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Design of Dual-Band Microstrip Antenna at L-Band and S-Band Frequencies for Synthetic Aperture Radar (SAR) Sensors

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Abstract - Synthetic Aperture Radar (SAR) is a remote sensing system using radar for high resolution image capture. The higher frequency used, the higher accuracy of the image detail that obtained, while, the lower frequency has a better image penetration capabilities. To combine these two advantages of the image result characteristic, SAR is designed to operate in two bands (dual-band). In this study, a dual-band antenna on 1.27 GHz (L-Band) and 3 GHz (S-Band) using slotted patch technique and proximity coupled feeding is designed. The material that used is the FR4 Epoxy dielectric with the relative permittivity of 4.6. As a result, the antenna operates at the frequency of 1.27 GHz with the return loss of -25.131 dB, VSWR 1.1201, and 19.9 MHz (return loss ⩽ -10 dB) bandwidth. While the return loss of 3 GHz is -16.802 dB, VSWR 1.3381, and bandwidth (return loss ⩽ -10 dB) 125.3 MHz.

Keywords - Microstrip Antenna, SAR, Dual-band, Slotted Patch

I. INTRODUCTION

Synthetic Aperture Radar (SAR) is a remote sensing technology that has many benefits. It can be operated in various weather conditions at night because it is an active system that operates on microwave frequency [1] [2]. Remote sensing has an important role in various topographical, environmental, and military applications. As an active sensor, SAR uses the basic principles of Radio Detection and Ranging (RADAR). It is referred as an active sensor because SAR must generate a microwaves signals to obtain an information from the observed object [1]. The way it works is by transmitting microwaves to an object that be observed, then capturing the echoes.

The implementation of different bands of the SAR will certainly produce different images [3]. The higher frequency used, the higher accuracy of the image detail that obtained, while, the lower frequency has a better image penetration capabilities. To combine these two advantages of the image result characteristic, SAR is designed to operate in two bands (dual-band). Currently, SAR operates on a specific frequency band. However, in the future generations, it will at least cover two of the three antenna frequency bands used [4].

Recently, many research about dual-band microstrip antennas for SAR application has been done [5] [6]. Because the antenna for SAR only consists of one antenna, which operates in two different frequencies, that can increase target collection on the SAR system [7], also reducing its size.

Some studies have designed dual-band antennas for SAR applications. Among them, there are dual-band antennas at C- and X-Band frequencies [7], L- and X-Band [8], L- and C-Band [5], S- and X-Band [9], even the combination of those three frequencies at once, C-, X-, and Ku- Band [10]. The study has a complex antenna design. There is also a use coaxial probe that difficult to do the modification by doing arrays on the antenna to produce higher gain as the specification needed.

Microstrip antenna designed in this research is expected to get the specification according to the requirement of SAR system which has two other operating frequency that is L-band and S-band. Using a slotted patch technique with proximity coupled feeding and simulated using CST Studio 2014 software.

This research journal consists of four parts, firstly the introduction, followed by an explanation of the research method, the results and discussion of the simulation before and after the optimization in the third part, and the last is the conclusion.

II. RESEARCH METHOD

The dual-band antenna that proposed in this study is a square patch microstrip antenna with a slotted patch technique. It uses a proximity coupled feeding, which is expected to be developed in SAR applications, with the specification is presented in Table 1.

Table 1.The Specifications of the Antenna

Operating Frequency	1.27 GHz (L Band) and 3 GHz (S-Band)
VSWR	≤ 2
Bandwidth	10 MHz

A. *Square Patch Microstrip Antenna*

Antenna is a device for transmitting or receiving radio waves [11]. One type of antenna is microstrip antenna which consists of three main layers, patch, the dielectric substrate, and the ground plane.

There are several basic shapes of the patch on the microstrip antenna, one of them is a rectangle. The rectangle microstrip antenna is the most popular among the others because it is easy to be analyzed and fabricated [11]. However, with different length and width values, the frequency optimization during simulation can be done by modifying those two parameters. Therefore, this research used a square-shaped patch, so that in doing frequency optimization we only need to modify one parameter.

The design of the antenna begins with the calculation of the antenna dimension required for the initial design. This step will affect the characteristics of the designed antenna directly. The higher frequency desired, the smaller antenna dimension obtained.

