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Design and Analysis of a High Frequency Bow-Tie Printed Ridge Gap Waveguide Antenna

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***Abstract:** Millimeter and microwave wave components are in high demand, which will have a substantial influence on the development of 5G networks. In this work, Ridge Gap Waveguide is used to develop a planar high-gain antenna. The main objective of this study is to develop a wideband, high-gain antenna capable of supporting the expected need for high data transmission in the future. For this reason, a thorough examination of PRGW has been presented, along with a series of high-gain antenna designs that have been extensively tested. In the future, this antenna array might be used for 5G connectivity, and it meets all mm-wave band specifications. We have designed a novel tri slotted PRGW antenna which size is small (3.256x3.256x0.03 mm3), but the gain, bandwidth, directivity and rad efficiency is high with respect to other larger PRGW antenna. Although the volume of the proposed antenna is small, also it provides better Gain, Directivity and VSWR with respect to the larger conventional PRGW antenna. Directivity, gain and rad efficiency is increased when the tri slot is mounted on the substrate. It can be said that this antenna is suitable for ultra-wideband wireless communications, remote sensing, satellite newsgathering, disaster management, etc.*

***Keywords:** Millimeter Wave, Printed Ridge Gap Waveguide, 5G Communication, Gain, Radiation Efficiency.*

1. INTRODUCTION

Millimeter wave antennas are used in short-range communications, future mm-wave mobile communications, sensor networks, and image systems [1] and have recently attracted much attention. The advancement of the global economy depends increasingly on the creative and

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engaging use of information and communication technology (ICT). An essential part of the global ICT strategy is the wireless communication network, which supports a wide range of sectors in one of the world's fastest-developing and most distinctive regions [2]. Many facets of human existence have been enhanced because of advances in wireless technology, including our capacity to communicate and interact socially and professionally [3]. The exceptional success of wireless communication may be seen in the quick speed of technological advancement. Wireless communication has progressed from a standard end-to-end telephone system to a technology that supports large data speeds, with the debut of the 2G system in 1991 and the 3G system in 2001 [4]. International mobile telecommunications advanced (IMT) utilization criteria for advanced strategy were met by 4G wireless systems [5]. In Multiple-input, multiple-output (MIMO) orthogonal frequency-division multiplexing is utilized in 4G networks. In addition to high data speeds, 4G wireless networks are capable of delivering very quick signal transmissions. For the development of 4G networks, LTE stands for long-term evolution. The theoretical limitations of data rates of 4th Generation (4G) networks are not adequate to deal with spectrum issues and difficulties. Because of this, we need to go beyond current technologies like the fifth generation [4] in order to overcome their shortcomings. When employing millimeter-wave frequency bands, an ultra-wide bandwidth system might theoretically be used to provide multi-gigabit per second connections in the future. The functioning of a future wireless communication system might make use of these frequencies. Much work has been done in the literature for mm-wave components and antennas to develop contemporary directing designs such as the Substrate Integrated Waveguide (SIW) [9]. Large mm-Wave structures have a lower efficiency because to their high transmission loss and poor efficiency despite the low profile of most of these designs and broad impedance bandwidth. When these damages occur, waves from the dielectric material propagate. The Gap Waveguide (GW) technology has recently been studied by a number of research organizations in order to implement mm-wave components that have achieved great efficiency in the mm-wave frequency range. For example, PRGW (Printed Ridge Gap Waveguide) has been used to overcome the bulk of the previously cited issues [10]. These components must be small and low loss, as well as economic, energy-efficient, and high-performance, in order to meet the high demands of the enormous future buyer market. Despite the fact that PRGW-based mm-wave components have recently been demonstrated, more development is required to meet the requirements of future technology. A small number of PRGW-based mm-wave components, for example, channels with broad bandwidth, have been written about [10, 11]. In addition, the suggested antenna has a small footprint but a substantial gain across a wide frequency range. The long-awaited dual-polarized antenna based on PRGW has finally been unveiled. The remainder of the document is laid out as follows. Sections II and III detail the theoretical Discussion and Design Procedure. Result Analysis is discussed in Section IV with a comparison table. Then, in Section V, we finished the study by outlining the potential value of our work.

Theoretical Discussion of the Proposed Antenna

Using metamaterials, soft and hard surfaces artificially maintain magnetic conductivity [12]. Generally speaking, a soft surface acts as a barrier to wave propagation, whereas a hard surface acts as a support for wave propagation. Contrary to popular belief, a dielectric

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substance with a dielectric constant greater than the medium's permittivity should be placed in the groove at a depth of d on hard surfaces. The following equation may be used to determine the depth,

$$\boldsymbol{d} = \frac{\lambda}{4}(\sqrt{\in} - \mathbf{1}) \quad (1)$$

Here λ is the frequency in free space, $\in$ which is denoted as the material's dielectric constant. Additionally, it is employed to boost aperture efficacy in hard waveguide horns. PEC/PMC strips are ideal for distinguishing between soft and hard surfaces. As long as the strip and spread direction are both longitudinal, a wave will propagate across a hard surface. Both transverse electrical and magnetic field components longitudinal area propagation will be blocked.

