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# Study and Optimization of Various Antenna Technologies for Millimeter Wave Communication

***Brindha R[1], Dr. G. Kavithaa[2]***

[1] *PG Scholar, Department of Communication Systems Engineering, Government college of Engineering – Salem-11, Tamil Nadu, India*
[2] *Associate Professor, Department of Electronics and Communication Engineering, Government college of Engineering – Salem-11, Tamil Nadu, India*

## ABSTRACT

5G wireless technology is designed to provide faster peak data speeds of multiple gigabits per second, extremely low latency, enormous capacity, and increased availability Using different technologies to create antennas, such as MIMO, mMIMO, and phased array, results in larger antennas that take up more area (MIMO), have complicated antenna structures, and are more expensive to produce. In this study, it is suggested to use an effective mix of technologies to reduce those problems. We will examine potential combinations of several antenna designing technologies in order to implement the antenna with greater efficiency. A patch antenna with a slot in the substrate and integrated SIW has been designed for the frequency of 26GHz, at a gain of 6.3dB. Designing an antenna with acavity and metamaterial in the ground plane, resonating at 62 GHz with a 4.8 dB overall gain with a bandwidth of 10Ghz.

**INDEX TERMS** 5G MM-WAVE, MIMO, Microstrip Antenna Substrate Integrated Waveguide, HFSS.

## INTRODUCTION

An antenna is a transducer that converts electrical signals into electromagnetic waves and electromagnetic waves into electrical signals. It is also defined as “a usually metallic device (as a rod or wire) for radiating or receiving radio waves.” An antenna plays a vital role in a communication system. It is used in both the transmission and reception of radio frequency signals. An antenna is a structure that is capable of radiating electromagnetic waves or receiving them. An antenna is generally a metallic object, often a wire or collection of wires used to convert high frequency current into electromagnetic waves and vice versa. Thus, a transmitting antenna converts electrical energy into electromagnetic waves, whereas a receiving antenna converts electromagnetic waves into electrical energy. Apart from their different functions, transmitting and receiving antennas behave identically i.e., their behavior is reciprocal.

## ANTENNA HISTORY

The first experiment that involved the coupling of electricity and magnetism and showed a definitive relationship was done by Faraday somewhere around the 1830s. He slid a magnet around the coils of a wire attached to a galvanometer. In moving the magnet, he was in effect creating a time-varying magnetic field, as a result (from Maxwell’s Equations), must have a time-varying electric field. The coil acted as a loop antenna and received the electromagnetic radiation, which was received (detected) by the galvanometer – the work of an antenna. Interestingly, the concept of electromagnetic waves had not even been thought up at this point.

## LITERATURE REVIEW

The base paper for our work is **“Design and Analysis of Dual Polarized Broadband Microstrip Patch Antenna for 5G mm Wave Antenna Module on FR4 Substrate”.** This paper was published by Gyoungdeuk Kim and SangkilKim, Department of Electrical and Electronic Engineering, Pusan National University, Busan, South Korea. This work was supported in part by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MSIT) under Grant 2020R1C1C1003362, and in part by Samsung Electronics Company Ltd. This study presents a dual polarized broadband microstrip patch antenna for a 5G mm Wave antenna module on an FR4 substrate. The proposed antenna was fabricated using a standard FR4 printed circuit board (PCB) process because of its low cost and ease of mass production. An air cavity structure was introduced to mitigate the high loss tangent of the FR4 substrate. Capacitive elements such as proximity L-probe feedings and parasitic patches are used to improve the impedance bandwidth of the patch antenna. For the polarization diversity of the massive multiple-input multiple-output (MIMO) capability, the antenna radiator was designed with a symmetrical structure, and the relative position of the L-probes excites the orthogonal resonant modes to enable dual linear polarization.