Before calculating the antenna dimensions, first determined the following values.

a) Operating frequency = 1.27 GHz, 3 GHz
b) ε_r FR4 (Epoxy) = 4.6
c) Patch thickness = 0.035 mm
d) Height of substrate = 1.6 mm

Here are the equations used to calculate the dimensions of the antenna [11].

1. Width of The Patch (W)

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

2. Length of The Patch (L)

Before calculating the length of the patch, it is necessary to calculate the relative dielectric constant (2), fringing effect (3), and the effective patch length (4) first.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-1/2} \tag{2}$$

$$\Delta L = 0{,}412h\,\frac{(\varepsilon_{reff}+0{,}3)(\frac{W}{h}+0{,}264)}{(\varepsilon_{reff}-0{,}258)(\frac{W}{h}+0{,}813)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

3. Length of The Ground Plane (Lg)

$$L_g = 6h + L \tag{6}$$

Where

c = Speed of light (3×10^8 m/s)
f_0 = Operating Frequency
ε_r = Dielectric constant
h = Height of substrate

Based on the calculations using equations (1) to (6) we find the patch and ground plane dimensions to be designed shown in Fig.1.

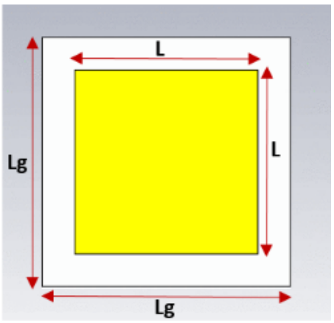


Fig.1. Dimension of Antenna Before Slotted

B. *Slotted Patch*

Recently, many microstrip antennas are developed to operates on two different frequencies or often referred as dual-band antenna. However, to design the antenna, it is required a technique. Commonly the techniques used are by stacking two different patches on the different substrate (stacked patch), coplanar, and by making a hole in the patch (slotted patch [4].

There have been many related studies that produce dual-band antennas using these techniques. However, the stacked patch technique has a weakness that is quite difficult to apply to create a dual-band antenna with a large frequency ratio [4], while the antenna to be designed has a large enough frequency ratio, which is 2.36. The Co-Planar technique is widely used to produce dual-band antennas whose resonance frequencies are so far apart that they have much different patch sizes between one frequency and the other [4].

In this research, the design of dual-band antenna uses slotted patch technique because of its capability of generating frequencies far enough with a simple design. In addition, slots on the patch can also increase the bandwidth [12] [13].

The shape of the slot is square. The dimension of the slot is calculated from the patch antenna dimension performed on equations (1) to (5) with a center frequency of 3 GHz. This slot design is actually a higher-frequency (3 GHz) patch dimension that is used as a hole in a lower-frequency (1.27 GHz) patch as shown in Fig.2.

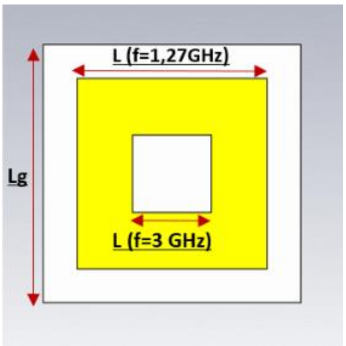


Fig.2. Slotted Patch Antenna

C. *Proximity Coupled Feeding*

Proximity coupled is a feeding technique by placing a feed line between two substrates. There is a ground plane at the bottom of the substrate and there is a patch on top of its upper substrate.

The main advantage using this technique is that it can eliminate the simulated/imitated radiation from the feed and provide a very high bandwidth, about 13%, due to the increasing of antenna thickness [14]. However, this technique also has drawbacks such as fabrication is more difficult because it uses two substrate elements where each element requires proper alignment.

The dimension of the feed line is calculated by the following equations [11].