A. Operation Principles and Architecture of Gap Waveguides

In 2009, Kildal came up with the idea of waveguide technology [13]. PEC-PMC parallel plate waveguide is the activity rule. When the separation between the PEC/PMC plates is below λ/4 [12], no propagation occurs. As a result of wave propagation along the PEC/PEC line, a stopband for the PEC-PMC plate is formed. The gap waveguide's fundamental premise is seen in "Fig. 1."

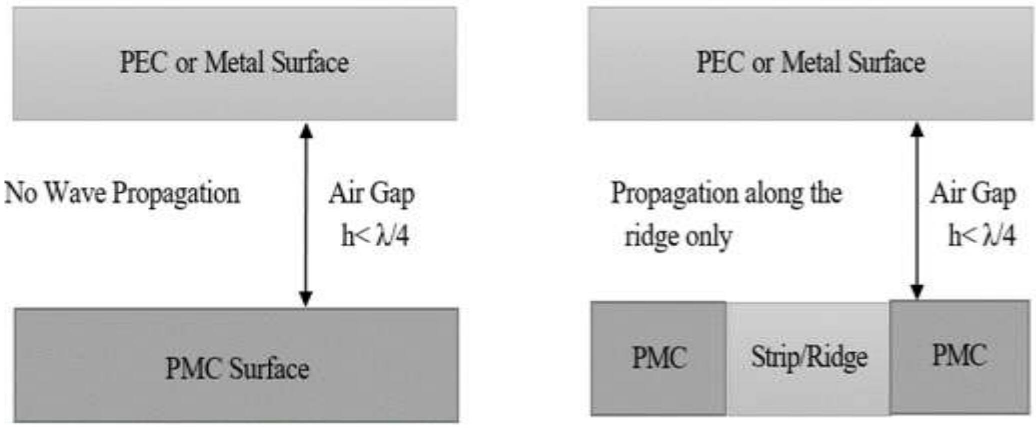

Fig. 01. (a) Parallel plate of PEC and PMC with air-gap, (b) Surface of PEC/PMC around Ridge.

It's possible to produce a high impedance surface, or AMC surface, using a bed of nails and a high ridge. This will allow waves to travel through the AMC surface. Ridge Gap Waveguide is the name given to this concept, which will be investigated in the next section. For high-frequency RF circuits and passive devices, among the best prospects for directional structures where the loss is lessened is the Ridge Gap Waveguide (RGW). The RGW is formed by two

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equal plates, one plate having occasional surfaces to inhibit wave propagation in any other direction than the required one. As a completed metal structure, there will be no dielectric losses. In contrast to a waveguide, the RGW does not contain side dividers. In "fig. 02," the metal of RGW is shown.

Design Procedure of the Proposed Antenna

The research work was carried out in multiple steps. After finalizing the research topic, we first studied the basic theory of antenna, PRGW, that is needed to carry our research work. We investigated the lacking's of the proposed architectures and produced our speaker recognition architecture. After finalizing the design, we implemented the overall method. To test the proposed model, we collected a popular dataset and ran tests and evaluations on our implemented architecture. "Fig. 03" illustrates the overall steps of the research procedure in a flow diagram.