**“Wideband, Low-Profile Patch Array Antenna with Corporate Stacked Microstrip and Substrate Integrated Waveguide Feeding Structure”** published by Jun Xu, Wei Hong, ZhiHao Jiang, and Hui Zhang in Feb, 2019.In this communication, a corporate stacked microstrip and substrate integrated waveguide (SIW) feeding structure is reported to be used to broaden the impedance bandwidth of a 4×4 patch array antenna. The proposed array antenna is based on a multilayer printed circuit board structure containing two dielectric substrates and four copper cladding layers. The radiating elements, which consist of slim rectangular patches with surrounding U-shaped parasitic patches, are located on the top layer. Every 5 four radiation elements are grouped together as a 2×2 subarray and fed by a microstrip power divider on the next copper layer through metalized blind vias. Four such sub arrays are corporate-fed by an SIW feeding network underneath. The design process and analysis of the array antenna are discussed. A prototype of the proposed array antenna is fabricated and measured, showing a good agreement between the simulation and measurement, thus validating the correctness of the design.

**Khan, M., &Chowdhury, M. (2020). Analysis of modal excitation in wideband slot-loaded microstrip patch antenna using theory of characteristic modes. IEEE Transactions on Antennas and Propagation,** in this communication, modal excitation of characteristic modes in the ultra-wideband (UWB) slot-loaded microstrip patch has been investigated. A comprehensive analysis of modal excitation due to straight and L-probe feed reveals physical insight about antenna 5odelling due to feeding structure. This communication analyzes the modal effect of feed inclusion in two steps, i.e., before and after excitation. The application of characteristic modes to antenna bandwidth enhancement serves as a demonstration of the broad utility of the theory of characteristic modes (TCM), where multiple resonant modes participate simultaneously to broaden the bandwidth. This communication also examines the potential capability of natural resonant modes to contribute to the impedance bandwidth upon excitation. The slot-loaded antenna exhibits 35% impedance bandwidth with the straight probe feed, but bandwidth increased up to 81% by changing the feed to L-probe. Hence, impedance bandwidth has been enhanced up to 46% (approx.) by exciting particular resonant modes via changing and optimizing a feed structure.

**“Design of Electrically Small Metamaterial Antenna with ELC and EBG Loading” published by Ke Li, Cheng Zhu, Long Li,Yuan-Ming Cai, and Chang-Hong Liang.** Abstract—In this paper, two novel metamaterial antennas 6 applied for WLAN and WiMAX are proposed. Antenna 1 is composed of a monopole radiator with an electric- (ELC)element. By employing these structures, three frequency bands of 2.49 2.55, 3.0 3.68, and 5.03 6.04 GHz are achieved. Each band is well matched and can be easily adjusted. Antenna 2is integrating with EBG structure, which has a good impedance matching in 2.49 2.53 GHz, together with an ultra-wideband of 2.95 6.07 GHz. Both antennas have operational bands covering WiMAX in 2.5/3.5/5.5-GHz and WLAN in 5.2/5.8-GHz, omnidirectional radiation patterns over the operating bands. The proposed antennas have the advantages of simple fabrication, miniaturization, and compactness, which can be applied to wireless mobile communication system.

**“A design method for substrate integrated waveguide electromagnetic bandgap (SIW-EBG) filters” presented by Serkan Simsek, Sasan Ahdi Rezaeieh.** In this paper, an efficient design method for substrate integrated waveguide electromagnetic bandgap (SIW-EBG) filters is proposed which provides direct dimensional synthesis approach for desired filter objectives without using network representations. The method is applied to the design of an X band SIWEBG filter and its response is compared with HFSS (high frequency structure simulator) simulations for validation purposes. Fairly good agreement between the results shows the applicability of the proposed method for SIW-EBG filter design. Substrate integrated waveguides (SIWs) are a kind of dielectric loaded waveguides which are comprised of metalized via holes in a planar dielectric substrate material. Substrate integrated wave-guides cannot be considered as ideal homogeneous rectangular waveguides due to the fact that the solid metalized via holes on the side walls of rectangular waveguides. However, 6odelling of SIW-EBG filters as an ideal waveguide structure will be good approximation which can subsequently be fed into a full-wave design environment in order to tune the design for meeting design objectives effectively.

