
Operational Frequency	3.129 – 10.8 GHz	3.6 – 11.06 GHz	Shifted to right (471MHz) & Left by (260MHZ)
Bandwidth Achieved	7.671 GHz	7.46 GHz	211 MHz

C. Antenna with Slotted Partial Ground with Addition of Stair & Stub

The antenna designed with slotted partial ground with addition of stair and stub was fabricated and upper and lower parts are shown in Fig. 14. The simulated and test results are plotted and shown in Fig. 13 for comparisons. It can be obeserved that the fabricated result is shifted to the right from the simulated results same as shown in Fig. 9 and 11.
The simulated and test results of designed and fabricated antennas are summarized in Table 6. The bandwidth obtained

is much higher than that in test results. The simulated radiation patterns of antenna with slotted partial ground with addition of stair and stub at four selected frequencies are shown in Fig. 15.

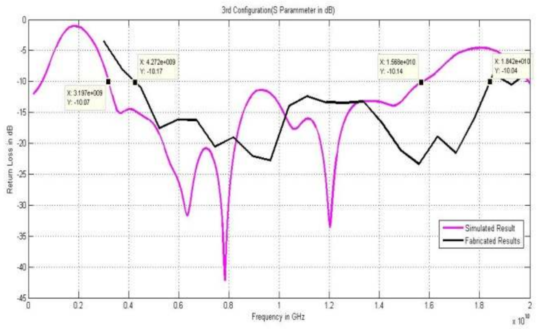

Figure 13: Comparison between Simulated and test results of antenna with slotted partial ground with addition of stair and stub.

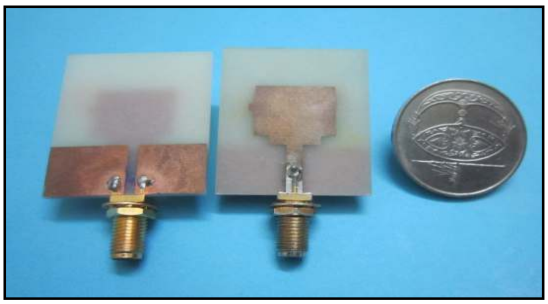

Figure 14: Fabricated antenna with slotted partial ground with addition of stair and stub.

Table 6: Summary of bandwidth achieved by simulated and fabricated results from antenna with slotted partial ground and stair.

	Simulated Result	Fabricated Result	Differences
Operational Frequency	3.197 – 15.68 GHz	4.27 – 18.42 GHz	Shifted to right 1GHz and 3 GHZ
Bandwidth Achieved	12.483 GHz	14.15 GHz	1.667 GHz

V. RESULTS AND ANALYSIS

In this paper, three antennas are designed and tested to operate in UWB frequencies and beyond it. The proposed antennas characteristics is investigated with various options and found to operate satisfactory. The complete antenna modeling and simulation is achieved by using CST Microwave Studio simulation package and the antennas test is done by using VNA Network analyzer. Various techniques have been used to enhance the proposed antenna characteristics. These techniques are: adding a step beneath the patch, using of slotted partial ground, using of tuning stub. Those parameters were considered in affecting the UWB performance of a given antenna. This is inclusive of parameters such as the dimensions of the patch, the

