Heaven's Light is Our Guide

DEPARTMENT OF ELECTRONICS & TELECOMMUNICATION ENGINEERING

Rajshahi University of Engineering & Technology, Bangladesh

Y shape Millimeter-Wave Antenna Based on SIW for 5G Application.

This thesis report is submitted to the Department of Electronics and Telecommunication Engineering, Rajshahi University of Engineering and Technology (RUET), for the partial fulfillment of the requirement for the degree of Bachelor of Science in Electronics and Telecommunication Engineering.

Author

Ishrat Jahan

Roll No: 1504034

Department of ETE, RUET.

Supervised by

Dr. Mst. Fateha Samad

Assistant Professor,

Department of ETE, RUET.

Acknowledgment

First and foremost, I offer my sincere gratitude to The Almighty ALLAH for his divine blessings, which made me possible to complete this thesis work successfully.

I would like to express my deepest gratitude to my supervisor Dr. Mst. Fateha Samad mam for her support through the thesis work. She supported me with motivation, patience, and immense knowledge. I am honored and thankful for having this opportunity to work under her supervision. I would also like to express my gratitude to all my other teachers of my department for suggesting me to get the desired result to accomplish my thesis work successfully. The inspiration gave me the motivation to come up with something beneficial.

30.11.2020 Ishrat Jahan

RUET, Rajshahi.

Heaven's Light is Our Guide

DEPARTMENT OF ELECTRONICS & TELECOMMUNICATION ENGINEERING

Rajshahi University of Engineering & Technology, Rajshahi.

CERTIFICATE

*This is to certify that the thesis paper entitled "**Y shape Millimeter-Wave Antenna Based on SIW for 5G Application.**" has been done by **Ishrat Jahan** under the supervision of **Dr. Mst. Fateha Samad**, Assistant Professor, Department of Electronics & Telecommunication Engineering, Rajshahi University of Engineering and Technology.*

Supervisor	**External Examiner**
---------------------------------------	---------------------------------------
Dr. Mst. Fateha Samad Assistant Professor, Department of Electronics & Telecommunication Engineering RUET, Rajshahi-6204.	

Head

Dr. Md. Munjure Mowla

Associate Professor,

Department of Electronics & Telecommunication Engineering
RUET, Rajshahi-6204.

Abstract

In the past few years, the fifth generation (5G) technology has been spreading all over the world with its billions of subscribers. The key enabling technologies such as heterogeneous networks, massive multiple-input-multiple-output (MIMO), and millimeter wave techniques have been identified to bring 5G to fruition. Antenna plays an imperative role to communicate in this 5G wireless communication using any of these techniques. The antenna that is proposed in this paper is "Y shape millimeter wave antenna based on SIW for 5G application". This thesis aims to design an antenna with high gain, efficiency, and data rate for the purpose of 5G application. It is highlighted that the millimeter wave characteristics play a key role in the 5G design due to its considerable bandwidth supports and high gain and efficiency achievement. SIW technology is also compatible for its design simplicity, compact shape and size and suitable for high frequency like millimeter-wave frequency band. So, an antenna based on SIW and having millimeter wave frequency is a great and reasonable choice for 5G application as this antenna implies the convenience of SIW as well as millimeter wave. The proposed antenna is designed on a substrate integrated waveguide (SIW) having copper top and bottom layers and substrate RogerRT5880 middle layer and Y shape slot cutting off from the top metallic layer. The overall antenna dimension is 10.7*4*0.431 mm3. 'CST Microwave studio' is used for the design. From the simulated result of the antenna, the values of reflection coefficient, VSWR, gain, directivity, radiation efficiency, total efficiency achieved are -25.66 dB, 1.11, 7.18 dBi, 7.646 dbi, 89.87%, and 89.62% respectively within the millimeter wave range.

Table of contents **Page No.**

Chapter 3

List of figures

List of figures **Page No.**

List of Tables

List of abbreviation

Abbreviation	Full Meaning
5G	Fifth generation
MIMO	Multiple-Input-Multiple-Output
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
SIW	Substrate Integrated Waveguide
HMSIW	Half Mode Substrate Integrated Waveguide
QMSIW	Quarter Mode Substrate Integrated Waveguide
FCC	Federation Communication committee
IoT	Internet of Things
GPRS	General packet radio services
LTE	Long-term Evolution Advanced
CDMA	Code Division Multiple Access
IEEE	Institute of Electrical and Electronics Engineers
OFDM	Orthogonal Frequency Division Multiplexing
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Inter-operability for Microwave Access

CHAPTER 1

Introduction

1.1 Introduction

In the past few decades, wireless communication is having far-reaching expansion and popularity all over the world. Billions of people are using wireless devices and are connected to the Internet of Things. With high speeds, superior reliability, and negligible latency, 5th Generation (5G) having based on the digital system of communication is expanding the wireless communication into new realms impacting every communication sector, industry, making safer transportation, remote healthcare, precision agriculture, digitized logistic and many more sectors. The forecast for future 10 years' traffic demand shows an increase in 1000 scales and more than 100 billion connections of Internet of Things, which imposes a big challenge for future wireless communication technology [1]. 5G is targeted to shed light on these high-capacity demands, high data rate, mobility, and high traffic volume density, strong device connection capabilities to deal with access requirements of the huge amount of IoT devices. To achieve these goals, to ensure the network is more efficient and deploy a new spectrum to support wider bandwidth requirements for 5G, three major technologies support the deployment of 5G [2]-

- Millimeter Wave;
- Massive MIMO (Multiple-Input-Multiple-Output);
- Beamforming.

The fastest 5G is known as millimeter wave. Millimeter wave frequency spectrum ranges from 30GHz to 300GHz. Millimeter wave opens up to more spectrum and permits high digital data rate and have attracted significant interest regarding meeting the capacity requirements of 5G [3]. There is an enormous expanse in the millimeter wave spectrum, more specifically 28 GHz and beyond that is largely overlooked until now. On October 22nd, 2015, Federal Communications Commission (FCC) proposed new rules (FCC 15138) for wireless broadband frequencies of 28 GHz, 37 GHz, 39 GHz, and 57-71 GHz bands, which are using for 5G applications [4]. The 60 GHz band

(57-71 GHz) more precisely 57GHz to 64GHz has been attracting a large public interest ever since it was released by the Federal Communications Commission (FCC) [5]. It is an unlicensed band. The key benefits that the emergency communications can take from using the 60 GHz spectrum band (57-64 GHz) is two-fold:

- It is an unlicensed band in which any wireless system is allowed to operate without a license granted by the FCC;
- Its historic abundance in the bandwidth of 14 GHz enables a myriad of high-data-rate applications for 5G communications.

Different types of millimeter wave antennas are being used so far within millimeter band spectrum for 5G application. For example- the Microstrip Patch antenna, Helical antenna, Horn antenna, Leaky Wave antenna, Substrate Integrated Waveguide (SIW) antenna, Circular Patch antenna, and different types of antenna array as well. But due to some flexibility and feasible features antenna based on substrate integrated waveguide are one of the promising candidates for the use in millimeter wave ranges for 5G application.

At higher frequencies, the existing platforms like microstrip and coplanar waveguide face loss related issues so they are not preferable. The capability to handle high power and high value of quality factor combined with advantages like simplicity, light - weight, and low cost at higher frequencies give SIW an edge over the existing platforms [6]. Presently, SIWs is becoming an inevitable choice for the implementation of high frequency integrated circuits. Basically, SIWs are the planar implementation of conventional rectangular waveguide. A typical SIW structure consists of two parallel metal plates separated by a dielectric substrate, with the bottom plate being the ground plane. Along the broader side of the metal plates, there are two rows of via holes or also called conducting cylinders, which are parallel to each other. These two rows of via holes connect the two metal plates through the substrate, thus confining the electromagnetic energy within the structure. They also connect the surface currents which maintain guided wave propagation in the structure [7]. Various shapes of slot or even periodic slots can be cut off from the top layer of the SIW structure to use as a predefined antenna for specific uses. Different shapes of antennas can be designed based on this SIW structure. The compact size, light weight, flexibility and low cost, easy design and implementation at millimeter wave frequencies, wide bandwidth, broadband high gain, and high efficiency make the antenna based on SIW more favorable to use in 5G applications. Though different antenna arrays based on SIW are also being used in 5G communications, but there are not so compact in size and their implementation is tough due to their difficult structures.

So, considering all the benefits of other forms of antenna, other frequency ranges and other technologies a millimeter wave antenna at 60GHz band (57GHz-64GHz) based on substrate integrated waveguide (SIW) can be a preferable choice for 5G applications.

1.2 Motivation

Nowadays the world is fully dependent on wireless communication. 5G can support up to millions of devices using wireless communication and the Internet of Things. 5G communications technology will bring new experiences to industry and society, including higher data rates or greater capacity, higher bandwidth, increased security, and lower latency. These developments will create new opportunities for advancing society and businesses. 5G is going to make a significant change in how we live in this world. Antenna has a vital role in this 5G application as antenna is one of the most essential devices for data transformation and wireless communication. The implementation of these high-level technologies will bring about new challenges for the designers of the physical infrastructure. These challenges undoubtedly include the antenna design. Recent technology developments have made advanced antenna systems a viable option for large scale deployments in 5G mobile networks [8]. The higher frequencies, wider bandwidths create significant challenges to antenna designers. Low-profile efficient antennas and antenna arrays to ensure reliable and interference-free communications are needed, but requirements for increased power, larger bandwidth, higher gain, and insensitivity to the presence of the human user further complicate the antenna and propagation aspects. This indicates the need for novel ideas and very innovative solutions in antenna design for high-frequency application [9]. That’s why research in the field of antenna design in selective ranges with a specific purpose is expanding for fulfilling the massive growth in wireless communication around the world. Study and research are required to design antenna to make it work at specific ranges, in this case in millimeter wave ranges so that it can be used for 5^{th} generation applications.

Voice, audio, video, data everything can be transported via wireless communication with high speed, high efficiency, no data loss, no traffic within minimum time in 5G. About 35 countries of the world are using 5^{th} generation in wireless communication [10]. In Bangladesh, we are mostly using 3^{rd} generation and 4^{th} generation of communication and in some specific subscriber, it's now having 4.5^{th} generation but the fastest and most effective 5^{th} generation is not using yet. So, this kind of research should come forward to develop antenna deploying 5^{th} generation application and expand its usages in our country as well as all over the world.

1.3 Objective

- The obvious objective of this thesis is to design a Y shaped Millimeter Wave antenna based on SIW for 5G application. The designed antenna must be unique and able to operate within the millimeter wave frequency range for the purpose of 5G applications.
- Another objective is to minimize the antenna dimension so that it can easily be moved and used. SIW is normally compact in size and light weight which gives an advantage to design the antenna with minimum dimension without any reasonable losses in the antenna's resulting parameters.
- To select specific frequency levels for simulation of antenna and also to select simulation port and feed point of the antenna accurately in order to get precise results within the specifically selected frequency level within which the antenna is operated.
- To optimize the antenna parameters into a certain level with the minimized dimension. The loss parameters must be as low as possible and the parameters like gain, effective efficiency, and total efficiency, bandwidth, reflection coefficient must be maximized up to a certain level within the operated frequency band.

1.4 Structure of the thesis

- **Chapter 1** covers the basic introduction of the thesis that consists of the information about 5G with its specifications and necessities, Millimeter Wave antenna based on SIW with its ranges, structure, advantages, how they are formed and why they are suitable for this exact application in 5G. This chapter also includes the motivation behind this thesis and the objectives of the thesis.
- **Chapter 2** covers the literature review which includes the previous work done on this field that is working on different millimeter wave antennas, SIW antennas for 5G applications. Here are also the discussion of the previous working methods, principles, formations, structures, advantages, applications, and results.
- **Chapter 3** covers the theory and methodology regarding the 5G and its applications, millimeter wave and its frequency spectrum range, substrate integrated waveguide and its convenience, antenna structure, models, and parameters of millimeter wave antenna based on SIW.
- **Chapter 4** covers the design and simulation. The designing methods and designing parameters are demonstrated and discussed in the design section and the simulated results are discussed and analyzed in the simulation part.
- **Chapter 5** covers the conclusion and future work. The whole summary of the thesis work has been demonstrated and the suggestion of future implementations and scopes of related works have been exhibited.

1.5 Summery

Y shaped Millimeter wave antenna based on SIW is constructed on a substrate integrated waveguide by cutting a Y shaped slot from the upper layer of the SIW. This antenna can work in the 60GHz band of millimeter wave spectrum with high gain, high efficiency which is favorable compared to other antenna working in other frequency spectrum and can use for 5G application. This antenna implies the convenience of SIW as well as millimeter wave which makes it more reasonable for use. So, in order to acquire better performance of the antenna in that specific 5G application, specific designs of the antenna must be developed.

