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Characterization of Flexible Rectangular Slot Antenna for Medical Applications

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ABSTRACT

Ultra-Wideband (UWB) Microwave imaging is a technique that uses wide-bandwidth electromagnetic signals for detecting an object in the internal structure of the human body. This paper introduces the characterization of a flexible rectangular slot microstrip antenna with the Coplanar Waveguide (CPW) operated at frequency 6.1 GHz. The measured return loss of -20.73 dB at 6.1 GHz is achieved. The flexible material used for substrate is polyethylene (PET) that is highly flexible, which increases the accuracy of object detection. The PET has a relative dielectric constant (εr) of 3 with a thickness of 0.135 mm. The patch and ground of antenna are printed with silver (Ag) ink. The rectangular slots increase the antenna bandwidth, antenna gain, and antenna efficiency.

Key words: Coplanar Waveguide (CPW), Microstrip Antenna, Ultra-Wideband (UWB), Flexible Antenna

1. INTRODUCTION

An antenna is known as a device that can receive and send signals. Therefore, the process of sending and receiving is a challenging interest, especially when the rapid development of communication technology becomes a problem. Besides that, the rapid development of communication systems, both portable and fixed, requires a high-speed data transition to a wider area due to an increase in network users. Because of this, they need a wide bandwidth (BW) to cover cellular and all wireless services. This can be made possible by using a low profile and ultra-wideband (UWB) antenna to reduce complexity and manufacturing costs [1].

Before starting to design broadband and UWB antennas, the antenna characteristics, design principles, and procedures must be known and considered. In addition, microstrip antenna design techniques, various analyses, feeding methods, structures, and shapes apply to improve antenna performance and characteristics. The microstrip patch antenna is a good choice for researchers because it has many advantages, such as being inexpensive, light, and easy to make the material. Many researchers have improved the parameter results to provide efficiency and better performance than the patch antenna design. The parameters considered for improvement are bandwidth, directivity, gain, and return loss [2]–[3]. Coplanar waveguide (CPW) is one part of the feeding technique on a microstrip antenna that can conduct electric current. The characteristic of a coplanar waveguide is that it consists of one conductor that functions as a medium of electrical current flowing into the patch and followed by two conductors as ground, which has a CPW Schema distance [4].

Recently, many researchers have researched cancer detection that used microwave imaging systems like Magnetic Resonance Images (MRI). The MRI has applications in image detection and image classification [5]–[6], Computed tomography (CT) screening that is conducted to identify cancer [7], mammography and ultrasound techniques that have fewer restrictions. One of the technologies that apply microwave imaging is UWB. To implement and design a UWB antenna, BW related work must be considered in accordance with the Federal Communications Commission (FCC) and required frequency bandwidth area. For example, the UWB standard used in Canada and the United States is 3.1-10.6 GHz and a bandwidth minimum of 500 MHz, which is not licensed and has no limitations on BW. It has high transmission, low cost, and less power consumption [8]–[9]. In [10], many UWB antennas are presented, and then their design procedures, contributions, appearance, and techniques are investigated. The antenna is a type of flexible microstrip. Flexible microstrip antennas are widely accepted because of their lightweight and easy manufacturing [11]. Flexible sensors are no longer limited to planar geometry and have the potential to become one of the leading technologies to help realize human welfare everywhere [12].

In this research, the antenna uses a substrate PET that is highly flexible with a relative permittivity of 3, and CPW feed is used to adjust with PET substrate, which can only be fabricated on one side. The characterization of a flexible antenna is done by adding rectangular slots to the patch, changing the ground length and gap width between the ground and feedline to get the desired return loss at frequency 6.1 GHz. UWB antennas can be applied to biomedicine to detect a tumor in the human body. The simulation is done using CST studio suite software.

2. DESIGN METHODOLOGY

2.1 Antenna Design

The antenna design consists of patch, substrate, and ground. The substrate used is PET, which has a relative dielectric constant (εr) 3. For patch, feedline, and ground, Silver (Ag) Annealed is used. This antenna work on a frequency of 6.1 GHz. The thickness of the substrate used is 0.135 mm. The microstrip antenna is designed with a CPW technique. The CPW technique is used because the PET substrate can only be fabricated on one side. To fabricate antennas with PET substrate, a printer with silver ink is used, and no shorting pins are involved; apart from a few properties, it can help such as lower radiation loss, wider bandwidth, and increased impedance matching. To increase the antenna performance, some characterization and optimization have been performed. They are adding some rectangular slots on the patch, widening the gap between ground and feed line, and decreasing the width of the ground and substrate to get return loss under -10 dB at frequency 6.1 GHz.