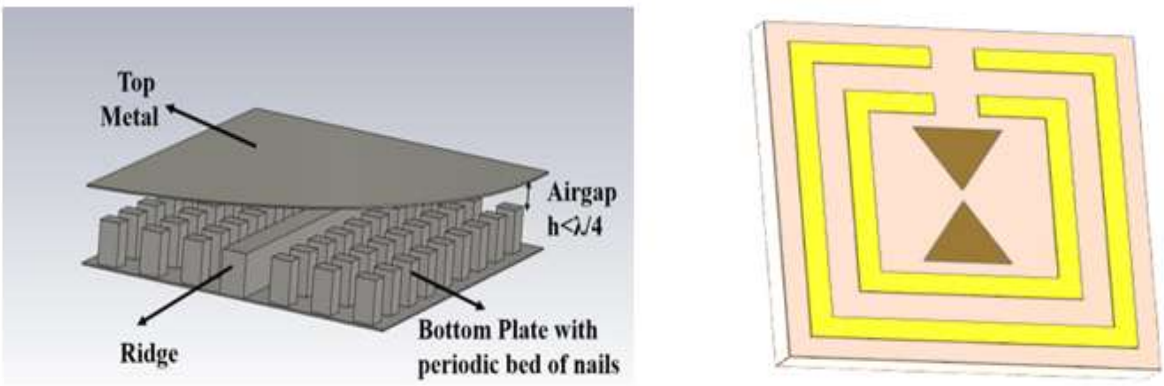

Fig. 02. Ridge surrounded by bed of nails

High-speed data transfer and extensive bandwidth make millimeter wave antennas for gigabit wireless communication ideal. However, breeding losses are higher at higher frequencies than at lower frequency bands. Wideband and high gain antennas are thus necessary to minimize the loss of this frequency range [2]. Low-frequency microstrip lines, having ultra-wideband capabilities, may be used advantageously. On the other hand, higher frequencies in micro-strip feeding networks result in an increase in both ohmic losses and surface waves [5]. Because of the larger Q-factor and reduced radiation loss of rectangular or hollow waveguides at higher frequencies, they are more complicated to build [8]. To ensure adequate electrical connectivity, the construction of sidewalls becomes quite complex. It is also possible to create an effective millimeter wave feeding network using a substrate integrated waveguide (SIW), which has electrical characteristics comparable to rectangular waveguides. A reduction in radiation efficiency of a larger magnitude improves SIW's performance [11]. The Ridge Gap.

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Waveguide (RGW) was proposed in 2009 as an alternate guiding structure for rectangular waveguides and microstrip lines at higher frequencies, with low loss and good power handling capabilities [12].

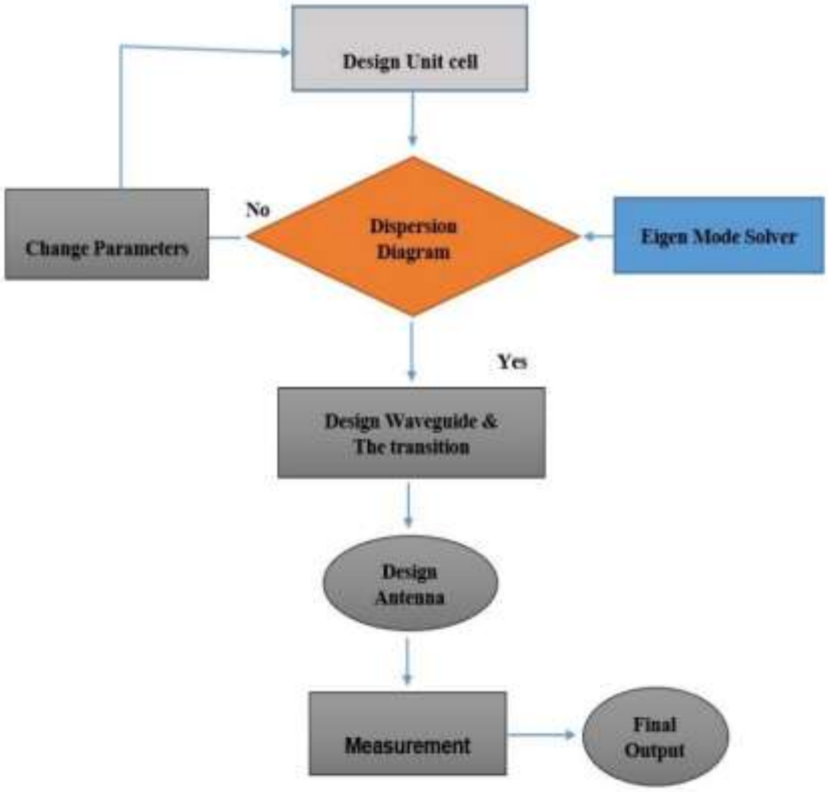

Fig. 03. Planned steps for completing the project

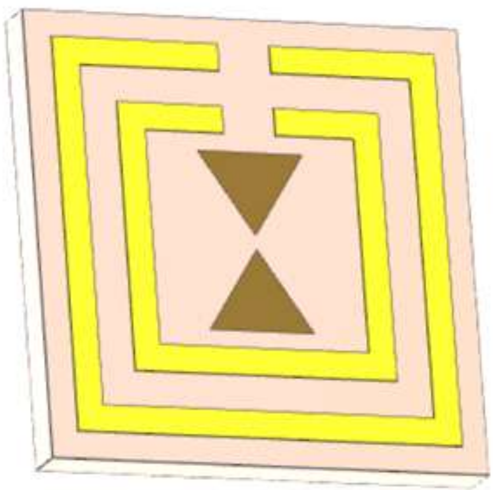

Fig. 04. PRGW Antenna with bow-tie slot

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"Fig. 04" shows a prototype model of PRGW Antenna with bow-tie slot. Gap waveguides may form parallel plate stop bands utilizing periodical structures, which is their fundamental property [10]. Rogers RT6002 with a ϵr of 2 is used to print the unit cell. The radiation shows that the band-gap of one ridged row of the unit cell is between 35 and 52 GHz, which can be depicted from the radiation. The PRGW is feed by a multi-layered elevated waveguide. Using the suggested 3-D perspective, it is possible to see how the change is aligned and how the feed line is precisely fixed.