Chapter 2

Literature Review

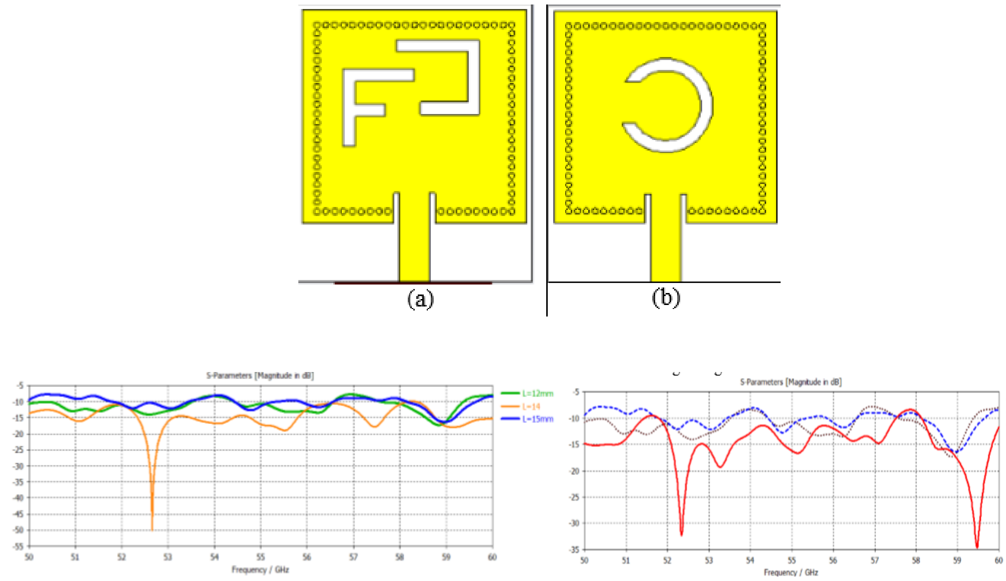
2.1 Introduction

Many types of research have already been done previously and still, it is being experimented currently on millimeter wave antenna based on SIW for 5G application. Different types of antennas in millimeter wave range have been used for 5G application and various SIW antennas have also been used for 5G communication. Basically, antenna using for 5G application is still under research as it is a very fast-growing and developing field and spreading swiftly all over the world. So, the literature review of various antennas using in 5G application is discussed below.

2.2 Literature review

Different types of antenna are found to be used within millimeter wave range for 5G application. Many of them are simple microstrip patch antenna, circular patch antenna, horn antenna, bow-tie antenna, leaky wave antenna, antenna array, and so on. Many antennas based on SIW, half mode SIW, quarter mode SIW are also used for 5G application with different slot shapes like longitudinal slot, bow-tie slot, T shape slot, L shape slot, periodic slot, cross slot, and so on. Different types of feed points and ports are also used. For the case of millimeter wave range variation like 28GHz band, 39GHz band, 60 GHz band, and 79 GHz band are seen for the same 5G applications.

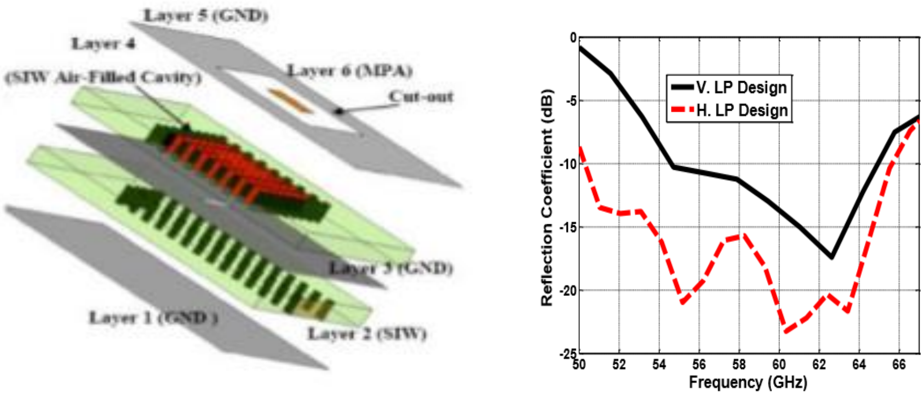
Fahadi et al. [11] described the Ultra-wideband (50 – 60 GHz) millimeter wave Substrate Integrated Waveguide (SIW) Antenna for 5G Applications. The proposed antenna is applying for 5G and feature WLAN. The proposed antenna is designed with two variant slot configurations having the shape of F - C slots and circular C slot shape as shown in figure 3.1(a)(b). For any antenna based on SIW, slot shape is significant because it influences the radiation properties as well as antenna performance. The antenna is constructed on Rogers RT5880lz (lossy) with a dielectric constant of 1.96, the thickness of l.27 mm, and a loss tangent of 0.0009. The antenna dimension is 47*40*1.97 mm. The diameter of via and via spacing between two consecutives via is 1mm and 1.5 mm respectively. For feeding a simple microstrip transmission line is used instead of any tapper structure. In both, the shape of the antenna's return loss shown in figures 2.1(c) and (d) shows results lower than -10dB within the range of 50-60 GHz which makes it feasible and robust. The average efficiency, gain obtained are 69%, 8.5dBi respectively. The bandwidth is 18.18%. From all the simulation results of the antenna parameters like return loss and gain it can be said that this design of antenna can be applicable for 5G application but the efficiency is only 69% which can be improved further by slightly changing the slot shape or dimension.



(c) (d)

Fig. 2.1. (a) SIW antenna with F-C slot, (b) SIW antenna with F-C slot, (c) The resonating frequency of the SIW antenna with FC Shape, (d) The resonating frequency of the SIW antenna with C Shape [11].

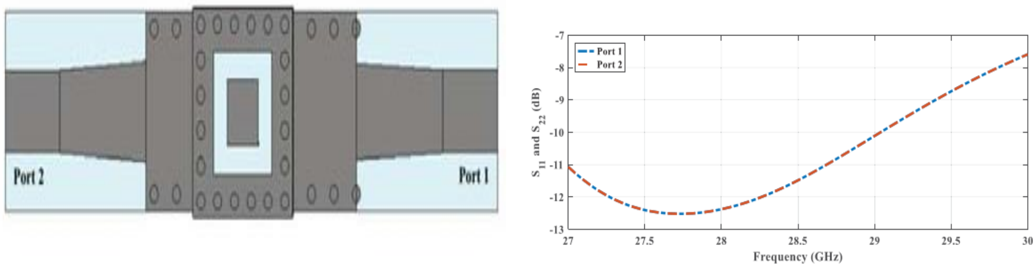
Wahab et al [12] demonstrate SIW-Integrated Patch Antenna Backed Air- Filled Cavity For 5G MMW Application shown in figure 2.2 (a), which was found to be good to discuss in this era of 5G application. The antenna is made up of dielectric substrate Roger RT5870 with dielectric constant 2.33. The antenna dimension is 7.50*6.80*2.57 mm. The diameter and spacing between two consecutive via are 0.3302 and 0.60 respectively. Two slots are cutting from the upper metallic layer-one in transverse and the other in the longitudinal direction to vertical and linear polarized radiation respectively. The simulation result shows that the reflection coefficient is good that is less than -10 dB and shows up to -24dB around 60GHz. But the radiation in horizontal linear polarization shows better return loss than that of the vertical linear polarization. So, the longitudinal slot design is the preferable design. The gain of the demonstrated antenna is found from 8.5 up to 11 dBi. The induced current density (A/m2) over the patch is shown at 60 GHz. In this design, an air-filled SIW cavity is integrated under the patch to improve radiation. In this case, a transverse slot is used to excite the patch generating a vertical linear polarized (V. LP) radiation as well as a horizontal linear polarized (H. LP) radiation with extended bandwidth. The structure has total five layers-three levels of metallic layers with SIW integrated into two dielectric layers to construct both the feed and the cavity which makes the design complex. The whole structure is excited by the TE10 waveguide fundamental mode through narrow slots.



(a) (b)

Fig. 2.2. (a) SIW-Integrated patch antenna, (b) Simulated Reflection Coefficient(dB) [12].

Shirichian et al. [13] developed a design of a circularly polarized SIW slot antenna for 5G base stations as shown in figure 2.3 (a). The antenna polarization is circular to make it robust against fading and mismatch. The designed two-port circularly polarized SIW antenna with different main lobe direction extends the number of output or input of the antenna. These two ports can make the base station to consolidate with two different devices simultaneously at different angles. The SIW slot antenna is fabricated on Roger 5880 with dielectric constant 2.2 and height 0.787 mm. The overall dimension of the proposed antenna is 22.2*5.98*.979. The diameter of vias and spacing among each of them is 0.50 mm and 0.56 mm respectively. The cross over and the square slot is taken in the upper metallic layer to make the antenna working at a definite frequency with high gain and axial ratio. The reflection coefficient of the antenna is less than -10 dB which is good and it is found up to -12.7dB in the 28 GHz band for both the ports. The gain of the antenna is 5.7 dBi. Though two-port of the antenna can be able to join more devices simultaneously and circular polarization would make the antenna rigid against the fading and mismatch but the gain and efficiency of the antenna can be better and it can be used in 60 GHz band of mm-Wave as it is more preferable in case of 5G application. Besides the antenna dimension can be reduced to some extent to make it compact.

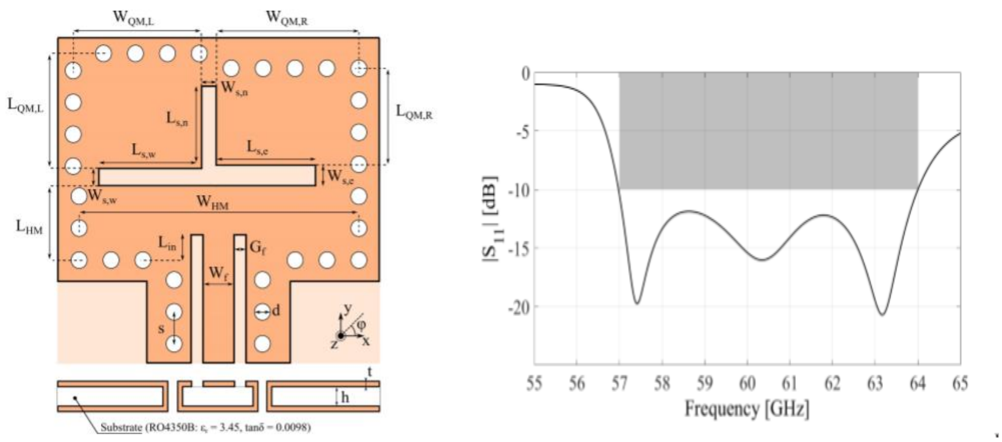


(a) (b)

Fig. 2.3. (a) Two ports antenna with cavity, (b) Simulated Reflection Coefficient(dB) of two ports antenna [13].

Deckmyn et al. [14] designed A Novel 60 GHz Wideband Coupled Half-Mode/Quarter-Mode Substrate Integrated Waveguide (HMSIW/QMSIW) Antenna which is a great use for 5G application working in millimeter wave band. The designed antenna is consisting of coupled half-mode and quarter-mode SIW resonant cavities for operation in the 60 GHz band which is different from conventional SIW. The antenna dimension is 3.7*3.3*0.56 mm^3 . The dielectric material used for this antenna is Rogers 4350B with dielectric constant of 3.45. The diameter of vias and spacing among each of them is 0.25 mm and 0.40 mm respectively. The HMSIW cavity is excited by a grounded coplanar waveguide (GCPW) transmission line. The reflection coefficient of the antenna found to be less than -10 dB in the frequency spectrum of 55-65 GHz which is good and it is found up to -21.3dB in the 63 GHz band as shown in the figure 2.4 (b) below. The gain of the antenna is 6.32 dBi. The bandwidth is 12% and the efficiency is

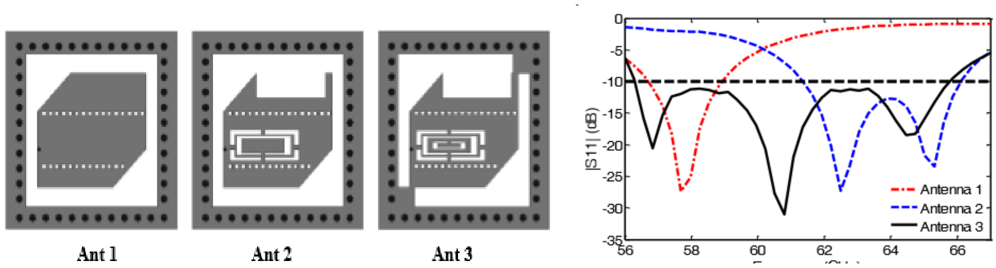
68%. A rectangular SIW resonant cavity can be miniaturized by bisecting it along fictitious quasi-magnetic walls, as such arriving at half-mode SIW (HMSIW) and quarter-mode. Though the antenna is very compact in size but the coupling of HMSIW and QMSIW make the structure a bit complex and the efficiency is only 68% which needs to be improved.



(a) (b)

Fig. 2.4 (a) HMSIW feeding cavity excited by a GCPW transmission line, (b) Simulated Reflection Coefficient(dB) of the antenna [14].