## 5G MM-WAVE

### *5G TECHNOLOGY*

5G is the next step in the evolution of mobile communication. It will be a key component of the Networked Society and will help realize the vision of essentially unlimited access to information and sharing of data anywhere and anytime for anyone and anything. 5G will therefore not only be about mobile connectivity for people. Rather, 5G aims to provide ubiquitous connectivity for any kind of device and any kind of application that may benefit from being connected. 5G works faster on mobile phones and other devices when compared to 4G LTE. 5G has low latency when compared to 4G which will support new applications such as AI, IoT and virtual reality efficiently. 5G can deliver up to 100 times more capacity than 4G. 5G has more bandwidth that will help transfer the data as soon as possible.

### *FREQUENCY SPECTRUM OF 5G*

5G is the combination of sub 6 and millimetre waves. The 5G spectrum bands have been categorized into 3 segments: 1. Sub-1Ghz frequency (low band) 2. Between 1-6 GHz (mid-band) 3. Above 6 GHz (high band or millimetre band) Fig.4.1 5G mm-Wave Spectrum 17 4.3 OVERVIEW OF 5G MM WAVE All mobile network activity travels over radio wave frequencies. As devices are added to the mix and more people use them more frequently, these frequencies are pressured. It’s not just cellular networks that use these frequencies; everything from microwaves to Wi-Fi routers to drones occupies some frequency on the radio wave spectrum. Right now, most of these devices exist in the 3 GHz to 6 GHz range, but these frequencies are filling up fast. As more devices come online, all that data is going to need more room to run. That’s where the millimetre wave spectrum comes into play. Millimetre waves often referred to as mm Waves or high-band 5G are frequencies starting at 24 GHz and beyond. As radio waves increase in frequency, each wave narrows in length. Because of its high frequencies, mm Wave has a limited range of only 300 to 500 feet and struggles to penetrate buildings. By contrast, 3G and 4G networks can travel further and better penetrate building materials. Until recently, millimetre waves were only used by satellite and radar systems, usually operated by the military and aerospace industry. But as data consumption has exploded, the industry saw the need and opportunity to use millimetre waves for next-generation mobile networks.

### *SUBSTRATE INTEGRATED WAVEGUIDE (SIW)*

In high-frequency applications, microstrip devices are not efficient, and because wavelength at high frequencies is small, microstrip device manufacturing requires very tight tolerances. At high frequencies waveguide devices are preferred however, their manufacturing process is difficult. Therefore, a new concept emerged: substrate integrated waveguide. SIW is a transition between microstrip and dielectric-filled waveguide (DFW). Dielectric filled waveguide is converted to substrate integrated waveguide (SIW) with the help of vias for the side walls of the waveguide.

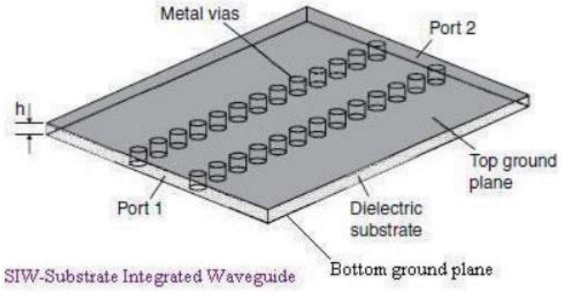


**Fig.1 Substrate integrated waveguide**

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 metallized posts or via holes that 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 fences. SIW is known to have similar guided wave and mode characteristics to a conventional rectangular waveguide with equivalent guide wavelength.

## ADVANTAGES OF SIW

- ❖ Power handling capabilities are higher.
- ❖ Radiation losses are lower.
- ❖ Fabrication cost of various rf components using SIW structure is lower.
- ❖ High-density integration can be achieved in mountains of discrete components on SIW structures.
- ❖ Due to the use of metal, conductor loss is lower.