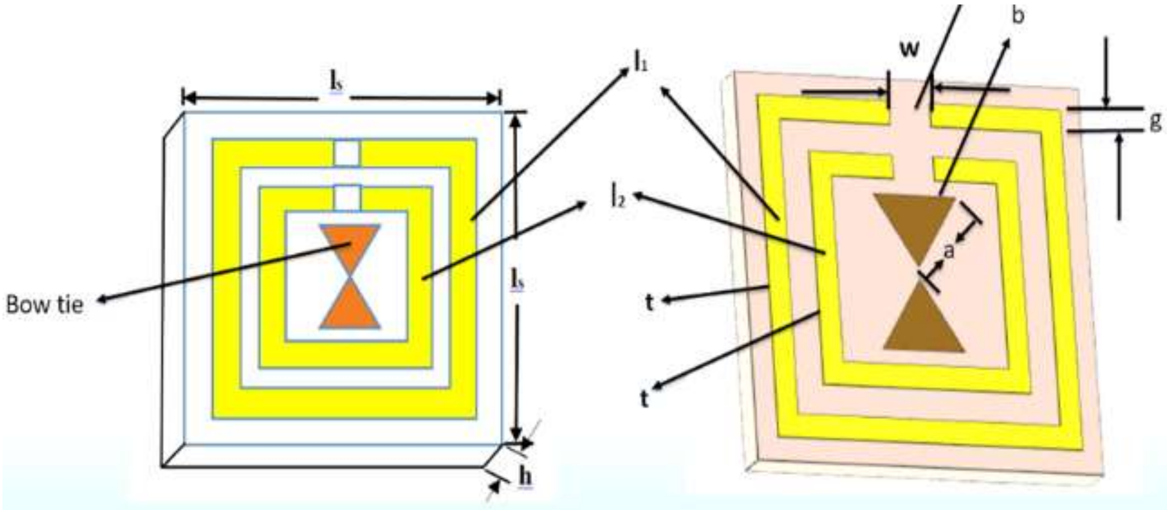

Fig. 05. PRGW Antenna with bow-tie slot with parameters

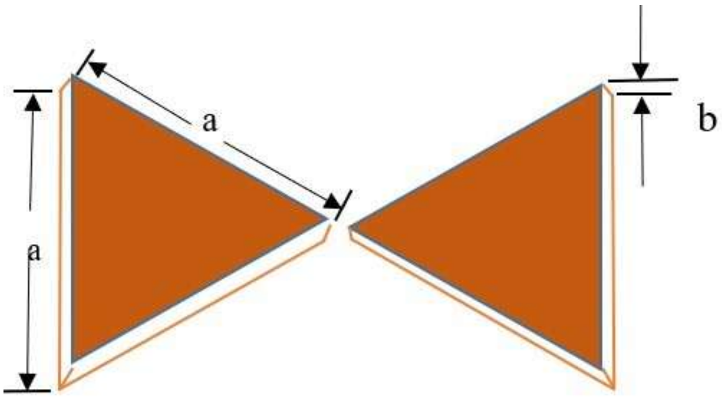

Fig. 06. Bow tie Slot

A. Proposed Antenna Structure

As seen in "fig. 6," PRGW with a bow-tie slot provides a broad bandwidth. At the center frequency, Slot antennas are capable of delivering a signal with a bandwidth of roughly 5% to 6%. "Fig. 5" depicts an elevated single element antenna, with its dimensions specified in "TABLE. I" as displayed. Three layers of PRGW antenna construction are applied to the Rogers RT6002 substrate: first, a ridge with periodic cells; second, a printed bow-tie antenna. On top of the bow-tie slot is a three-layer groove structure. As a low-cost method that can be

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implemented at our manufacturing facilities, we've opted for a step-shaped aperture for our design—the planned antenna's emission patterns in the E and H planes.

Table. I. Constructional Parameters of Designed antenna

Parameters	**Dimension (mm)**	**Parameters**	**Dimension (mm)**
Gap, g	0.15 mm	Spelt wide, s	0.15 mm
Substrate height, h	0.25 mm	Thickness, t	0.017 mm
Outer ring width, l1	1.1 mm	Ring Wide, w	0.2 mm
Inner ring width, l2	1.5 mm	Length, a	0.5 mm
Wire width, lw	0.14 mm	Length, b	0.6 mm

Table. II. Optimized Designed antenna Parameters

Parameters	**Dimension (mm)**	**Parameters**	**Dimension (mm)**
Gap, g	0.1 mm	Spelt wide, s	0.14 mm
Substrate height, h	0.03 mm	Thickness, t	0.20 mm
Outer ring width, l1	2.6025 mm	Ring Wide, w	0.15 mm
Inner ring width, l2	1.5 mm	Length, a	0.3 mm
Wire width, lw	0.14 mm	Length, b	0.46 mm