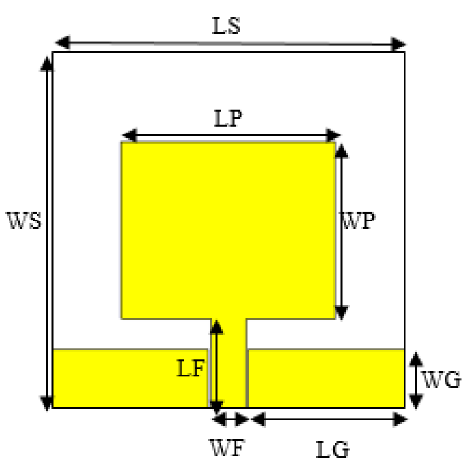

Figure 1: The proposed antenna geometry

Table 1 : Dimensions of Rectangular Antenna

Parameter	Dimension (mm)
LS	30
WS	30
LP	18.27
WP	14.89
LF	3
WF	9.75
LG	13.3
WG	5

2.2 Mathematical Equation

There is a basic equation that can be a reference to get the S_{11} parameter at the desired frequency. The following are the mathematical equation for calculating rectangular antenna dimensions [12]:

Width (W) calculation:

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

The effective εr calculation is based on the height, εr, and the width of the patch antenna calculated.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

Effective length calculation:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} \quad (3)$$

Length extension ΔL calculation:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

Actual patch length calculation:

$$L = L_{eff} - 2\Delta L \quad (5)$$

Where the following parameters used are:

f_0 = the Resonance Frequency
W = the Width of the Patch
L = the Length of the Patch
h = the thickness
ε_0 = the relative Permittivity of the dielectric substrate
c = the Speed of light: 3 x 10^8

The CPW impedance can be calculated by the following equation [3]:

$$k = \frac{a}{b} \quad (6)$$

Variable *a* is the width of the transmission line, and variable *b* is the width of the transmission line plus gaps on both sides of the transmission line. There is a calculation *k*, which is the filling factor in measuring the presence of an electric field that passes through a dielectric material by reviewing the values of *a* and *b*. After getting the value *k*, then look for *k'*, *kl*, *kl'* with the formula:

$$k' = \sqrt{1-k^2} \quad (7)$$

$$kl = \frac{\tanh\left(\frac{\pi a}{4h}\right)}{\tanh\left(\frac{\pi b}{4h}\right)} \quad (8)$$

$$kl' = \sqrt{1-kl^2} \quad (9)$$

After calculating these parameters, the ε_{eff} and Zo values are obtained by the following equation:

$$\varepsilon eff = \frac{1+\varepsilon r\frac{K(k')K(kl)}{K(k)K(kl')}}{1+\frac{K(k')K(kl)}{K(k)K(kl')}} \quad (10)$$

$$Zo = \frac{60\pi}{\sqrt{\varepsilon eff}}\frac{1}{\frac{K(k)K(kl)}{K(k')K(kl')}} \quad (11)$$

CPW length calculation can use the following equation:

$$Lf = 0.573\lambda g \quad (12)$$

3. Characterization and Optimization of the Antenna

In this section, the characterization stages will be performed on the antenna by adding a slot to the patch antenna, to get the desired frequency.

Fig. 2 (a) shows the CPW antenna design and Fig. 2 (b) displays the return loss parameter of -48.39 dB and a working frequency of 5.7 GHz with a bandwidth of 2.4 GHz. The return loss value is quite good, but the resulting work frequency is not as expected as 6.1 GHz. Therefore, it is necessary to characterize the addition of slots on the antenna.