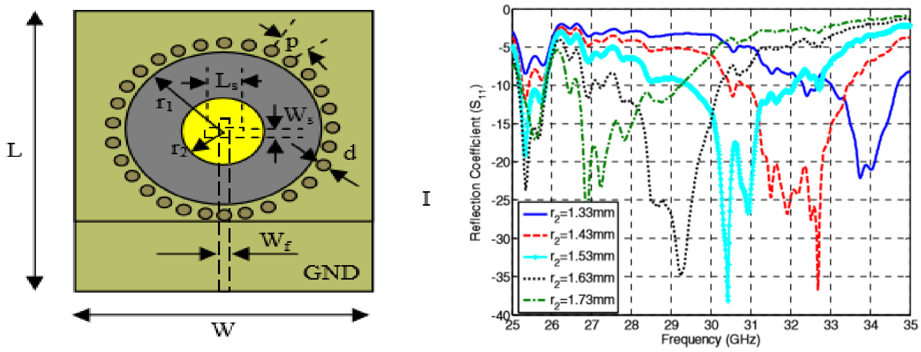
Wali et al [15] presented a broadband SIW antenna for 5G applications which is designed in a V band of millimeter wave with impedance bandwidth from 56.2-65.2 GHz. This band is chosen as its unlicensed (mm-Wave) frequency band at 60 GHz (57-66 GHz) and has shown great promise to obtain a high data rate and reduced co-channel interference. The proposed antenna is designed on RT/Duroid 5880 with relative permittivity 2.2 and height (h) 0.254mm. A 3×3.3 mm2 corner-truncated and symmetrically slotted patch is printed on the top layer of the substrate and is fed by the probe. To suppress the surface waves and confining the energy underneath the radiating patch and increasing the radiation efficiency of the antenna, many via holes are drilled into the substrate symmetrically. Four L-shaped and two C-shaped slots are made in the center of the patch to make it independent to adjust the required broadband antenna operation. The antenna has a small overall size of 5.2×5.2 mm2. Several steps are taken to introduce the slots in the design as shown in figure 2.5 (a) and adjust the frequency. The reflection coefficient of the antenna found to be less than -10 dB in the frequency spectrum of 56-66 GHz which is good and it is found up to -32.3dB in the 60 GHz band as shown in figure 2.11. The gain of the antenna is 7.75 dBi. The bandwidth is 15% and dual beam radiation patterns are obtained within the impedance bandwidth. In the 3rd step that is antenna three shows better performance than the other two. The size of the proposed is very compact which makes it easier to use and move and bandwidth is enough to use its 5G wireless application.



(a) (b)

Fig.2.5. (a) Steps towards proposed antenna, (b) Simulated Reflection Coefficient(dB) of the antennas 1-3 [15].

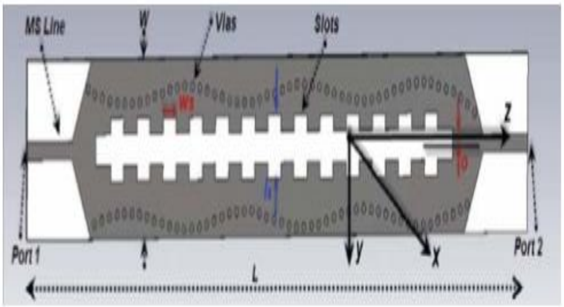
Ayman Elboushi and Abdelrazik Sebak [16] describe a high gain mm-Wave hybrid antenna using SIW technology which is prominent to be used for 5G application. Slot feeding mechanism is employed to excite the dominant mode TM010 in a circular patch radiator which is used to feed a surface mounted circular SIW. Instead of coplanar fed waveguide antenna, cavity backed waveguide antenna, hybrid dielectric resonator here the designed antenna is an ordinary circular patch based on substrate integrated waveguide as shown in figure 2.6 (a), within the frequency range 25-35 GHz. The overall antenna weight and size are small compared with classical antennas which allow integration and forming arrays for increasing the overall gain. A microstrip circular patch is printed on a dielectric substrate Roger RT5870 with low permittivity 2.33 and 0.7874-mm-thick which act as grounded substrate. The patch is fed by a 50Ω microstrip line on the backside of a second 0.635-mm-thick dielectric layer Roger RT6010 with a higher permittivity 10.2 and through a rectangular aperture etched in the common ground plane with a width nearly equals to a quarter guided wavelength at the center frequency of 30 GHz. This feeding mechanism excites the mode TM010 in the circular patch which feeds a surface mounted SIW open-ended circular waveguide. As the radius of the circular patch has the dominant effect on the antenna resonance frequency so various radius has been experimented to get good performance of reflection coefficient as shown in figure 2.16(b).

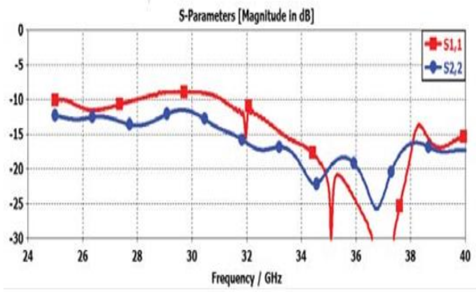


(a) (b)

Fig. 2.6. (a) Geometry of the proposed antenna, (b) Simulated Reflection Coefficient(dB) with variation of radius [16].

Mianroodi et al. [17] proposed a dual-port dual-band (28/38 GHz) SIW Leaky Wave antenna for 5G base stations. A stepped long slot on the top side of a SIW waveguide is designed in this antenna with a changing width in order to create a wide and rotating beam, which is desired in some specific 5G applications. One of the unique benefits of the design is its embedded duplexer separating the 28 GHz and 38 GHz ports at opposite sides of the antenna. The proposed stepped long slot (SLS) LWA is a SIW, constructed with a substrate RT/ Doruid 5880 (dielectric constant=2.2 and loss tangent=0.0009) with the thickness of 1.575 mm covered by copper on both sides with two periodic sinusoidal rows of metalized vias as shown in figure 2.17(a). The dimension of the SIW is 100*20*1.575 mm^3 . The diameter of the via and the distance between two vias are 1 mm and 2mm respectively and vias have a sinusoidal structure with a period of 2mm. Port 1 is set for the 38 GHz band and Port 2 for the 28 GHz band. The simulated reflection coefficients for both frequency 28 GHz and 38 GHz are S11 and S22 respectively of the periodic SLS SIW LWA at both left and rights] port. The reflection coefficient in port 1 (38GHz port) remains less than -10 dB from 32 to 40 GHz with 23% bandwidth and for port 2 (28 GHz port) from 26 to 29 GHz with 11% bandwidth which is shown in the figure. The gain of the antenna is 11.56 dBi. The direction of the main beam in both bands is rotated to the desired direction.

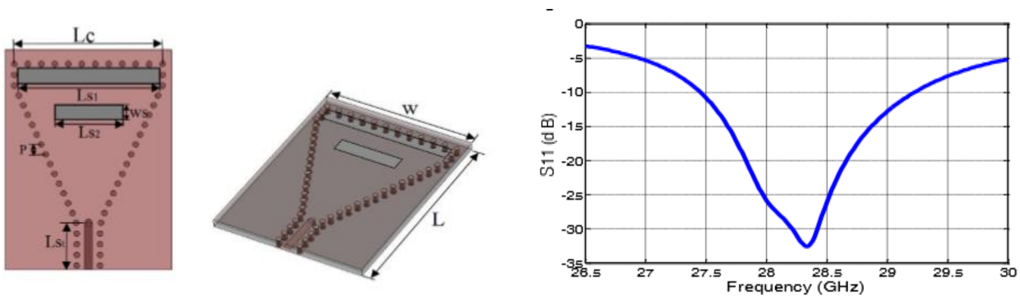




(a) (b)

Fig. 2.7. (a) Geometry of SIW with periodic slot, (b)Simulated Reflection Coefficient(dB) [17].

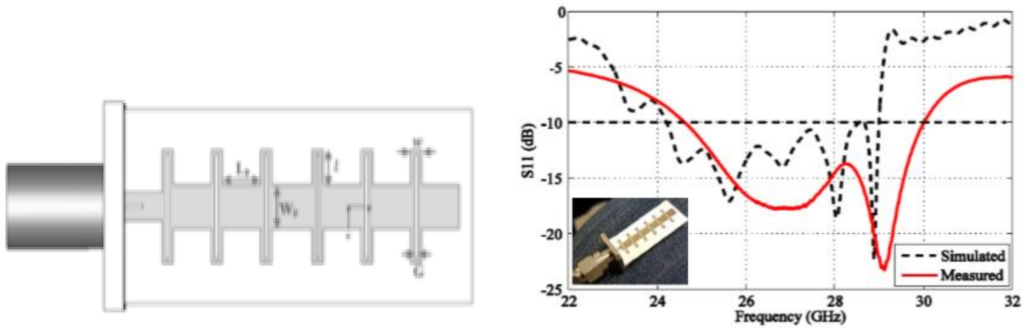
Asaadi and Sebak [18] developed broadside high gain H-plane substrate integrated horn antenna for future 5G applications. With upliftment of substrate integrated waveguide technology (SIW), construction of H-plane horn antenna with a low profile and low weight has become engaging because of its strong potential of integration. The proposed antenna is fed by substrate integrated rectangular coaxial cable (SIRC). The compact H-plane SIW horn antenna is implemented with a total dimension 36.6*26.7*1.775 mm^3 with two RT/Duroid 5880 layers on the top of each other with total thickness h= 1.572 mm, εr = 2.2, and tanδ = 0.0009. The SIW horn antenna is built by two flaring rows of metal vias. The antenna is fed by a substrate integrated rectangular coaxial cable, and the metal strip of the SIRC extends toward the mouth of the horn and is terminated with a metallic via connected to the ground plane. Figure 2.8(a) shows the proposed antenna structure and figure 2.8(b) shows the reflection coefficient in the frequency ranges from 26.5-30 GHz. The antenna shows a good return loss which is less than -10dB with a bandwidth about 6.7%. The gain of the proposed antenna is seen at about 13.3 dBi. E-plane and H-plane of the antenna radiation pattem show a good radiation performance.This designed SIW horn antenna shows great performance comparing to that of an ordinary horn antenna so it is considered a good candidate in 5G applications.



(a) (b)

Fig. 2.8. (a) Geometry of the proposed antenna, (b) Simulated Reflection Coefficient(dB) of the antenna [18].

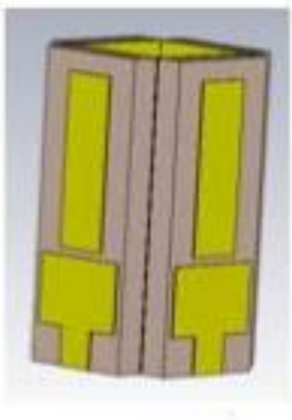
There is diversity in the antenna type which has been used for 5G applications so far. The antenna array is also popular in the case of using in 5G application. Jilani and Alomainy [19] proposed Millimeter-Wave conformal antenna array for 5G wireless applications. The presented antenna is a compact, flexible and wideband antenna array designed at millimeter-wave frequencies for upcoming 5G applications. The concept of the Franklin array is geometrically modified to transform a conventional narrowband antenna into a wideband antenna array. Measurements show that the designed array covers 24.6–30 GHz. The 28 GHz band has been chosen for the 5G application because 28GHz is extensively highlighted for 5G and have lower atmospheric absorptions and relatively lesser attenuations while these effects become more leading at higher frequencies. There are six elements of the MMW array with a total dimension of 12 × 28.2 × 0.4 mm3 with a continuous ground plane at the bottom. The height of substrate (h) is suggested to be 0.4 mm to get a considerable return loss while retaining the desired flexibility of the substrate. The designed array is fabricated on a surface treated PET film with dielectric constant 3.2. It shows a return loss maximum of -24 dB at 29 GHz with a bandwidth of about 26.36%. The peak gain is 8.3 dBi at 28-GHz, and efficiency is approximately 60% in the maximum operating range. The proposed antenna array can be a great choice for 5G application considering all its gain, bandwidth, and directivity but the antenna efficiency seems to be not so high and the array structure is quite difficult to design instead of a single design structure.



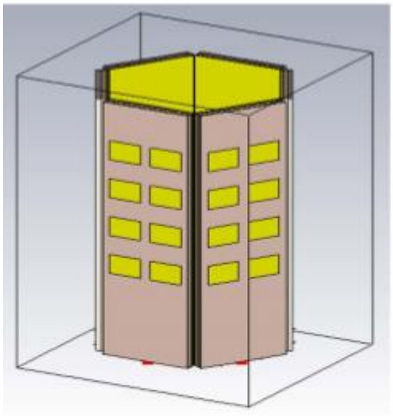
(a) (b)

Fig. 2.9. (a) Proposed MMW LWA array, (b) Simulated Reflection Coefficient(dB) of the MMW LWA antenna [19].

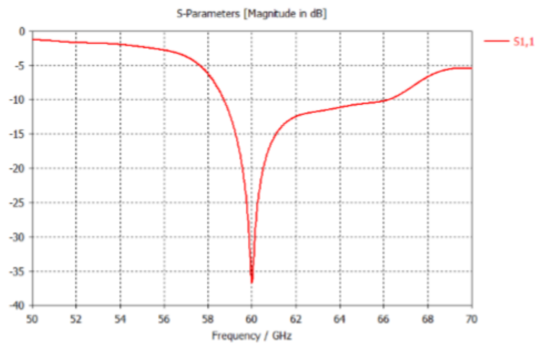
Another antenna array has been designed in 5G application which can be discussed. Yusnita Rahayu and Pratama [20] developed a new design of a 60-GHz quasi-Yagi and stacked series planar antenna array for 5G wireless application. The microstrip Quasi-Yagi antenna, as the combination of the microstrip antenna and Yagi antenna, is developed with characteristics of high gain and directivity, wide bandwidth, low cost, and ease of fabrication. Here 2X2 microstrip Quasi-Yagi antenna and 2X6 stacked series planar antenna is designed as shown in figure 2.10(a). The proposed Quasi-Yagi antenna dimension is 7.1*2.6*0.787 mm3 and the stacked series planar is 13.85*1.8 mm and is printed on 0.787 mm-thick Rogers Duroid RT5880 substrate with dielectric constant 2.20 and loss tangent (tan δ) of 0.0002. For the Quasi-Yagi antenna, the simulated return loss provides -27.85 dB at 60.01 GHz with VSWR ≤ 1.08. The bandwidth of 3.49 GHz is obtained with respect to-10 dB. For the Stack Planar antenna, the simulated return loss provides -37.61 dB at 60 GHz with VSWR ≤ 1.17. The bandwidth of 8 GHz is obtained with respect to -10 dB. As shown in Fig.2.10(b) the directional radiation pattern is achieved with a maximum gain antenna of 7.3 dB for 60 GHz. These two antennas can be considered as a good candidate for use in 5G application, but the antenna size is not compact, due to more array element the configuration is complicated.



