Grenze International Journal of Engineering and Technology, Jan Issue

Dual Microwave and Millimeter Wave Planar Shared Aperture Antenna for 5G Vehicle to Vehicle Communication

Darshan T G[1] and Kumaraswamy H V[2]
[1-2]Department of Electronics and Telecommunication, RV College of Engineering Bengaluru, Karnataka

***Abstract*— A form of antenna system that can function at both microwave and millimeter-wave frequencies is known as Dual Microwave and Millimeter Wave Planar Shared-Aperture (DM2W). In this technique, microwave and millimeter wave circuits share a single aperture to minimize system size, weight, and cost. Communication systems that need a lot of bandwidth and fast data rates might benefit greatly from the dual microwave and millimeter wave planar shared-aperture technology. With the use of this technique, it is feasible to create antennas with a single aperture that can function throughout a broad frequency range, from microwave to millimeter wave frequencies. V2V communication, a crucial element of the future intelligent transportation system (ITS), has the potential to be enabled and improved by 5G technology. Real-time information transmission between cars is made possible through vehicle-to-vehicle (V2V) communication, which can increase safety, lessen traffic, and improve the driving experience. Overall, 5G technology has transformed V2V communication and made driving safer, more effective, and more pleasant. In the upcoming years, we may anticipate seeing a wider use of V2V communication as 5G networks continue to develop and grow.**

A planar substrate-integrated wideband dual port microwave/millimeter wave antenna is the subject of the proposed study. It comprises of a millimeter-wave Parallel Plate Resonator Antenna (PPRA) and a microwave magneto-electric (ME) dipole antenna. The antenna is created and constructed using planar laminate substrates. It is simple to merge the planar structure with the electronics. Because the two antenna components share the same radiation aperture, the design will be small. A dual-frequency antenna encompassing the 5.9 GHz V2V band and the 28 GHz 5G band will be designed. The observed lower and higher band bandwidths will be significantly wider than those of the conventional substrate- integrated devices.

***Index Terms*— Dual microwave, millimeter-wave, planar shared aperture antenna, Parallel plate Resonator antenna**

I. INTRODUCTION

Due to the fast development of mobile communications, navigation, vehicle-to-vehicle (V2V) communications, and the internet of things (IoT), the spectrum in the microwave band has become congested. As a result, the millimeter-wave spectrum has increasingly become the carrier frequency for modern communication systems, providing a significantly broader bandwidth and a greater data rate. Due to the substantial transmission loss, millimeter wave coverage is, however, somewhat limited. The microwave technology, on the other hand, can offer more signal coverage but a slower data rate. The microwave and millimeter-wave systems both have comparable

Grenze ID: 01.GIJET.10.1.349

advantages and disadvantages. Therefore, having a system that offers both the microwave and millimeter-wave channels at the same time should be beneficial.

The microwave system is becoming increasingly congested due to the fast expansion of wireless communication. Because of its abundant spectrum resource and ability to sustain a higher data rate, millimeter-wave technology has so gained increasing interest. It cannot entirely take the place of these microwave band wireless applications, though. Therefore, the future generation wireless communication system must incorporate both millimeter-wave technology and the microwave system. As a result, the antenna must be capable of concurrently operating in the microwave and millimeter-wave frequency ranges.

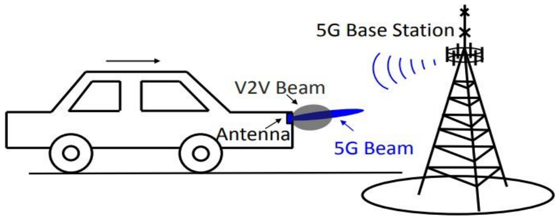


Fig 1: Application scenarios for 5G millimeter wave and V2V connectivity

The frequency ratios of the distinct resonant modes in the traditional dual-band microstrip antenna and dielectric resonator antenna (DRA) depicted in the application scenario in Fig[1] are typically lower and may make them unsuitable for simultaneous operations in the microwave and millimeter-wave bands. Installing two independent millimeter- and microwave antennas inside the system is an easy fix. The size of the system as a whole will eventually rise as a result.

In order to serve both safety-related and non-safety applications within the 5G cellular networks, the 3GPP standards organization has established the V2V services. A communication platform for automobiles is anticipated to be provided via the direct link, commonly referred to as the PC5 interface, and the new radio adapter in 5G. Vehicles will utilize the PC5 interface in particular to send safety messages to alert one another to potential road dangers. The current 5G-V2V standard enables higher layer security techniques specified by additional standards within the ITS domain to manage V2V message protection. To maintain system compatibility and save implementation costs, it could be better to have an encryption solution at the 5G connectivity layer.