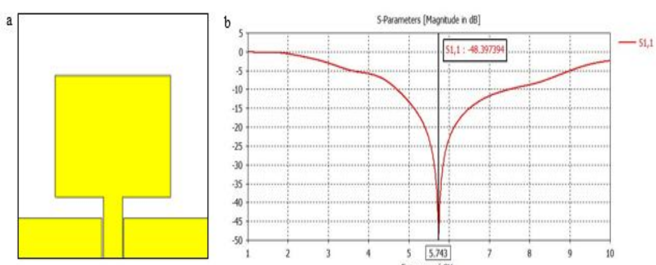

Figure 2: (a) The initial antenna geometry; (b) Simulated S_{11}

The initial step in the characterization process is to add the first slot with a length of A = 5.5 mm, B = 12.895 mm, and C = 14.27 mm on the antenna patch with a width of 1 mm. Characterization by adding the first slot can be seen in Fig. 3 (a) and the return loss from the simulation results of adding the first slot in Fig. 3 (b). It shows the working frequency of the initial design shifting to the left. The frequency obtained is 5.662 GHz, with a return loss of -48.31. Therefore, it is necessary to characterize by adding slots at a later stage.

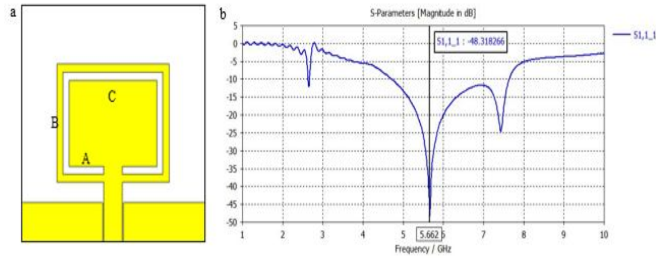

Figure 3: The design of the antenna and the result (a) First rectangular slot added; (b) Simulated S_{11}.

The second step in the characterization process is the addition of a second slot with a length of D = 3.653 mm, E = 6.89 mm, and F = 10.27 mm on the antenna patch. Adding the width of the second slot by 1 mm and the distance between the first and second slots by 1 mm can be seen in Fig. 4 (a), and Fig. 4 (b) is a simulated result of adding a second slot. Based on the graph shows the working frequency of the initial design with resulting return loss with a value of -41 dB at frequency 5.734 GHz.

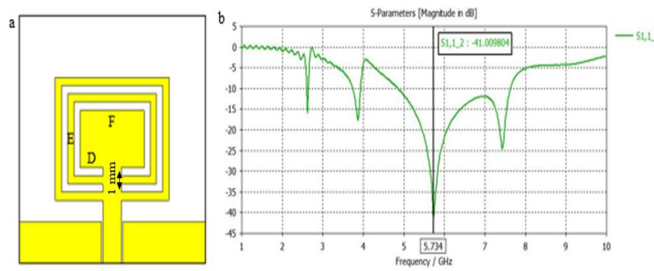

Figure 4: The design of the antenna and the result (a) Second slot added; (b) Simulated S_{11}.

The third step in the characterization process is adding a third slot to the patch antenna. It can be seen in Fig. 5 (a) that the antenna design was added to the third slot with length G = 4,254 mm and H = 7,308 mm with a distance between the second slot and the third slot of 1 mm. The return loss results from the simulation of adding the third slot can be seen in Fig. 5 (b). The working frequency and return loss value of -38 dB for the 5.66 GHz frequency are obtained, which has not changed much and is still not in accordance with antenna performance characteristics specified. Therefore it is necessary to characterize again.

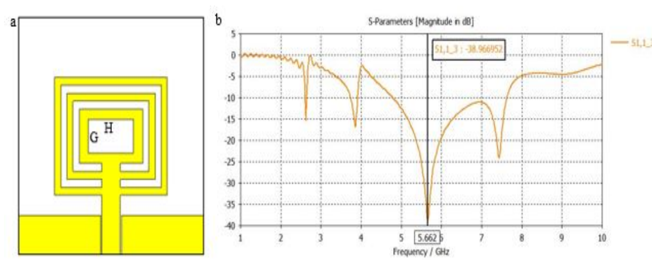

Figure 5: The design of the antenna and the result (a) Third slot added; (b) Simulated S_{11}.

The fourth step in the characterization process is the addition of a fourth slot with a length of I = 6.5 mm on the patch antenna. It can be seen in Fig. 6 (a) that the antenna design adds the fourth slot with a width of 1 mm, and the return loss results in Fig. 6 (b). It shows the working frequency of the initial design with the addition of a fourth slot, and this is the final stage for the addition of slots: the frequency shifts and resulting return loss of -36.23 dB for the 5.67 GHz frequency.

