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Measurement Engineering to Design a Truncated Ground Plane Compact Circular Ring Monopole Patch Antenna for Ultra Wideband Applications

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Abstract

In this paper, using in-depth simulations and measurements, a simple and compact design is engineered for making a circular ring microstrip patch antenna radiating element which is suitable for different ultra wide band(UWB) applications. This design approach is different because it has not utilized the usual method of using a set of electromagnetic equations and calculations to make the radiating antenna. Measurements and simulations were performed on Microwave CST. Using this measurement engineering approach, novelty of proposed antenna structure is obtained by making the required changes in the ground plane. The measurements showed that truncating the ground plane by a square shape structure of 2.5mm by 2.5mm size at the feed point was practically significant to provide an impedance bandwidth ($S_{11} < -10dB$) ranging from 2.75 GHz to 32.035 GHz with a VSWR which is less than 2. For this entire bandwidth the directivity has shown a variation from 0.8 dBi to 7.9 dBi. The compact size (33mm x28mm x1.57mm), low design complexity, very high bandwidth, good directivity and satisfying VSWR has made this antenna unique among all previously presented UWB antennas.

Keywords *Circular ring patch antenna, bandwidth, scattering parameters, parameter optimization*

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1. Introduction

Ultra-wideband (UWB) is a radio technology that has the advantages of using very low power spectral density (PSD) with fractional bandwidth ≥ 0.2 -0.25 or a bandwidth of at least 500 MHz. This range is usable for high bandwidth applications in engineering, medical sciences and other areas of science[1-5]. Designing a UWB communication system, entails state-of-the-art design of transmitters, receivers and radiating elements, i.e. antennas. In this paper the focus is the design of a contemporary UWB antenna with desired characteristics low volume and size.

Antennas are the radiating elements with the purpose of sending and receiving signals to and from wireless channel. In addition to many other features, speed of transmission and reception process carries a challenging research interest for a high speed communication system. Of the many factors, the high speed communication needs a high bandwidth to cover mobile and other wireless facilities. With this need of broad bandwidth, UWB antennas with low profile are the best resource for high speed communications.

In designing a UWB antenna it is important to consider the design principles, procedures and final antenna characteristics. Hence there should be no ambiguity in them. Because of their inherent advantages, the most popular of UWB antennas are microstrip patch antennas [6-8]. Microstrip Antenna (MSA) has a three layer structure namely radiating patch, ground plane and substrate (dielectric). The substrate lies between patch and ground plane. Literature study showed that microstrip antenna's type, shape, design analytics, and feeding procedures are the commonly accepted methods to improve the antenna's characteristics and performances[9-15]. These attributes help to improve the antenna parameters including return loss, gain, directivity, and bandwidth. The design process involves that the antenna designer first determines any of these parameter(s) as the required output then tries to optimize their antenna design accordingly.

Most importantly in the design of the UWB antenna, the working bandwidth should be considered according to the Federal Communications Commission (FCC). The UWB standard used in USA and Canada is unlicensed band of approximately 7.5 GHz ranging from 3.1 to 10.6 GHz. In addition, FCC has also limited the emissions for the maximum power-efficiency which is -41.3dBm/MHz [16, 17].

A conventional microstrip patch antenna has the intrinsic properties of narrow impedance bandwidth which means that the antenna will show resonance on a single (ideally) or to a narrow band of frequencies (in practical). Several techniques have been used to enhance the impedance bandwidth of the microstrip patch antenna. Some of the commonly stated techniques in the literature study included an insertion of a slot in a patch in the form of square, ring or U-shaped slot [18-22], truncating the ground plane and designing aperture coupled patch antennas[23, 24], using integrated band pass filter [25], making use of optimally designed impedance matching network. In all these configurations, parts of the system that a designer has to model in finding antenna radiation are the surfaces of the metals, having surface charge density, which radiate electromagnetic fields. A low Q factor or alternatively high bandwidth antenna has also been achieved by increasing the thickness of the dielectric substrate [26], thus making more room for radiated energy than stored energy. However, high bandwidth antenna has a lower gain value. But by using an array configuration for the elements, the problem of lower gain and lower power handling capacity can be overcome.

In this research, we have proposed the antenna design and its measurement engineering of a high bandwidth UWB antenna along with a moderate structure size and good directivity bandwidth.

2. Background / Motivation from previous Work

In the beginning the parametric values were achieved after the theoretical and numerical analysis of various types of Microstrip Antennas (MSA's). In rectangular patch we have two parameters (Length and Width) for changing their different modes. Similarly in our design, the patch is circular ring type also have two parameters (outer radius R and inner radius r) by which we can change their modes. So we put all the values of our proposed antenna in well known equations of rectangular patch antenna to find the length and width. Here we supposed that the value of width and length is equal to the outer radius (R) and inner radius (r) respectively of the proposed antenna which is circular ring type. The width of rectangular patch can be found as:

$$w = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

Here c is the velocity of light and is equal to 3×10^8 m/s.

f_0 is the resonance frequency and is equal to 10 GHz.

and ϵ_r is the relative permittivity of FR-4 which is used for substrate material, its value is 4.3.

Substituting the values in eq. (1) give us,

$$w = \frac{3 \times 10^8}{2 \times 10^{10} \sqrt{\frac{4.9+1}{2}}}$$

$$w = 8.89 \text{ mm} \quad (2)$$

Here we have supposed that the value of width in eq (2) will be equal to outer radius (R) of our proposed antenna

$$\boxed{R = w = 8.89 \text{ mm}} \quad (3)$$

Similarly to find actual length (L) the following equations were used,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{2}\right)^{-\frac{1}{2}} \quad (4)$$

Here h is the height of substrate and is equal to 1.57 mm and ϵ_{eff} is the effective permittivity.

$$L_{eff} = \frac{c}{2f_0 \sqrt{\epsilon_{eff}}} \quad (5)$$

Here L_{eff} is the effective length of rectangular patch

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258) \left(\frac{w}{h} + 0.8\right)} \quad (6)$$

Here ΔL is the change in length of rectangular patch

$$L = L_{eff} - 2\Delta L \quad (7)$$

Finally L is the actual length of rectangular patch

After solving the above equations (4), (5), (6) and (7), L is found as,

$$L = 6.26\text{mm} \quad (8)$$

We have supposed that this value of L in eq. (8) is equal to the inner radius (r) of our proposed antenna

$$\boxed{r = L = 6.26\text{mm}} \quad (9)$$

With the help of eq (3) and eq (9) we also calculated the length and width of ground plane and truncation was performed just by rectangle shape in a simple way that one side was made twice to the other side. After getting all initial parametric values, we simulated the antenna and found the bandwidth 0.8512 GHz with reflection coefficient $S_{11} < -10\text{dB}$. The simulation is shown in Fig 1

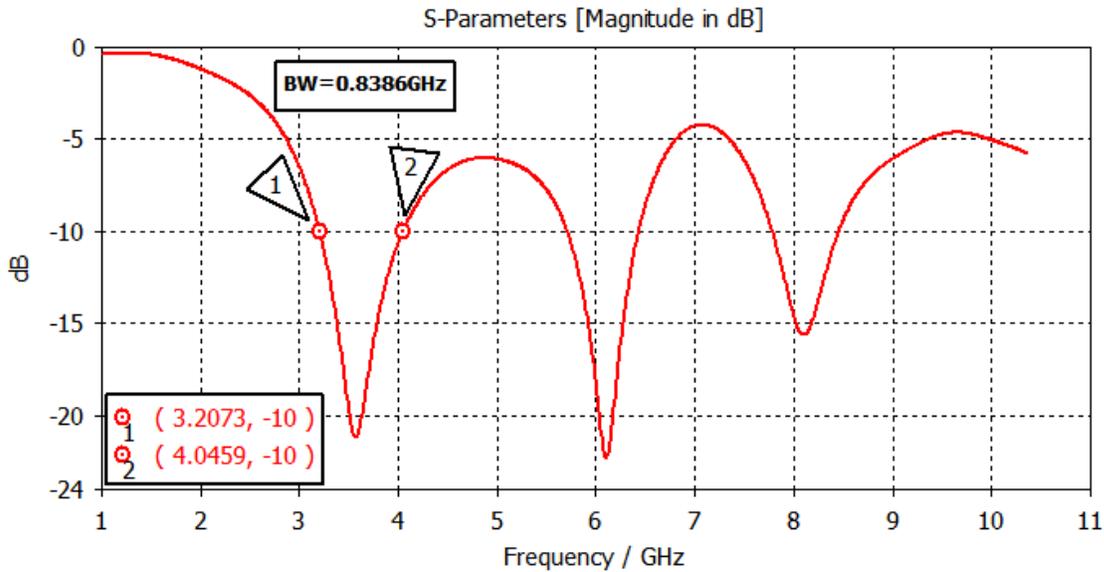


Fig. 1 Frequency vs. reflection coefficient (S_{11}) graph, when outer radius $R = 8.89\text{mm}$ and Inner radius $r = 6.26\text{mm}$.

These initial parametric values made it possible to get a bandwidth by simulating our antenna. The obtained bandwidth was quite narrow but provided us with the values to initiate the design process.

3. Problem Definition

The bandwidth of Ultra-wide band antenna depends on different design techniques e.g. patch shapes and feeding techniques. In this context, lots of configurations have been studied but the large size was the main problem to achieve the appropriate bandwidth. The antenna size and the bandwidth are dependent on each other. If bandwidth needs to be increased, then this requires the increase in the antenna size gradually. However we want antenna size to be compact and minimal.

Several antennas for suitable Ultra wideband applications have been tested such as stacked patch antenna wide slot antenna[27], tapered slot[28] and also other more antennas are designed and investigated in order to get the best fit antenna satisfying UWB requirements.

Some of the major issues of concern in the present available UWB antennas include the following:

1. Most of the designs are multifaceted which lead to complexity in the fabrication process.
2. Many tested designs have low band width and for achieving high band width, antenna size has to be increased implicitly [29].
3. Some designs have good band width but unsatisfactory antenna characteristics and also have greater VSWR values [30].

Considering the above mentioned problems , the aim of this work was research to obtain an antenna which is simple in design, have high bandwidth, satisfactory antenna characteristics, low VSWR and have compact antenna size too; all suitable for ultra wideband applications.

4. Research Methodology

As discussed above, in the design of an antenna there are many parameters. For a patch antenna, these include the parameters of substrate, patch and ground plane. A complex combination of them can give varying characteristics of beam width, bandwidth, radiation patterns, directivity and gain to an antenna. In this research we developed the research methodology for measuring the effect of the antenna parameters to identify most suitable values of them for meeting the requirements. In this approach of measurement engineering we explored the effect of individual parameters on antenna characteristics. At a single instant only one parameter is made to vary while others remained constant. Following section shows this detailed analysis.

5. Analysis on the Simulations of Antenna's Parameters

The geometry of the proposed optimized antenna is shown in Fig 2 and Table 1. Antenna has been oriented in xy -plane whereas its normal lies in the direction of z -axis. The overall size of the antenna is $33mm \times 28mm \times 1.57mm$, with FR4 substrate (lossy) having permittivity, $\epsilon_r = 4.9$. Various feed types can be used to feed the antenna including coplanar waveguide feed, probe feed, aperture coupled feed and microstrip line feed. Feed type used in this research work is 50 ohm microstrip line feed.

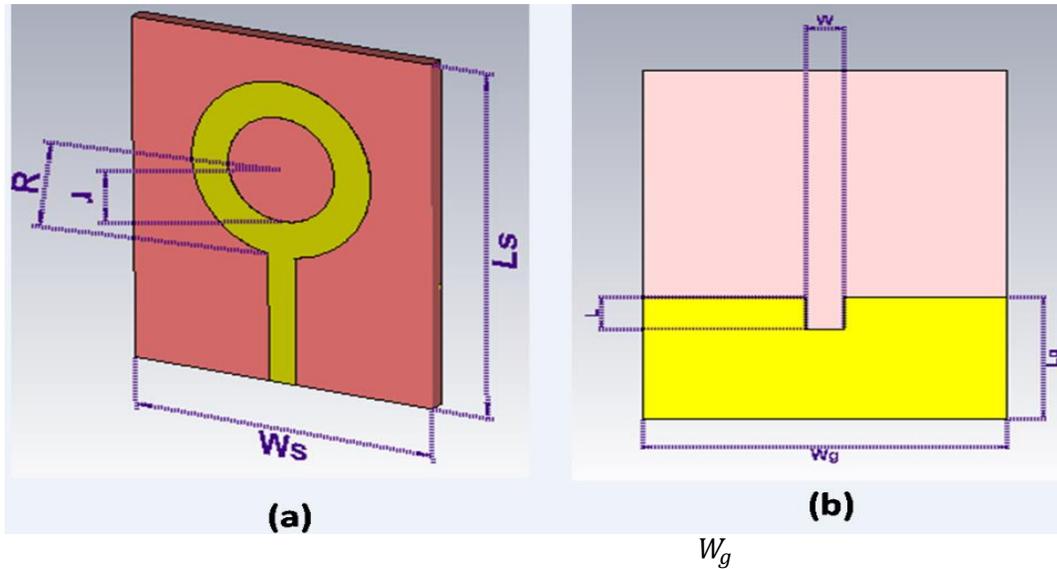


Fig. 2 Optimized and proposed antenna geometry

The designed values shown in Table 1 are final optimized values. However they were obtained after quite lengthy simulations.