B. Optimized design of the antenna

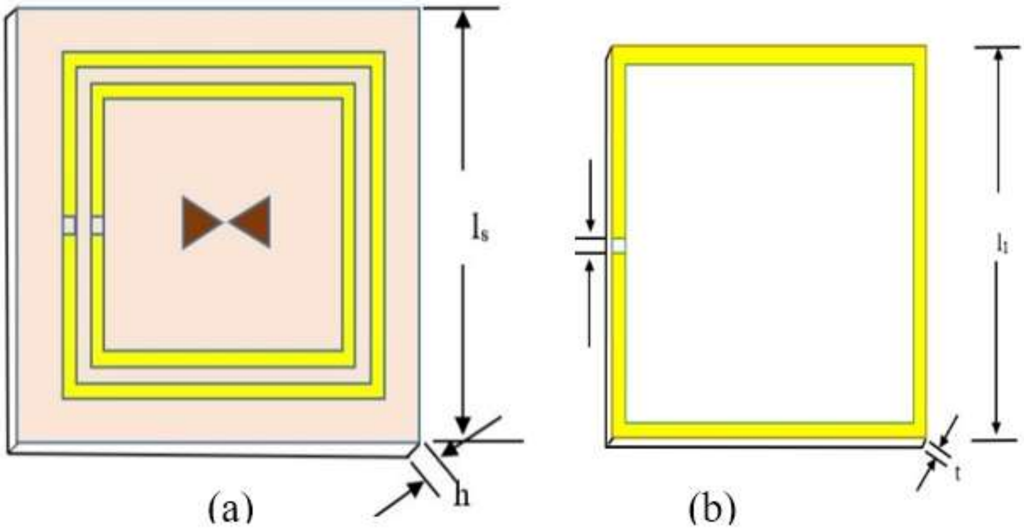

Fig. 7. (a) Optimized design of the PRGW antenna, (b) Optimized design of Unit Cell design

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We have designed and optimized the antenna by using "CST Microwave Studio" software and in "fig. 07. The antenna's optimal design is shown. The values of the parameters may be found in "TABLE. II."

2. SIMULATED RESULT ANALYSIS

A. Simulated Results of the dual-band PRGW Antenna

The proposed antenna is operated in dual-band frequency. The frequency band is 35-52 GHz. The size of the proposed antenna is 1.25×1.256×0.25 mm3. The simulation results of the designed dual-band antenna using waveguide ports are at resonance frequencies fr1= 37.84 GHz and fr2 = 44.32 GHz are presented in this section. The simulated return loss at fr1 is -13.166 dB and at fr2 is -13.516 dB, shown in "fig. 8", whereas VSWR at these resonance frequencies are 1.5629 dB and 1.5342 dB, respectively as shown in "fig. 9".

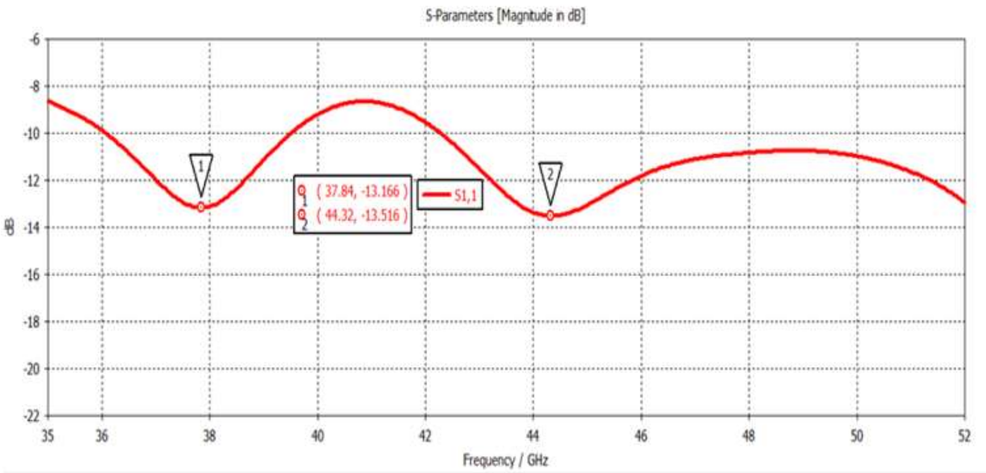

Fig. 8. Simulated S11 or Return loss dual-band for PRGW antenna.

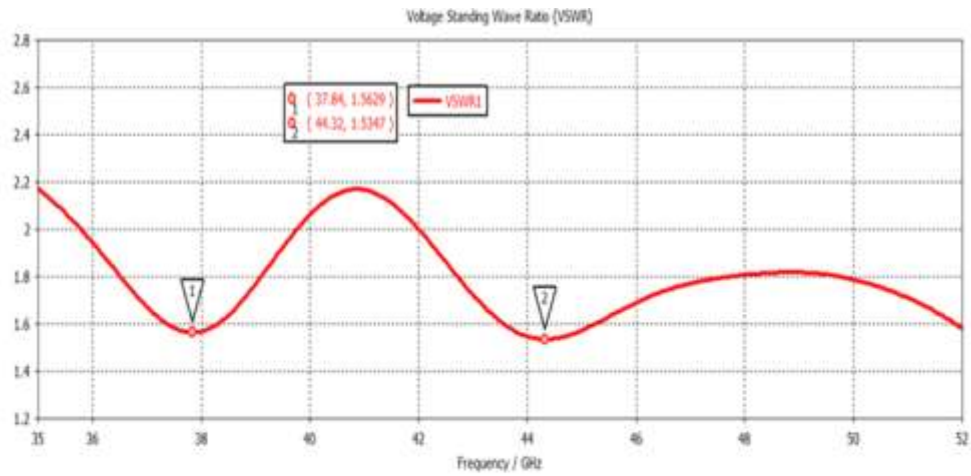

Fig. 9: VSWR curve dual-band for PRGW antenna Dual-band antenna at resonance frequencies fr1 and fr2 are gain and directivity shown in "fig. 10" & "fig. 11".