(a)



(b)



(c)

Fig:2.10. (a)The geometry of proposed Quasi-Yagi antenna array, (b) The geometry of proposed 2X6 stacked series planar antenna array,(c) Simulated Reflection Coefficient(dB) of the proposed array [20].

2.3 Comparison between existing works

With the help of the discussion about the literature reviews of the previously used antenna in 5G application it is found that various kinds of millimeter wave antennas, as well as SIW antenna, has been used so far for example- Horn antenna, Microstrip patch antenna, Circular Patch antenna, Bow-tie antenna, antenna array, Leaky wave antenna and so on because of their good return loss, high gain, and efficiency, spreading radiation pattern, and good impedance bandwidth.

We can compare the antenna on different factors for easy understanding and finding out the best types for future use. The factors could be size or weight of antenna, materials used in antenna design, feeding techniques of the antenna, antenna port, the frequency range of antenna operation, and antenna parameters like gain, bandwidth, and efficiency as well.

At higher frequencies, the existing platforms like microstrip and coplanar waveguide face loss related issues so they are not preferable. The capability to handle high power and high value of quality factor combined with advantages like simplicity, light - weight, and low cost at higher frequencies give SIW an edge over the existing platforms. If we analyze all the antennas in the above-mentioned literature review, we can see the variation in the antenna size. For the use of 5G application, the antenna size should be as compact as possible so that it can be used easily and the light weighted antenna is preferable in case of moving and working. The leaky wave antenna [17] shows the highest size among all and the SIW-integrated patch antenna shows the lowest dimension. Both the antenna array [19]-[20] shows comparatively higher dimension and complicated design structure. The SIW slot antenna [12] shows a complex structure as it is consisting of five layers in SIW structure while the other antennas are on the layered SIW.

There are different dielectric substrates is used in the antenna design with different dielectric constant. Most of them have used Roger RT5880 with dielectric constant 2.2 [13], [15], [17], [18], [20]. Some used Roger RT5870 with dielectric constant 2.33 [12], [16], Roger RT4350B with dielectric constant 3.48 [14], Roger RT4232 with dielectric constant 3.30 [19].

Different types of slot shapes have also be noticed. The slot shape affects radiation pattern and radiation efficiency so it should be taken under consideration while designing. F-C slot [11], Longitudinal and Horizontal slot [12], Cross over and square slot [13], Periodic slot [17],[19], T slot [14], Circular slot [16], L-C slot [15] are seen. The diameter of via, the distance between the center of two consecutive via, number of via, and the arrangement of rows of vias are also taken under consideration as they all effect to delimit the propagation area of the antenna.

Different types of feeding techniques and lines are also found. The microstrip transmission line fed [16],[17],[15], circular polarized fed [12],[13], grounded circular polarized waveguide fed (GCPW) [14], coaxial cable transmission line [18] are seen. The circular polarization would make the antenna rigid against the fading and mismatch. The GCPW feeding helps to enhance the strength and enables compact antenna topology. But microstrip transmission line fed is more reliable and can be fitted easily to the antenna.

Some of the designs are found the have two ports which help it to connect with more devices simultaneously [13],[17] compared to a single port antenna but two ports find difficulty in case of feeding the ports and design complexity and size increment of the antenna occurs.

The above discussed antennas operate at different millimeter wave frequency band for 5G application like 28GHz band [13], [18], [19], 38GHz band [16],[17], 60GHz band [11],[12],[14],[15],[20]. Though all the frequency bands have their own advantages for the purpose of using in 5G application. The unlicensed 60 GHz band is allocated for a short-range high-speed wireless communication system. This wide bandwidth is capable of handling high data rates up to multiple gigabits per second as well as reducing the co-channel interference. 28GHz band is extensively highlighted for 5G because of lower atmospheric absorptions and relatively lesser attenuations while these effects become more prominent at higher frequencies []. But in most cases 60 GHz is used for its advantages over 28 GHz like frequency reuse in 60 GHz band is easier than 28 GHz band and 60 GHz is considered as an unlicensed band by FCC. Within this frequency range, the reflection coefficient below -10 dB is granted to be good and considerable for using it in 5G application.

Depending on the size of the antenna, antenna structure, material that constructs the antenna, the frequency within which the antenna is operated the antenna parameters vary. Variations in the antenna efficiency, gain and impedance bandwidth are found as a result. The highest antenna gain is found for SIW horn antenna [17] which is 13.3 dBi and the lowest is found in circularly polarized SIW slot which is 5.7 dBi. Normally a range of gain 7-11 dBi is considered as good. The impedance bandwidth is also found almost above 10% which is considered to be good except for [18] which is 6.7%.

The efficiency of the antennas also shows variations as well. From the above literature review, efficiency is found 69% [11] and 60% [19] which is good but there is scope to improve it further.

The overall comparisons among the antenna can be shown with the help of the following table 2.1 showing variations of the dielectric substrate, dimensions, frequency range, gain, return loss among the antennas of existing works.

Table 2.1 Comparison between existing works

Antenna Name	**Dielectric Substrate**	**Dimension (mm3)**	**Frequency Range (GHz)**	**Gain (dBi)**	**Return loss (dB)**	**Reference**
Ultra-wide band MMW SIW antenna	Roger RT5880LZ	47*40*1.97	50-60	8.5	-15	[11]
SIW patch antenna	Roger RT5870	7.5*6.8*2.57	50-66	8.5	-23	[12]
Circularly polarized SIW slot antenna	Roger RT5880	3.7*3.3*0.76	27-30	5.79	-20	[13]
Wideband coupled HM/QM SIW antenna	Roger RT4350B	5.2*5.2*0.45	55-65	6.32	-20	[14]
Broadband MMW antenna	Roger RT5880	20*15*1.42	56-66	9	-32	[15]

MMW hybrid antenna	Roger RT5870	100*20*1.57	25-35	10	<-10	[16]
SIW Leaky wave antenna	Roger RT5880	26.7*36.6*1.5	24-40	11.56	-25	[17]
SIW Horn antenna	Roger RT5880	12*28.2*0.40	26.5-30	13.3	-30	[18]
MMW conformal antenna array	Roger RO4232	13.8*1.8*2	22-32	8.3	-22	[19]
Quasi-Yagi & Stacked series planar antenna	Roger RT5880	7.1*2.6*0.78	50-70	8	-30	[20]

2.4 Conclusion

For the use of 5G application SIW is one of the best choices of the antenna as it is compact, light-weighted, budget-friendly, easy to design and manufacture, and also it achieves high gain and efficiency in the millimeter wave frequency band spectrum. We have to measure the dimension and slot shape accurately according to the operated frequency band to get acceptable results.

Chapter 3

Theory

3.1 Introduction

5G technology is the most recent innovation in the field of the wireless communication system. Various types of antennas are used for the purpose of 5G applications. Different criteria are to be fulfilled in order to use an antenna in 5G application. Millimeter wave spectrum range is one of the main criteria in 5G. Again, the working principle, methods, structure, capabilities of these antennas used in 5G applications are also different. To design an antenna there are several parameters that are to be firstly calculated and then designed carefully. The theory related to the demands of any antenna for using in 5G application, working principle of millimeter wave antenna based on SIW and their parameters have been discussed below.

3.2 5G Technology

5G is the 5th generation mobile network. It is a new global wireless standard after 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices. 5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connect new industries.

3.2.1 5G Evolution

The aim of wireless communication is to ensure better quality, reliable communication just like wired communication, and each new generation of services represents a big step in that direction. This evolution journey was started in 1979 from 1G and it is still continuing to 5G. Each of the Generations has standards that must be met to officially use the G terminology which stands for generation. Each generation has requirements that specify things like throughput, delay, etc. that need to be met to be considered part of that generation.

The very first generation of the commercial cellular network was introduced in the late '70s with fully implemented standards being established throughout the 80's. It was introduced in 1987 by Telecom (known today as Telstra), Australia received its first cellular mobile phone network utilizing a 1G analog system. 1G is an analog technology and the phones generally had poor battery life and voice quality was large without much security, and would sometimes experience call drops. The maximum speed of 1G is 2.4 Kbps [21]. Cell phones received their first major upgrade by moving from 1G to 2G. The main difference between the two mobile telephone systems (1G and 2G), is that the radio signals used by the 1G network are analog, while 2G networks are digital. The main aim of this generation was to serve secure and reliable communication channels. It implemented the concept of CDMA and GSM. Provided small data services like SMS and MMS. Second generation 2G cellular telecom networks were commercially launched on the GSM standard in 1991. 2G capabilities are achieved by allowing multiple users on a single channel via multiplexing. The max speed of 2G with General Packet Radio Service (GPRS) is 50 Kbps or 1 Mbps with Enhanced Data Rates for GSM Evolution. Before making the major leap from 2G to 3G wireless networks, the lesser-known 2.5G and 2.75G was an interim standard that bridged the gap [22]. Third generation sets the standards for most of the wireless technology we have come to know and love. Web browsing, email, video downloading, picture sharing, and other Smartphone technology were introduced in the third generation. Introduced commercially in 2001, the goals set out for third generation mobile communication were to facilitate greater voice and data capacity, support a wider range of applications, and increase data transmission at a lower cost. In 3G, Universal access and portability across different device types are made possible. 3G increased the efficiency of the frequency spectrum by improving how audio is compressed during a call, so more simultaneous calls can happen in the same frequency range. Like 2G, 3G evolved into 3.5G and 3.75G as more features were introduced in order to bring about 4G. A 3G phone cannot communicate through a 4G network, but newer generations of phones are practically always designed to be backward compatible, so a 4G phone can communicate through a 3G or even 2G network [23]. 4G is a very different technology as compared to 3G and was made possible practically only because of the advancements in the technology in the last 10 years. Its purpose is to provide high speed, high quality, and high capacity to users while improving security and lower the cost of voice and data services, multimedia, and internet over IP. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, 3D television, and cloud computing. The key technologies that have made this possible are MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing). The two important 4G standards are WiMAX (has now fizzled out) and LTE (has seen widespread deployment) [24]. The max speed of a 4G network when the device is moving is 100 Mbps or 1 Gbps for low mobility communication like when stationary or walking, latency reduced from around 300ms to less than 100ms, and significantly lower congestion. When 4G first became available, it was simply a little faster than 3G. 4G is not the same as 4G LTE which is very close to meeting the criteria of the standards. 5G is a generation currently under development, that's intended to improve on 4G. 5G promises significantly faster data rates, higher connection density, much lower latency, among other improvements. Some of the plans for 5G include device-to-device communication, better battery consumption, and improved overall wireless coverage. The max speed of 5G is aimed at being as fast as 35.46 Gbps, which is over 35 times faster than 4G [25].

With the help of the following table 3.1, all the five generations and evolution of 5G from the beginning can be summarized.

Table 3.1 Evolution from 1G to 5G

Features	1G	2G	3G	4G	5G
Start/Development	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Technology	AMPS, NMT	GSM	WCDMA	LTE, WiMAX	MM Wave, MIMO
Frequency	30 KHz	1.8 GHz	1.6-2 GHz	2-8 GHz	3-300 GHz
Bandwidth	2 kbps	64 kbps	2 Mbps	Up to 1 Gbps	1 Gbps and higher
Access System	FDMA	TDMA	CDMA	CDMA	OFDM
Core Network	PSTN	PSTN	Packet network	Internet	Internet

3.2.2 5G Spectrum

5G needs a significant amount of new harmonized mobile spectrum and in that case, defragmenting and clearing prime bands should be prioritized. Regulators should aim to make available 80-100 MHz of contiguous spectrum per operator in prime 5G mid-bands (e.g. 3.5 GHz) and around 1 GHz per operator in high-bands (e.g. mm Wave spectrum). 5G needs spectrum across low, mid, and high spectrum ranges to deliver widespread coverage and support all use cases. All three have important roles to play: - Low-bands (e.g. sub-1 GHz) support widespread coverage across urban, suburban, and rural areas and help support the Internet of Things (IoT) services. - Mid-bands typically offer a good mixture of coverage and capacity benefits. The majority of commercial 5G networks are relying on a spectrum within the GHz range. In the long term, more spectrum is needed to maintain 5G quality of service and growing demand, in bands between 3 and 24 GHz. - High-bands are needed to meet the ultra-high broadband speeds envisioned for 5G. Currently, 26 GHz, 28 GHz, 40 GHz, and 60 GHz have the most international support and momentum [26].

For the use of 5G technology, there is an enormous expanse in the millimeter wave spectrum, more specifically 28 GHz and beyond that is largely overlooked until now. On October 22nd 2015, FCC proposed new rules (FCC 15138) for wireless broadband frequencies of 28 GHz, 37 GHz, 39 GHz, and 64 -71 GHz bands. Researchers are targeting these frequencies for 5G applications. Internet of Things (loT). loT is a system of physical items to gather and exchange information. For more direct incorporation between the physical world and computer-based frameworks, loT enables these devices to be detected and controlled remotely to enhance efficiency. The terms loT and 5G are used conversely because of the shared traits in the intents of both.

3.2.3 Attribute of 5G

5G is more favorable in the research field because of its enormous attributes. They are discussed below-

- **Throughput**

  5G has the potential to deliver speeds many times faster than today's 4G, powering uses such as intelligent video, remote diagnostics, and mobile command centers for live audio and video.5G networks will one day offer peak data rates of up to 10 Gbps. So far, 5G has demonstrated speeds of 600 to 800 Mbps downlink and 250 Mbps uplink in third-party testing.