Table 1 Antenna Parameters

	Parameter Label	Parameters' symbol	Dimension(mm)
Substrate	Substrate length	L_s	33
	Substrate width	W_s	28
Patch	Patch outer radius	R	8.4
	Patch inner radius	r	4
Feed	Feed line height	F_h	12.3
	Feed line width	F_w	2.55
Ground	Ground plane length	L_g	11.5
	Ground plane width	W_g	28
Square	Square length	L	2.5
	Square width	W	2.5

Simulations and measurements performed to reach these values are presented in this section. Simulations were performed on the following parameters.

- 5.1 Effect of the patch outer radius (R)
- 5.2 Effect of the patch inner radius (r)
- 5.3 Effect of the ground plane length (L_g)
- 5.4 Effect of the ground width (W_g)

5.5 Effect of the feed line width (F_w)

5.6 Effect of the feed line height (F_h)

5.7 Effect of the truncation of the ground

5.1 Effect of the patch outer radius (R)

For the optimization of the patch, we have first optimized the outer radius of the circular patch, Simulations performed and as shown in Fig2 showed that by increasing the value of “R” we get a lower value of the lower frequency band of UWB, i.e. f_L frequency. It was also noted in the simulations that after a very specific value (here $R = 8.3\text{mm}$) if outer radius is increased, then there is no change in f_L frequency. Simulations carried out are shown in Fig. 3. They show changes in reflection coefficient (S_{11}) vs. entire frequency graph for different outer radius of the circular patch (R).

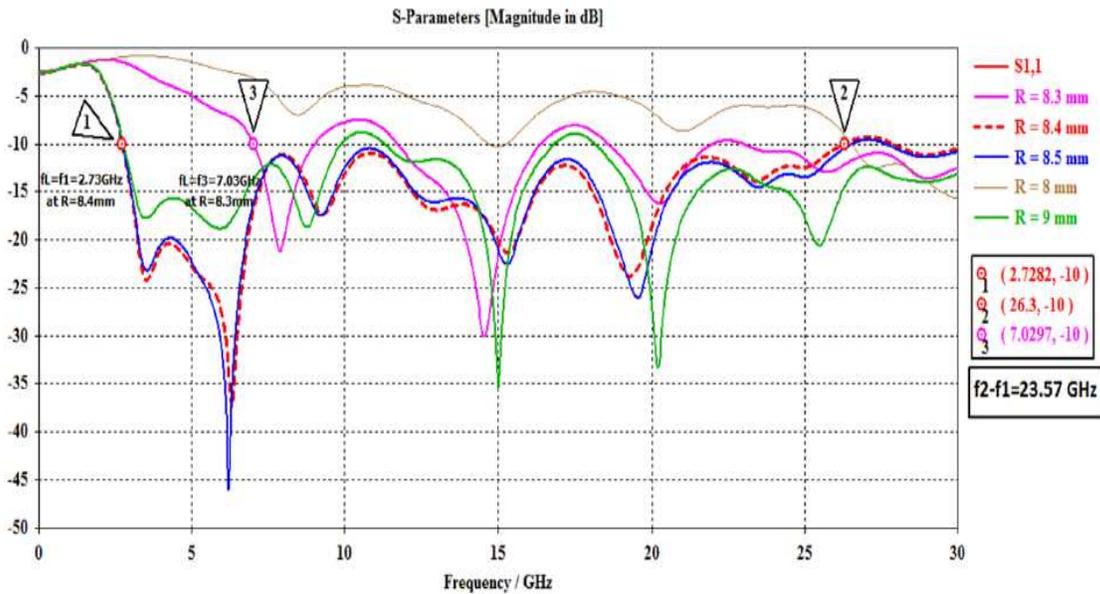


Fig 3 Frequency vs. reflection coefficient (S_{11}) graph for different patch outer radius(R)

It is clearly observable that in this design both the achieved bandwidth and lowest resonance frequency are dependent on the radius of the circular patch(R).From the Fig 3 it can be seen that when $R = 8.4\text{mm}$ then the reflection coefficient is below then -10dB over the entire frequency band of interest. For values of $R \geq 8.4$ mm, $S_{11} < -10$ dB for the whole bandwidth of UWB.

Hence, considering the requirement of compact size, the optimized value of outer radius was taken as $R = 8.4\text{mm}$.

5.2 Effect of the patch inner radius (r)

For different values of the inner radius $r = 5 \text{ mm}$, 4.75 mm , 4 mm , 3 mm and 2 mm , simulations were carried out to explore significant change in the reflection coefficient of antenna. This is as shown in Fig. 4.

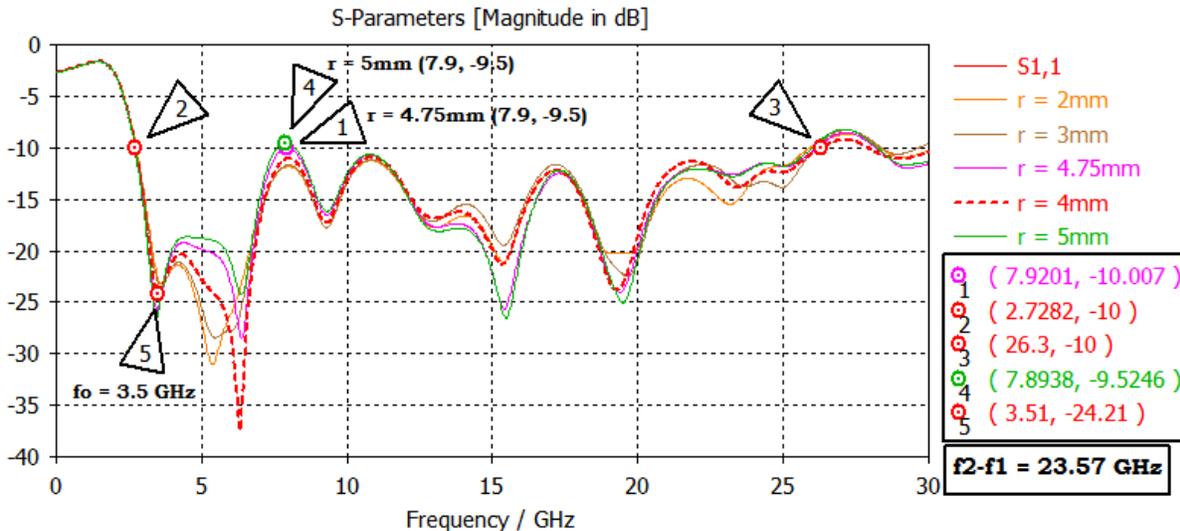


Fig. 4 Frequency vs. reflection coefficient graph for different patch inner Radius (r).

From Fig 4, it is seen that changing effective inner radius of circular patch has significant effect on resonance frequency and return loss. Increasing of the effective inner patch radius doesn't change notably the other characteristics except reflection behavior of planar antenna. It is also seen in Fig 3 that at marker 3 ($r = 4.75 \text{ mm}$) the reflection coefficient is exactly equal to -10 dB and at marker 4 ($r = 5 \text{ mm}$) reflection coefficient is -9.5 dB . Hence below $r = 4.75 \text{ mm}$ reflection coefficient would be less than -10 dB in magnitude and above $r = 4.75 \text{ mm}$ reflection coefficient would be greater than -10 dB in magnitude. It is seen from the Fig 4 that when $r = 4 \text{ mm}$ then the reflection coefficient is less than -10 dB over the entire frequency band of interest and the resonating frequency is 3.5 GHz .

Hence, considering the requirement of compact size, the optimized value of patch inner radius was taken as $r = 4 \text{ m}$.

5.3 Effect of the ground plane length (l_g)

For different values of the ground plain length, $L_g = 12.5 \text{ mm}$, 12 mm or 11.5 mm and 11 mm , respective variations in the reflection coefficient were obtained. From the simulations it is concluded that as the value of L_g is decreased, the antenna started behaving more effectively

with respect to reflection coefficient (S_{11}). The plot of Reflection coefficient (S_{11}) vs. entire frequency graph for different ground plane length L_g is provided in Fig 5.

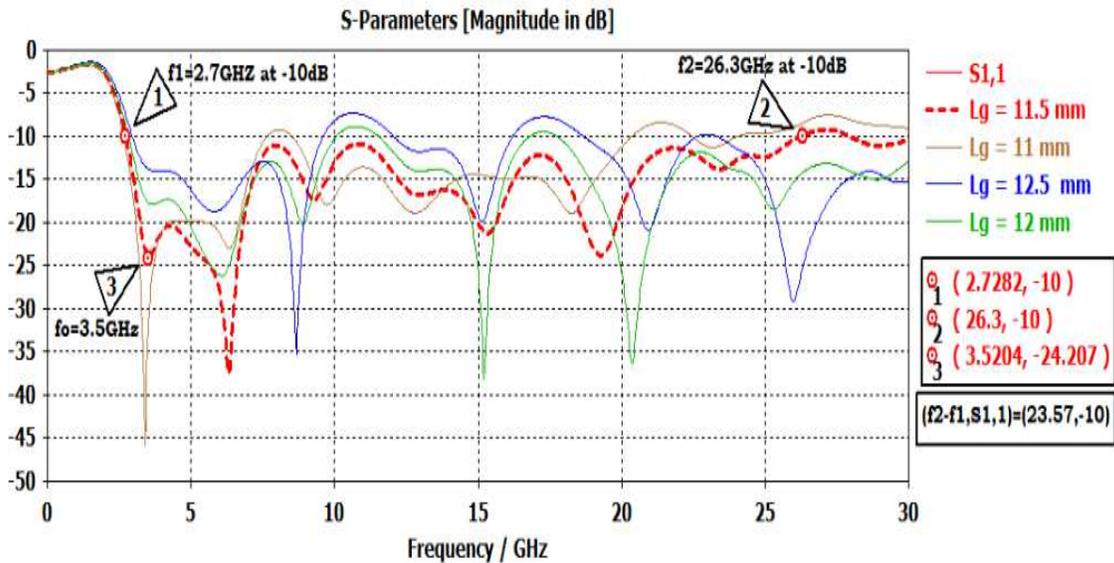


Fig. 5 Frequency vs. reflection coefficient graph for different ground plane length (L_g)

From the graph it is seen that the changing ground plane length has also significant effect on f_L and f_R . It is observable from Fig 4 that when $L_g = 11.5$ mm then the reflection coefficient $S_{11} < -10$ dB over the entire frequency band of interest and the resonating frequency is 3.5 GHz. At lower value of L_g , S_{11} is not consistent to be less than -10 dB.

Hence, considering the requirement of compact size, the optimized value of ground plane length was taken as $L_g = 11.5$ mm.

5.4 Effect of the ground plan width (W_g)

In this simulation, effect of the ground plane width on the reflection behavior of the proposed antenna was explored for different values of the ground plane width $W_g = 28$ mm, 24.5 mm and 22 mm. It was investigated that as W_g was reduced, a corresponding change appeared in the reflection coefficient of antenna. For $W_g = 28$ mm, provided the best behavior of proposed antenna. At this specific value we obtained $S_{11} = -11.06$ dB. This showed that it is a good selection for the performance of antenna. The simulations are shown in Fig 6.

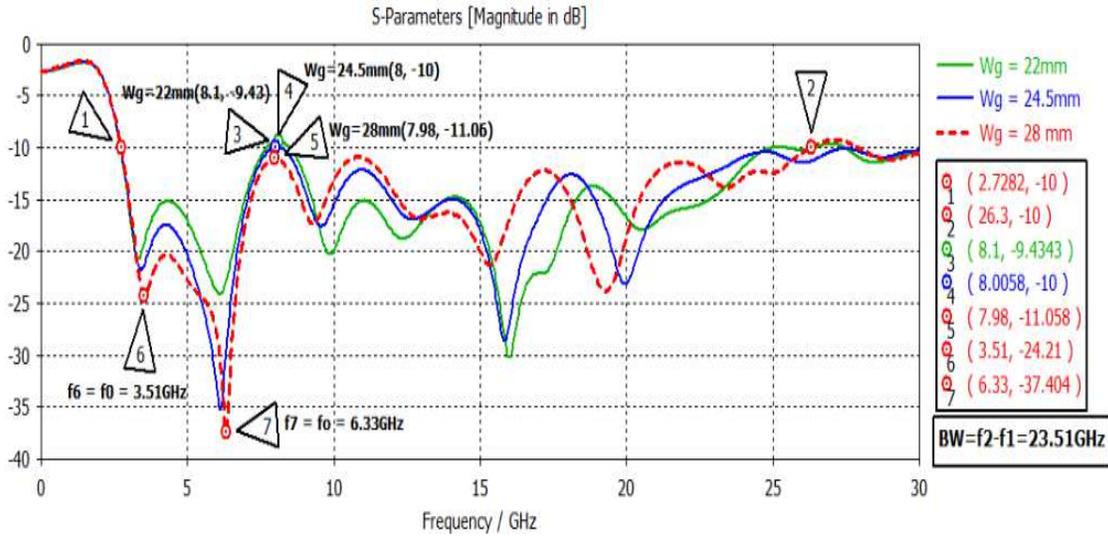


Fig. 6 Frequency vs. reflection coefficient graph for different values of ground plan width (W_g).

