Design of a slotted Substrate Integrated Waveguide Antenna for 5G

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Abstract : As advancements in technology, it is necessary to provide fast access to users by increasing the bandwidth and data rate to achieve the data capacity available in the presently licensed spectrum. The spectrum scarcity issue may be resolved by using millimeter wave frequencies bands. In this paper, a substrate integrated waveguide antenna with a logarithmic round slot is presented. Proposed antenna is working at 38 GHz frequency for millimeter wave applications. The size of antenna is 27.06x7.50 mm^2 with Rogers RT/duroid substrate height of 0.25 mm. Antenna showing gain of 7.68 dBi with efficiency of 86.82% at 38 GHz frequency. Antenna covers frequency from 38.4 GHz to 38.6 GHz with bandwidth of 0.2 GHz. A computer simulation technology tool is used to design and simulate the antenna.

***IndexTerms* –Antenna, Millimeter wave, Slot, Substrate integrated waveguide.**

I. INTRODUCTION

Wireless communication is the unguided transmission and reception of information signals through radio waves traveling from one point to another without using physical connections like cable, wire, fiber, or any other type of electrical conductors. It is the core component of any nation-wide telecommunication network comprising terrestrial and space borne communication systems. The radiating element called ‘antenna’ plays a key function to establish radio connectivity between transmitting and receiving ends. The advancement in electronic device technology, switching technology, and availability of new radio spectrum for telecommunication services has necessitated a synchronized advancement in antenna technology in order to develop and implement emerging telecommunication systems [1].

In the present scenario, the telecommunication infrastructure is heavily loaded by the varied nature of intense traffic including voice, data, multimedia, video, etc. Therefore, emerging technologies like IoT, Big data analytics, Block chain, etc demands enormous channel bandwidth to support high speed integrated services. Apart from this, there is another big challenge that is a scarcity of spectrum, which necessitates the development of new spectral efficient technologies to ensure optimal resource utilization. Millimeter Waves (MMW) in the frequency range 28 GHz-300 GHz is a strong contender to address spectrum scarcity [2]. In 5G, the two frequency bands are designated as frequency range-1 (FR1) and frequency range-2 (FR2). FR1 covers low-band i.e. below 1 GHz and mid-band i.e. between 1-6 GHz. The 5G FR1 band is now supported by adequate technology development and ready for commissioning. However, the FR2 band in millimeter wave spectrum above 24 GHz allocated for the next generation 5G called 5G New Radio (5G NR) has limited technology development. The millimeter wave communication has so far been underutilized and therefore, FR2 5G bands are now starting to gain momentum and have tremendous research scope. Therefore, the design and development of compact dual band antenna structures at millimeter wave frequency bands also have tremendous research potential [3].