1. Width of Feed Line (Wf)

$$B = \frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} \quad (7)$$

$$A = \frac{Z_o}{60}\left[\frac{\varepsilon_R+1}{2}\right]^{1/2} + \frac{\varepsilon_R-1}{\varepsilon_R+1}\left[0.23 + \frac{0.11}{\varepsilon_R}\right] \quad (8)$$

$$W = \begin{cases} \frac{8he^A}{e^{2A-2}} & A > 1.52 \\ \frac{2h}{\pi}\left[\begin{matrix} B - 1 - \ln(2B-1) + \\ \frac{\varepsilon_R - 1}{2\varepsilon_R}\left(\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_R}\right) \end{matrix}\right] & A < 1.52 \end{cases} \quad (9)$$

2. Length of Feed Line (Lf)

$$\lambda_o = \frac{c}{f} \quad (10)$$

$$\lambda_d = \frac{\lambda_o}{\sqrt{\varepsilon_r}} \quad (11)$$

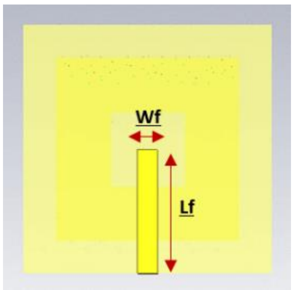
$$Lf = \frac{\lambda d}{4} \quad (12)$$

Where

Z_o = Impedance
c = Speed of light ($3x10^8$ m/s)
f = Operating Frequency
h = Height of substrate
ε_r = Dielectric constant
λ_o = Free space wavelength
λ_d = Dielectric wavelength

Based on equation (7) to (12), the dimensions of the designed feed line is shown in Fig.3.

(a)



(b)

Fig.3. Proximity Coupled Feeding; (a) Side; (b) Front

III. RESULT AND DISCUSSION

The design of the antenna in this research use FR4 Epoxy with relative permittivity 4.6, substrate thickness 1.6 mm, and conductor thickness is 0.035 mm. The desired dual-band antenna is having a center frequency at 1.27 GHz and 3 GHz. By calculating dimensions of the antenna according to frequency and characteristics of materials used, then get antenna dimensions as in Table 2.

Table 2. Antenna Dimension Before Optimization

Variable	Dimensions (mm)	Description
L	54.368	Length of patch
L Slot	22.162	Length ofslot
Lg	73.568	Length of ground plane
Wf	5.926	Width of feed line
Lf	27.53	Length of feed line

A. *Antenna Simulation Results Before Optimization*

The step after calculating dimensions of the antenna is to design the antenna according to the calculated dimension using CST Studio 2014 software.

The simulation result of return loss from antenna before optimization shown in Fig.4. From the graph, it can be seen that there will be some resonance frequency but the return loss is still big enough.

There is only one frequency that has a return loss$\leqslant$ -10 dB at a frequency of 2.293 GHz, so the antenna cannot be called a dual-band.

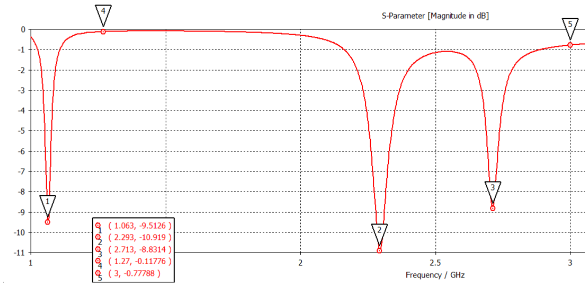


Fig.4. Simulation Result of Return Loss Before Optimization

Return loss is the ratio between the amplitude of the reflected wave to the amplitude of the transmitted wave. The desired return loss value in this study is ⩽ -10 dB. A large return loss value signifies many reflected waves because the transmission line with load input impedance (antenna) has not match. The closest frequency for L-Band is 1.063 GHz with a return loss of -9.5126 dB which has not met the criteria of tolerance. As for the nearest S-Band is a frequency of 2.713 GHz with a return loss of -8.8314 dB.

As for the simulation results VSWR of the antenna design before optimization shown in Fig.5. From the graph shows that the return loss is related to the VSWR value. Frequencies that have a small return loss will have a small VSWR as well. The best condition is when VSWR 1 which means no reflection, ie when the channel is in the perfect matching state. However, in fact, it is difficult to get a perfect VSWR value. This desired VSWR criterion of this study is ⩽ 2. At the closest frequency from the desired specification, VSWR has not entered criteria which 2.0054 at 1.063 GHz and 2.1335 at 2.713 GHz.