- **Service deployment**

  Network virtualization (i.e., using software to perform network functions) enables service and application deployment without having to install additional hardware. This will lead to a reduction in typical service deployment time from 6 months to 90 minutes.

- **Mobility**

  5G technology is designed to enable devices that are traveling up to 500 kph (310 mph) to stay connected to the network.

- **Connected devices**

  The number of connected devices will be more than three times the global population in upcoming years. 5G will be capable of supporting up to 1 M devices in a square kilometer. This will allow cities to tap into the power of 5G for things like smart streetlights, remote security monitoring, intelligent rail, and smart parking solutions.

- **Energy efficiency**

  Sustainability is one of the core values of 5G. 5G will have lower energy requirements for network operation which is only 10% of current device consumption. Also, with 5G, complex functions could happen within the network, near the end-user.

- **Data Volume**

  The 5G standard is designed to support up to 10 TB/s/km2. This means that a 5G network can carry a massive amount of data for a large number of simultaneous users. So, users in high-density areas—like airports, stadiums, and urban areas—will all experience the fast speeds and low latency of 5G service.

- **Low latency**

  5G's rapid end-to-end latency (the time it takes for data to travel from the user, over the network to the central processor and back again) will be one of the drivers of true technological change, bringing data transit speed to many times less than the blink of an eye. 1ms latency and very high availability, reliability, and security to support services such as autonomous vehicles and mobile healthcare. All kinds of new applications become possible once you reach very low levels of latency, including Immersive extended reality (XR), combining augmented reality (AR), virtual reality (VR) and mixed reality (MR), Autonomous driving, Computer vision, Haptics-enabled tactile internet, Robotics and so on.

- **Reliability**

  5G offers the most reliable LTE network all over the world.

- **Massive machine-type communications**

  Including the ability to support at least one million IoT connections per square kilometre1 with very long battery life and wide coverage including inside buildings.

- **Fixed wireless access-**

  Including the ability to offer fiber type speeds to homes and businesses in both developed and developing markets using new mm wave wider frequency bands, massive MIMO, and 3D beamforming technologies.

3.2.4 Technology Used in Deploying 5G

Three major technologies support the deployment of 5G [2]-

- **Millimeter Wave Network Deployment**

  5G requires much higher bandwidth up to GHz ranges. The current sub-3 GHz cellular band will not support wider bandwidths, so the only way to make 5G work is to move the system to a higher frequency band. The frequency bands that have this potential are mm-Wave bands, as the next-generation 5G cellular networks promise improvements in network capacity, data rates, and latency. 5G networks will have much lower antenna heights, potentially introducing significant propagation blockage in mmWave.

- **Massive MIMO (Multiple-Input-Multiple-Output)**

  Massive MIMO is an extension of multi-user MIMO, meaning the number of base station antennas is much larger than the number of UEs in the cell. Typically, the number of antennas is about 48-64, but with 5G, more antennas are required to make the beam much narrower. This allows the base station to deliver RF energy to the UE efficiently and precisely. As 5G massive MIMO implementation moves to mmWave frequencies, the physical size of the antenna has reduced, making the antenna small, easy to install, and maintain.

- **Beamforming**

  Beamforming is a MIMO technology that uses multiple antennas to control the direction of a wave-front by appropriately weighing the magnitude and phase of each antenna signal. Used to achieve efficiency, Beamforming overcomes path loss, channel noise, and cross-talk. Because path loss is much greater in the mmWave band than sub-6 GHz, beamforming is crucial to the success of 5G networks.

3.2.5 Antenna used in 5G

The design complexities that 5G introduces to improve spectral efficiency and data rates increase substantially with the number of active antennas and antenna arrays needed for its devices. Combined with the related issues of millimeter-wave signal processing, new modulation, power, etc. our goal is to resolve the 5G complexities by designing an optimized antenna.

For the purpose of using an antenna in 5G technology, there are some specifications. The main point while designing an antenna for 5G application is the size and frequency leading capability of the antenna. The antenna must work smoothly in the required frequency ranges used for 5G that is in wideband range or mmWave range from 3 GHz to 300 GHz. The size of the antenna should be as small and compact as possible so that it can be carried and handled easily. Then the antenna used in this field should have high gain and efficiency and low loss so that the reason for its use is fulfilled [27]. Antenna characteristics regarding reflection coefficient, mutual coupling, radiation pattern should also be taken into concern while designing.

Different types of antennas using so far for 5G applications are microstrip patch antenna, horn antenna, lens antenna, leaky wave antenna, circular patch antenna, spiral antenna, substrate integrate waveguide antenna, and different types of antenna array as well.

3.3 Millimeter Wave antenna

The millimeter-wave region of the electromagnetic spectrum is commonly defined as the 30- to 300-GHz frequency band or the 1-cm to 1-mm wavelength range. The antenna used within this range is basically called a millimeter wave antenna [28]. Utilization of this frequency band for the design of data transmission and sensing systems has a number of advantages:

I. The very large bandwidth resolves the spectrum crowding problem and permits communication at very high data rates.
II. The short wavelength allows the design of antennas of high directivity but reasonable size so that high-resolution radar and radiometric systems and very compact guidance systems become feasible.
III. Millimeter waves can travel through fog, snow, and dust much more readily than infrared or optical waves.
IV. Finally, millimeter-wave transmitters and receivers lend themselves to integrated and, eventually, monolithic design approaches, which results in rugged, compact, and inexpensive design.

For these advantages, this category of the antenna is also very suitable for 5G application. Millimeter Wave antenna may include any kind of antenna that belongs to its range for example- microstrip patch antenna, horn antenna, lens antenna, leaky wave antenna, circular patch antenna, spiral antenna, substrate integrate waveguide antenna, and different types of antenna array as well and they have already used as millimeter wave antenna for various purposes. But for the specific use of millimeter wave antenna frequency spectrum is an important factor that also influences the antenna type including the parameters [29].

3.3.1 Spectrum of Millimeter Wave antenna

Millimeter wave spectrum is the band of spectrum between 30 GHz and 300 GHz. Service operators have begun investigating mm wave technology to evaluate the best candidate frequencies for use in 5G. The International Telecommunication Union and 3GPP have aligned on a plan for two phases of research for 5G standards. The first phase, set to conclude in for frequencies less than 40 GHz to address the more urgent subset of the commercial needs. The second phase focuses on frequencies up to 100 GHz, according to National Instruments.

- 57 GHz to 64 GHz unlicensed.
- Seven gigahertz in total 28 GHz/38 GHz licensed but underutilized.
- Three gigahertz in total 71 GHz/81 GHz/92 GHz Light-licensed band: 12.9 gigahertz in total.

Wedged between microwave and infrared waves, this spectrum can be used for high-speed wireless communications as seen with the latest 802.11ad Wi-Fi standard (operating at 60 GHz). It is being considered by a standards organization, the Federal Communications Commission, and researchers as the way to bring “5G” into the future by allocating more bandwidth to deliver faster, higher-quality video, and multimedia content and services. High frequency means narrow wavelengths, and for millimeter waves that sit in the range of 1 millimeter to 10 millimeters [30].

There are various telecommunication standards that specify the carrier frequency in the mmWave frequency range. IEEE 802.16 specifies a frequency range of 10–66 GHz for wireless metropolitan area networks (MANs). IEEE 802.15 and ECMA-387 standards specify a frequency range of 57–66 GHz for high data rate personal area networks. IEEE 802.11ad specifies the 60-GHz frequency for wireless local area network (LAN) applications. The band 36.0 – 40.0 GHz is used for licensed high-speed microwave data links, and the 60 GHz band can be used for unlicensed short-range (1.7 km) data links with data throughputs up to 2.5 Gbit/s. It is used commonly in flat terrain. The 71–76, 81–86, and 92–95 GHz bands are also used for point-to-point high-bandwidth communication links. These higher frequencies do not suffer from oxygen absorption but require a transmitting license in the US from the Federal Communications Commission (FCC). There are plans for 10 Gbit/s links using these frequencies as well. In the case of the 92–95 GHz band, a small 100 MHz range has been reserved for space-borne radios, limiting this reserved range to a transmission rate of under a few gigabits per second [31].

IEEE 802.11ad specifies the 60-GHz frequency band (57-64 GHz) as an unlicensed band. The 60 GHz band is an excellent choice for high-speed Internet, data, and voice communications offering the following key benefits-

- Unlicensed operation: It is an unlicensed band in which any wireless system is allowed to operate without a license granted by the FCC. No need to spend significant time and money to obtain a license from FCC.
- High level of frequency: The communication needs of multiple customers within a small geographic region can be satisfied. Its historic abundance in the bandwidth of 14 GHz enables a myriad of high-data-rate applications for 5G communications.
- Highly secure operation: High security resulting from short transmission distances due to oxygen absorption and narrow antenna beam width ·
- Virtually interference-free operation: Resulting from short transmission distances due to oxygen absorption, narrow antenna beam width, and limited use of 60 GHz spectrum.

So, the 60 GHz frequency band is a better option to use by any millimeter wave antenna for 5G application.

3.4 SIW Technology

Substrate integrated waveguide (SIW) technology, which represents an emerging approach for the implementation and integration of microwave and millimeter-wave components and wireless systems and shows advantages compared to other conventional antennas like microstrip or coplanar waveguide. SIW technology combines the advantages of classical microstrip circuits like low cost, easy fabrication, compact size, low weight, and metallic waveguides like low losses, complete shielding, high power handling capability.

3.4.1 SIW as Antenna

A Substrate integrated waveguide (SIW) also known as a post-wall waveguide or laminated waveguide is a synthetic rectangular electromagnetic waveguide formed in a dielectric substrate by densely arraying metalized posts or via-holes which connect the upper and lower metal plates of the substrate. The waveguide can be easily fabricated with low-cost mass-production using through-hole techniques where the post walls consist of via fences. SIW is known to have similar guided wave and mode characteristics to a conventional rectangular waveguide with equivalent guide wavelength. SIW can be designed as open wave-guiding structures and energy leakage will take place when the uniformity of those guides is perturbed or they are not excited in an appropriate mode. These leakage effects may be used positively for the design of antennas by deliberately introducing perturbations in these guides so that they radiate in a controlled fashion. By cutting the slot as per the requirement from the top layer of SIW and connecting it with proper transition line and port mode SIW structure can be used as antenna.

3.4.2 Principles of SIW

I. **Geometry**- SIW is basically a three-layered waveguide. A mid-layer which is composed of dielectric substrate is covered on both the upper and lower faces by metallic layers. The substrate embeds two parallel rows of metallic via-holes delimiting the wave propagation area.

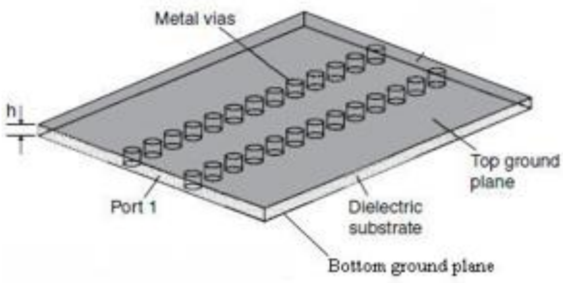


Fig. 3.1. Geometry of SIW [32].

II. **Transverse magnetic propagation modes**

In a classical solid-walled rectangular waveguide, the general formulation of propagation involves a superposition of transverse electric (TE) and transverse magnetic (TM) modes [32]. Each of these is associated with particular fields and currents. In the case of TM modes, the current in the vertical walls is longitudinal that is parallel to the propagation axis. So, it is impossible for such modes to appear in SIW that is the electrical current cannot propagate from via to via. Only TE modes are able to propagate through SIW. Each mode appears above a precise cut-off frequency determined by the waveguide dimensions and the filling medium. For TM modes, decreasing the waveguide thickness increases the cut-off frequency. In the case of SIW, the thickness is so low that the cut-off frequency of TM modes is much higher than the dominant mode.

III. Effective width

One of the objectives of the SIW geometry is to reproduce the characteristic propagation modes of rectangular waveguides inside a thin template. The width of the waveguide is an essential parameter of those modes. In the typical SIW geometry, the distance between the two vias rows from center-to-center is also needed. Due to the vias geometry, this distance cannot be utilized directly; because of the space between successive vias and their circular shape, the signal inside the guide does not behave exactly as it would in a perfectly rectangular waveguide of the same width.

To apply waveguide theory to SIWs, an effective width can be used. When ‘a’ is the distance between via rows, d is the diameter of the via, and s is the distance between two vias, it takes into account the shape of the vias and space in-between. A common simple equation is:

$$a_{eff} = a - \frac{d^2}{0.95s}$$

and a more refined equation used for large values $\frac{d}{a}$ is:

$$a_{eff=a-1.08}\frac{d^2}{s} + .1\frac{d^2}{a}$$

IV. Design Equation

The cutoff frequency of the regular rectangular waveguide is defined as [33]:,

$$\boldsymbol{f_c} = \sqrt{\left(\frac{\boldsymbol{m\pi}}{\boldsymbol{a}}\right)^{\boldsymbol{2}} + \left(\frac{\boldsymbol{n\pi}}{\boldsymbol{b}}\right)^{\boldsymbol{2}}}$$

where c is the speed of light in free space (3x108m/sec), m and n are mode indices, a and b are dimensions of the waveguide.