From the graph it is very clear that there is no change in f_L as the value of ground plan width is increased but only there was improvement in reflection coefficient of antenna as shown by marker 3,4 and 5 in Fig 5. It was measured that when $W_g = 28$ mm then the reflection coefficient was less than -10 dB over the entire frequency band of interest and at this value maximum band width was obtained. At $W_g = 24$ mm reflection coefficient was exactly equal to -10 dB; so this value was measured to be a boundary value for the improvement of reflection coefficient. If W_g is increased above 24 mm, good reflection coefficient was obtained and below this value there was poor reflection coefficient.

Hence, considering the requirement of compact size, the optimized value of ground plane width was taken as $W_g = 28$ mm.

5.5 Effect of feed-height (F_h)

For different values of the feed width, $F_h = 12.7$ mm, 12.5 mm, 12.3 mm, 12 mm, 11.7 mm. Simulations were carried out to measure that increase in the feed-line height, good performance of antenna with respect to its reflective behavior was obtained. This behavior increased as feed height was increased from its appropriate value. Simulations are shown in Fig. 7.

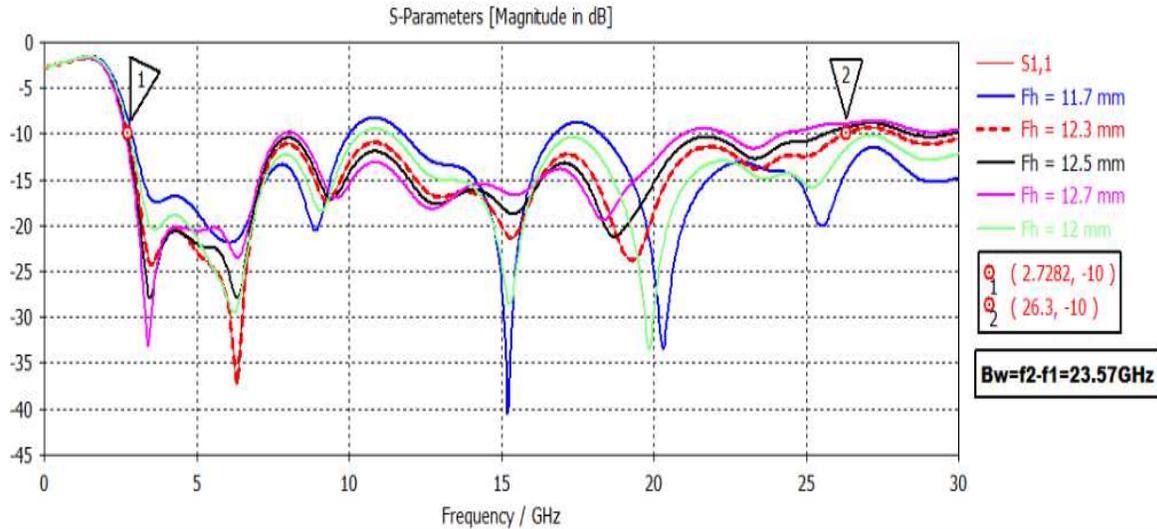


Fig. 7 Frequency vs. reflection coefficient graph for different values of feed height (F_h)

5.6 Effect of Feed-line Width (F_w)

For different values of the feed width, $F_w = 2.55$ mm, 3 mm and 2 mm it was measured that as the feed-line width was increased from 2 mm to 2.5 mm good performance of antenna was obtained with respect to its reflective behavior. Simulations of these measurements analysis are shown in Fig 8.

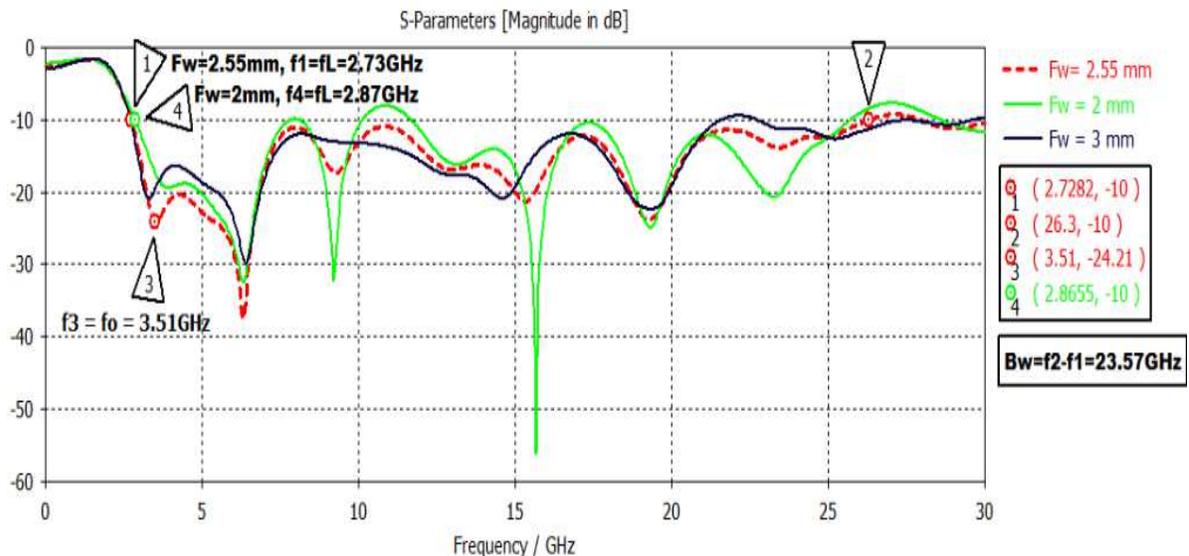


Fig. 8 Frequency vs. reflection coefficient graph for different values of feed width (F_w).

Fig 8, also investigated that the changing feed-line width has effect on resonance frequency (f_r) and f_L .

Hence, considering the requirement of compact size, the optimized value of ground plane width was taken as $F_w = 2.55$ mm.

5.7 Effect of Truncation of the ground plane

There is a very useful and effective technique for reducing the reflection coefficient. This is done by truncating the ground plane into rectangular or square shape geometry. This behavior of antenna is simulated and measured in this section.

5.7.1 By square shape

Ground plan was truncated by different values into a square shape geometry, i.e. $L \times W = (4 \times 4)\text{mm}^2$, $L \times W = (3.5 \times 3.5)\text{mm}^2$, $L \times W = (3.0 \times 3.0)\text{mm}^2$, $L \times W = (2.5 \times 2.5)\text{mm}^2$, $L \times W = (1.5 \times 1.5)\text{mm}^2$, $L \times W = (1.0 \times 1.0)\text{mm}^2$. Simulations have been performed by using all these values to achieve desired band width. Results show different range of bandwidth according to the dimensions of square shape as shown in Fig 9.

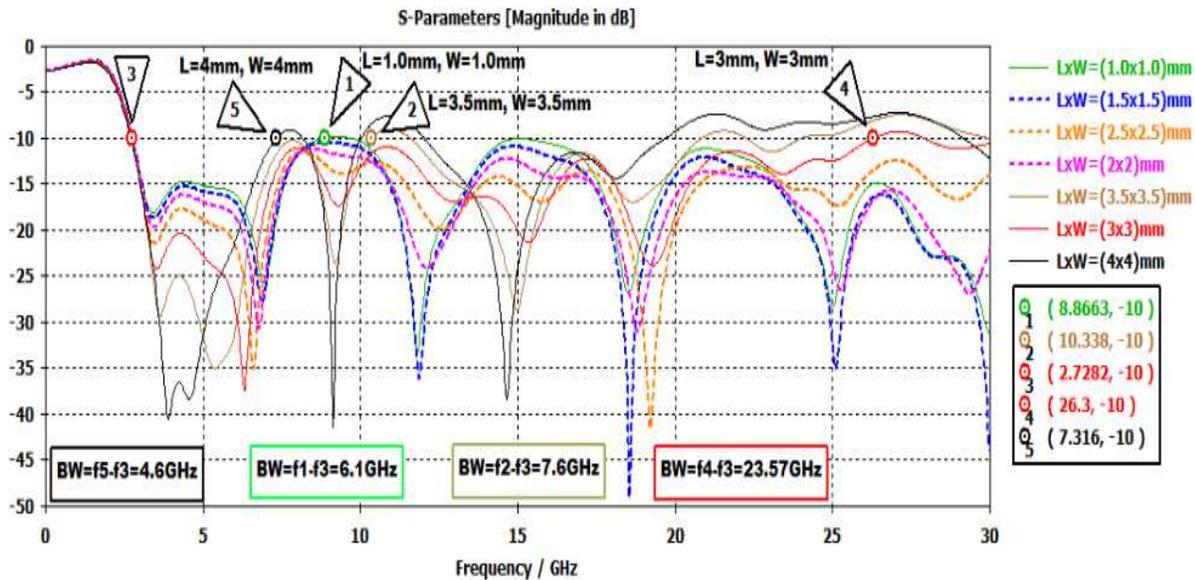


Fig. 9 Frequency vs. reflection coefficient graph for different dimension of square shape ground plain

Simulations in Fig. 9 showed that f_L remained constant for all the different dimensions of square shaped ground plane while reflection coefficient was less than -10dB and f_H on each curve varied. Bandwidth was increased as we dimensions of square were decreased. When the dimensions of square shaped ground plane were made $L \times W = (2.5 \times 2.5)\text{mm}^2$, the bandwidth was achieved up 28.7 GHz. The value of bandwidth continuously increased as dimension or areas of square were decreased but when the dimension was made $L \times W = (1.0 \times 1.0)\text{mm}^2$

then again bandwidth started decreasing. This behaviour and relationship of bandwidth against the dimensions of ground plane are summarized in Table 2.

Table 2. Bandwidth values for various Dimensions of antenna, when truncation is performed by Square shape.

S. NO.	Dimension (mm)	Area (mm ²)	Bandwidth (BW) (GHz)
1	4 x 4	16	3.59
2	3.5 x 3.5	12.25	7.61
3	3 x 3	9	23.57
4	2.5 x 2.5	6.25	29.23
5	2 x 2	4	BW > 30 GHz
6	1.5 x 1.5	2.25	BW > 30 GHz
7	1 x 1	1	6.1

5.7.2 By rectangular shape

Just like it was done for square shaped ground plane, here the ground plan was truncated by different values of rectangular shape dimensions, i.e. $L \times W = (3 \times 1.5)\text{mm}^2$, $(1.5 \times 3)\text{mm}^2$, $(3 \times 3.5)\text{mm}^2$, $(3.5 \times 3)\text{mm}^2$, $(3.5 \times 2.5)\text{mm}^2$ and $(0.75 \times 1.5)\text{mm}^2$. Simulations are shown in Fig 10.

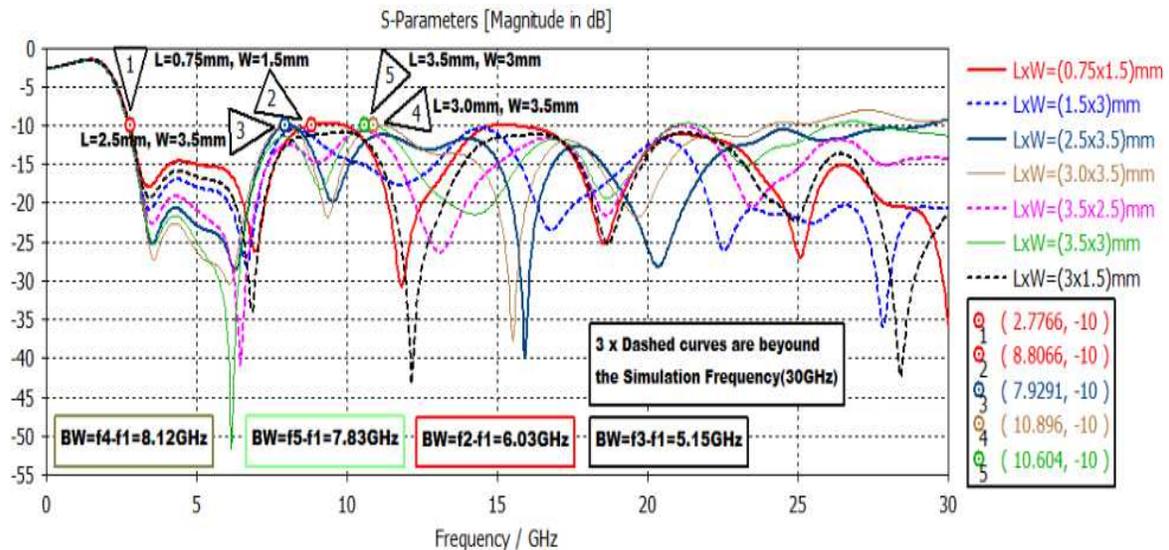


Fig.10 Frequency vs. reflection coefficient graph for different dimension of rectangle before optimization

Simulations in Fig 10 showed that f_L remained constant for all the different dimensions of rectangular shaped ground plane while reflection coefficient was less than -10dB and f_H on each curve varies. Bandwidth was decreased as the dimensions or area of rectangle was decreased. But when the dimensions of rectangle shaped ground plane were made $L \times W = (2.5 \times 3.5)\text{mm}^2$, $L \times W = (1.5 \times 3.0)\text{mm}^2$ the increment in bandwidth were achieved beyond the simulation frequency (30GHz). when we continuously decreases the dimension or area of rectangle then at $L \times W = (0.75 \times 1.5)\text{mm}^2$ the value of bandwidth again decreased. This behaviour and relationship of bandwidth against the dimensions of ground plane are summarized in Table 3.