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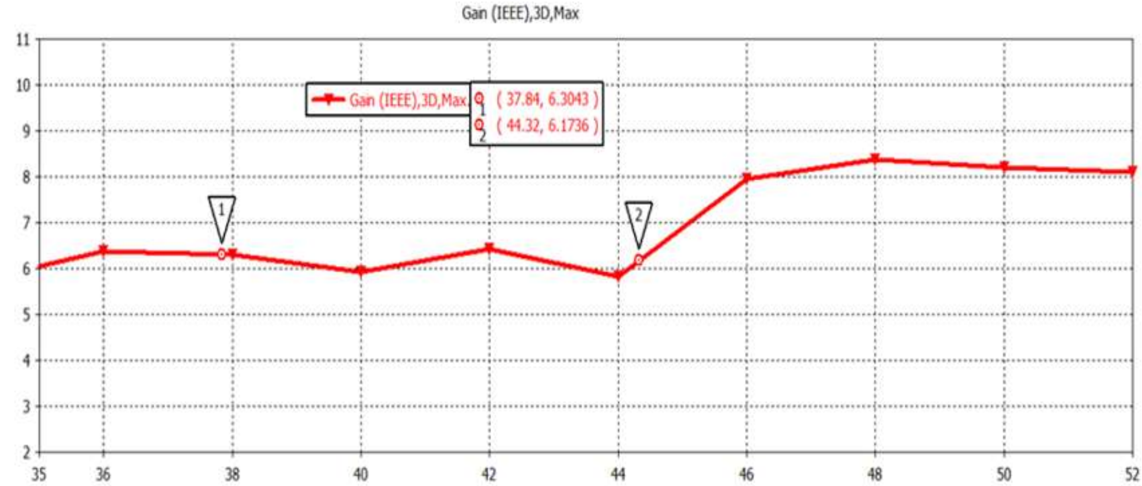

Fig. 10: Gain curve for dual-band PRGW antenna

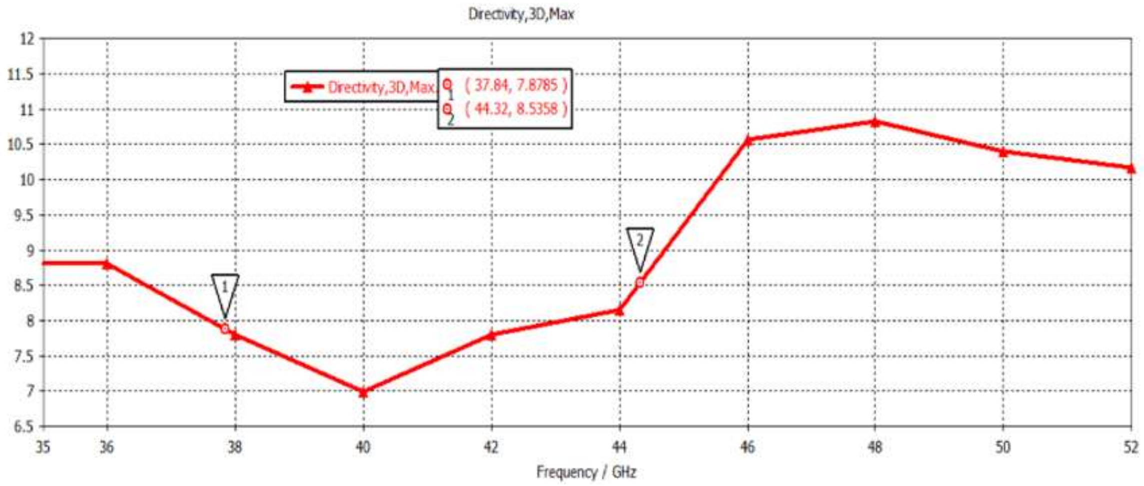

Fig. 11: Directivity curve for dual-band PRGW antenna

Here Gain at resonance frequencies fr1 and fr2 are 6.3043 dB and 6.172 dB. Directivity at resonance frequencies fr1 and fr2 are 7.8785 dB and 8.5358 dB. "TABLE. III" shows the all-resultant values of the designed dual-band PRGW Antenna.