For TE10 the cutoff frequency will be:

$$\boldsymbol{f_c = \frac{c}{\lambda_c} = \frac{c}{2a\sqrt{\epsilon_r}}}$$

For dielectric-filled waveguide, the relation between the waveguide as SIW and the rectangular waveguide can be written as,

$$\boldsymbol{\lambda_c = 2 * a_{RWG}\sqrt{\epsilon_r}}$$

To prevent the leakage between vias, the relation between the diameter of the vias and the separation between vias should satisfy the following condition,

$$\boldsymbol{\frac{s}{d} < 2.5}$$

On the other hand, to prevent the bandgap, the following equation should hold,

$$\boldsymbol{0.05 < \frac{s}{\lambda_c} < 0.25}$$

V. Transitions

SIWs are promising structures that can be used in complex microwave systems as an antenna, interconnects, filters, etc. However, a problem may arise: the connection of the SIWs with other kinds of transmission line like microstrip, coplanar and coaxial cable. The goal of such transitions between two different topologies of the transmission line is to excite the correct transmission mode in the SIW cavity with the minimum loss of power and on the broadest possible frequency range.

Two different transitions are mainly used [34]. First, the tapered transition allowing to convert a microstrip line into a SIW, and secondly a transition between a coplanar line and a SIW. The tapered transition from microstrip to SIW is useful for thin substrates. In this case, the radiation losses associated with microstrip lines are not too significant. This transition is massively used. But this is not applicable to thick substrates where leakages are important. In that situation, a coplanar excitation of the SIW is recommended. The drawback of the coplanar transition is the narrower bandwidth.

These two kinds of transitions involve lines that are embedded in the same substrate, which is not the case for coaxial lines. There exists no direct transition between a coaxial line and a SIW: another planar line have to be used to convert properly the coaxial TEM propagation modes to the TE modes in SIW.

3.4.3 Attributes of SIW

SIW is more preferable to microstrip or coplanar waveguide to be used as antenna. There are several attributes that make the SIW more favorable.

- SIW technology combines the advantages of classical microstrip circuits like low cost, easy fabrication, compact size, low weight, and metallic waveguides like low losses, complete shielding, high power handling capability.
- Power handling capabilities are higher than any conventional waveguide structure like microstrip or coplanar waveguide.
- High-density integration can be achieved in the discrete component of the SIW structure of microwave and millimeter-wave systems.
- Reliable and compatible with high frequency and low radiation losses.
- The fabrication cost of various components using SIW structure is lower due to its favorable size and structure.
- One attraction to SIW is that the amount of metal that carries the signal is far greater than it would be in microstrip. Due to the use of metal, conductor loss is lower.
- Flexibility in use with high gain and broadband efficiency.

3.5 Performance Parameters of Antenna

There are some parameters to measure antenna performance in any application [35]. These are discussed below-

3.5.1 Directivity

In electromagnetics, directivity is a parameter of an antenna or optical system which measures the degree to which the radiation emitted is concentrated in a single direction. The directivity of an antenna is defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided. The directivity of an antenna is the maximal value of its directive gain.

3.5.2 Gain

The gain of an antenna $G(\theta,\phi)$(in a given direction) is defined as "the ratio of the intensity, in a given direction, to the radiation intensity $U(\theta,\phi)$ that would be obtained if the power accepted by the antenna is radiated isotopically. The power gain or simply gain of an antenna in a given direction takes efficiency into account by being defined as the ratio of its radiation intensity in that direction to the mean radiation intensity of a perfectly efficient antenna.

$$G(\theta,\phi) = \frac{U(\theta,\phi)}{P_{in} * 4\pi}$$

3.5.3 Bandwidth

Bandwidth is another fundamental antenna parameter that describes the range of frequencies over which the antenna can properly radiate or receive energy. Often, the desired bandwidth is one of the determining parameters used to decide upon an antenna.

3.5.4 VSWR

VSWR stands for Voltage Standing Wave Ratio. The VSWR parameter is a measure that numerically describes how well the antenna's is impedance matched to the radio or transmission line connected to it. It is a function of the reflection coefficient (Γ).

$$VSWR = \frac{1+[\Gamma]}{1-[\Gamma]}$$

3.5.5 Return Loss

Return loss is the loss of power in the signal returned/reflected by a discontinuity in a transmission line. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

$$Return\ Loss(dB) = 10\ log_{10} \frac{P_i}{P_r}$$

Here, P_i is the incident power and P_r is the reflected power.

3.5.6 Antenna Efficiency

Antenna Efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna. Simply, an Antenna is meant to radiate power given at its input, with minimum losses. The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line.

$$Antenna\ Efficiency, \eta = \frac{P_{rad}}{P_{in}}$$

Here, P_{rad} is the radiated power and P_{in} is the input power of the antenna.

3.5.7 Radiation intensity

Radiation intensity in a given direction is defined as “the power radiated from an antenna per unit solid angle.” The radiation intensity is a far-field parameter and it can be obtained by simply multiplying the radiation density by the square of the distance.

3.5.8 Radiation pattern

Radiation pattern (or antenna pattern or far-field pattern) refers to the directional (angular) dependence of the strength of the radio waves from the antenna or other source. A radiation lobe is a “portion of the radiation pattern bounded by regions of relatively weak radiation intensity.” This demonstrates a symmetrical three-dimensional polar pattern with several radiation lobes.

3.5.9 Input Impedance

Input impedance is defined as “the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point [36].

3.6 Feeding Port

The antenna feed is the location on the antenna where the feedline from the receiver or transmitter connects or attaches. Antenna feed might consist of a feed horn, orthomode transducer, polarizer, frequency diplexer, waveguide, waveguide switches, rotary joint, etc. According to the feed the feeding port is also selected. In the case of millimeter wave antenna based on SIW, waveguide port is selected [37].

3.7 Conclusion

With the help of proper and accurate knowledge about the antenna theory, parameters, their equations, calculations, and applications the desired antenna can be designed. The range, spectrum, characteristics of millimeter wave and the fundamentals regarding the 5G, its pros and cons will help to decide the antenna type, its dimensions, its applications without any defect and losses and ensure better performance of the antenna.

Chapter 4

Design and Simulation

4.1 Introduction

The Y shaped Millimeter Wave antenna based on SIW is designed using some rules and following some equations for the dimensions of the antenna to get the required results of the parameters after simulation which is needed to use this antenna for 5G application. Finite Element Method (FEM) and Frequency Domain Solver has been used for design and simulation. For obtaining better antenna performance and desired result, the antenna must be drawn according to the simple laws of measurement which are discussed below.

4.2 Materials of the Designed Antenna Structures

4.2.1 Materials of the Top and Bottom Layer

The proposed antenna is basically three-layered. The top and bottom are the metallic layers which are made of metal. Usually, metals like copper, nickels, etc. are used in these layers. Due to the availability and budget-friendly nature copper is more favorable. For the design of the top and bottom layers, copper is used. Using the SIW instead of a metallic waveguide has a great impact on the decrease of the antenna weight.

4.2.2 Materials of the Middle Layer

The middle layer of the proposed antenna consists of a dielectric substrate. There are several dielectric substrates that have been used for antenna design according to the demand of antenna results like Roger RT5880, Roger RT5880LZ, Roger RT6010LM. For the design of the proposed antenna Roger RT5880 is used. The dielectric constant of Roger RT5880 is 2.2.

4.2.3 Materials of Via

Along the broader side of the metal plates, there are rows of via holes or also called conducting cylinders, which are parallel to each other. These two rows of via holes connect the two metal plates through the substrate, thus confining the electromagnetic energy within the structure. They also connect the surface currents which maintain guided wave propagation in the structure. The via is also a metallic conductor made up of copper in this antenna design.

4.3 Dimensions of the Designed Antenna Structures

4.3.1 Dimensions of the Middle and Bottom Layers

Both the middle dielectric layer and bottom metallic layer have the same length and width but different heights. The length(L) and width(W) of the middle and bottom layers are 10.7 millimeters and 4 millimeters respectively. The height(h) of the dielectric middle layer is 0.381 millimeters and the height(t) of the metallic middle layer is 0.025 millimeters. The frequency range is selected previously to use this antenna for 5G application. So, using the following formulas the length and width are calculated for the design.

The cutoff frequency of the regular rectangular waveguide is defined as [38]:,

$$\boldsymbol{f_c} = \sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{W}\right)^2}$$

Where, c= speed of light in free space=3x108m/sec;

$\pi = 3.1416$;

L= Length of the wave guide;

w= Width of the wave guide;

$\boldsymbol{\epsilon_r}$=dielectric constant;

m and n are mode indices.

For TE10 the cutoff frequency will be,

$$\boldsymbol{f_c = \frac{c}{\lambda_c} = \frac{c}{2w\sqrt{\epsilon_r}}}$$

For dielectric-filled waveguide, the relation between the waveguide as SIW and the rectangular waveguide can be written as:

$$\boldsymbol{\lambda_c = 2 * w\sqrt{\epsilon_r}}$$

4.3.2 Dimensions of the Top Layer

In this design, we provide a tapered microstrip transition. It is widely used and has quite a few advantages of being less lossy, capacity to cover the entire bandwidth. Basically, the taper transforms quasi TEM mode of the microstrip line into dominant TE10 mode of the rectangular waveguide. The taper length is generally chosen to be a multiple of a quarter wavelength so that the return loss is minimal. The taper length depends on the difference between the width of the SIW and the microstrip line. So, the overall length(L) of the top layer is 10.7 mm which is segmented into three parts- the body, the tapper, and the microstrip line. The overall width(w) of the top layer is 4 mm. The height(h) of the top layer is 0.025 mm. The length(L1) and width of the body of the top layer is 9 mm and 4 mm respectively. The width(w5) of the tapper is 1.75 mm and the length(L4) of the tapper is 0.85 mm. The length(L5) and width(w6) of the microstrip line is 0.85 mm and 0.65 mm respectively.

4.3.3 Dimensions of the Via

To prevent the leakage between vias, the relation between the diameter of the vias and the separation between vias should satisfy the following condition [38]:,

$$\boldsymbol{\frac{s}{d} < 2.5}$$

Where d= Diameter of the via;

S= Spacing between two consecutive vias.

On the other hand, to prevent the bandgap, the following equation should hold:

$$\boldsymbol{0.05 < \frac{s}{\lambda_c} < 0.25}$$

There is total 102 vias, 51 vias in each longitudinal row, and 19 vias on one side connecting the two rows. The diameter(d) of the via is 0.1 mm and the spacing(s) between two vias is 0.15 mm respectively. The distance(w1) between two via rows is 3.05 mm.

4.3.4 Dimensions of the Y Shaped Slot

The slot is a cut off portion from the top metallic layer. The shape, position, and orientation of the slot decides the radiation pattern. The overall length of the slot is 6.6 mm which has two part-the head which is the V shaped structure and the tail which is the I shaped structure. The length of head(L3) is 1.15 mm, the overall width of head is 1.8 mm but each curved slice has a width(w3) of 0.45 mm and they are separated by a distance(w4) of 0.9 mm. The length(L2) and width(w2) of the tail of the slot are 5.45 mm and 1 mm respectively. The height of the slot is 0.431 mm.

The following table shows the overall dimensions of all the layers, vias, and slots of the designed antenna.

Table 4.1 Parameters used for designing antenna

Parameters	Values
L	10.7
L1	9
L2	5.45
L3	1.15
L4	0.85
L5	0.85
w	4
w1	3.05
w2	0.65
w3	0.45
w4	0.9
w5	1.75
w6	0.65
d	0.1
s	0.15

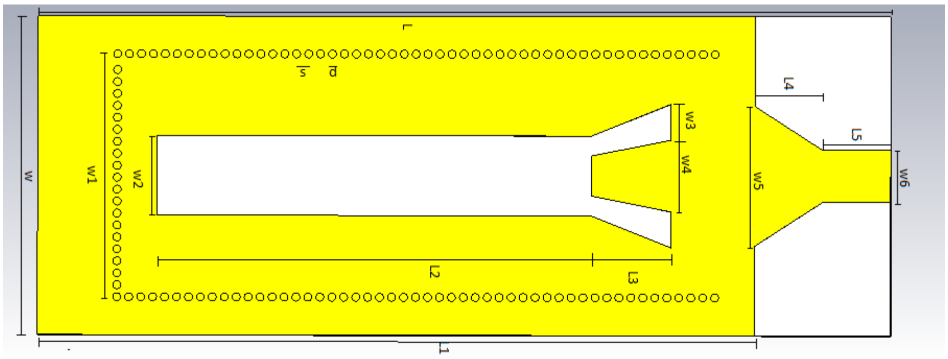


Fig. 4.1 Geometry of proposed antenna.

4.4 Analysis of the simulation

The EM solver chosen for simulation is the frequency domain solver, based on the antenna structure and the range of frequency. The choice of EM solver also depends on the size of the structure. Usually, when the biggest dimension of the antenna is smaller than 10 λ, then using the frequency solver would be the best option. Compared to the time domain solver, the frequency domain solver could be less time-consuming. Besides, usually, the frequency solver is preferred over the time domain solver when limited frequency range applications are faced.

4.4.1. Reflection Coefficient

Figure 4.2 shows the reflection coefficient of the designed antenna. The frequency range is taken in 60 GHz band that is from 57 GHz to 64 GHz and the resonant frequency is found at 59.66 GHz with a maximum value -25.66 dB. Reflection coefficient(dB) achieved lower than -10 dB make the antenna more reliable and robust for the application of feature wireless communications and hence, alludes the better antenna performance and input-output current ratio is matched. Within 57-64 GHz frequency range, achieves 0.72 GHz impedance bandwidth with respect to -10dB reference line and the values of the reflection coefficient is also good up to -25dB.