The fabrication of the planar shared-aperture dual-band dual-circular polarization (CP) array antennas on a single-layer substrate makes it simple to expand the array to a greater size.Thus, each array member is created by joining two patches that are tuned to different frequencies. Two types of feed networks are discussed in order to construct arrays with higher gain, which may be used in systems that require both narrowband and wideband. The Fabry-Perot and reflect array methods are both included into the dual-band high-gain shared- aperture antenna. In the S-band (2.45 GHz), the antenna functions as a Fabry-Perot cavity antenna (FPCA), and in the X- band (10 GHz), it functions as a reflect array antenna (RA). The antenna features a straightforward design with just two layers of printed circuit board. The bottom layer serves as the RA's reflecting surface, the FPCA's ground plane, and the source antenna. The primary antenna that drives the RA is located in the top layer, which also acts as a superstrate for a FPCA that is somewhat reflecting. Thus, although having the identical physical aperture, the FPCA and RA operate separately.

An integrated broadband dual port microwave/millimeter wavelength antenna on a planar substrate is the subject of the proposed study. A millimeter-wave PPRA and the microwave magneto-electric (ME) dipole antenna make up the device. The two antenna components sharing an identical radiation aperture will allow for a small overall design. Design, construction, and testing will be done on a dual-frequency antenna that covers the 5.9 GHz V2V band and the 28 GHz 5G spectrum. When compared to conventional substrate-integrated devices, the obtained bandwidth of the lower and higher bands will be substantially broader.

II. Related Work

The investigation will center on a planar wideband dual- frequency antenna. A small shared-aperture structure has been created by combining the microwave ME-dipole antenna with millimeter-wave PPRA. By applying copper to the two rectangular holes' sidewalls, a pair of parallel plates have been created in the antenna substrates. To the microwave ME dipole antenna, the PPRA supplies the magnetic current. The approach may be extended to alternative dual frequency designs with other frequency ratios, and the planned aperture antenna should be able to operate for both communication modes V2V and 5G millimeter-wave connections at the same time.

A. Dual Microwave-Millimeter Wave Shared Antenna

A form of antenna system that can function at both microwave and millimeter-wave frequencies is known as Dual Microwave and Millimeter Wave Planar Shared-Aperture (DM2W). In this technique, microwave and millimeter wave circuits share a single aperture to minimize system size, weight, and cost. Communication systems that need a lot of bandwidth and fast data rates might benefit greatly from the dual microwave and millimeter wave planar shared-aperture technology. With the use of this technique, it is feasible to create antennas with a single aperture that can function throughout a broad frequency range, ranging microwave until millimeter wave frequencies.

With the use of this technology, the antenna's size and weight may be decreased since planar circuits can be merged into a single substrate. The shared aperture method enhances the overall performance of the antenna while allowing for a reduction in the number of components. This technology also makes it possible to combine a number of operations, including polarization control and beam scanning, into a single antenna system. In general, the dual microwave and millimeter wave planar shared-aperture technology is a potential strategy for the creation of small, light, and high-performance antenna systems that can function across a broad frequency range.

Two antennas that are intended to operate through the same aperture, or the passageway from which electromagnetic waves flow, make up the DM2W system.A microwave antenna, functioning within the frequency range from 1 to 10 GHz, serves as the initial antennas in the DM2W system. A millimeter-wave antenna, used for frequencies between 30 and 100 GHz, is the second antenna. The two antennas can cooperate compactly and effectively since they are made to share an identical aperture.The DM2W technology is frequently employed in wireless networks, satellite communications, and radar systems. In comparison to conventional antenna systems, it has more benefits, such as wider bandwidth, better performance, and a smaller and lighter design. It is made up of a millimeter-wave parallel-plate resonator antenna (PPRA) and a microwave magnetoelectric (ME) dipole antenna.

B. 5G for V2V Communication

The capabilities of vehicle-to-vehicle (V2V) communication have substantially improved thanks to 5G (fifth-generation) technology, as shown in Fig[2], enabling more effective, trustworthy, and secure communication between cars. V2V communication is a significant part of Intelligent Transportation Systems (ITS) and improves traffic control, road safety, and the driving experience as a whole. Extremely low communication latency and great reliability are provided by 5G's ultra reliable low latency communication (URLLC) capabilities, which are crucial for V2V communication. Due to the ability to share time-sensitive information between cars in real-time, prospective risks and abrupt changes in traffic circumstances may be responded to quickly.

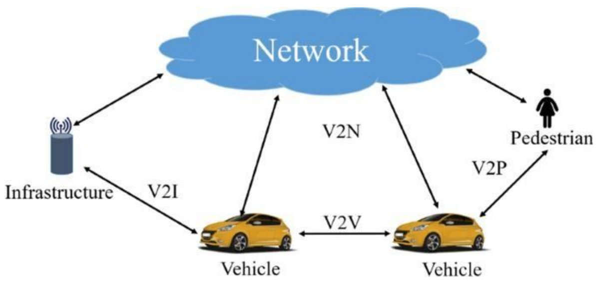


Fig 2: V2V communication using 5G technologies

The simultaneous communication of many devices is made possible by the huge Machine Type Communication capabilities of 5G. Being able to connect with other surrounding cars and infrastructure elements like traffic signals and road sensors is crucial for V2V communication.