Table. III. Simulated overall outcomes of the proposed antenna

Antenna	Size mm3	Res. Freq.(GHz)	S-Parameter (dB)	VSWR	Gain (dB)	Directivity (dB)	Rad Efficiency (%)
Bow tie PRGW Antennas	1.25×1.25×0.25	37.84	-13.16	1.56	6.31	7.88	69.60
		44.32	-13.51	1.53	6.18	8.54	69.60

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B. Simulated Results of the triple-band PRGW Antenna

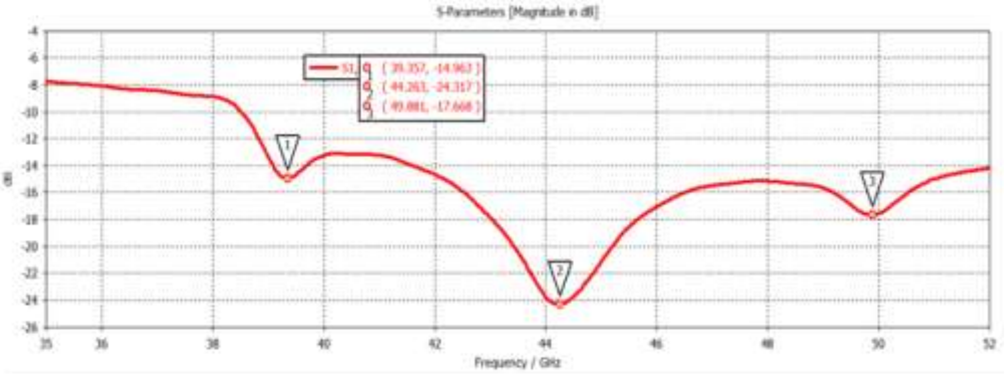

Fig. 12: Simulated S11 or Return loss triple-band for PRGW antenna

The proposed antenna is operated in triple-band frequency. The frequency band is 35-52 GHz. The size of the proposed antenna is 3.25×3.256×0.03 mm3. The size of the proposed antenna is small, but its gain, directivity, VSWR and radiation efficiency is moderately higher than the conventional large PRGW antennas. The simulation results of the designed triple-band antenna using waveguide ports are at resonance frequencies fr1 = 39.36 GHz, fr2 = 44.24 GHz and fr3 = 49.88 GHz are presented in this section. The simulated return loss at fr1 is -14.963 dB, at fr2 is -24.317 dB and at fr3 is -17.668, which are shown in "fig. 12".

Whereas VSWR at these resonance frequencies are at fr1 is 1.43, at fr2 is 1.12 and at fr3 1.30 which respectively as shown in "Fig. 13". This indicates antenna impedance is considerably matched with the waveguide port impedance as less amount of power is reflected back from the antenna's input terminal. For these three resonant frequencies, the predicted bandwidth is 0.604 GHz, 2.637GHz, and 1.392GHz, respectively. But the whole value of the S-parameter under -10dB is considered as the antenna's bandwidth. As a result, the bandwidth of our antenna can be said 35-52 GHz.