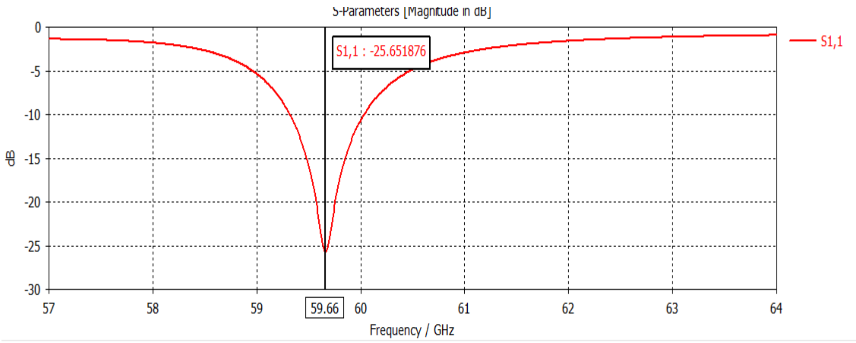


Fig. 4.2. The reflection coefficient(S11).

4.4.2. Voltage standing Wave Ratio (VSWR)

The voltage standing wave ratio (VSWR) is defined as the measure that numerically describes how well the antenna is impedance matched to the antenna transmission line. It is a function of the reflection coefficient. The lower the value of VSWR, the better performance for an antenna. Fig 4.3 shows the resultant VSWR. In the following figure, we can see that the VSWR is 1.11 which is nearly close to value 1 to its nearly resonant frequency 59.66 GHz.

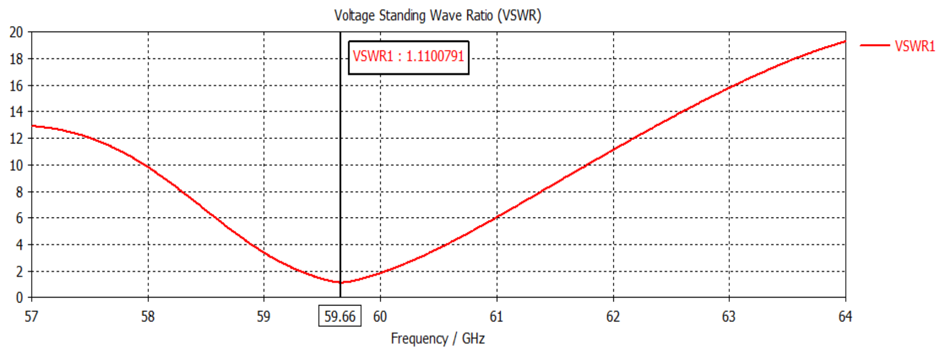


Fig. 4.3. Voltage standing Wave Ratio (VSWR).

4.4.3. Surface Current

The surface current at 59.66 GHz is presented in fig.4.4. There is a low loss at microstrip line feeding due to tapering that is microstrip feeding to SIW interconnection and surface current is high at starting edge of the structure.

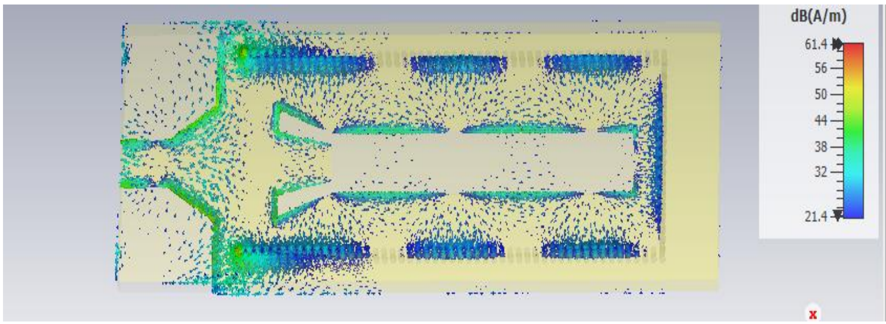
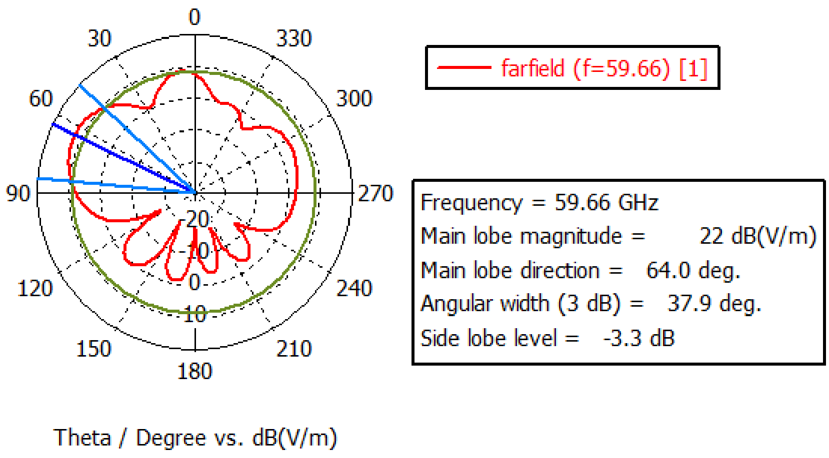


Fig. 4.4. Surface Current.

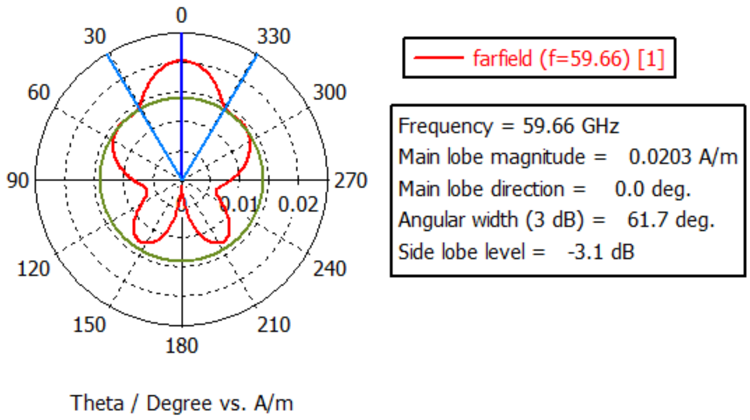
4.4.4. Radiation Pattern

The radiation pattern is defined as how the power radiated from the antenna in a certain direction. It has a major lobe which defines the maximum radiated power at a certain direction and are some minor lobes that define the loss of power radiated by the antenna. Figure 4.5 (a) shows E field, (b) shows H field, and (c) shows 3D view of the far-field radiation pattern. From the figures of the far-field radiation pattern, we can see, the E-plane and H-plane of the proposed antenna shows an anomaly in shape, but it can be realized as omnidirectional radiation.



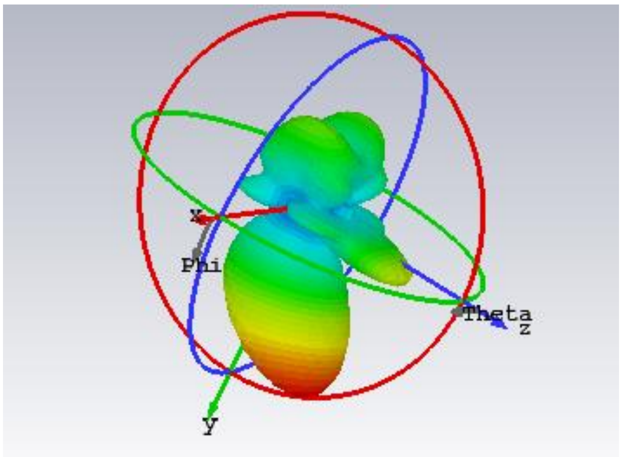
(a)

In the above fig 4.5(a), we can see that at the resonant frequency 59.66 GHz, the main lobe direction is at 64.0 degrees with angular width or 3 dB half-power beamwidth at 37.9 degrees. This means that at 64 degrees, the antenna radiates maximum power. The side lobe of the antenna at this resonant frequency is -3.3 dB.



(b)

In the above fig 4.5(b), we can see the H plane at the resonant frequency with almost similar main lobe direction and side lobe level except for the value of main lobe magnitude.

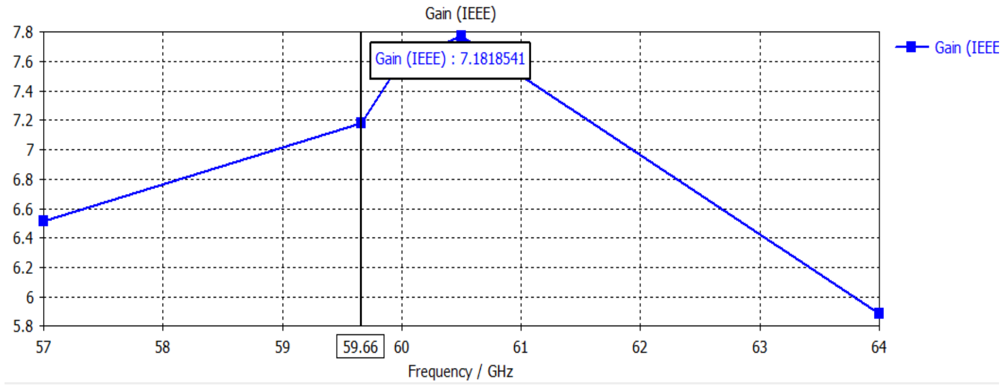


(c)

Fig. 4.5. (a) E Field radiation pattern, (b) H Field radiation pattern, (c) 3D Radiation pattern.

4.4.5. Antenna Gain

The gain is another parameter of concern. A relatively high gained value of the antenna denotes the high output value of the antenna. Every antenna has some loss of power due to distance, weather effect, temperature, and other noises from the device itself. The designed antenna gain plot is shown below.



(a)

From figure 4.6(a) it is seen that antenna gain is 7.18 dBi which can be considered as high gain. The following figure 4.6(b) shows the 3D gain plot at the resonant frequency.

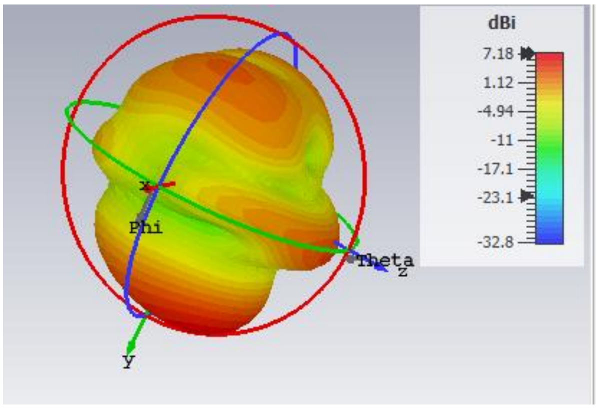


Fig. 4.6. (a) 1D Antenna gain plot at 59.66 GHz, (b) 3D Antenna gain plot at 59.66 GHz.

4.4.6. Directivity of Antenna

The more the antenna is directive the more the signal can be transmitted and received. Figure 4.8 shows the directivity of the designed antenna which is 7.646 dBi.

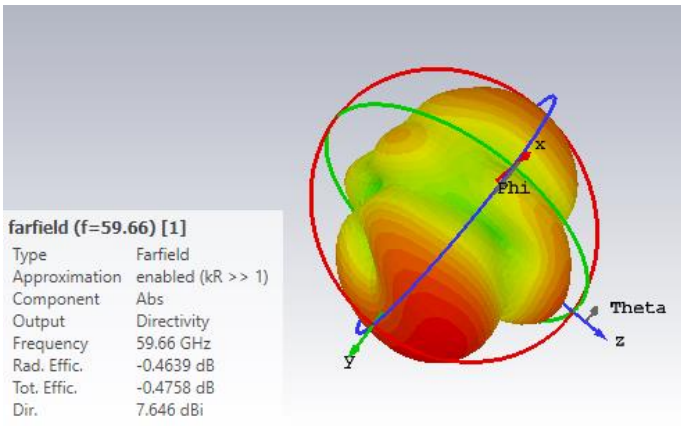


Fig. 4.7. 3D Antenna directivity plot at 59.66 GHz.

4.4.7. Antenna Efficiency

The total efficiency of the designed antenna 89.62% is and the radiation efficiency of the designed antenna is 89.87% which is which can be termed as very good in case of performance.

The simulation results can be summarized with the help of the table below-

Table 4.2 Different antenna parameter at 59.66 GHz

Parameter	Value
Reflection Coefficient	-25.66 dB
VSWR	1.11
Gain	7.18 dBi
Directivity	7.646 dBi
Radiation efficiency	89.87%
Total efficiency	89.62%

4.5 Comparison between this author's work and existing works

With the help of table 4.3 we can summarize this proposed work and compare it with the existing works containing dielectric substrate, dimension, frequency range, gain, return loss parameters of the antennas.

Table 4.3 Comparison between this author's work and existing works

Antenna Name	**Dielectric Substrate**	**Dimension (mm3)**	**Frequency Range (GHz)**	**Gain (dBi)**	**Return loss (dB)**	**Frequency (%)**	**References**
MMW Y-slot antenna based on SIW	Roger RT5880	10.7*4*.431	57-64	7.18	-25	13.33	Proposed work
Ultra-wide band MMW SIW antenna	Roger RT5880LZ	47*40*1.97	50-60	8.5	-15	18.18	[11]
Circularly polarized SIW slot antenna	Roger RT5880	3.7*3.3*0.76	27-30	5.79	-20	10.3	[13]
Wideband coupled HM/QM SIW antenna	Roger RT4350B	5.2*5.2*0.45	55-65	6.32	-20	12	[14]

MMW hybrid antenna	Roger RT5870	100*20*1.57	25-35	10	<-10	24.5	[16]
MMW conformal antenna array	Roger RO4232	13.8*1.8*2	22-32	8.3	-22	26	[19]

From the comparison table 4.3, we can see the proposed antenna shows many advantages over the existing work. The proposed antenna dimension is better, more compact and light-weighted than most of the existing work of [11], [15], [16], [17], [18], [19] which gives the privilege of using and moving it easily. The proposed antenna also shows a unique slot shape which is the Y slot where the existing antennas are showing the longitudinal, transverse, square, or cross-over slot shape. The via diameter, distances, and arrangement in rows gives good leakage which can be found by the surface current in figure 4.4. The proposed antenna has one port to make the structure simple. The proposed antenna used a 50ohm microstrip transmission line for feeding which is available and gives good impedance matching and also comparatively reliable to connect with other devices.