In spite of variable signal strength or high mobility, V2V communication is still successful because to 5G's expanded coverage and better connection. Particular channels or bands of frequencies can be set aside in 5G networks for V2V communication. By doing this, it is made sure that V2V communications are sent and received without being hampered by other network traffic.

Vehicles can communicate their locations, speeds, and intents thanks to 5G, enabling sophisticated collision mitigation and cooperative sensing systems. Based on this real-time data, vehicles can issue warnings or take evasive action. Due to 5G's short latency and great dependability, platooning and cooperative driving situations are made possible. Vehicles may move near to one another while still maintaining safe distances, which lowers air resistance and fuel consumption. Vehicles can communicate route ideas, traffic updates, and traffic information using V2V communication over 5G. This aids in optimizing traffic flow and facilitates dynamic traffic management. cars can communicate with one another through V2V in emergency circumstances, broadcasting distress signals that enable neighboring cars to react rapidly and emergency services to respond more efficiently. Advanced security measures are incorporated into 5G networks to solve issues with data privacy and illegal access in V2V communication. All things considered, 5G technology has the potential to transform V2V communication and make driving safer, more effective, and more pleasant. In the upcoming years, we may anticipate seeing a wider use of V2V communication as 5G networks continue to develop and grow.

III. PROPOSED METHODOLOGY

The Dual microwave and Millimeter wave planar shared aperture antenna for Vehicle to Vehicle Communication and 5G Streamless Connection is the foundation of the proposed work.A planar wideband dual frequency antenna with a shared aperture can be designed and its performance examined to achieve this.

An apparatus used to send and receive electromagnetic waves in the microwave frequency range is called a microwave antenna. It is a crucial part of many contemporary communication systems, such as radar systems, satellite communication systems, and cellular networks.A microwave antenna's primary job is to transform electrical impulses into electromagnetic waves and the other way around. Broadband access and high-speed, point-to-point wireless local area networks (WLANs) are two examples of the many products and services that may be provided using the millimeter wave region of the electromagnetic spectrum. There are several applications for millimeter wave, such as telecommunications, short-range radar, and airport security scanners.

Vehicle-to-vehicle communications, often known as V2V communications, are a kind of communication technology that enables wireless vehicle communication. Dedicated short-range communication (DSRC) technology is used by V2V systems to send and receive data between cars.The 3GPP standards organization has specified V2V services to accommodate both safety-related and non-safety applications in the 5G cellular networks. It is anticipated that a connection platform for automobiles will be provided using both the new radio interface in 5G and the direct link known as the PC5 interface. The 5G- V2V standard enables higher layer security solutions specified by other standards in the ITS domain to manage V2V message protection. To maintain security solution at the 5G access layer and to save implementation costs, it could be better to have a security solutions at 5G access layer.

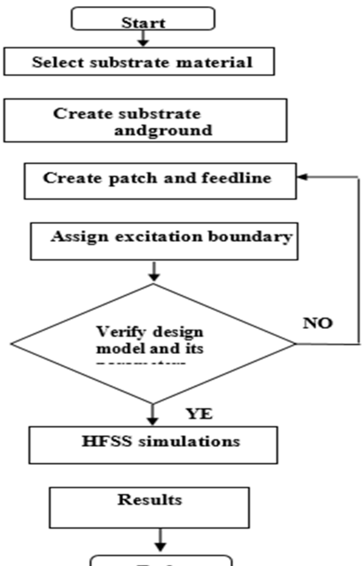


Fig 3: Flow chart of antenna design

The work incorporates a small dual-port dual frequency planar shared-aperture antenna with a high frequency ratio. The flow is shown in Fig[3]. It is made up of a millimeter-wave parallel- plate resonator antenna (PPRA) and a microwave magnetoelectric (ME) dipole antenna. It has two vertical conducting walls that act as a magnetic source for the lower- band ME dipole while also forming an upper band parallel-plate resonator. Because it uses a common aperture structure, the design is quite small. For the purpose of demonstration, a dual- frequency antenna encompassing both the 28-GHz 5G band (27.5-28.35 GHz) and the 5.9-GHz vehicle-to-vehicle (V2V) band

(5.855-5.925 GHz) will be developed, made, and measured. The developed antenna should be able to be used on moving platforms for simultaneous 5G millimeter-wave connections and V2V communications.