Table 3. Bandwidth values for various dimensions of antenna, when truncation is performed by rectangle shape

S.NO	Dimension(mm)	Area (mm ²)	Bandwidth (BW) (GHz)
1	3.5 x 3	10.5	8.16
2	3 x 3.5	10.5	7.86
3	3.5 x 2.5	8.75	5.19
4	2.5 x 3.5	8.75	BW > 30GHz
5	1.5 x 3.0	4	BW > 30GHz
6	3.0 x 1.5	4	BW > 30GHz
7	0.75x1.5	1.125	6.03

Simulating for both rectangular and square ground plane shows that high bandwidth can be achieved by either of them. But comparatively square shaped ground plane provided higher bandwidth and practically they are easier to be fabricated. Hence therefore square shaped ground plane structure was considered for the final design.

6. Results

Simulations were carried out for bandwidth measurements using both non-optimized and optimized truncated ground plane antenna structures. The simulation results for S_{11} (dB) are shown in Fig. 11

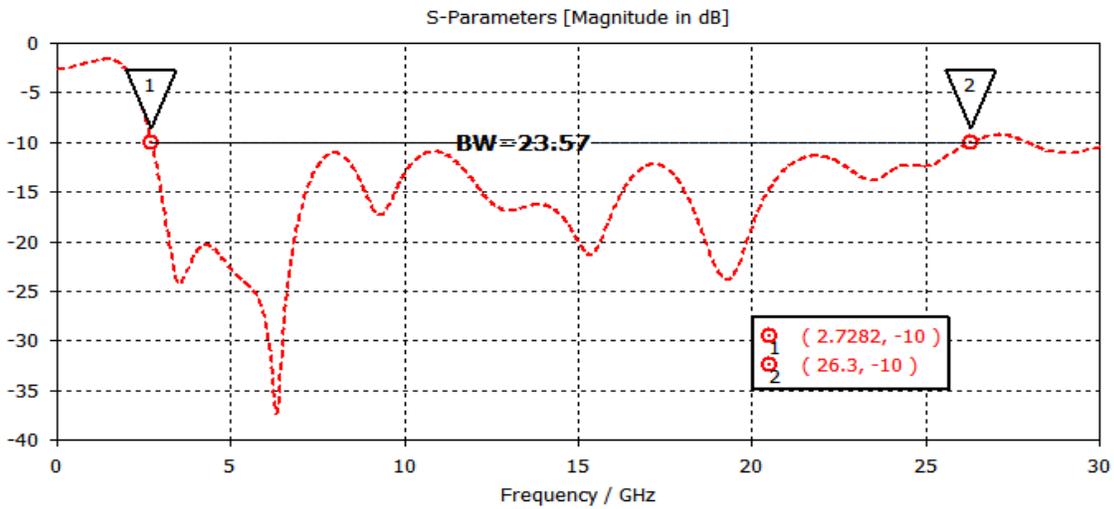


Fig. 11 Simulated result for non optimized truncated ground plane, S_{11} parameter magnitude in dB

In Fig 12 are shown the simulation results when the truncated ground plane optimized to square shape was used. This clearly shows the increase in bandwidth as compared to non-optimized truncated plane

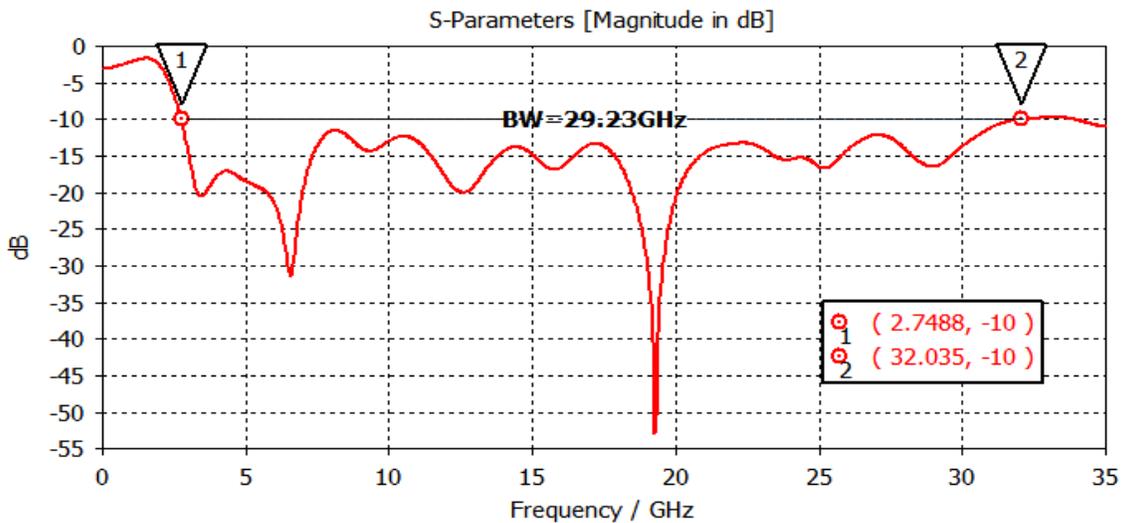


Fig. 12 Simulated result for optimized truncated round plane, S_{11} parameter magnitude in dB

The vector network analyzer (VNA) was used to verify the simulated result. These are shown in Fig. 12

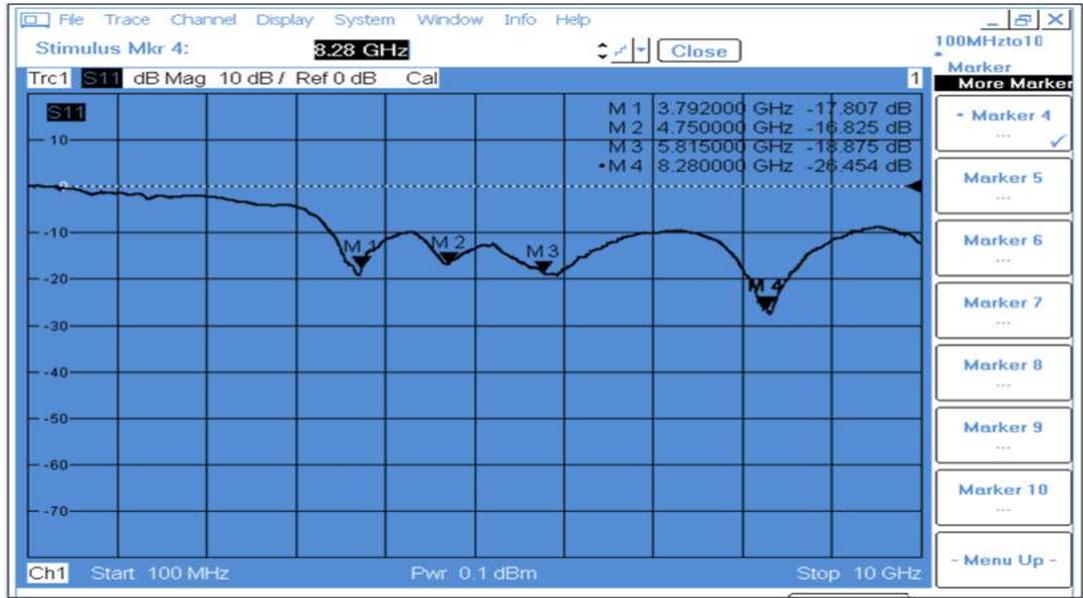


Fig. 13 Measured result from 400MHz to 10GHz, S_{11} parameter magnitude in dB

The directivity of the optimized antenna and voltage standing wave ratio are shown in Fig 14 and Fig 15 respectively.

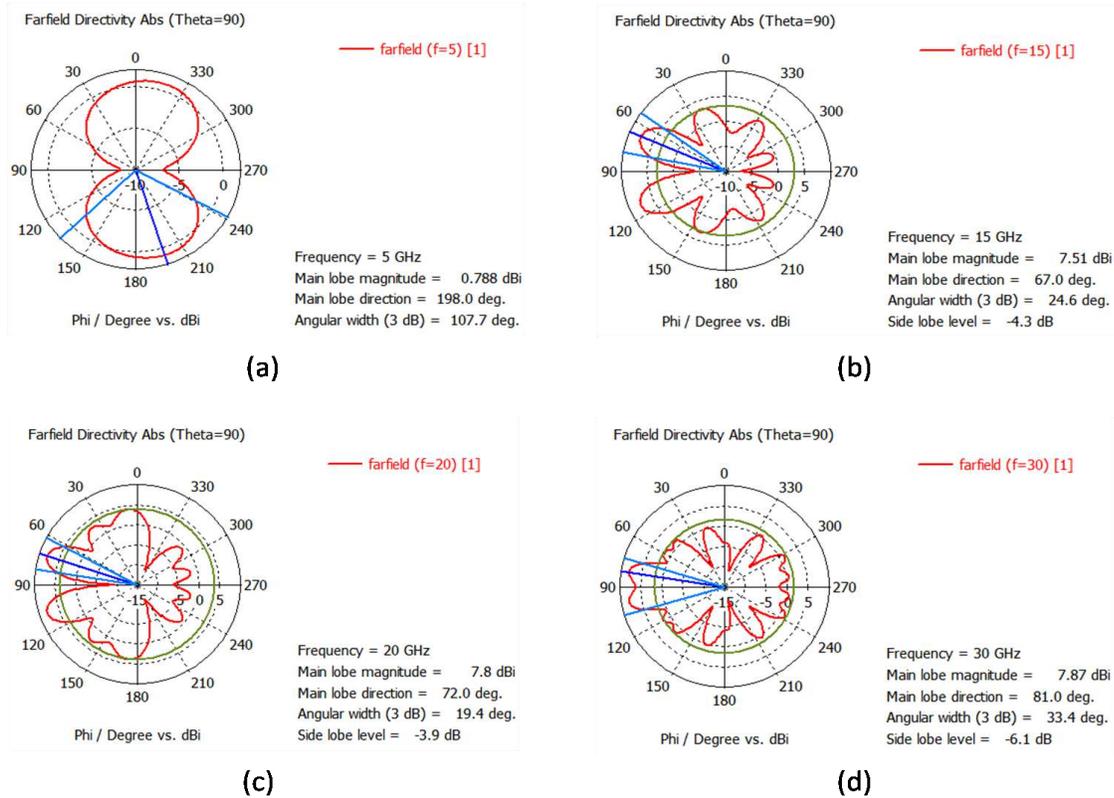


Fig. 14 Directivity of optimized Antenna at (a) 5GHz, (b) 15GHz, (c) 20GHz and (d) 30GHz

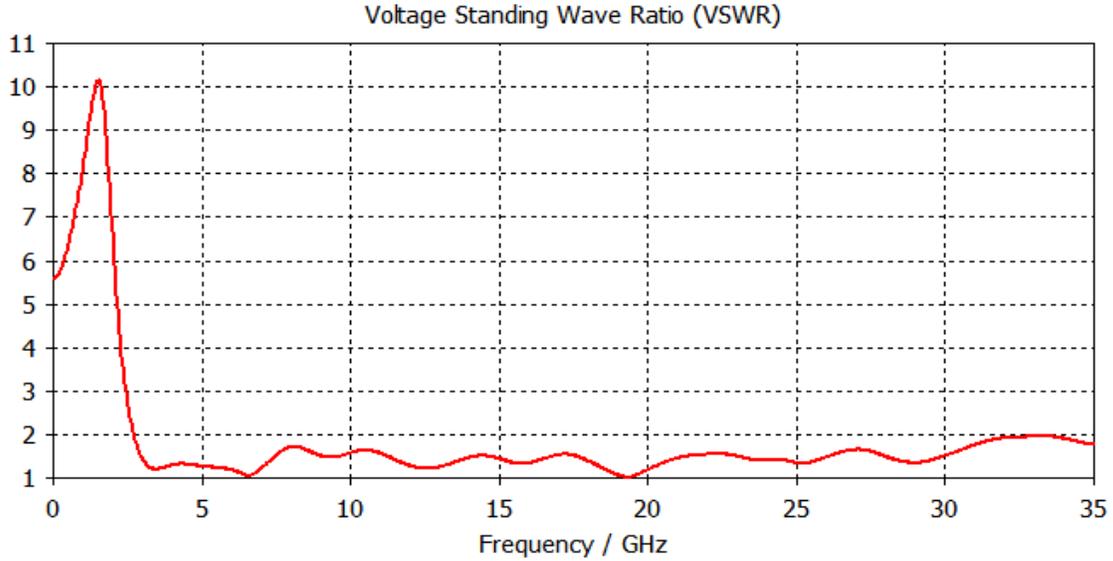


Fig. 15 Voltage Standing Wave Ratio graph for proposed optimized Antenna

Since in the proposed antenna the primary concern was increase in bandwidth along with moderate structure size of antenna, below in Table 4 some previous reported antennas are listed with the comparison in term of size and bandwidth with this design.