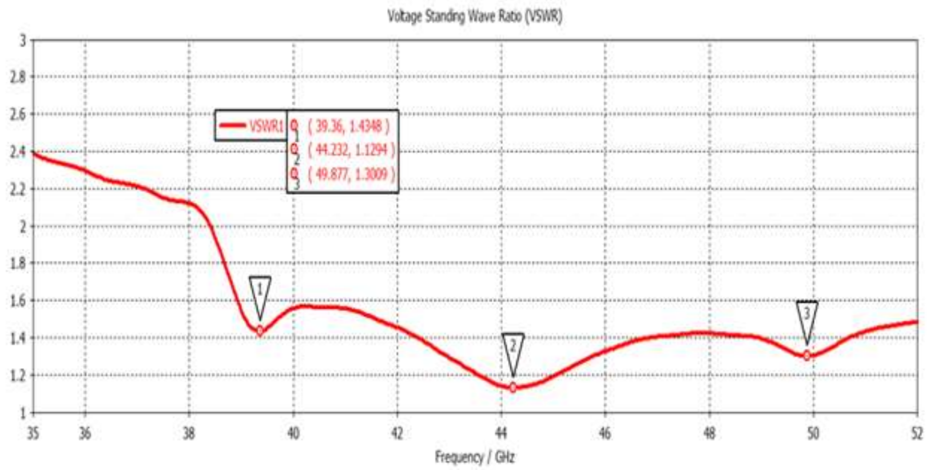

Fig. 13: VSWR curve for triple-band PRGW antenna

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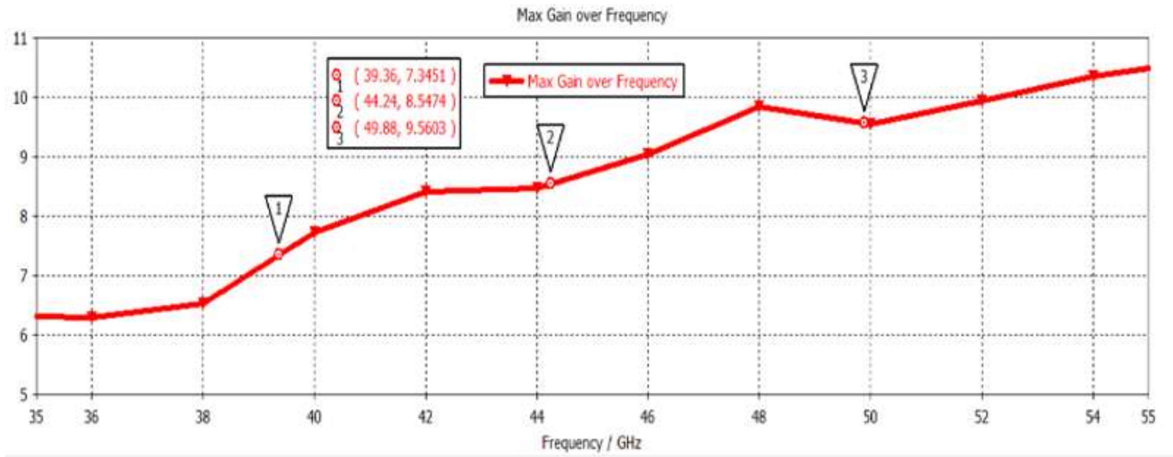

Fig. 14. Simulated max gain over frequency for the proposed PRGW antenna

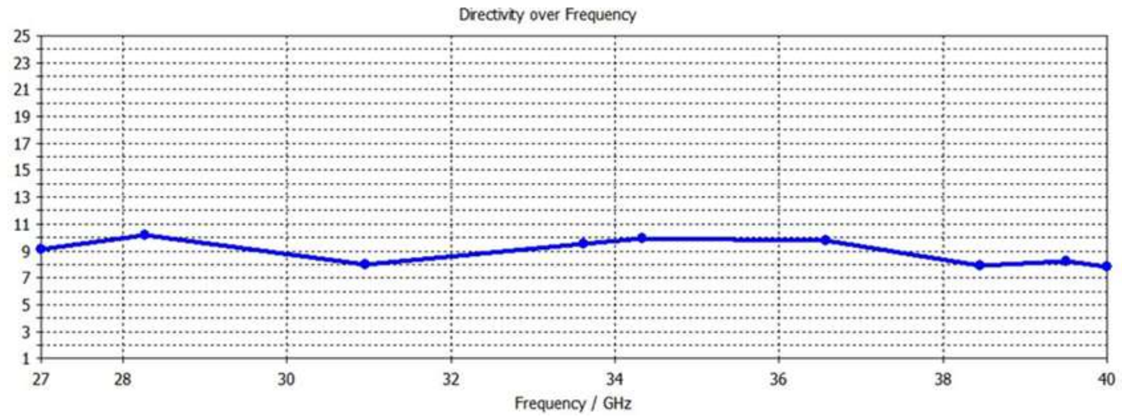

Fig. 15. Simulated directivity over frequency for the proposed PRGW antenna

The range of the gain of the proposed triple-band in resonance points is 7.18–11 dB, which is suitable because the antenna's size is relatively much more compact than the PRGW antenna. The simulated gains of the proposed three- band antenna, as well as the three PRGW antennas, are given in "Fig. 14" and "Fig. 15" respectively.

Table. IV. An evaluation of the proposed antenna concerning other research

Ref.	Size in mm3	Operating Bands in GHz	Bandwidth in GHz	Gain (dB)	S para-meter
[01]	42x 36x 1.6	3.7-18	5.2	1.8-6.9	-27-29-23-20-18-17

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[05]	88x 52x 1	5-15	5-15	4-11.5	-17, -28, -19, -23, -34, -43, -22
[03]	40.16 x 42.56 x 1.4	3.1-10.6	3.1-10.6	2-5	-24, -20, -12, -14, -36
[04]	89.52 x107. 68	1.35-4	1.35-4	5.31, 5.12	-32, -27
Proposed Bow tie PRGW	3.256 ×3.25 6× 0.03	35-52	0.604-2.637	7.34-10	-14.963, -24.317, -17.668

As a result of this comparison, we found that our proposed antenna has a higher gain at a higher frequency band (35-52 GHz) and is smaller in size. The comparison is shown in "TABLE. IV"

3. CONCLUSIONS

The size of the proposed antenna is small, but its gain, directivity, VSWR and radiation efficiency is moderately high than the conventional large PRGW antennas. In this research work, PRGW is being proposed antenna because of its better gain, directivity and VSWR. When three slots are inserted, then the average gain, directivity, rad efficiency is increased. The proposed antenna is operating in Triple band frequency. The frequency band is 35-52 GHz. The size of the proposed antenna is 3.25×3.256×0.03 mm3. S11 or Return loss for the proposed PRGW antenna is shown in Figure 4.6 and also shown the compared S11 or return loss for the three antennae in Figure 4.7. The return loss or S11 is calculated from the resonance frequency of 39.36GHz, 44.24GHz, and 49.88GHz. But the whole value of the S-parameter under -10dB is considered as bandwidth. As a result, the bandwidth of our antenna can be said 35-52 GHz. So, the proposed antenna is efficient in satellite communication [12].

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