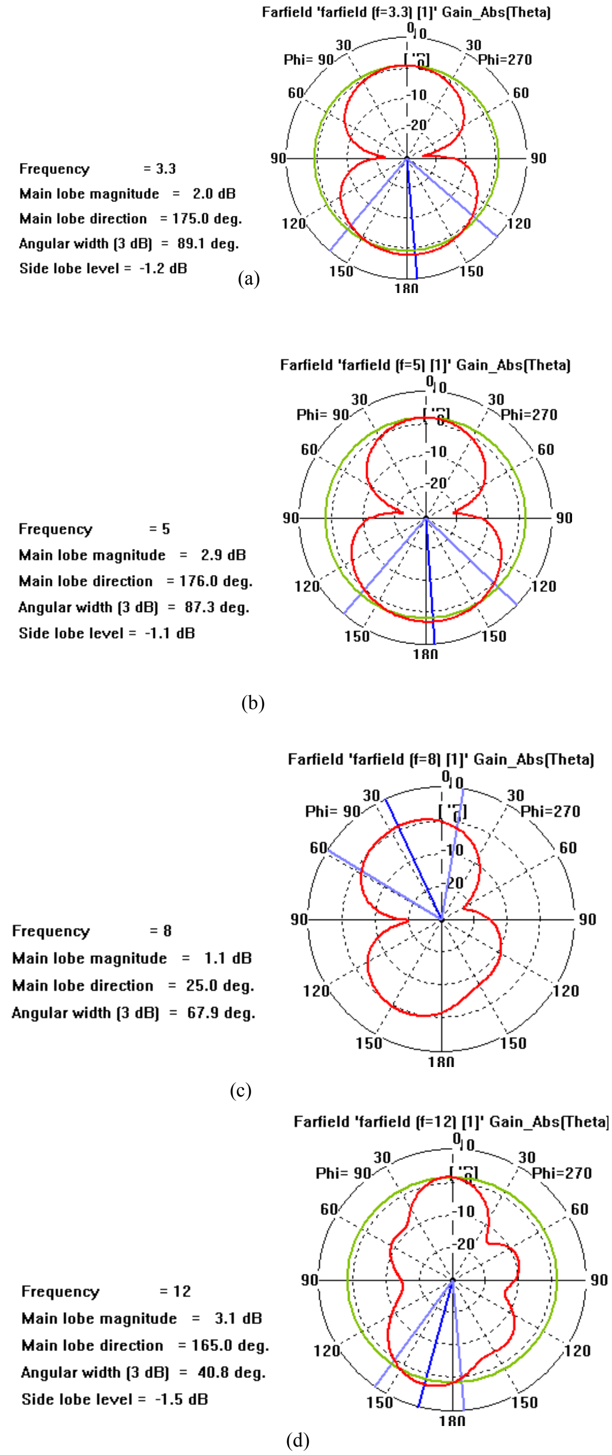

Figure 15: Simulated E-plane characteristics over frequencies (a) 3.3 GHz, (b) 5 GHz, (c) 8 GHz and (d) 12 GHz.

dimension s of the partial ground, the slot in the partial ground, the additional stairs and the stub. However, all of these parameters are successfully designed, fabricated and tested.

A simple rectangular patch antenna is designed initially. Then, all three techniques are adopted into design in order to increase the bandwidth. As for the 1st configuration, the techniques introduced are partial grounding and stairs. It has been found that the normal patch with solid partial ground and symmetrical feeding could achieve less than 6 GHz bandwidth. While, adding extra stair beneath the patch has increased the achieved bandwidth close to 10 GHz. Then, in the 2nd configuration, the design is introduced an additional technique, which is small slotted partial ground [10-11]. All of these techniques are used in the design of the 3rd configuration which addition of stair, slotted partial ground and an addition of tuning stub[12]. Combining the stair, the slotted partial ground and the tuning stub are found to achieve higher bandwidth with better return loss characteristics and reached up to 13GHz with a reasonable radiation pattern and gain. The simulated results of the third configuration have shown that the antenna bandwidth is ranging between 3.2 to 15.68 GHz, while surprisingly the measured results have shown that the actual bandwidth is ranging from 4.27 to 18.42 GHz with a shift of 1 GHz and 3GHz. It has been noticed that throughout the simulation that symmetrical fed patch antenna with symmetrical slotted ground suffers from a notch frequencies at range of 15.7 GHz to 20 GHz with poor return loss characteristics after 20 GHz. While, extra resonant frequencies can be achieved in this range (15-20 GHZ) if unsymmetrical fed line is used with unsymmetrical slotted ground [13-14].

Table 7: Summary of simulated and measured results for three techniques used for UWB antenna design.

Types	Techniques Used	Simulated Results (GHz)	Measured Results (GHz)	Gain (dB)
Config-1	Partial Ground & Stair	3.105-12.43 (BW = 9.325)	3.88–11.724 (BW= 7.844)	6.6 (max)
Config-2	Slotted Partial Ground & Stair	3.129 – 10.8 (BW= 7.671)	3.6 – 11.06 (BW= 7.46)	6.6 (max)
Config-3	Slotted Partial Ground, Stair & Addition of Tuning Stub	3.197–15.68 (BW = 12.483)	4.27–18.42 (BW= 14.15)	7.5 (max)

The reason for discrepancy in the simulated and measured results might be due to many reasons such as: the accuracy of the fabrication, the additional soldering pieces, the extended part of the connectors and some inaccuracies from the simulation package[15].

The radiation patterns of antennas are investigated over few selected frequencies. And it has been found the three antennas have almost omni directional patterns over frequencies ranging from 3 to 6GHz while the three antennas become more directive after 6 GHz.

The simulated gain of the three antennas are analyzed and compared. It has been found that the 3rd configuration has an average of 5.5 dB over its operating frequencies and a peak of 7.5dB at 14 GHz. The summary of the approaches that mentioned in this paper together with achieved results are tabulated in 7.

VI. Conclusion

A novel approach for microstrip patch antenna to achieve ultra wideband is designed, simulated, fabricated and tested successfully. The antenna is designed by integrating slotted partial ground with stair and addition of tuning stub with rectangular patch antenna. The designed antenna can operate from 3.2 - 15.7 GHz frequency bands with more than 12 GHz band width with 7.5 dB maximum gain. The return loss is reached up to -40 dB and radiation patterns are acceptable throughout the entire frequency range. In addition, the antenna's structure offers great advantages due to its simple design and small dimensions.

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