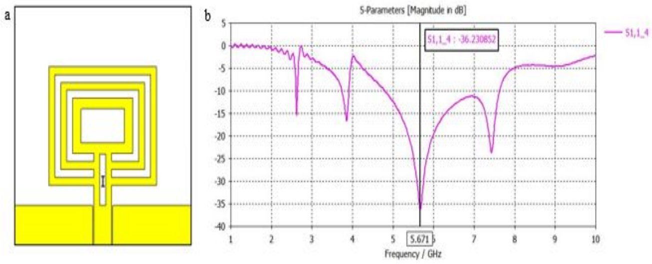

Figure 6: The design of the antenna and the result (a) Fourth slot added; (b) Simulated S_{11}.

Table 2 shows the characterization of the antenna design by only changing the gap width between the feeding line and the ground, whereas the other dimensions are fixed. Variations in the width of the gap made are 0.195 mm to 2.3 mm, with an increase of 1 mm.

Table 2 – Characterization of gap width between the feeding line and ground antenna.

The gap between Feeding Line and Ground (mm)	Return Loss (dB)	Frequency (GHz)
0.195	-36.04	5.68
0.21	-36.87	5.69
0.22	-37.77	5.7
0.23	-37.40	5.76

The best results are obtained at a patch length of 0.23 mm, with a return loss value of -37.40 dB at frequency 5.76 GHz. Fig. 7 shows any change in the gap width between the feeding line and the antenna ground caused a slight change in the antenna's working frequency.

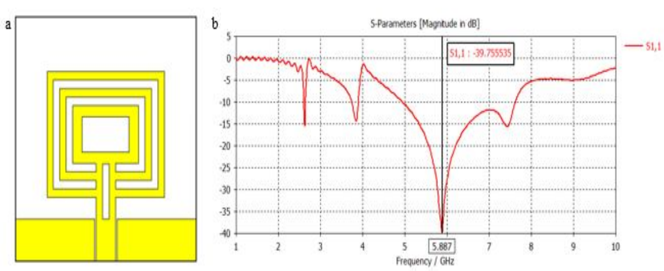

Figure 7: The design of the antenna and the result (a) After widened the gap; (b) Simulated S_{11}.

Table 3 shows the characterization of the antenna design by only changing the dimension of the ground length, whereas the other dimensions remain. The variation in ground length (LG) made is 13.3 mm to 9.3 mm, with a decrease of 1 mm, and the ground width (WG) is fixed.

Table 3: Characterization of Antenna Ground Length.

LG (mm)	WG (mm)	Return Loss (dB)	Frequency (GHz)
13.3	5	-37.40	5.76
12.3	5	-42.42	5.89
11.3	5	-28.86	6
10.3	5	-24.50	6.07
9.3	5	-21.77	6.1

The best results are obtained on the patch length of 9.3 mm with a return loss value of -21.7 dB at frequency 6.1 GHz. From the results of the characterization that has been done, it can be seen that any changes in the dimensions of the antenna patch length caused changes in the antenna's working frequency.

Fig. 8 shows the final results of the antenna that has been characterized and optimized to produce a return loss value of -21.84 dB at frequency 6.1 GHz.

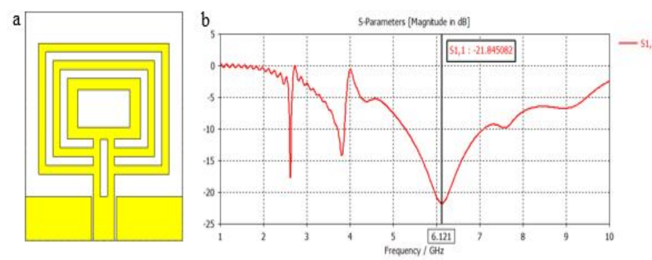

Figure 8: The design of the antenna and the result (a) Final design; (b) Simulated S_{11}.

Fig. 9 shows the final antenna design with its parameters. The lists are in Table 4.