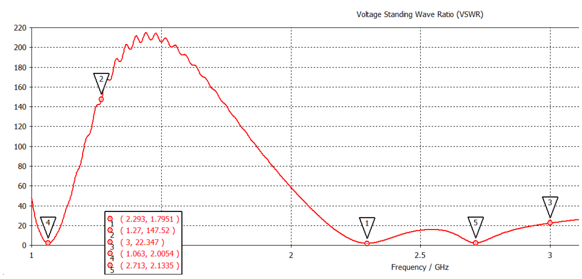
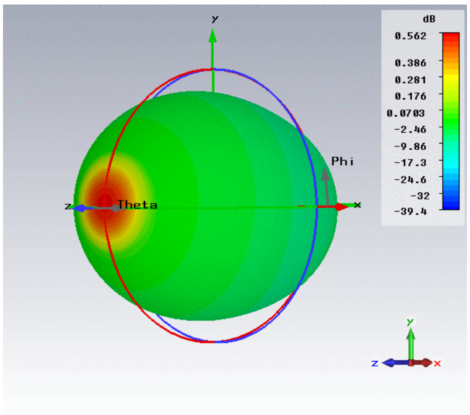


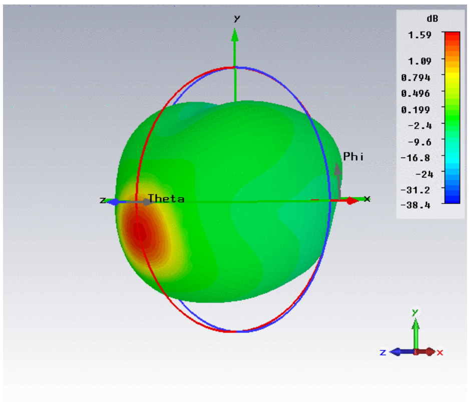
Fig.5. Simulation Result of VSWR Before Optimization

Figure 6 is an antenna gain simulation result. It is shown that the gain value at the frequency of 1.063 GHz is still very small at 0.562 dB Fig.6 (a), while in Fig.6 (b) the gain value at 2.713 GHz is 1.59

In Fig.7 show that the antenna at a frequency of 1.063 GHz or 2.713 GHz has a unidirectional radiation pattern. In case of polarization, the two frequencies have linear polarization which is shown in Fig.8 with the axial ratio value is 40 dB. Because the result is not as what expected, the next step to do is modifying the dimensions of the antenna to reach optimization.

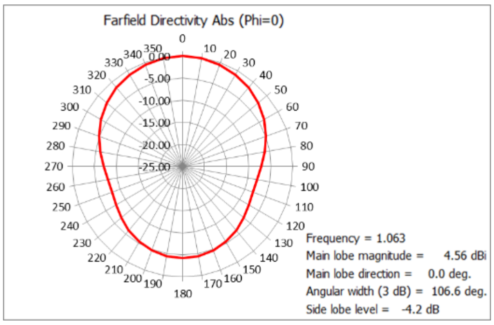


(a)

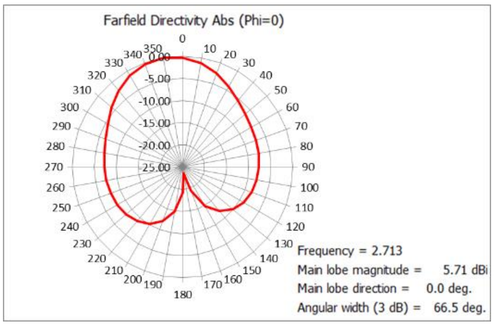


(b)

Fig.6. Simulation Result of Gain Before Optimization; (a) 1.27 GHz; (b) 3 GHz



(a)



(b)

Fig.7. Simulation Result of Radiation Pattern Before Optimization; (a) 1.27 GHz; (b) 3 GHz

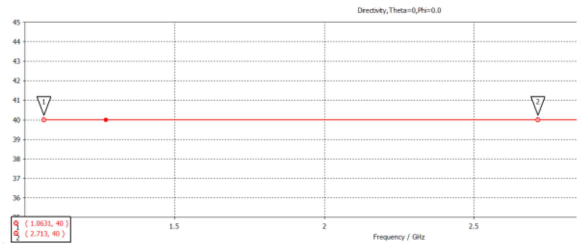


Fig.8. Simulation Result of Axial Ratio Before Optimization

B. Antenna Simulation Results After Optimization

Optimization is done by modifying the dimensions of the antenna. In order to get a low return loss, the modification is made on the feed part by changing the width and the length of the feed line. In addition, to shift the frequency of the antenna, the made changes in patch dimensions, and slots. Antenna dimension after optimization shown in Table 3.