At high frequency radiation and propagation, losses are higher so to reduce the effect of these losses high gain antennas are required. Therefore, by using an emerging technology i.e. substrate integrated waveguide we can achieve good performance of the antenna for millimeter wave frequencies. At higher frequency wavelength is small, so manufacturing of microstrip devices not efficient and requires high tolerance [4]. It is good to choose a waveguide device at a high frequency still manufacturing procedure is difficult. For this reason, a substrate integrated waveguide (SIW), which is also referred to as post wall and laminated waveguide is suitable at high frequency. SIW is bridging the gap between microstrip and waveguide. Substrate integrated waveguide structure consists two parallel rows of metallic vias on the substrate which is between the top and bottom metallic layers [5]. There are many advantages of SIW over rectangular waveguides like SIW can operate at high frequency, has high quality factor, high power handling capabilities, and easy integration to other circuits [6]. Also, it is based on the theory of substrate integrated circuits i.e. convert a non planar structure into a planar structure [7]. For different applications, there are various slotted SIW antennas designed for millimeter wave applications. In [8] slotted SIW filtenna is designed at 38 GHz frequency with one and two longitudinal slots. Achieved gain of 5.27 dBi for one slot and 6.76 dBi for two slots. A compact SIW slotted antenna is presented in the paper [9] for a 5G mobile application. Observed gain of 5dB and efficiency of 98.8% at 28 GHz. To obtained high bandwidth a U shape SIW slot antenna is presented in [10] with gain of 7.15 dBi. In paper [11] a low cost substrate integrated waveguide antenna presented operating at 28 GHz. The design consists a single slot on FR4 substrate material, with an achieved gain of 4.7 dBi. In paper [12] a dual band antenna designed for 28 and 38 GHz frequency with two unequal slots to improve the performance of antenna. A single element SIW antenna is designed with gain of 5.2 dBi at 28 GHz and gain of 5.9 dBi at 38 GHz. The observed bandwidth at 28 GHz and 38 GHz is 0.45 GHz and 2.2 GHz, respectively. Paper [13] presented a compact SIW slotted antenna for fifth generation applications. The proposed miniature structure makes it suitable for millimeter wave applications with improved performance in terms of gain, efficiency, and beamwidth. Another design in which a circularly polarized substrate integrated waveguide antenna is presented with an arrow shape slot on the substrate material. This shape of the slot improves the bandwidth of the antenna [14]. In paper [15] to improve antenna bandwidth, a coupled quarter mode dual band antenna is presented for next generation wireless communication. It is observed that the impedance bandwidth at 28 GHz is 2.6 GHz and for 38 GHz is 2.2 GHz.

This paper presents a slotted SIW antenna for millimeter wave applications. Section II presents the substrate integrated waveguide theory. Section III showing the proposed antenna design. Section IV presents the antenna performance with the results. Finally the paper is concluded in Section V.

II. Substrate Integrated Waveguide

This section presents a theory of SIW and design rules to create the SIW structure. It is a waveguide like structure with two rows of metallic vias including top and bottom metallic layers. By using the SIW structure we can integrate all the active, passive components and antennas on the same substrate. While designing SIW structure, there are some parameters we have to take into consideration like diameter of vias (d), the distance between vias (p), width of waveguide (w), and height of substrate (h) [16]. The structure of SIW is showing in Fig. 1.

In SIW structure only transverse electric modes present, it does not support transverse magnetic modes because of the presence of vias. The equivalent width for SIW is given by [17], where a_{SIW} is the equivalent width of SIW, w_{SIW} is width, d is vias diameter and p is distance between vias.

$$a_{\text{SIW}} = w_{\text{SIW}} - \frac{d^2}{0.95p} \qquad (1)$$

To reduce the losses in the substrate integrate waveguide structure there are two design rules are D ≤ 2d and $\lambda_g/5$. By the proper choice of conductor and dielectric material, we can reduce dielectric and conductor losses. The radiation losses occur because of the space between vias. At millimeter frequencies, planar circuits generally suffer from radiation originating at bends and discontinuities [5]. In this work, we are using substrate integrated waveguide technology to design the antenna for fifth generation applications.

III. Antenna Design

This section presents the design of proposed antenna with logarithmic round shape slot. To design the antenna a substrate integrated waveguide technology is used. The geometry of the proposed design is showing in Fig. 2 here round vias on the substrate material create a SIW structure on design. The diameter of via, d is 0.5 mm and pitch between two vias, p is 1.0 mm. To design the antenna Rogers 5880 material is used with substrate height of 0.254 mm, dielectric constant of 2.2, and loss tangent of 0.003. To improve the antenna performance a logarithmic round shape slot is etched on the conducting plane. To design logarithmic slots the radius and other parameters are calculated. Where radius R1 and R2 calculated by [18]

$$R_1 = k * e^{\alpha * \varphi} \qquad (2)$$
$$R_2 = k * e^{\alpha * (\varphi - \delta)} \qquad (3)$$

Where value of K is 0.25mm and δ=90^0, α=0.35, and φ=5. Proposed design is feed by 50 ohm impedance line with a transition section called microstrip to SIW transition [19]. This transition also helps to improve the performance of antenna. All the dimensions and parameters are mentioned in Table 1.