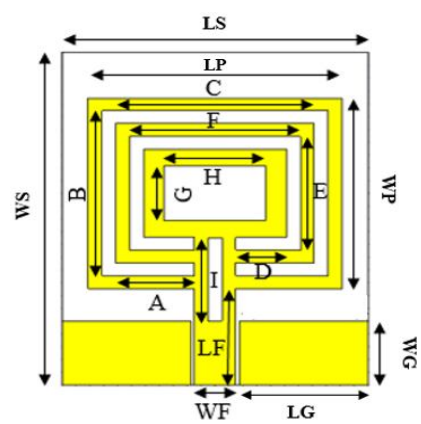

Figure 9: Final Antenna design

Table 4 : Dimensions of the Antenna after Characterization.

Parameter	Dimension (mm)
LS	22
WS	30
LP	18.27
WP	14.89
LF	3
WF	9.75
LG	9.3
WG	5
A	5.5
B	12.895
C	14.27
D	3.635
E	6.89
F	10.27
G	4.254
H	7.308
I	6.5

4. Result and Simulation

4.1. Comparison Between Simulation Result and Fabrication

Simulated return loss and gain will be discussed in this section. The antenna should meet the minimum UWB bandwidth requirement in the frequency range. Fig. 10 shows the fabricated antenna. The antenna was fabricated using the inkjet printer. The fabrication process was done for proving that the antenna can be used for biomedical applications with a flexible structure. There is trouble fitting the SMA connector to the substrate, whereas the substrate made from PET like a plastic. So to fix it should be glued it up first, and then it can be soldered with SMA connector on it.

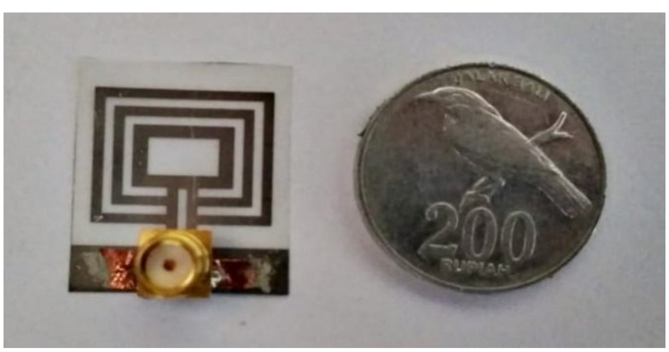

Figure 10: The Fabricated of the Proposed Antenna

By modifying the antenna parameters such as adding slots to antennas patch, it can make dual-band antennas and increase antenna bandwidth, antenna gain, and antenna efficiency. Then by doing some correct characterization like widening the gap between feed line and ground will produce a good parameter value from the previous antenna designs.

Fig. 11 shows the S_{11} parameter of the proposed antenna. From the simulation, the antenna works well in the range of 5.3 – 7 GHz with respect to -10 dB, whereas fabricated antenna operates in the range 2.5 – 9.1 GHz that is below -10 dB. The return loss of -21.77 dB for simulation and -20.73 dB for measurement is achieved at 6.1 GHz. The minimum bandwidth of the UWB requirement was met.

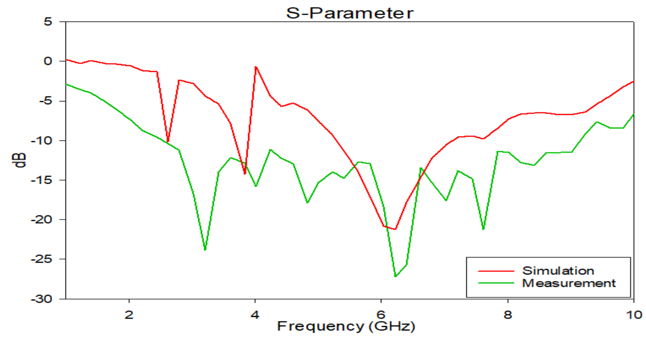

Figure 11: The Simulated S_{11} Parameter of the Proposed Antenna

Fig. 12 shows the simulated antenna gain. The gain obtained is 2.42 dBi.