Table 4. Bandwidth values for various dimensions of some previously presented antennas

Refrences	Size (WxL) (mm) ²	Operating band (f_H-f_L) GHz	Band Width (BW)GHz
[7]	39 × 36.6	3.5 – 17	13.5
[8]	32 × 25	2.85 – 15.25	12.4
[9]	30 × 30	0.020 – 20	19.98
[10]	60 × 55	2.0 – 14.65	12.65
[11]	22 × 25	3.1-12.18	9.08
[12]	25 × 35	3.54 – 12	8.46
[23]	17 × 25	2.1 – 15.8	13.7
<i>Proposed Antenna (non-optimized ground plane)</i>	33×28	2.73–26.3	23.57
<i>Proposed Antenna (optimized ground plane)</i>	33 × 28	2.75–32.04	29.3

7. Conclusions

In this paper, we have successfully designed and developed a compact in size and high bandwidth UWB antenna using simulations and measurement engineering. In this study, in-depth simulations were carried out to show the design process and setting of antenna parameters. The final antenna structure is engineered to be compatible in low volume requirements such as in body area networks and others.

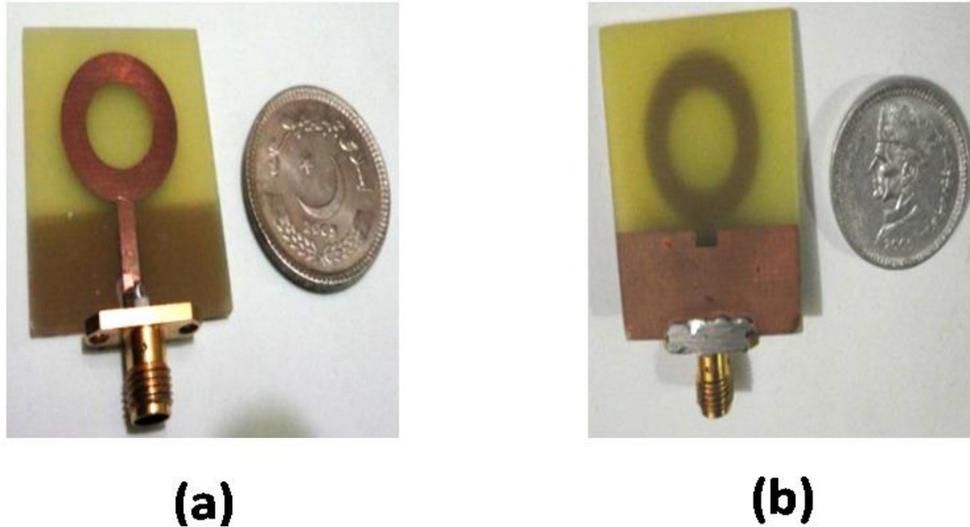


Fig. 16 (a) Front side (b) Back side of fabricated antenna

7. Declarations

Funding (The author(s) received no specific funding for this work)

Conflicts of interest/Competing interests (NO authors have competing interests)

Availability of data and material (All data are fully available without restriction)

Code availability (Available)

Authors' contributions (All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Syed Zeeshan Ali] and [Ikram e Khuda]. The first draft of the manuscript was written by [Syed Zeeshan Ali] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript)

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Figures

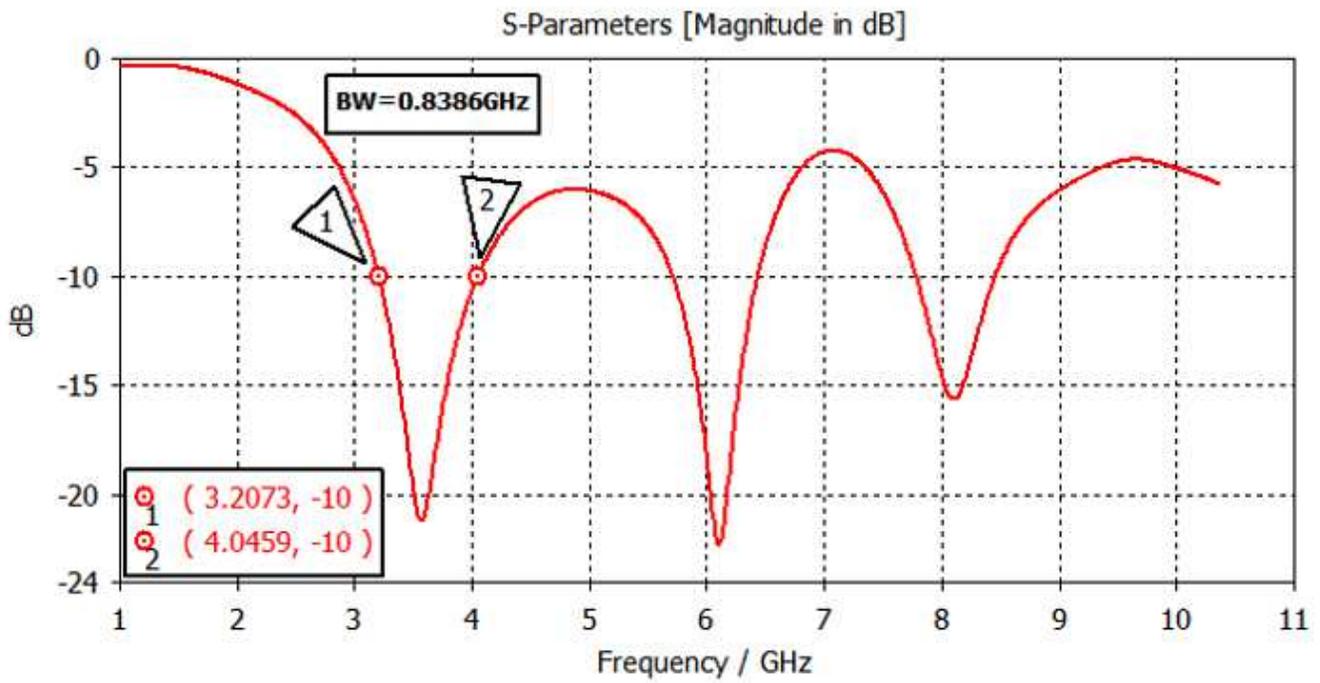


Figure 1

Frequency vs. reflection coefficient (S_{11}) graph, when outer radius $R = 8.89\text{mm}$ and Inner radius $r = 6.26\text{mm}$.

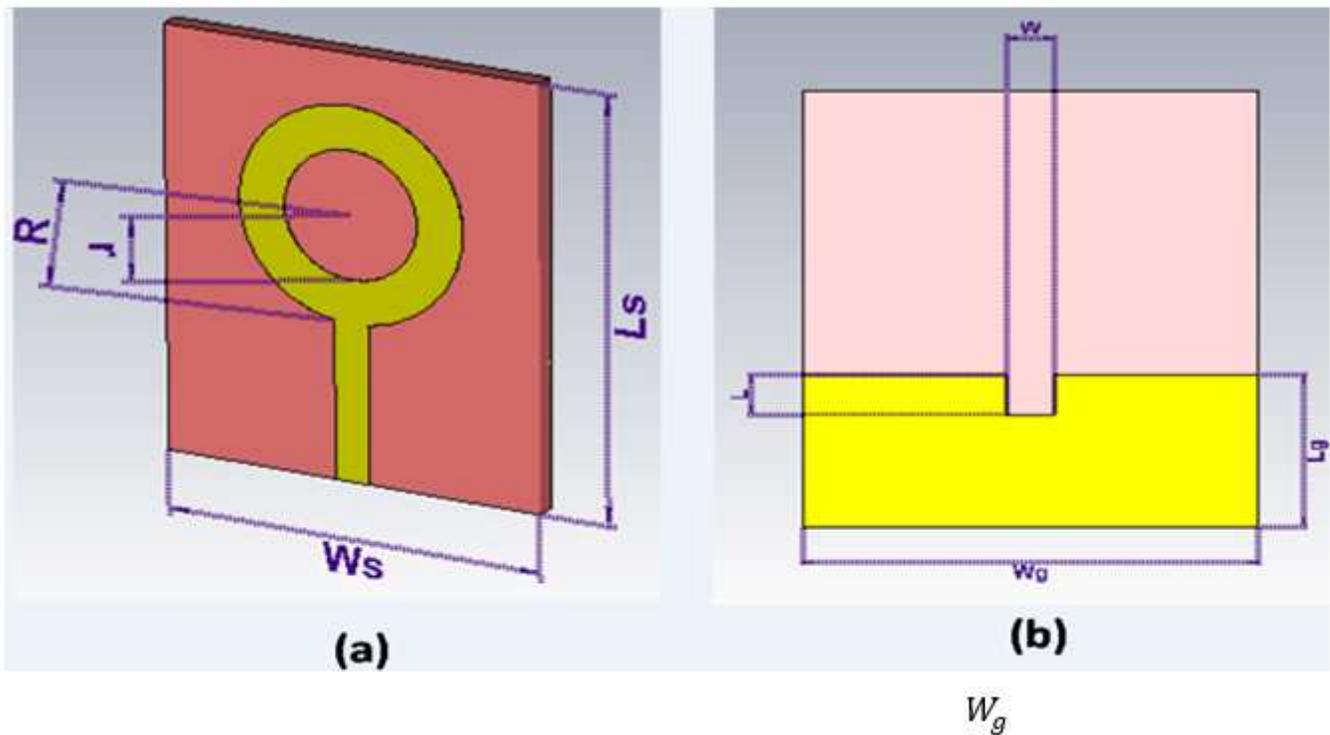


Figure 2

Optimized and proposed antenna geometry

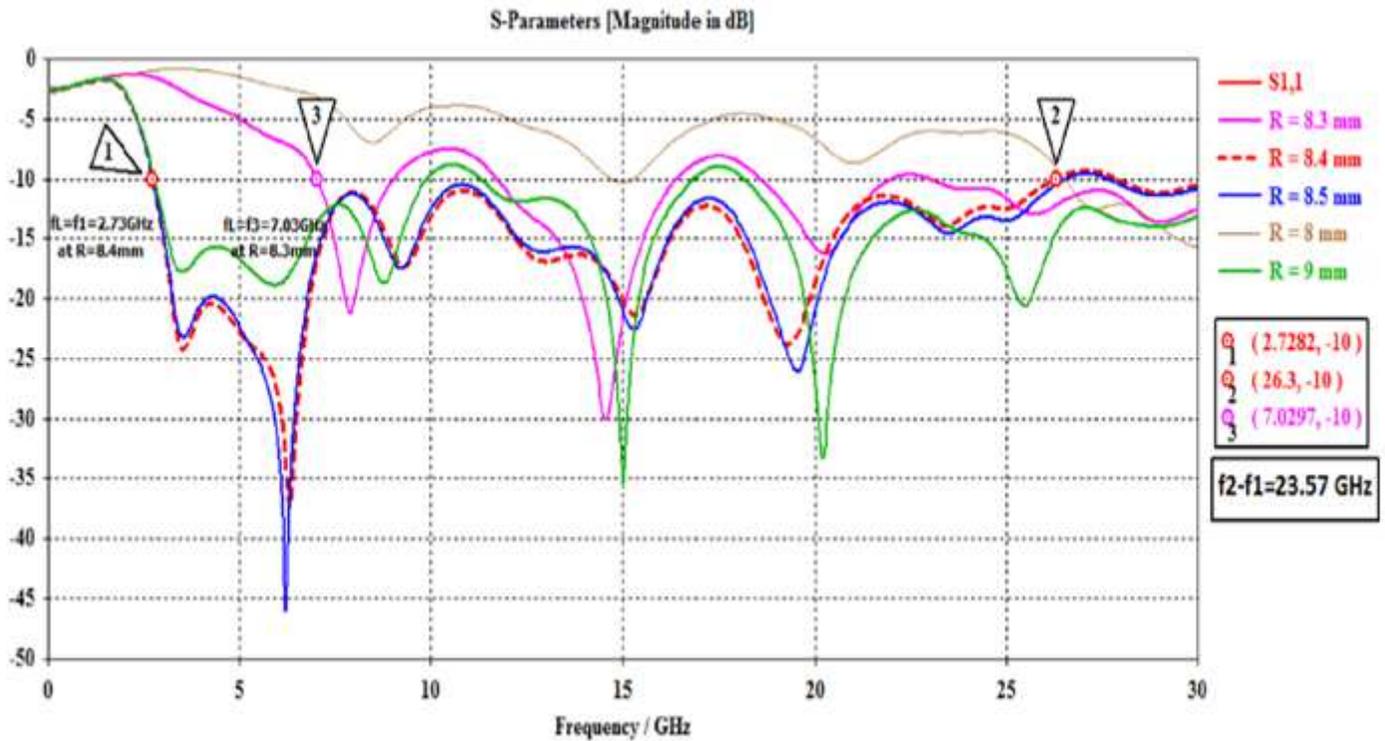


Figure 3

Frequency vs. reflection coefficient (S₁₁) graph for different patch outer radius(R)