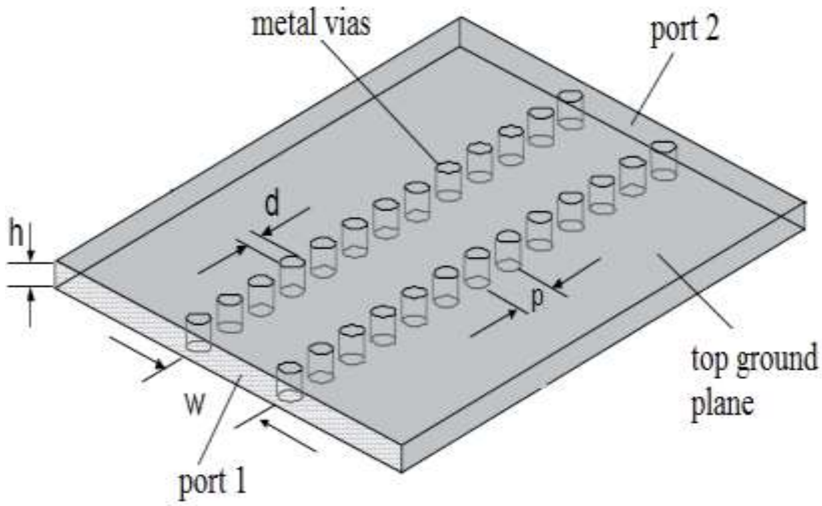

Figure 1 Substrate integrated waveguide structure [16]

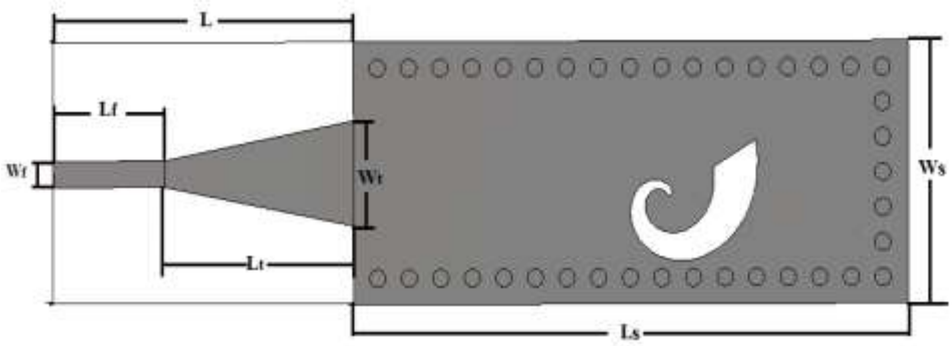

Figure 2 Top view of logarithmic slot SIW antenna

Table 1 Parameters and dimensions of the proposed antenna

Parameter	Dimensions	Description
L_s	17.56	SIW substrate length
W_s	7.50	SIW substrate width
L	9.50	Microstrip substrate length
L_f	3.50	Feed line length
W_f	0.75	Feed line width
L_t	6.10	Taper length
W_t	3.0	Taper width

IV. Results and Discussion

This section presents the simulation results for the proposed antenna design. A computer simulation technology tool is used to design and simulate the antenna. The simulated return loss for the antenna at 38 GHz is -23.23 dB with the -10 dB bandwidth of 0.2 GHz. The return loss plot for the proposed design is showing in Fig. 3. Antenna provide good efficiency at 38 GHz frequency. Fig. 4 showing efficiency plot for the antenna. At 38 GHz frequency achieved radiation efficiency is 86.82 % and total efficiency is 76.40 %.