IV. Antenna Configuration

The planar wideband dual frequency antenna with a common aperture is configured as shown in Fig[4]. It contains three dielectric substrates: the lowest substrate is the feeding substrate and has a thickness of tf and a dielectric constant of rf, while the two above substrates are antenna substrates with the same thickness (ta) and dielectric constant (ra) values. Two thin rectangular holes with a width of w0, length of l0, and depth of 2ta are created in each of the two antenna substrates. Each hole has copper-coated side walls that are shorted to the surface. As a result, a parallelplate resonator (PPR) functioning in the upper band is created by the two covered holes.

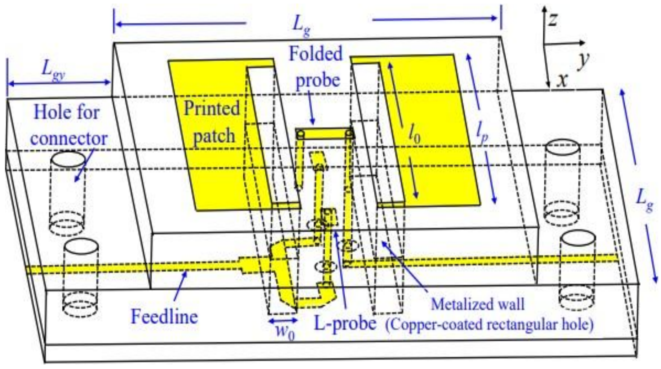


Fig 4: Configuration of planar wideband shared-aperture dual-frequency antenna

The distance s between the two parallel plates, as seen in Fig. 4, defines the PPR's resonant frequency. To produce symmetrical radiation patterns, the PPR is differentially activated by a pair of L-probes in the xoz plane. Vias that join the feed network of the feed substrate to the top surface of the lower antenna substrate are used to manufacture the L-probes. To prevent physical overlaps and significant coupling with the feed network of the lower-band antenna portion, each L-probe is displaced from the center.
The two shorted parallel plates (covered rectangular holes) supply the lower band magneto-electric (ME) dipole antenna with the necessary x-directed magnetic current. Referring to Fig. 2, each parallel plate is attached to a patch that is printed on the top surface of the upper antenna substrate and has dimensions of wp and lp. The two patches come together to create an electric dipole that gives the ME dipole the necessary y-directed electric current. The magnetic and electric currents are excited using the folded probe in the illustration. It features a horizontal strip with a length of l1 and a width of w1 that connects two vias of different lengths. On the underside of the feed substrate, Fig. also depicts the printed feedlines for the two antenna ports. The pair of L-probes receive differential signals from an anti-phase T junction, while the folded probe of the ME dipole is coupled to a straightforward 50-microstrip line with a width of wf1.

V. Operating Principles

The operating principles of dual frequency planar wideband shared aperture antenna is illustrated in upper band parallel plate resonator antenna and lower band ME dipole antenna as shown in the Fig [5].

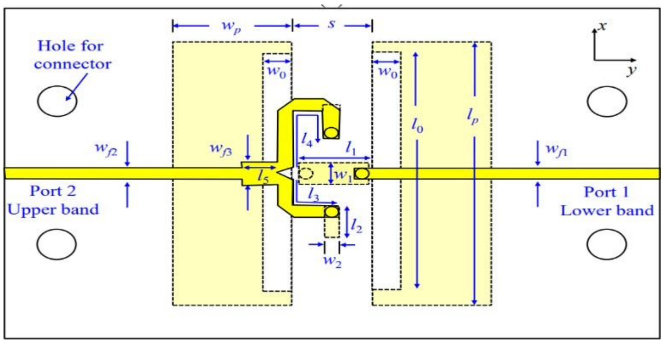


Fig 5: Operating principles of Dual frequency planar shared aperture antenna

A. Upper-Band PPRA

With the exception of the fact that the gap between the two parallel plates is now filled with the dielectric rather than air, the spacing s between the two parallel plates determines the resonant frequency f2 of the PPRA. To describe the PPRA and the impact of the separations on the PPRA's reflection coefficient, a parametric research will be conducted such that when s increases, the frequency band shifts downward and the matching degrades. You can improve match by adjusting the L- probe's dimensions. Therefore, the lower-band ME dipole is also significantly impacted by this separation, so the PPRA component should be constructed first. Additionally, the impact of εra on the reflection coefficient will be investigated in order to confirm that a bigger εra will result in a lower operating frequency.