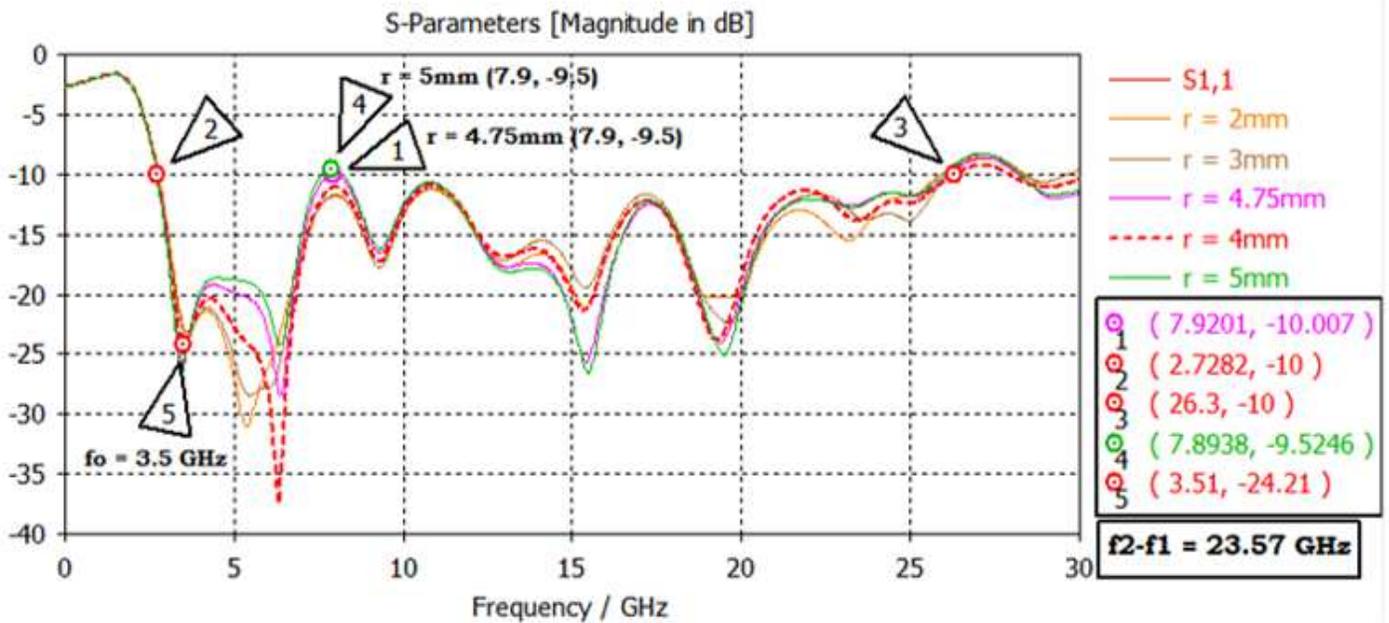


Figure 4

Frequency vs. reflection coefficient graph for different patch inner Radius (r).

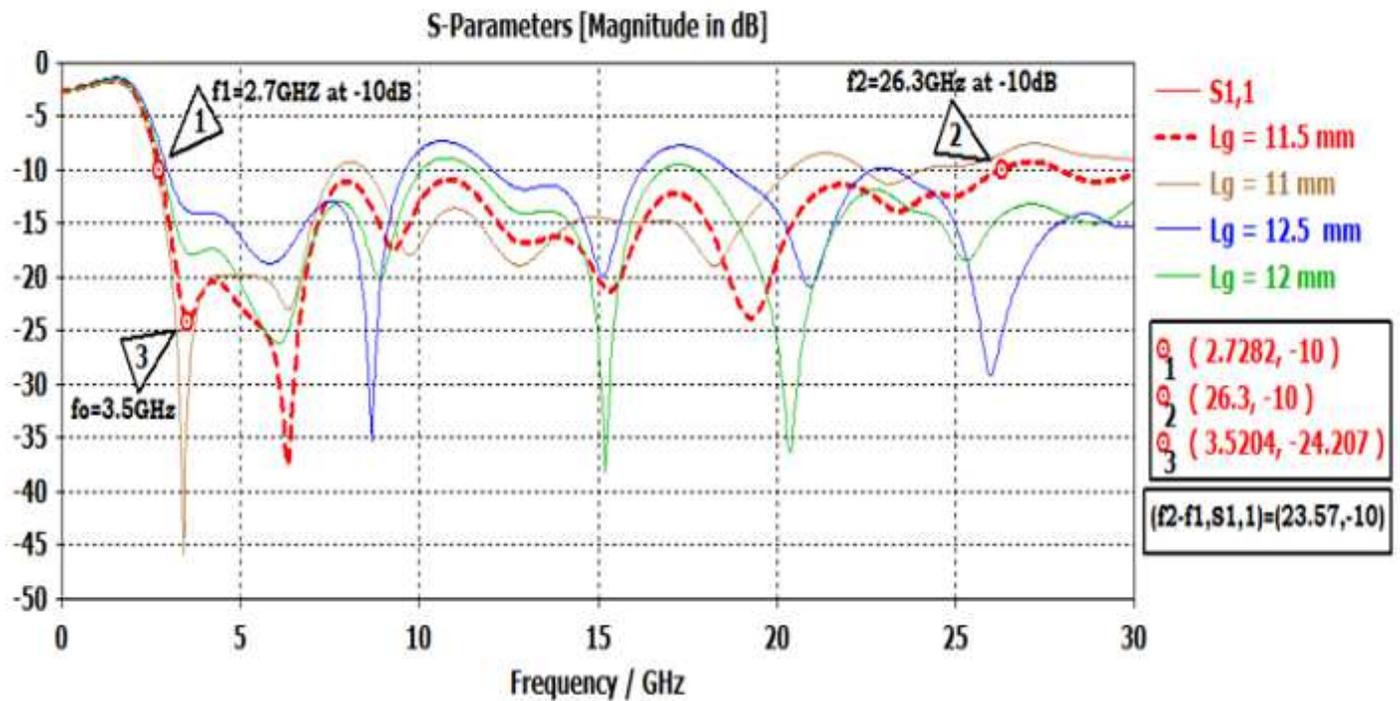


Figure 5

Frequency vs. reflection coefficient graph for different ground plane length (L_g)

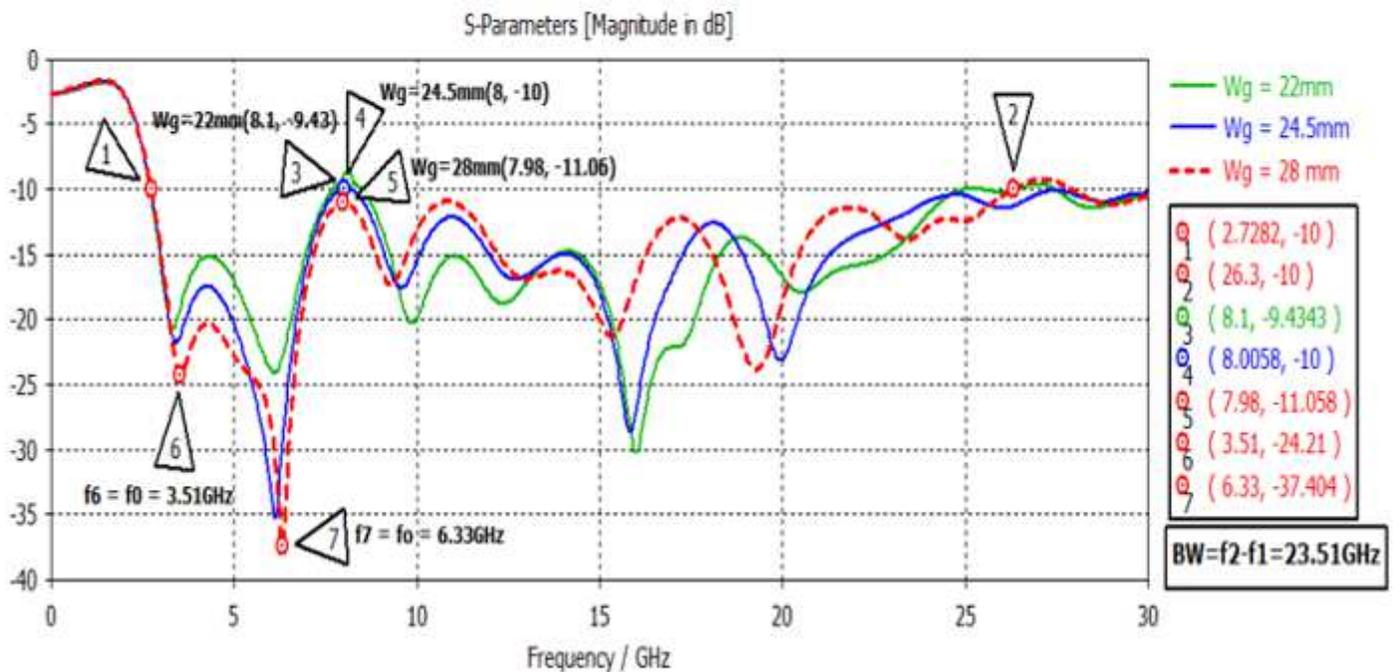


Figure 6

Frequency vs. reflection coefficient graph for different values of ground plan width (W_g).

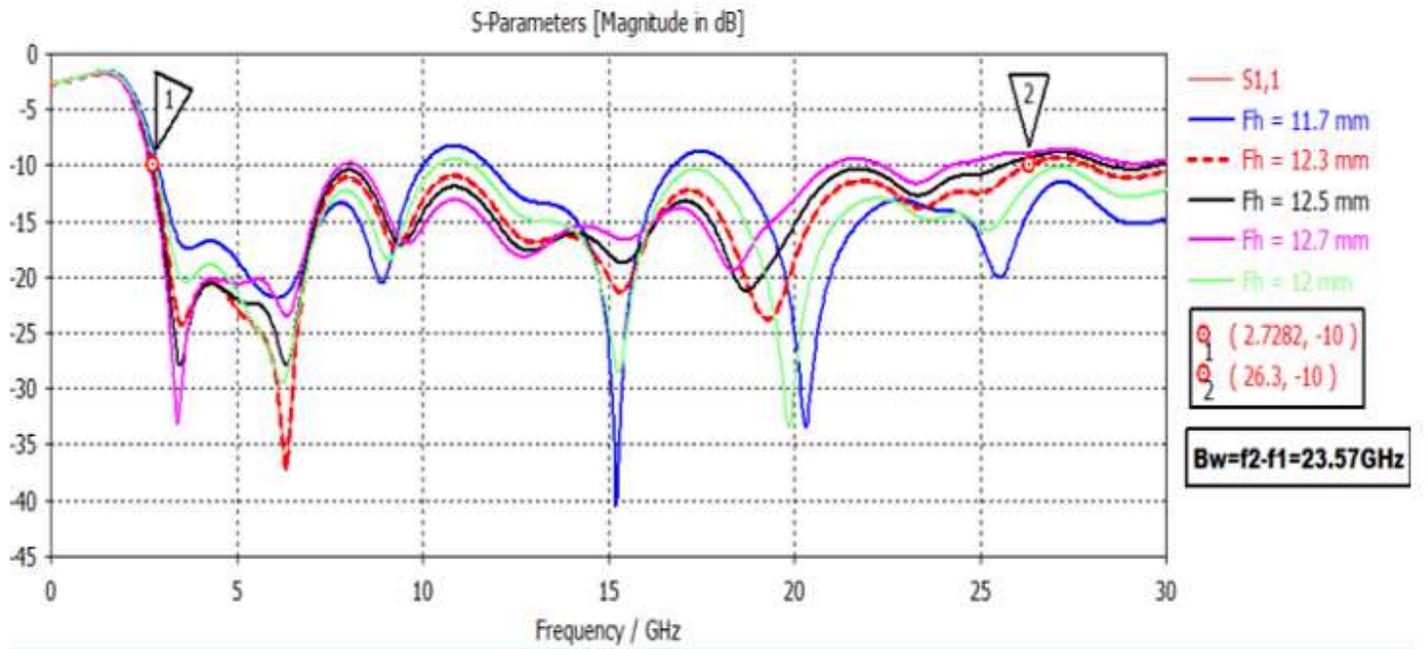


Figure 7

Frequency vs. reflection coefficient graph for different values of feed height (Fh)

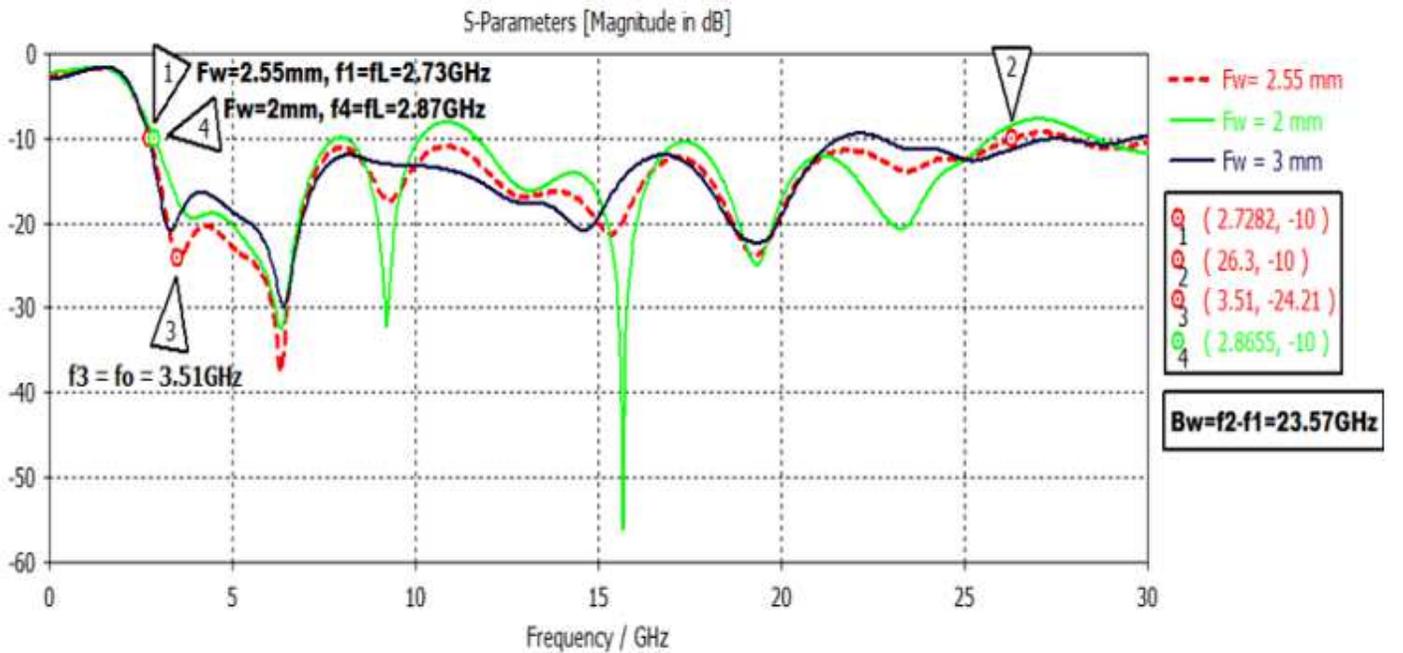


Figure 8

Frequency vs. reflection coefficient graph for different values of feed width (Fw).