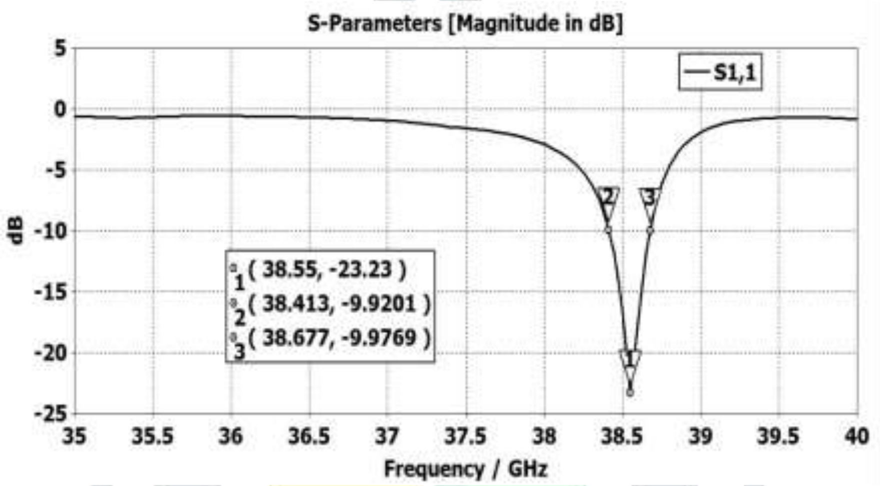

Figure 3 Return loss plot vs. frequency plot at 38 GHz

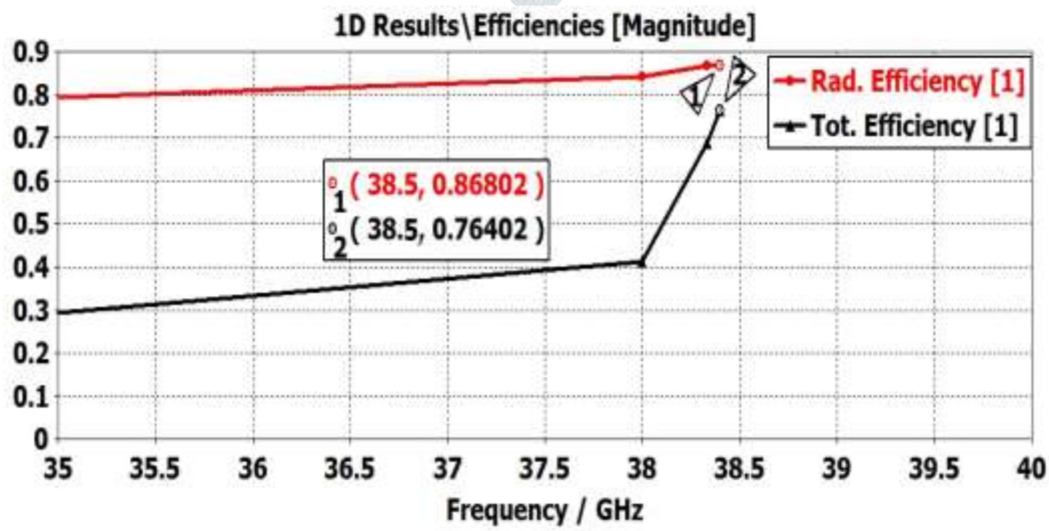

Figure 4 Efficiency plot at 38 GHz

Fig. 5. Showing the radiation pattern of the antenna. Antenna has directional radiation properties with beamwidth of 23.9^0. Fig. 6 presents the three dimensional radiation plot for the proposed design. It is observed that antenna achieved gain of 8.17 dBi at 38 GHz frequency.