B. Lower-Band ME Dipole Antenna

The separations between the parallel plates of the ME dipole antenna are specified by the PPRA design, and the height of the parallel plates is constrained by the combined thickness of both antenna substrates. The printed patches' length (lp) and width (wp) are hence the tuning parameters. Even though its adjusting range is constrained by s, the folded probe's complete length may be utilized to tune the ME dipole.
The impact of patch width wp on the upper-band PPRA and lower-band ME dipole antenna reflection coefficients. While the lower-band ME dipole's operating frequency drops as wp increases, indicating that wp has a large impact on that dipole. The impedance bandwidth is extremely constrained when the patch width (wp) is 5 mm. A larger impedance bandwidth is attained when it is increased to 7 mm. The imbalance back radiation from the magnetic and electric sources, however, cannot cancel each other out in this scenario since the gap s (magnetic source) remains fixed while the patch width (electric source) widens. The antenna gain would drop and the back radiation would intensify.
One can increase the frequency ratio even more. To acquire a trade-off between frequency ratio and radiation properties, though, can also be beneficial. It is possible to acquire the simulated E- and H-field distribution in the antenna substrates at 28 GHz. Both the E- and H fields are discovered to be mostly spread across the parallel plates.

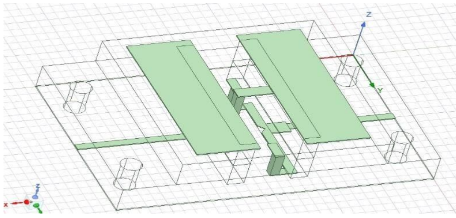
VI. Simulation And Analysis

By examining the characteristics of the microwave ME dipole antenna for the lower band and the millimeter-wave PPRA for the upper band, a planar wideband dual-frequency antenna has been developed. The height of the PPRA has been calculated using the duroid material of the antenna substrate and the thickness of the substrate. PPRA was created using the setups shown in Table [1] and an expected parallel plate separation distance based on resonant frequency. The proposed ME dipole antenna receives magnetic current from a parallel plate resonator formed by two coated holes, and the starting values of the patch are set.

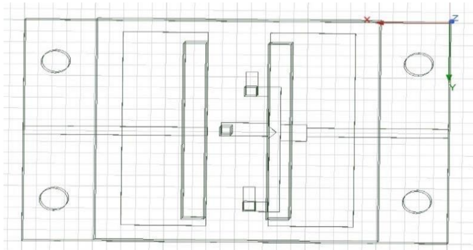
TABLE I: Design Specifications for dual frequency shared aperture antenna

Parameters	Values in mm
Width of patch (Wp)	6
Length of patch (Lp)	17.5
Length of substrate (Lg)	20
Separation of PPRA (S)	4.4
Feedline 1 Width (Wf1)	0.76
Feedline 2 Width (Wf2)	0.78
Antenna substrate dielectric constant (Ɛra)	2.94
Feedline substrate dielectric constant (Ɛrf)	2.2

Dual microwave and millimeter wave planar shared aperture antennas are being implemented for vehicle-to-vehicle communication and 5G streamless connections as shown in fig[6]. A planar wideband dual frequency antenna with a shared aperture can be designed and its performance examined to achieve this.Lower- and upper-band results will be measured with an HFSS simulator, and the S-parameters will be examined for the radiation pattern and antenna gain.



(a)



(b)

Fig 6: Design schematic of planar shared aperture antenna (a) Front view (b) Top View

VII. Results And Discussions

The upper band s-parameter plot in Fig[7] corresponds to a higher frequency range of 28GHz. The S11 parameter reflection coefficient plot will show how much of the incident signal at the upper frequency is reflected back from the antenna.

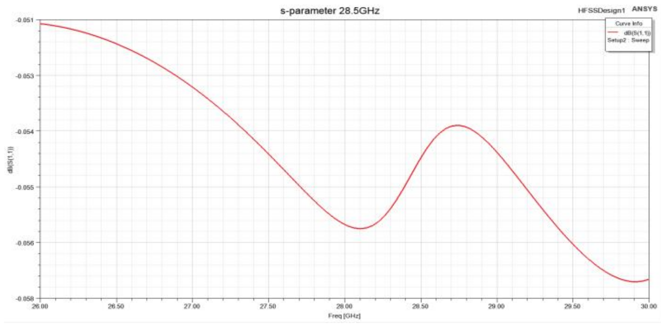


Fig 7: S-parameter plot of upper band

The lower band s-parameter plot in Fig[8] corresponds to a lower frequency range of 5.5GHz. The S11 parameter plot will now show how much of the incident signal at the lower frequency is reflected back from the antenna. The actual shapes of the S-parameter plots will depend on the design and characteristics of your dual-frequency planar shared aperture antenna

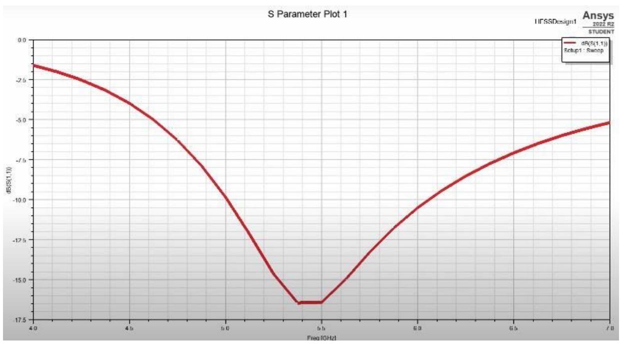


Fig 8: S-parameter plot of lower band

The radiation pattern of an antenna at a specific frequency, such as 28 GHz in the upper band in Fig[9] provide insights into the antenna's directional characteristics, gain, and beam width the radiation pattern illustrates the antenna's characteristics as a function of elevation angle.