Table 3. Antenna Dimension AFTER Optimization

Variable	Dimensions (mm)	Description
L	47.5	Length of patch
L Slot	16.5	Length of slot
Lg	73.568	Length of ground plane
Wf	3	Width of feed line
Lf	38	Length of feed line

When doing optimization, the first thing to do is to shift frequency to fit the desired specifications. The antenna design results before optimization get closest frequency value at L-Band and S-Band lower than the desired 1.063 GHz and 2.713 GHz. Therefore modifications are made by minimizing the size of the patch so that the frequency shifts higher. Smaller patch sizes can be obtained by minimizing patch dimensions or increasing slot dimension. Minimize return loss can be done with modifications to the feed line. But with the dimension of the feed line changed, the frequency generated can be a slight shift that is not so significant that it needs to be done again frequency optimization.

After modification on the patch and slot dimensions, as well as the feed line, the result of return loss as shown in Fig.9. From the graph can be seen,

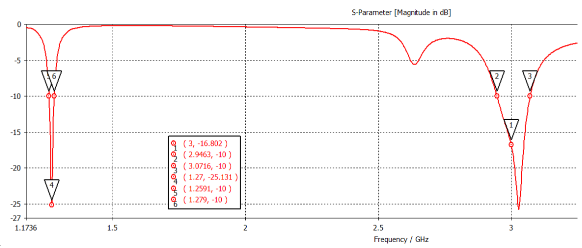


Fig.9. Simulation Result of Return Loss After Optimization

The antenna has two resonance frequency which can be said as dual-band antenna.With the return loss ⩽ -10 dB the frequency range on the L-Band band is 1.2591-1.279 GHz, whereas in the S-Band band is 2.9463-3.0716. With these frequency band ranges, the resulting bandwidth is 19.9 MHz (L-Band) and 125.3 MHz (S-Band), which meet the desired specifications. The desired operating frequency was already in accordance with the specification with low return loss is quite low compared with the results before the optimization is -25.131 dB at 1.27 GHz and -16.802 dB at 3 GHz.

VSWR of both frequencies after optimization can be seen in Fig.10. From the graph, it can be observed VSWR at 1.27 GHz and 3GHz. At 1.27 GHz VSWR is 1.1201 with bandwidth (VSWR⩽ 2) 20.9 MHz. While at 3 GHz VSWR is 1.3381 with bandwidth (VSWR ⩽ 2) 131.4 MHz. The results of this study have a bandwidth VSWR ⩽ 2 slightly wider than the return loss bandwidth ⩽ 2. However, both meet the desired bandwidth specification that is 10 MHz.

Based on Fig.11 (a) the gain generated after optimization at 1.27 GHz is 3.16 dB, which increases compared to the gain before optimization is 0.562 dB. Similarly, at the 3 GHz frequency, it can be seen in Fig.11 (b) the gain rises from the previous 1.59 dB. to 2.01 dB.

The type of radiation pattern and polarization after optimization has not changed. Can be seen in Fig.12, both have unidirectional radiation pattern.

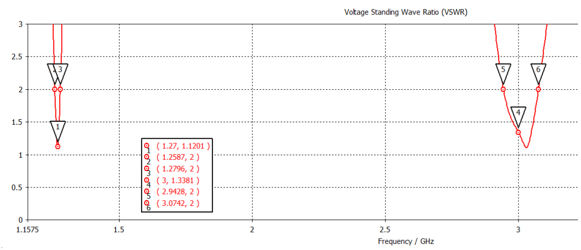
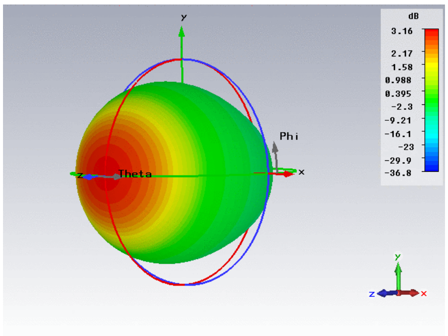
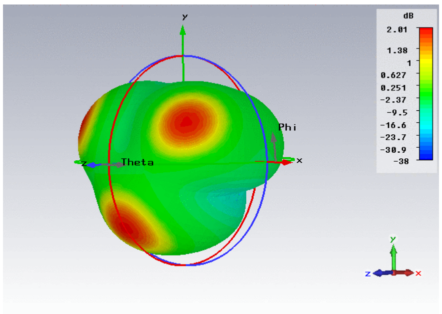