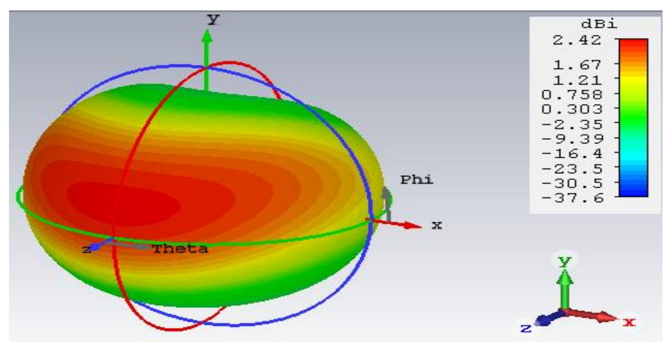

Figure 12 : The Simulated Antenna Gain

The antenna is directed to the human body at the rear position. Fig 13 (a) shows the radiation pattern of the simulated antenna, and the rear position is at 180 degrees. Fig 13 (b) shows the radiation pattern of the fabricated antenna and the rear position at 0 degrees.

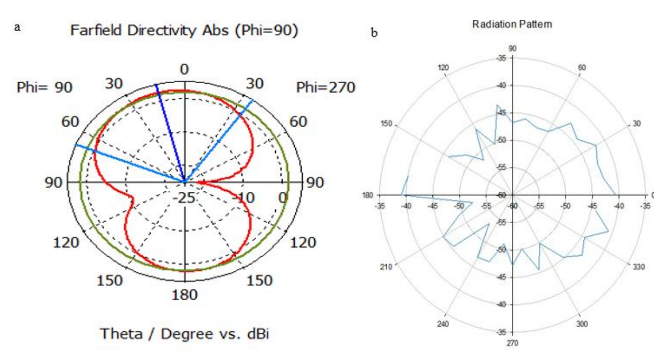

Figure 13: The Radiation Pattern of (a) simulated antenna; (b) fabricated antenna

4.2. Comparison of the Proposed Antenna with Other Research

Several studies have designed antennas using hard substrates such as FR-4[10]. Antenna properties are obtained (e.g., bandwidth and return loss) and get the best value. So it can be used for biomedical applications. But with the best results, the antenna has the disadvantage of being a substrate. The substrate is very hard, so the detection process is sometimes inaccurate. Because the object under study has a different form of structure, therefore, other innovations have been carried out by several researchers in the use of substrates. The substrate model that can be used for biomedical applications is a flexible structure. The flexible substrate is believed to increase the accuracy of detecting objects in organs that have different structures. The following are some antenna studies for biomedical applications that use flexible substrates shown in Table 5.

Table 5 shows a comparison of the antennas using a different substrate. The first research uses FR4 as a substrate and results in the bandwidth of 3.3568 – 12.604 GHz. The second research uses Roger ultralam 3850 as a substrate and shows the bandwidth of 110 MHz & 600 MHz.The third research uses Polyester as a substrate and shows a bandwidth of 6.76 GHz. The fourth research uses Cotton as a substrate and results in a bandwidth of 9.6 GHz. The variant of substrates has flexible structures that used to increase the accuracy of object detection on body organs. The proposed antenna of this paper also used the flexible substrate for biomedical applications. These results are acceptable and comparable.

Table 5 : Comparison of the Antenna Properties.

Referenc e	Substrate	Bandwidth (GHz)
[13]	FR – 4	3.3568 – 12.604
[14]	Roger Ultralam 3850	110 MHz & 600 MHz
[15]	Polyester	4.97 – 11.73
[16]	Cotton	1.6 – 11.2

5. CONCLUSION

The proposed antenna is designed with an initial antenna dimension calculation value before optimization has not reached the desired parameter specifications. The antenna uses a PET substrate that is highly flexible, which increases the accuracy of object detection. The antenna is using the coplanar waveguide technique, which facilitates printing during fabrication and installation of ports on one side. Then another advantage is obtained by using this technique to get a wide bandwidth so that it becomes UWB and can be used for imaging on medical.

The characterization of a flexible antenna by adding rectangular slots to the patch to increase return loss and shift the frequency slightly, changing the ground length is to change the frequency and gap width between the ground and feedline to get the desired return loss at frequency 6.1 GHz. The antenna works at frequency 6.1 GHz and bandwidth of 6.6 GHz, and the radiation pattern is bidirectional. The antenna works well in the range of 5.3 – 7 GHz with respect to -10 dB, whereas fabricated antenna operates in the range 2.5 – 9.1 GHz that is below -10 dB. The return loss of -21.77 dB for simulation and -20.73 dB for measurement is achieved at 6.1 GHz. The gain obtained is 2.42 dbi, and it can be used for biomedical applications.

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