### FORMULA

The efficient width and length of the resonant SIW cavity are given by,

$$a_{eff} = a_{SIW} - \frac{d^2}{0.95p}$$

$$l_{eff} = l_{SIW} - \frac{d^2}{0.95p}$$

Whereas SIW and are the width and length of the resonant SIW cavity, d and p are the diameters and the distance between adjacent vias respectively.

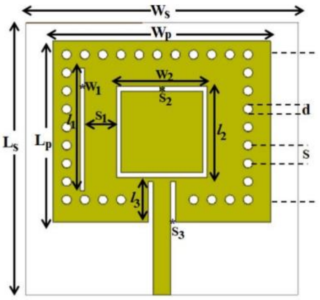


**Fig 2.SIW cavity with via hole**

## METAMATERIAL

Metamaterial type antennas are a promising new technology that has the potential to revolutionize the field of antenna design. By utilizing the unique properties of metamaterials, these antennas are able to achieve high performance in a compact, lightweight package. As research in this field continues, we can expect to see even more advanced metamaterial type antennas that will enable new and exciting applications in a wide range of fields. Fig 7.1 Complementary Split Ring Resonator Metamaterials are artificial materials that have unique properties not found in naturally occurring materials. One of the key applications of metamaterials is in antenna design, where they are used to create compact, high-performance antennas. In this documentation, we will explore the concept of metamaterial type antennas in detail. Metamaterial type antennas are antennas that utilize metamaterials in design. Metamaterials are used to create antennas that are smaller in size, have higher gain, and wider bandwidth than traditional antennas.

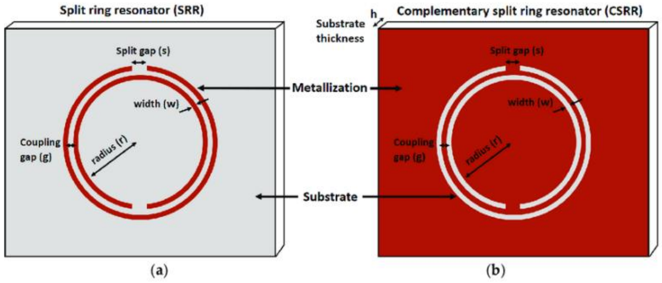


**Fig 3. Complementary Split Ring Resonator**

## ADVANTAGES OF METAMATERIAL

- ❖ Smaller size than traditional antennas
- ❖ Wide bandwidth
- ❖ High gain, low profile, and conformal shapes
- ❖ Versatile for a variety of applications
- ❖ Enables new and exciting applications
- ❖ Potential for even more advanced metamaterials and antennas

**FORMULA**

**Operating Frequency**

$$f_c = \frac{1}{2\pi\sqrt{LC_{total}}}$$

**LENGTH**

$$L = \mu_0\left(R + \frac{w}{2}\right)\left(ln\frac{8\left(R + \frac{w}{2}\right)}{h + w} - 0.5\right)$$

**Coupling**

$$C_{surface} \approx \frac{2\varepsilon_0 h}{\pi}\ln\frac{4R}{g} \quad C_{gap} = \varepsilon_0\left[\frac{wh}{g} + \frac{2\pi h}{ln\left(\frac{2.4h}{w}\right)}\right]$$

$$C_{total} = C_{gap} + C_{Surface}$$

**Effective Length And Width**

$$L_{eff} = \lambda/2n W_{eff} = \lambda/2\sin\theta$$

### *PROPOSED WORK*

In this study, using efficient combination of technologies are proposed to minimize existing issues. In order to implement the antenna with higher efficiency, we are going to analyse the possible combination of various antenna designing technologies.