Fig.10. Simulation Result of VSWR After Optimization

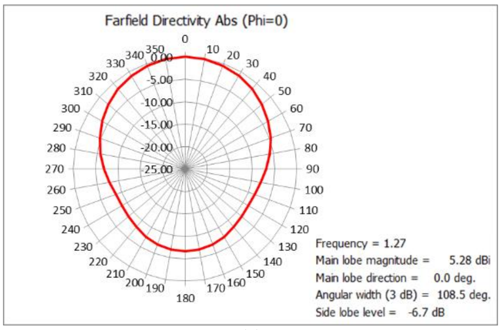


(a)

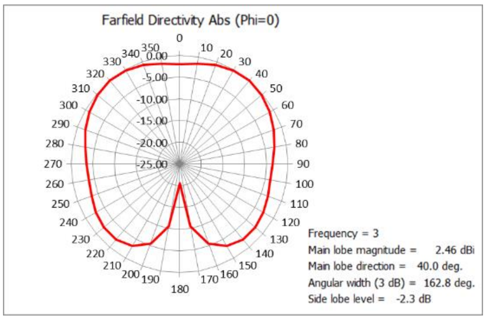


(b)

Fig.11. Simulation Result of Gain After Optimization; (a) 1.27 GHz; (b) 3 GHz



(a)



(b)

Fig.12. Simulation Radiation Pattern After Optimization; (a) 1.27 GHz; (b) 3 GHz

While in Fig.13 states the value of the axial ratio of 40 dB for the frequency of 1.27 GHz and 3 GHz, which means its polarization is linear.

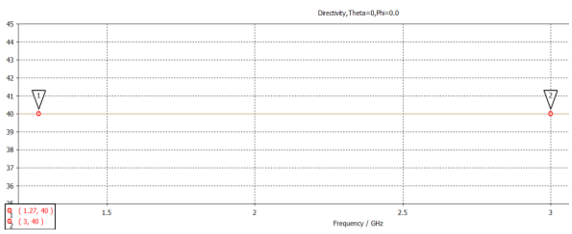


Fig.13. Simulation Result of Axial Ratio After Optimization

Comparison of antenna simulation results before and after optimization based on some antenna parameters can be seen in Table 4.

Table 4. Antenna Dimension Before and After Optimization

Parameter	Before Optimization		After Optimization	
Frequency	1.063 GHz	2.713 GHz	1.27 GHz	3 GHz
Return Loss	-9.5126 dB	-8.8314 dB.	-25.131 dB	-16.802 dB
VSWR	2.0054	2.1335	1.1201	1.3381
Bandwidth (RL)	-	-	19.9 MHz	125.3 MHz.
Bandwidth (VSWR)	-	-	20.9 MHz	131.4 MHz
Gain	0.562 dB	1.59 dB	3.19 dB	2.01 dB
Radiation Pattern	Uni-directional	Uni-directional	Uni-directional	Uni-directional
Polarization	Linier	Linier	Linier	Linier

IV. CONCLUSION

By using the slotted patch technique successfully designed dual-band antenna for SAR application. The antenna operates at the frequency of 1.27 GHz (L-Band) with the return loss value of -25.131 dB, VSWR 1.1173, bandwidth (return loss ≤ -10) 19.9 MHz and 3.1 dB gain. While the operating frequency of 3 GHz (S-Band) the return loss value obtained is -16.802 dB, VSWR 1.3381, bandwidth (return loss ≤ -10) 125.3 MHz, and gain 2.1 dB. Both operating frequencies have unidirectional radiation pattern and linear polarization.

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