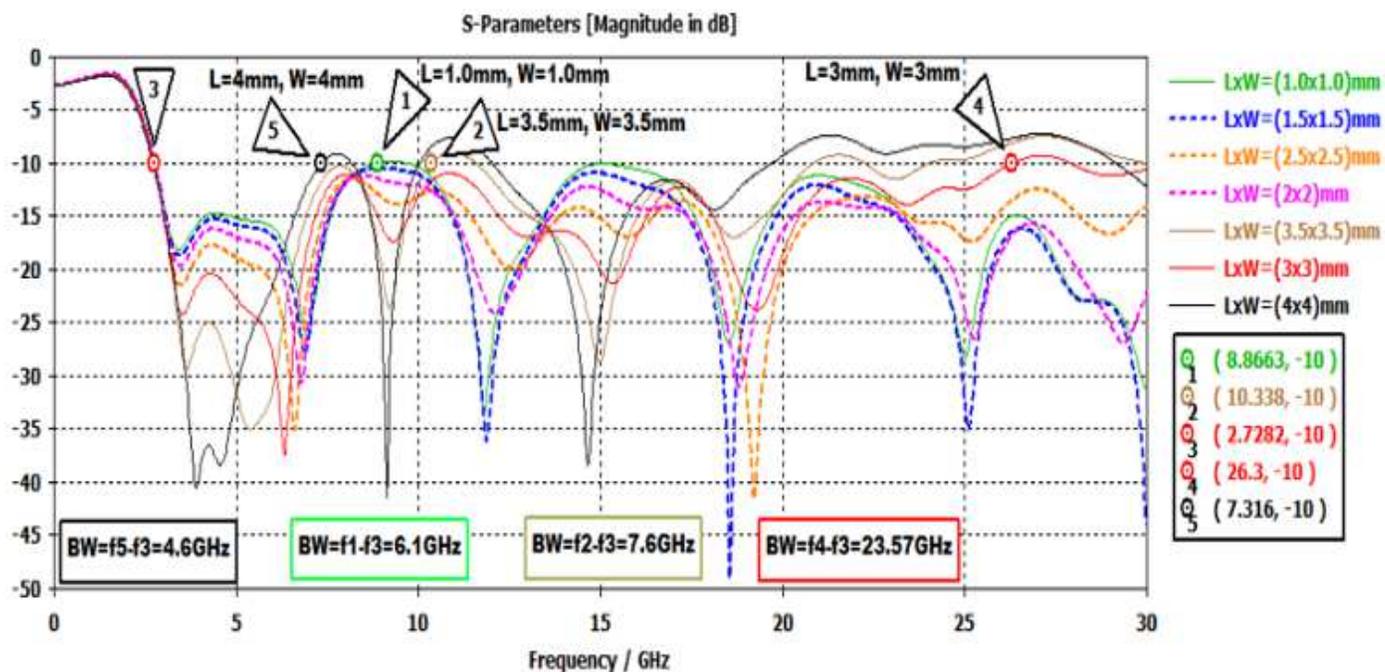


Figure 9

Frequency vs. reflection coefficient graph for different dimension of square shape ground plain

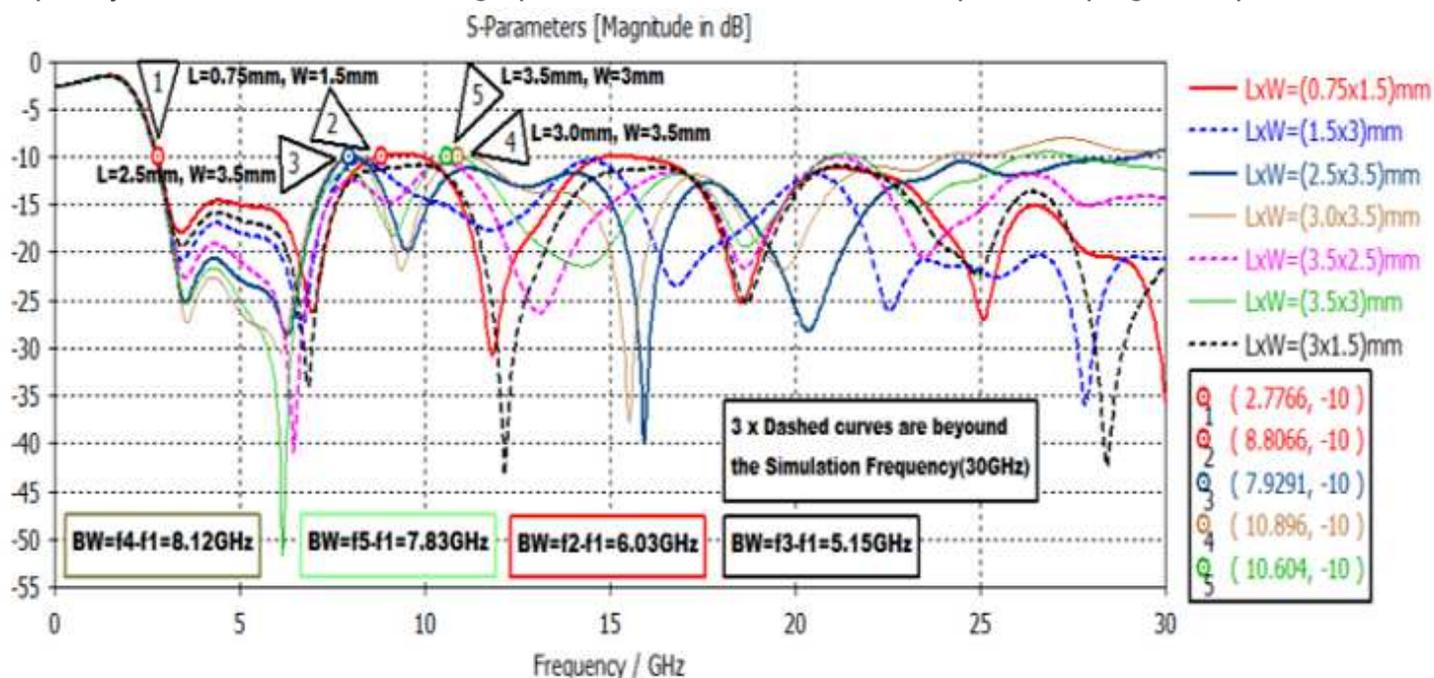


Figure 10

Frequency vs. reflection coefficient graph for different dimension of rectangle before optimization

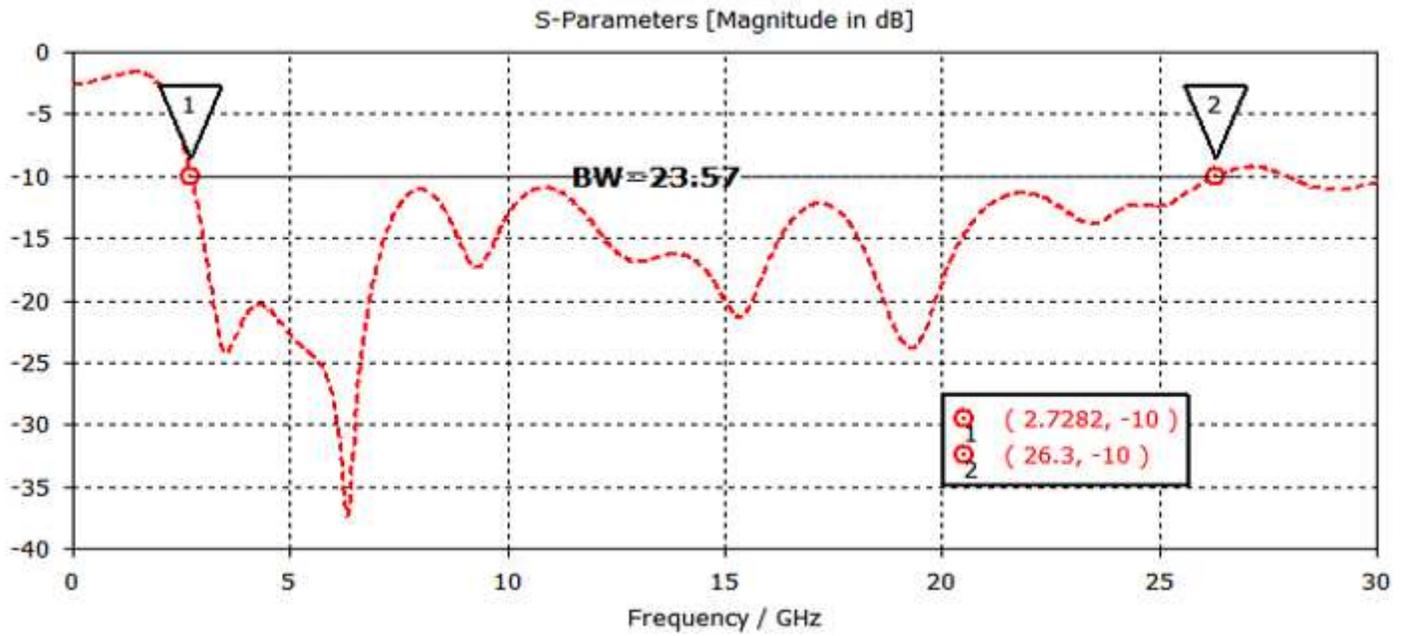


Figure 11

Simulated result for non optimized truncated ground plane, S11 parameter magnitude in dB

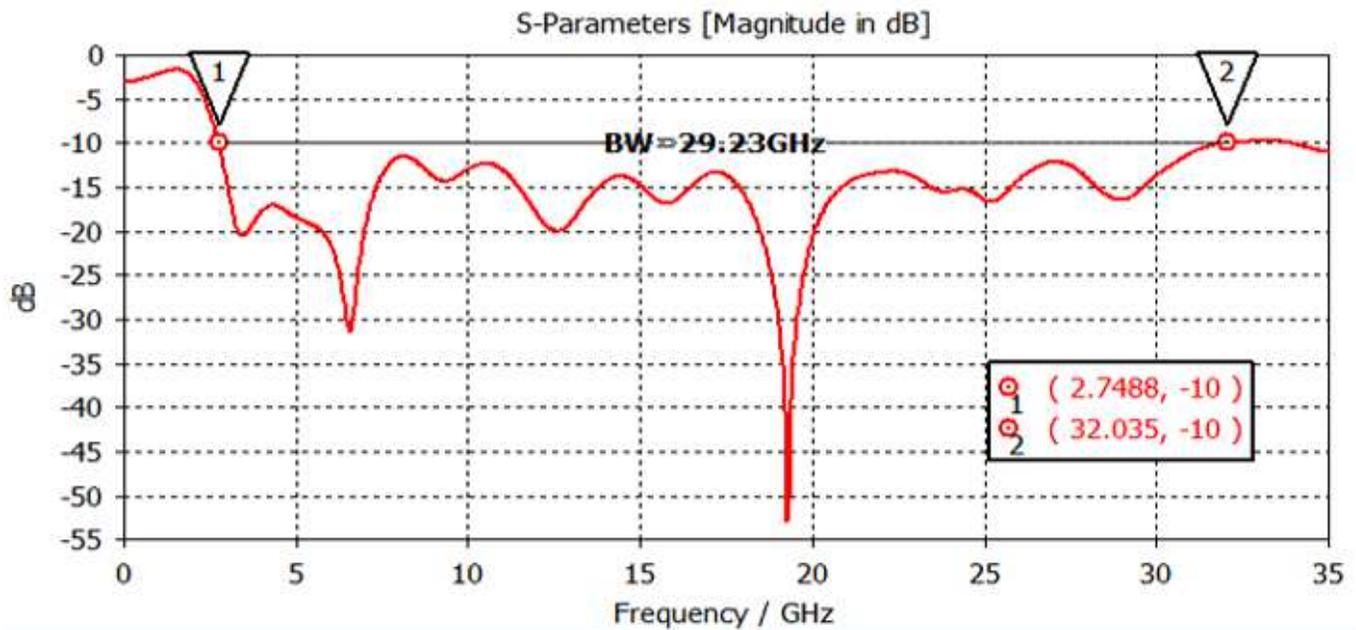


Figure 12

Simulated result for optimized truncated round plane, S11 parameter magnitude in dB