## DESIGN SPECIFICATION

The proposed design is modelled by a rectangular-shaped inset feed patch, the patch size is 3.2605mm × 2.47818mm. In this design full ground of 4.7245mm × 3.9421mm on a bottom layer is used to get the desired frequency and FR4 substrate is used with the relative permittivity of 4.4 with the thickness of 0.244mm. For proper impedance matching over the complete band, we have chosen a microstrip line of 0.4783mm × 2.1824mm.

| SOLID MATERIAL | DIMENSION |
|---|---|
| SUBSTRATE | 4.7245mm × 3.9421mm |
| PATCH | 3.2605mm × 2.47818mm |
| FEED | 0.4783mm × 2.1824mm. |
| HEIGHT | 0.244mm |

**Table 1. Specifications of single patch antenna**

Substrate Integrated Waveguide (SIW) techniques are used in the form of cylindrical vias of copper material in the radius of 0.5mm, which is acting as a connection between ground and patch. It is placed in a symmetrical manner on both sides of the patch at a distance of 2mm. Single Electromagnetic Band Gap (EBG) structure as a cavity is placed in the middle of the substrate with the dimension 0.9054mm×0.6737mm in the thickness of 0.1mm. As for increasing the gain by suppressing the surface waves.

## STRUCTURE

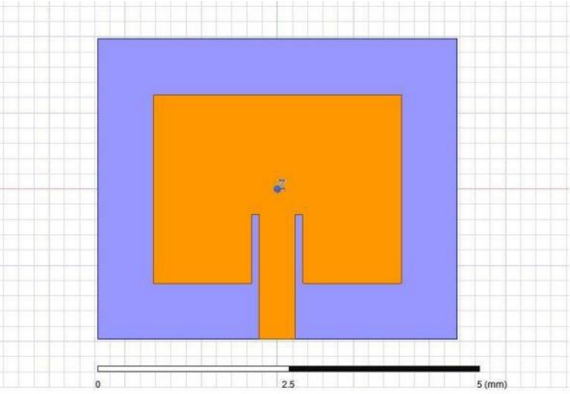


**Fig 4. Structure of antenna Top view**

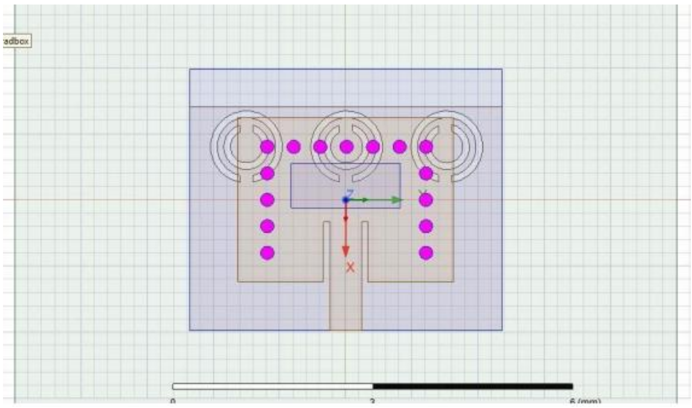