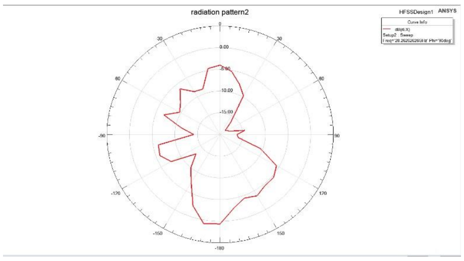


Fig 9: Radiation pattern of upper band at 28GHz

The radiation pattern of an antenna operating in the lower band at a frequency of 6 GHz for a dual-frequency planar shared aperture antenna in Fig[10] provide insights into its directional characteristics and radiation properties. The directivity of the antenna, related to its gain, can be determined by integrating the radiation pattern over all angles.

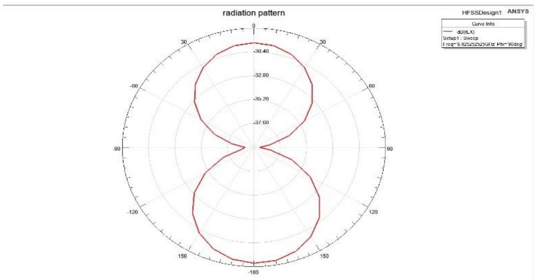


Fig 10: Radiation pattern of lower band at 6GHz

The gain plot for a dual-frequency planar shared aperture antenna in Fig[11] illustrates how effectively the antenna concentrates its radiated energy in different directions at two distinct frequencies.

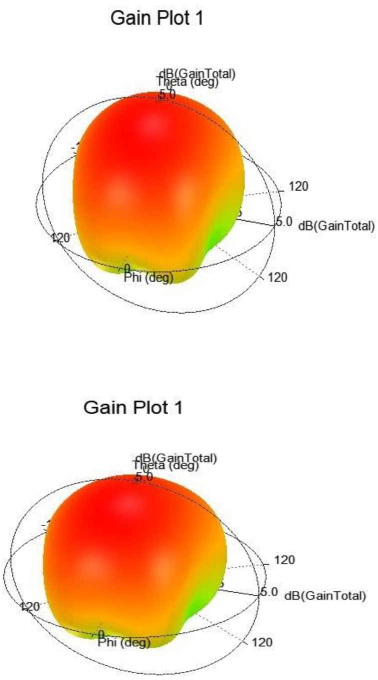
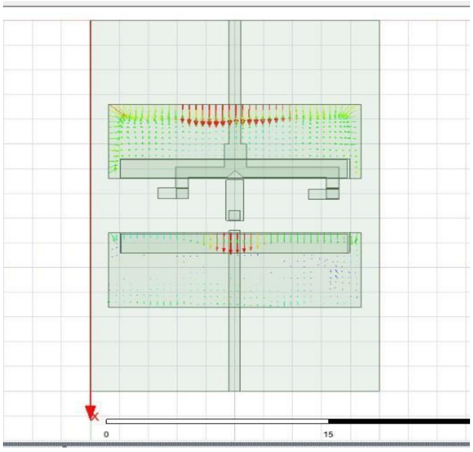
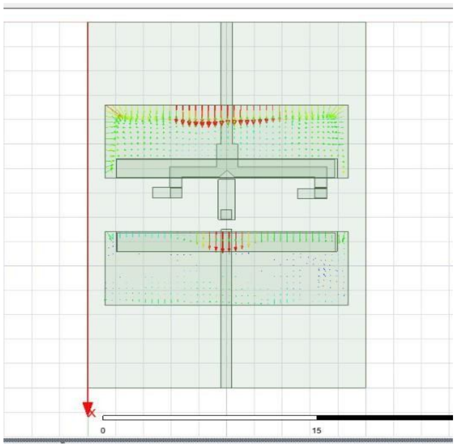


Fig 11: 3D Gain plot for antenna design

The electric field (E-field) and magnetic field (H-field) patterns over relays for a dual-frequency planar shared aperture antenna in Fig[12] provide insights into electromagnetic energy distributed around the relays at the two distinct frequencies. These patterns help understand the spatial characteristics of the antenna's radiation and it interactions with nearby structures.