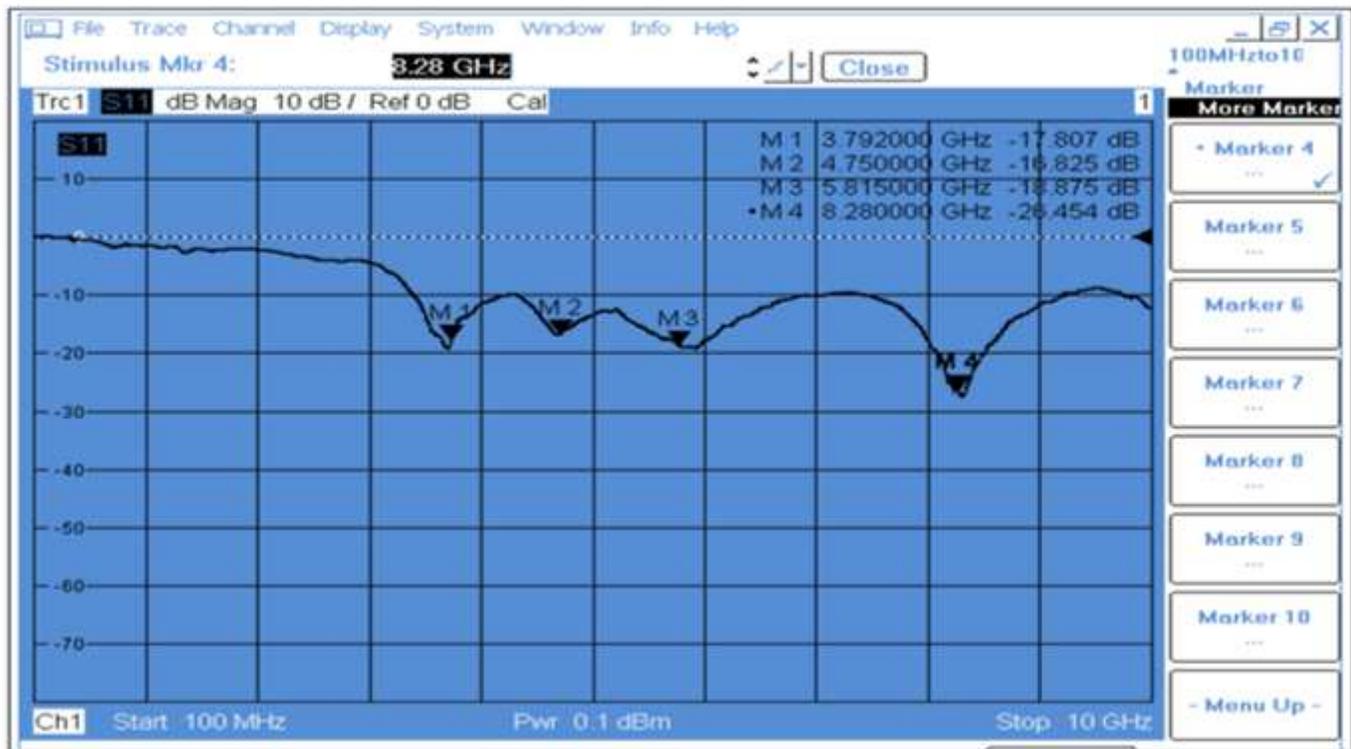


Figure 13

Measured result from 400MHz to 10GHz, S11 parameter magnitude in dB

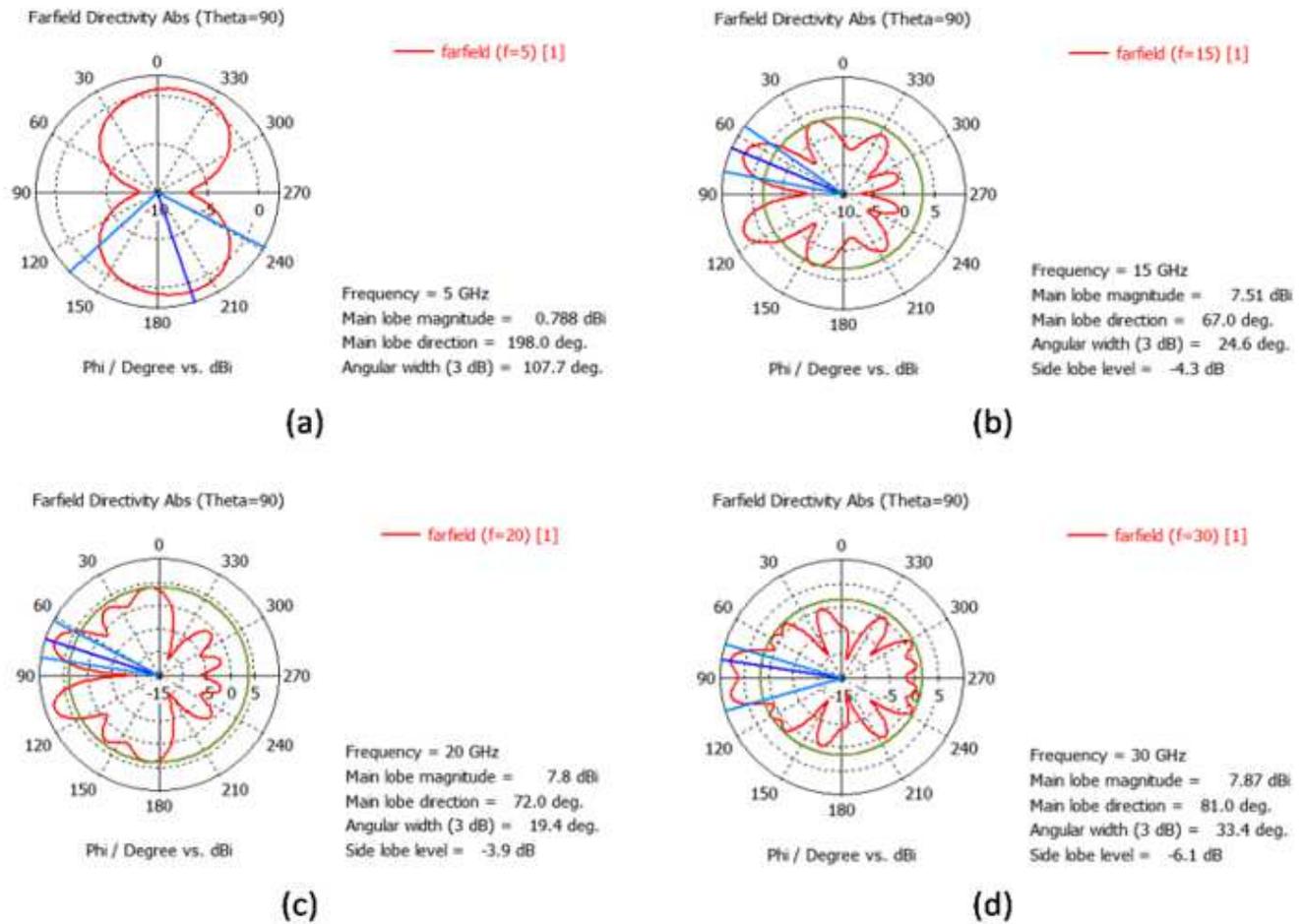


Figure 14

Directivity of optimized Antenna at (a) 5GHz, (b) 15GHz, (c) 20GHz and (d) 30GHz

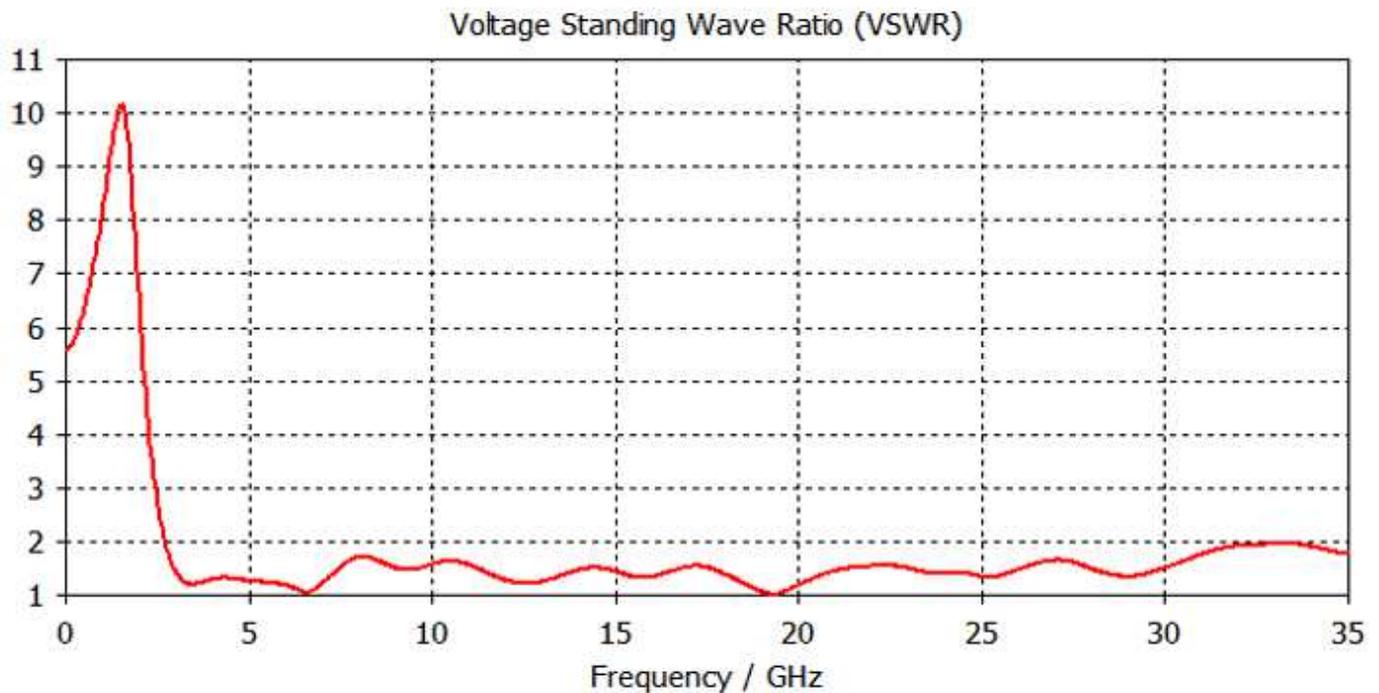
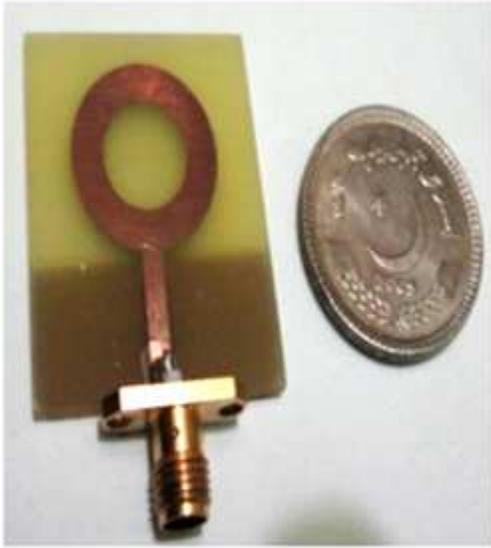
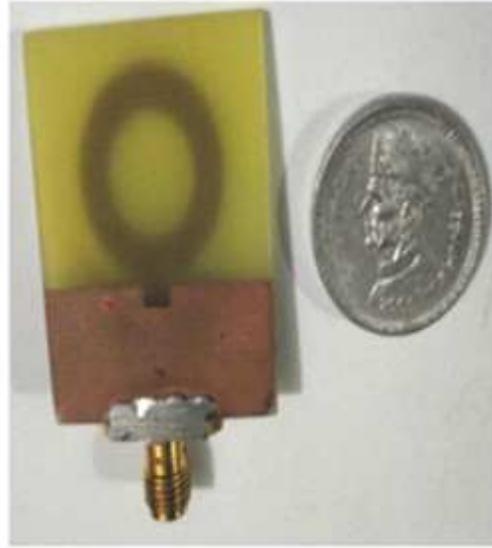


Figure 15

Voltage Standing Wave Ratio graph for proposed optimized Antenna



(a)



(b)

Figure 16

(a) Front side (b) Back side of fabricated antenna