**Fig 5. Structure of antenna Top View with Internal views**

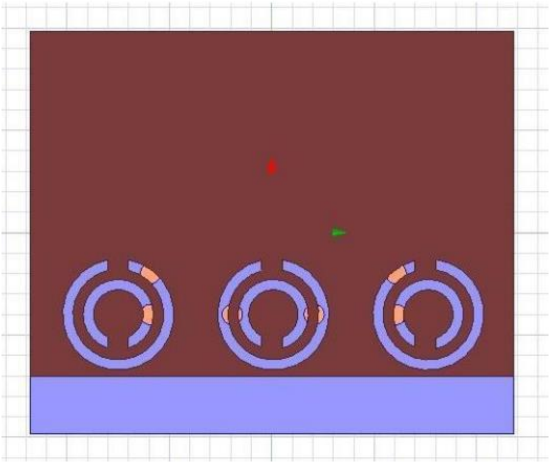


**Fig 6. Structure of antenna Bottom view**

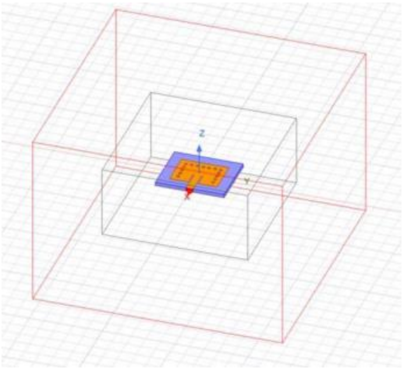
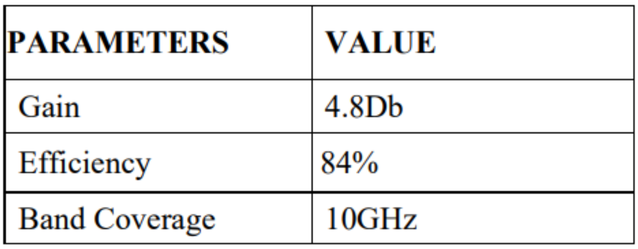


**Fig 7.D view of an antenna**

The single antenna the single antenna design is modelled by a rectangular-shaped patch which is connected to the ground by the lumped port. The antennas are mounted on a low-cost FR4 epoxy substrate of dielectric loss tangent 0.019 and relative permittivity of 4.4.

## ANTENNA PARAMETERS

The various antenna parameters for the above-stimulated antenna design are tabulated below,



| PARAMETERS | VALUE |
|---|---|
| Gain | 4.8Db |
| Efficiency | 84% |
| Band Coverage | 10GHz |

**Table 2. Parameters of the antenna**

## RESULT

### *RETURN LOSS(S11)*

- Return loss is generally considered below -10dB
- The proposed microstrip patch antenna covers frequency from 25.5Ghz to 27Ghz which resonates at 26 GHz

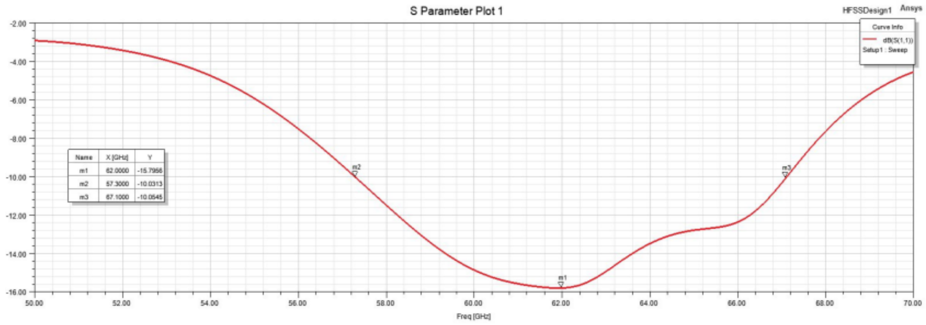


Fig 8. Return loss plot

## *2D GAIN VS FREQUENCY*

➢ Antenna gain is the ability of the antenna to radiate more or less in any direction compared to the theoretical antenna. ➢ The proposed antenna gain is 6dB.

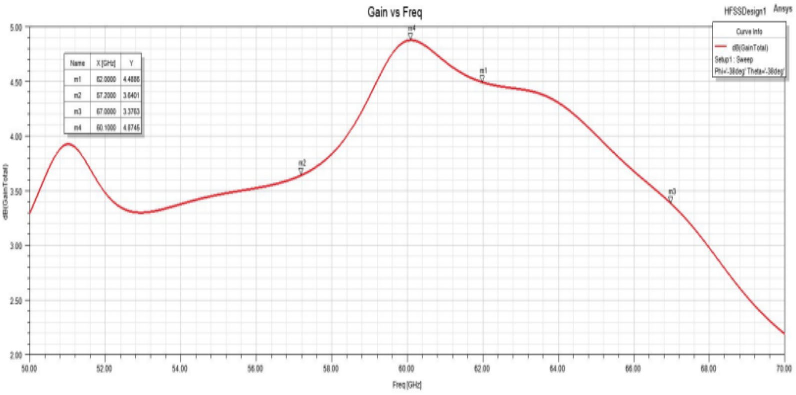


Fig 9. Frequency vs Gain

## VSWR

➢ VSWR stands for Voltage Standing Wave Ratio.