(a)



(b)

Fig 12: Field over relays (a) E-Field (b) H-Field

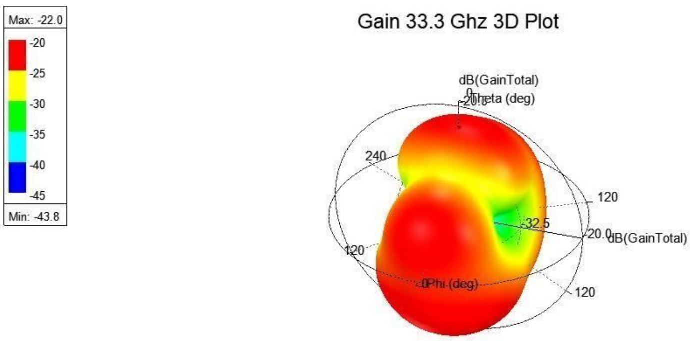


Fig 13: 3D Gain plot for33.3GHz

The field gain patterns over relays for a dual-frequency planar shared aperture antenna in Fig.13 provide insights into electromagnetic energy distributed around the relays at the two distinct frequencies. These patterns help understand the spatial characteristics of the antenna's radiation and its interactions with nearby structures. The Gain plot is estimated for the material bronze and roger, and it has observed higher gain of 20dB as changing the material.

VIII. CONCLUSION

A planar wideband dual-frequency antenna has been thoroughly investigated. A compact shared-aperture structure has been developed by combining the microwave ME-dipole antenna with millimeter-wave PPRA. Copper was applied to the sidewalls of the two rectangular holesin the antenna substrates to form two parallel plates. PPRA provides the magnetic current needed by the microwave ME dipole antenna. For demonstration purposes, a dual-frequency antenna that functions at both the 5.9 GHz V2V band and the 28 GHz 5G band has been developed and tested. Its boresight radiation patterns have been observed. The lower and higher bands' recorded peak antenna gains are 5 dBi and 8.1 dBi, respectively. After changing the substrate material to bronze and roger RO3006, the highest peak antenna gain records at 20dBi.Finally, it should be noted that the concept may be used for other dual frequency systems with other frequency ratios.

REFERENCES

[1] C. Dehos, J. L. González, A. De Domenico, D. Kténas and L. Dussopt, "Millimeter-wave access and backhauling: the solution to the exponential data traffic increase in 5G mobile communications systems?," in IEEE Communications Magazine, vol. 52, no. 9, pp. 88-95, September 2014, doi: 10.1109/MCOM.2014.6894457.

[2] D. Choudhury, "5G wireless and millimeter wave technology evolution: An overview," 2015 IEEE MTT-S International Microwave Symposium, Phoenix, AZ, USA, 2015, pp. 1-4, doi: 10.1109/MWSYM.2015.7167093.

[3] S. Mondal, D. Nandi and R. Bera, "V2X Communication Test Bed for Smart Electrical Vehicle with 5G IOV Technology," 2020 URSI Regional Conference on Radio Science (URSI-RCRS), Varanasi, India, 2020, pp. 1-4, doi: 10.23919/URSIRCRS49211.2020.9113571.

[4] S. A. B., E. F. Sundarsingh and H. A., "A Compact Conformal Windshield Antenna for Location Tracking on Vehicular Platforms," in IEEE Transactions on Vehicular Technology, vol. 68, no. 4, pp. 4047-4050, April 2019, doi: 10.1109/TVT.2019.2898709.

[5] Pi-Wei Chen, Choon Sae Lee and V. Nalbandian, "Planar double-layer leaky-wave microstrip antenna," in IEEE Transactions on Antennas and Propagation, vol. 50, no. 6, pp. 832-835, June 2002, doi: 10.1109/TAP.2002.1017664.

[6] S. Wang, L. Zhu, G. Zhang, J. Yang, J. Wang and W. Wu, "Dual-Band Dual-CP All-Metal Antenna With Large Signal Coverage and High Isolation Over Two Bands for Vehicular Communications," in IEEE Transactions on Vehicular Technology, vol. 69, no. 1, pp. 1131-1135, Jan. 2020, doi: 10.1109/TVT.2019.2952880.

[7] L. Ge, S. Gao, Y. Li, W. Qin and J. Wang, "A Low- Profile Dual-Band Antenna With Different Polarization and Radiation Properties Over Two Bands for Vehicular Communications," in IEEE Transactions on Vehicular Technology, vol. 68, no. 1, pp. 1004-1008, Jan. 2019, doi: 10.1109/TVT.2018.2881765.

[8] X. -Q. Zhu, Y. -X. Guo and W. Wu, "A Compact Dual- Band Antenna for Wireless Body-Area Network Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 98-101, 2016, doi: 10.1109/LAWP.2015.2431822.

[9] K. -F. Lee, S. L. S. Yang and A. A. Kishk, "Dual- and Multiband U-Slot Patch Antennas," in IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 645-647, 2008, doi: 10.1109/LAWP.2008.2010342.