The antenna shows the exact V band of millimeter wave frequency spectrum between 57-64 GHz which is most appreciated by FCC as it is considered as an unlicensed band [32] for 5G application which is better than the 28GHz band in [13], [16], [19] or 38GHz band in [17].

The antenna gain is 7.8 which is good as gain in between the range 7-11 dB are considerably good in this category of antenna application [33]. The return loss less than -10 dB is a good consideration [34] while the proposed design shows a return loss of -25 dB. The VSWR is 1.11 and VSWR <2 is a good consideration. The E-field and H-field radiation pattern show broadside and omnidirectional patterns with good stability over the impedance bandwidth. The side lobe level is also narrow that helps to avoid unnecessary interferences. The proposed design also shows 13.33% impedance bandwidth. The efficiency of the proposed is very good which is 89.87% and it very high compared to 69% [11] and 60% [19]. So, considering all the facts the design is quite simple and suitable for 5G application.

4.6 Conclusion

From all the above discussion, we can see for sure is that to increase the antenna performance and use the antenna in the 5G application, the major concern is antenna designing and operating frequency. We could design several slot shapes in several feeding and port but keeping in mind about final and appreciable parametric results, it is necessary to give proper antenna dimension.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

From all the above discussion, it is shown that the MMW Y shape antenna based on SIW is convenient to use for 5G application for its better performance found after simulation in the millimeter wave frequency spectrum band. An efficient finite element method (FET) optimization technique can be used to design this antenna and frequency domain solver to simulate the required result. The performances of the best-selected antenna structures are validated and compared using commercial simulators. The finite element method and frequency domain solver has proven its advantage for quickly finding the simulation result for antenna designs. A millimeter-wave Y shaped antenna based on for 5G application is designed in this work, the antenna combines the qualities of miniaturization with compact size, light weight, simple structure, high gain, good VSWR, considerable radiation pattern, good return loss, and most importantly a very high antenna efficiency.

5.2 Future work

In every work, there are some limitations. The antenna gain can be minimized further without maximizing the compact size and dimension. As antenna for 5G application is a vast and fast-growing field new designs, antenna shapes are discovering to meet the up growing demand in this field so we can modify the antenna structure and frequency band consideration for getting better performance parameters from the simulation.

References

[1] Quan Yuan, Quanzhi Quan, Yong Mo, Hao Chen, "Research on Mixed Planning Method of 5G and LTE", Third International Conference on Information and Computer Technology (ICICT), p.5. 2020.

[2] Li Xin, Chen Xuqi, "5G Key Technology Evolution and Network Construction [J]". Telecom Express, pp. 6-9,2017.

[3] T. S. Rappaport, Shu Sun, R. Mayzus, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!" in IEEE Access, vol. 1, pp. 335-349, 2013.

[4] Horwitz, Jeremy, "The definitive guide to 5G low, mid, and high band speeds". Venture Beat online magazine, Retrieved April 23, 2020.

[5] C. Park and T. S. Rappaport, "Short-range wireless communications for next generation networks: UWB, 60 GHz millimeter-wave WPAN, and ZigBee," IEEE Wireless Communication, August, 2007.

[6] Bozzi, M., A. Georgiadis, and K.Wu,, "Review of substrate integrated waveguide circuits and antennas", IET Microwave Antennas Propagation, vol.5, pp.909-920, June 2011.

[7] M. Bozzi, A. Georgiadis, and K.Wu, "Review of substrate-integrated waveguide circuits and antennas", IET Microwaves, Antennas and Propagation, vol. 5, no. 8, pp. 909–920,2011.

[8] M. Shafi, A. F. Molisch, P. J. Smith et al., "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," IEEE Journal on Selected Areas in Communications, vol. 35, no. 6, pp. 1201–1221, 2017.

[9] Neus Padros, Juan I. Ortigosa, James Baker, Magdy F. Iskander, "Comparative Study of High-Performance GPS Receiving Antenna Designs", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 45, NO. 4, APRIL, 1997.

[10] Louiza Yala, Sihem Cherrared , Grzegorz PanekSofiane Imadali, Ayoub Bousselmi, "5G Experimentation Framework: Architecture Specifications, Design and Deployment", 23rd conference on Innovation in Cloud, Internet and Network(ICIN),2020.

[11] Najib AL-Fadhali, Huda A. Majid, Rosli Omar, M. K. A. Rahim, 5S. H. Dahlan, Adel Y. I., and 7B. A. F. Esmail, “ Ultra-wideband (50 – 60 GHz) mm-Wave Substrate Integrated Waveguide (SIW) Antenna for 5G Applications”, IEEE 10th Control and System Graduate Research Colloquium (ICSGRC 2019), pp 1-4, August 2019.
[12] Abdel-Wahab, Al-Saedi, Safavi-Naeini, Ying Wang, "SIW-Integrated Patch Antenna Backed Air- Filled Cavity For 5G MMW Application”, Global Symposium in Millimeter Waves (GSMM), 2016.
[13] Mehedi Shirichian, Gholamreza Moradi, Reza Sarraf Shirazi, Vahid Hassanzade, “Design a Circularly Polarized SIW Slot antenna For 5G Base Stations”, 5th International Conference on Millimeter-Wave and Terahertz Technologies (MMWaTT), pp.1-4,2018.
[14] T. Deckmyn, S. Agneessens, A. C. F. Reniers, A. B. Smolders, M. Cauwe, D. Vande Ginste, H. Rogier, "A Novel 60 GHz Wideband Coupled Half-Mode/QuarterMode Substrate Integrated Waveguide Antenna", IEEE Transactions on Antennas and Propagation, to be published, doi: 10.1109/TAP.2017.2760360.
[15] Muhammad R. Wali, Farooq A. Tahir, Muhammad U. Khan, R. Hussain, “A Broadband SIW Antenna for 5G Applications”, IEEE International Symposium on Antenna and Propagation & USNC/URSI National science Meeting,2018.
[16] Ayman Elboushi, Abdelrazik Sebak, “HIGH GAIN MMW HYBRID ANTENNA USING SIW TECHNOLOGY”, 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), IEEE, 2012.
[17] R. Yazdani Mianroodi1, H. Aliakbarian1, Guy A. E. Vandenbosch, “Dual-Port Dual-Band (28/38 GHz) SIW Leaky Wave Antenna for 5G Base Stations”, 12Th European Conference on Antenna and Propagation (EuCAP),2018.
[18] Muftah Asaadi,Abdelrazik Sebak, “ Broadside High Gain H-plane Substrate Integrated Horn Antenna For Future 5G Applications ”, IEEE International Symposiums on Antennas and Propagation (APSURSI),2016.
[19] Syeda Fizzah Jilani, Akram Alomainy “Millimeter-Wave Conformal Antenna Array for 5G Wireless Applications”, IEEE International Symposium on Antenna and Propagation & USNC/URSI National science Meeting,2017.
[20] Yusnita Rahayu , Septyo Adi Pratama, “New Design of 60-GHz Quasi-Yagi and Stacked Series Planar Antenna Array for 5G Wireless Application”,16th International

Conference on Quality in Research (QIR): International Symposiums on Electrical and Computer Engineering, pp.1-6, 2017.

[21] T. S. Rappaport, J. H. Reed, and B. D. Woerner, "Position location using wireless communications on highways of the future," IEEE Communication Magazine, vol. 34, pp. 33–41, Oct. 1996.

[22] He-Sheng Lin and Yi-Cheng Lin, "Millimeter-wave MIMO Antennas with Polarization and Pattern Diversity for 5G Mobile Communications", IEEE International Symposium on Antenna Propagation, pp.1-2, 2017.

[23] F. Hillebrand, "The creation of standards for global mobile communication: GSM and UMTS standardization from 1982 to 2000", IEEE Wireless Communication., vol. 20, pp. 24–33, Oct. 2013.

[24] R. S. Campos, "Evolution of positioning techniques in cellular networks, from 2G to 4G", Wireless Communication Mob. Comput., 2017.

[25] Y. Liu, X. Shi, S. He, and Z. Shi, "Prospective positioning architecture and technologies in 5G networks", IEEE Network, vol. 31, pp. 115– 121, Nov. 2017

[26] W. H. Chin, Z. Fan, and R. Haines, "Emerging technologies and research challenges for 5G wireless networks", IEEE Wireless Communications Magazine, vol. 21, no. 2, pp. 106–112, 2014.

[27] W. Hong, Z. H. Jiang, C. Yu et al., "Multibeam antenna technologies for 5G wireless communications", IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pp. 6231–6249, 2017.

[28] A. F. Kay, "Millimeter-wave antennas", IEEE Access, vol. 54, pp. 641–647, April 1966.

[29] A. Shahmansoori, G. E. Garcia, G. Destino, G. Seco-Granados, and H. Wymeersch, "5G position and orientation estimation through millimeter wave MIMO", IEEE Globecom Workshops, Dec. 2015.

[30] T. S. Rappaport, R. W. Heath, Jr., R. C. Daniels, and J. N. Murdock, "Millimeter Wave Wireless Communications", Englewood Cliffs, NJ, USA: Prentice Hall, 2015.

[31] Z. Pi and F. Khan, "An introduction to millimeter-wave mobile broadband systems," IEEE Communication Magazine, vol. 49, no. 6, pp. 101–107, Jun. 2011.

[32] N. Nasimuddin, Z. N. Chen, and X. Qing, "Substrate integrated metamaterial-based leaky-wave antenna with improved boresight radiation bandwidth", IEEE Transaction on Antennas Propagation, vol. 61, no. 7, pp. 3451–3457, 2013.

[33] A.A.Oliner and D.R.Jackson, "Leaky wave antennas", chapter 11, "Antenna Engineering Handbook", 2007.

[34] J. E. Rayas-Sanchez and V. Gutierrez-Ayala, "A General EM-Based Design Procedure for Single-Layer Substrate Integrated Waveguide Interconnects with Microstrip Transitions", IEEE MTT-S Int. Microwave Symposium, Dig., Atlanta, GA, Jun. 2008, pp. 983-986.

[35] Carr, J., "Practical Antenna Handbook", Tab Books, Blue Ridge Summit, PA, ISBN: 0-8306-9270-3.,1989.

[36] Trevor S. Bird, “IEEE Standard Definitions of Terms for Antennas”, IEEE Antennas & Propagation Magazine, vol.51, pp. 1-32,1993.

[37] H. Jin, K.-S. Chin, W. Che, C.-C. Chang, H.-J. Li, and Q. Xue, “Differential-fed patch antenna arrays with low cross polarization and wide bandwidths,” IEEE Antennas Wireless Propag. Lett., vol. 13, pp. 1069-1072, 2014.

[38] K. Wu, D. Deslandes and Y. Cassivi, 2003. The Substrate Integrated Circuits - A New Concept for High-Frequency Electronics and Optoelectronics. International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service (TELSIKS), pp. 1-8.

[39] J. Qiao, L. X. Cai, and X. Shen, “Enabling multi-hop concurrent transmissions in 60 GHz wireless personal area networks”, IEEE Transactions on Wireless Communications, vol. 10, no. 11, pp. 3824–3833,2011.

[40] W. Hong, K. H. Baek, Y. Lee, Y. Kim and S. T. Ko, “Study and prototyping of practically large-scale mmWave antenna systems for 5G cellular devices”, IEEE Communications Magazine, vol. 52, no. 9, pp. 63-69,2014.

[41] W. Hong, K. Baek, L. Youngju, and K. Yoon Geon, “Design and analysis of a low-profile 28 GHz beam steering antenna solution for Future 5G cellular applications”, IEEE MTT-S International Microwave Symposium (IMS2014), 2014, pp. 1-4,2014.

[42] C. Jin, R. Li, A. Alphones, and X. Bao, 2013 “Quarter-mode substrate integrated waveguide and its application to antennas design”, IEEE Transactions on Antennas and Propagation, vol. 61, no. 6, pp. 2921–2928,2013.

[43] J. Zhang, X. Ge, Q. Li, M. Guizani and Y. Zhang, “5G Millimeter-Wave Antenna Array: Design and Challenges”, IEEE Wireless Communications, vol. 24, no. 2, pp. 106-112,2017.

[44] J. Pi and F. Khan, “An introduction to mm-wave mobile broadband systems, IEEE Communications Magazine, pp. 101–107,2011.
[45] Professor T.Venkat Narayana Rao, Aasha S. A. and Sravya Tirumalaraju, “5G TECHNOLOGIES – AN ANECDOTE OF NETWORK SERVICE FOR THE FUTURE”, IEEE Journal of Global Research in Computer Science, Volume 2, No. 7,2011.
[46] F. Xu and K. Wu, “Guided-Wave and Leakage Characteristics of Substrate Integrated Waveguide”, IEEE Transactions on Microwave Theory and Techniques, vol. 53, no. 1, pp. 66–73, 2005.