➢ The voltage standing wave ratio (VSWR) is also a common parameter used to characterize the matching property of a transmitting antenna

➢ VSWR value under 2 is considered suitable for most antenna applications

➢ The VSWR for this antenna element is observed for the band of 25.5Ghz to 27Ghz.

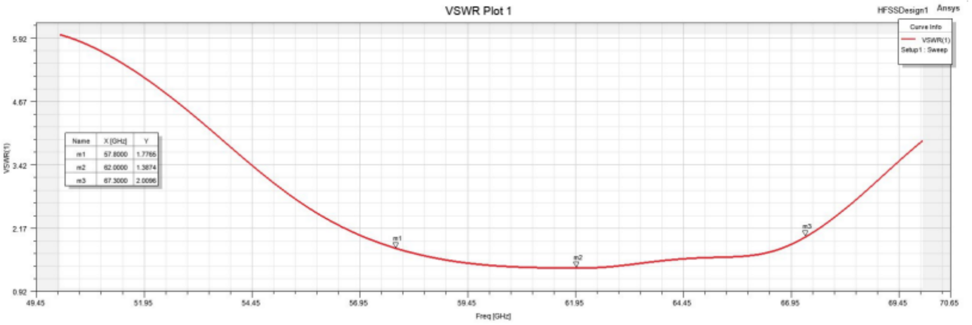


Fig 10. Frequency vs VSWR plot

## OVERALL GAIN

This is a 3d polar plot of Overall gain

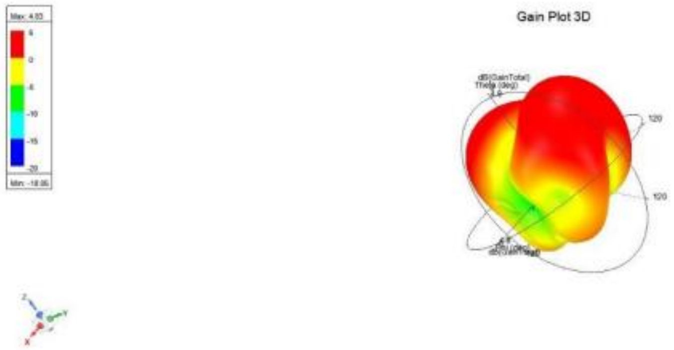


**Fig 11. Overall Gain**

## RESULT COMPARISION

| Antenna Parameter/ Antenna | Plain Patch | Patch with SIW | Patch with Slotted Substrate | Copper Patch with SIW and Slotted Substrate | Combination of SIW, Metamaterial & EBG |
|---|---|---|---|---|---|
| $S_{11}$ | -19.27dB | -14.8 dB | -18 dB | -14.8 dB | |
| Overall Gain | 5.9 dB | 9.79 dB | 3.8 dB | 14.7 dB | 4.8dB |
| Bandwith | ≈ 1GHz | ≈ 1.5 GHz | Multiband resonance ≈ 1.2 GHz | ≈ 2 GHz | ≈10Ghz |

**Table 3. Result Comparison**

## CONCLUSION

Nowadays 5G is one of the most sophisticated wireless technologies. The design of a 5G antenna for millimetre wave communication is a crucial component in enabling high-speed, low-latency wireless connectivity in the 5G network. Millimetre wave frequencies offer a significant bandwidth advantage. The socio-economic impact of 5G has yet to be analysed. The proposed combination of antenna has been designed and simulated using HFSS 13.0. Due to technologies involved, the form factor is slightly increased. Compared to MIMO, due to far ultra-wideband antenna, the form factor is small. The antenna resonating at a frequency at 62 GHz with a Gain and Bandwidth of 4.8dB and 10 GHz has been designed by using SIW air cavity along with split ring resonator on the ground plane. Defective ground has been allocated to increase the bandwidth around 10 GHz.

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