[10] A. A. Deshmukh, T. Tirodkar and K. P. Ray, "Analysis of slot cut multi-band rectangular microstrip antenna," 2013 International Conference on Advances in Technology and Engineering (ICATE), Mumbai, India, 2013, pp. 1-5, doi: 10.1109/ICAdTE.2013.6524724.

[11] Y. X. Sun and K. W. Leung, "Dual-Band and Wideband Dual-Polarized Cylindrical Dielectric Resonator Antennas," in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 384-387, 2013, doi: 10.1109/LAWP.2013.2251993.

[12] S. Wu, J. Li, J. Shi, Y. Cao, S. Yan and J. Chen, "Dual- Band Dual-Circularly Polarized Shared-Aperture mmWave Antenna," 2022 IEEE 5th International Conference on Electronic Information and Communication Technology (ICEICT), Hefei, China, 2022, pp. 402-404, doi: 10.1109/ICEICT55736.2022.9909173.

[13] C. -X. Mao, S. Gao, Y. Wang, Q. Luo and Q. -X. Chu, "A Shared-Aperture Dual-Band Dual-Polarized Filtering- Antenna-Array With Improved Frequency Response," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 4, pp. 1836-1844, April 2017, doi: 10.1109/TAP.2017.2670325.

[14] C. -X. Mao, S. Gao, Y. Wang, Q. -X. Chu and X. -X. Yang, "Dual-Band Circularly Polarized Shared-Aperture Array for C -/ X -Band Satellite Communications," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 10, pp. 5171-5178, Oct. 2017, doi: 10.1109/TAP.2017.2740981.

[15] J. Wang, J. xiang Ge, Y. Zhou, H. Xia and X. zhi Yang, "Design of a High-Isolation 35/94-GHz Dual-Frequency Orthogonal-Polarization Cassegrain Antenna," in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 1297-1300, 2017, doi: 10.1109/LAWP.2016.2633284.

[16] C. -X. Mao, S. Gao, Q. Luo, T. Rommel and Q. -X. Chu, "Low-Cost X/Ku/Ka-Band Dual-Polarized Array With Shared Aperture," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 7, pp. 3520-3527, July 2017, doi: 10.1109/TAP.2017.2700161.

[17] L. Y. Feng and K. W. Leung, "Dual-Frequency Folded- Parallel-Plate Antenna With Large Frequency Ratio," in IEEE Transactions on Antennas and Propagation, vol. 64, no. 1, pp. 340-345, Jan. 2016, doi: 10.1109/TAP.2015.2500607.

[18] L. Y. Feng and K. W. Leung, "Wideband Dual- Frequency Antenna With Large Frequency Ratio," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 3, pp. 1981-1986, March 2019, doi: 10.1109/TAP.2019.2891336. [19]

[19] Y. Cai, C. Ke, Y. Ni, J. Zhang and H. Zhu, "Power allocation for NOMA in D2D relay communications," in China Communications, vol. 18, no. 1, pp. 61-69, Jan. 2021, doi: 10.23919/JCC.2021.01.006.
[20] B. J. Xiang, S. Y. Zheng, H. Wong, Y. M. Pan, K. X. Wang and M. H. Xia, "A Flexible Dual-Band Antenna With Large Frequency Ratio and Different Radiation Properties Over the Two Bands," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 2, pp. 657-667, Feb. 2018, doi: 10.1109/TAP.2017.2786321.
[21] J. F. Zhang, Y. J. Cheng, Y. R. Ding and C. X. Bai, "A Dual-Band Shared-Aperture Antenna With Large Frequency Ratio, High Aperture Reuse Efficiency, and High Channel Isolation," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 2, pp. 853-860, Feb. 2019, doi: 10.1109/TAP.2018.2882697.
[22] L. Zhang, K. Y. See, B. Zhang and Y. P. Zhang, "Integration of Dual-Band Monopole and Microstrip Grid Array for Single-Chip Tri-Band Application," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 1, pp. 439-443, Jan. 2013, doi: 10.1109/TAP.2012.2215295.
[23] D. Wang and C. H. Chan, "Multiband Antenna for WiFi and WiGig Communications," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 309-312, 2016, doi: 10.1109/LAWP.2015.2443013.
[24] L. Y. Feng and K. W. Leung, "Dual-Frequency Folded- Parallel-Plate Antenna With Large Frequency Ratio," in IEEE Transactions on Antennas and Propagation, vol. 64, no. 1, pp. 340-345, Jan. 2016, doi: 10.1109/TAP.2015.2500607.
[25] L. Ge and K. M. Luk, "A Magneto-Electric Dipole Antenna With Low-Profile and Simple Structure," in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 140- 142, 2013, doi: 10.1109/LAWP.2013.2244054.