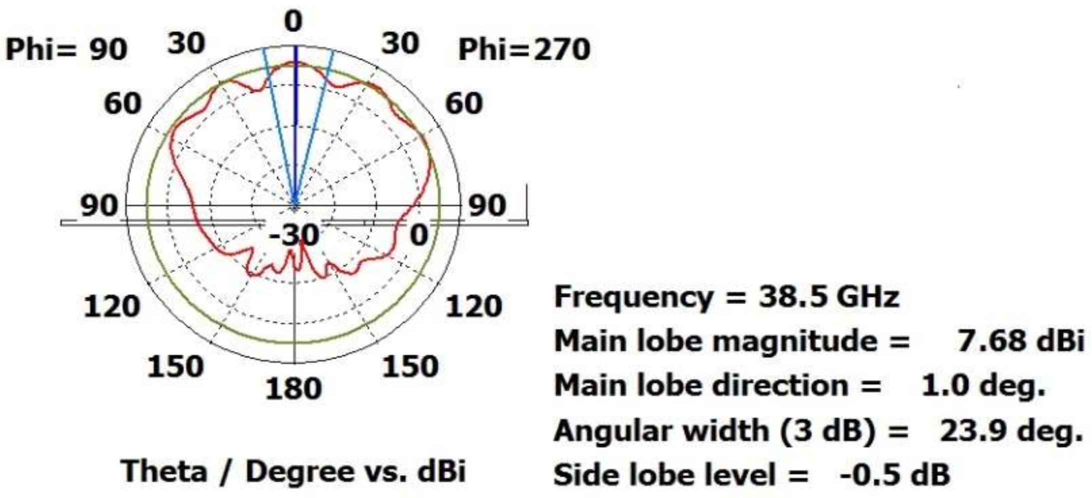

Figure 5 Radiation pattern in polar form

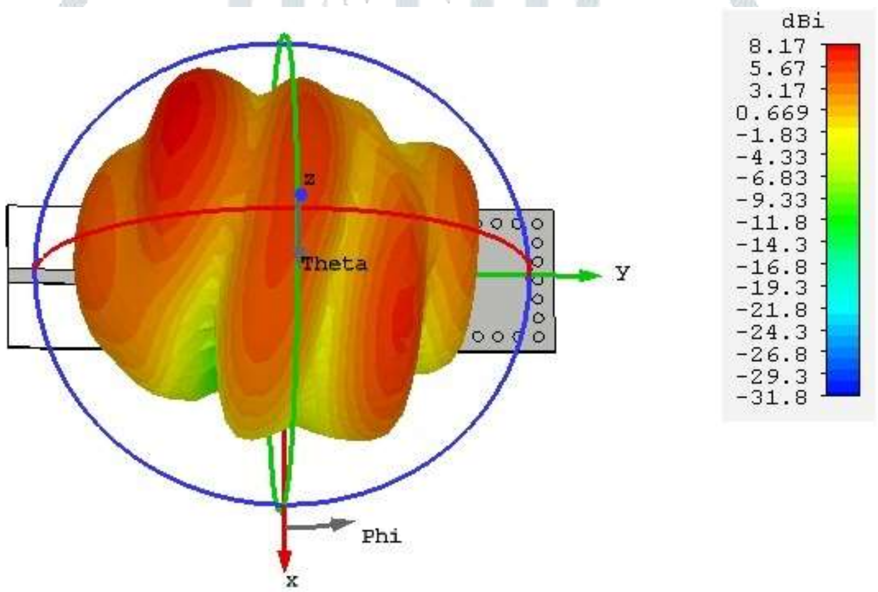

Figure 6 Three dimensional radiation pattern at 38 GHz

V. CONCLUSION

A SIW based logarithmic round slot antenna presented for millimeter wave communication. The logarithmic slot in the proposed design improves the performance of antenna which mainly enhance the antenna gain. The proposed antenna provides higher gain of 8.17 dBi at 38 GHz frequency. The antenna covers -10 dB impedance bandwidth of 0.2 GHz with radiation efficiency of 86.80%. In future work we can create the array design for this compact antenna to improve the performance. The proposed high gain antenna is suitable for future fifth generation wireless communication networks.

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