REVOLUTIONIZING CONNECTIVITY: A 360 DEGREE PATTERN DIVERSITY INTEGRATED MICROWAVE AND mm-WAVE MIMO ANTENNA MODULE FOR 5G IoT

[1] Dr. D. Tilak Raju,[2]Mrs. P. Gowri Swetha,[3] Polarapu Sravani Sowjanya, [4]Uha Tejaswi Doddi,[5]Ummetha Meghana, [6] Periyala S V R S Krishna Neeraja
[1]Associate Professor,[2]Assistant Professor, [3,4,5,6] B.Tech,[1,2,3,4,5]Department of Electronics and Communication Engineering, Vignan's Institute of Engineering for Women, Duvvada, Visakhapatnam, India

ABSTRACT
The 5G-enabled IoT, along with artificial intelligence, willrevolutionize the world by realizing smart cities, smarthealthcare, smart farming, smart factories, intelligent transportation system (ITS), and augmented/virtual reality. [1]To ensure seamless connectivity, this antenna is designed to provide 360degree pattern diversity, which enhances the reliability and performance of wireless communication on various directions.The complete coverage of the operating frequencybands from microwave bands to millimeter (mm-wave) isrequired for the realization of the fifth-generation (5G) Internet ofThing (IoT) systems. Integrated antenna systems that support multiple wireless standards (microwave and millimeter-wave bands) have become a pivotal issue in future wireless networks. The joint implementation of these frequency bands that can provide long-range and short-range radio accesses within a wireless system is desired. Here, we present a multiband antenna operating at the microwave (2.5/3.5/5.5/7.5 GHz) and mm-wave bands(23–31 GHz), and its 12-port MIMO configuration with patterndiversity affording 360◦ coverage for 5G IoT applications. Themultiband characteristics are obtained by adding well-designedquarter-wavelength stubs. The antenna operates at the importantfrequency bands from 2.37–2.65, 3.25–3.85, 5.0–6.1, and 7.15–8.5 GHz (|S11| < –10 dB), while it resonates from 23–31 GHzat the mm-wave band with the desired radiation characteristics.Moreover, the antenna has more than 95% radiation efficiencyand a stable gain (> 2.5 dBi at microwave band and 6.5 dBi atmm-wave bands) characteristics. In addition, the single-elementantenna is translated to design a 2 × 2 MIMO antenna. ThisMIMO unit is further utilized in the formation of 2 × 4 andthe proposed 3 × 4 (12-port) MIMO configurations to achievespectral and pattern diversity. Considering the unique three-dimensional arrangement of the antenna elements, the 12-portMIMO system is the only one of its kind that offers the codesignof microwave and mm-wave antenna, good isolation, and patterndiversity, providing complete 360◦ space coverage in elevationand azimuth planes. The proposed antenna module is suitablefor 5G IoT, especially in an indoor scenario for smart houses,offices, and vehicle-to-everything communications.

Keywords: Fifth-generation (5G) communication, Internetof Things (IoT) antenna, MIMO antenna, pattern diversity,sub-6 GHz and millimeter wave (mm-wave) antenna, vehicular communication.

INTRODUCTION
In the era of 5G Internet of Things (IoT), where speed, efficiency, and reliability are paramount, this integrated Microwave and mm-Wave MIMO Antenna Module stands at the forefront of innovation. It is designed to meet the ever-growing demands of next-generation wireless networks.

This revolutionary technology seamlessly integrates microwave and millimeter wave frequencies, unlocking unparalleled performance for a vast array of IoT applications.

This antenna module is designed to resonate at both microwave and mm-waves. The microwave frequencies at which it operates is between 2.37 to 2.65GHz, 3.25-3.85GHz, 5.0-6.1GHz, 7.15-8.5GHz and the mm-waves frequency bands are between 21-31GHz. Firstly, a single element antenna is designed which are five stubs where each stubs resonates at a particular frequency like 2.5, 3.5, 5.5 and 7.5GHz. To overcome the bandwidth limitations another two stubs are designed at the back side of the antenna whose frequencies are 2.4 and 3.7GHz. This single element antenna is then converted into MIMO antenna. The MIMO antenna consists of four ports which are used to exploit multipath propagation for high data rates.

Whether it's enhancing smart cities, powering autonomous vehicles, or enabling real-time healthcare monitoring, our Integrated Microwave and mm-Wave MIMO Antenna Module redefines the possibilities of 5G IoT.

LITERATURESURVEY

[2]L. Chettri and R. Bera, “A comprehensive survey on Internet of Things (IoT) toward 5G wireless systems”. This paper provides an overview of the Internet of Things(IoT) in 5G wireless systems. [3] J.Lan, Z. Yu, J. Zhou, and W. Hong, “An aperture-sharing arrayfor (3.5, 28) GHz terminals with steerable beam in millimeter-waveband,” IEEE Trans. Antennas Propag., vol. 68, no. 5, pp. 4114–4119,May 2020. The major findings of this journal is, it enhances connectivity and coverage by sharing the aperture and the main disadvantage is that the mm-wave band requires more complex hardware and increases the cost. [4] Y. Liu, Y. Li, L. Ge, J. Wang, and B. Ai, “A compact heptabandmode-composite antenna for sub (6, 28, and 38) GHz applications,”IEEE Trans. Antennas Propag., vol. 68, no. 4, pp. 2593–2602,Apr. 2020.By combining different antennaelements it can effectively support various wireless communication applications, from lower frequency like 6GHz to higher frequencies like 28 and 38 GHz.But the designing and implementation of a such a complex system can be challenging and may require advance engineering expertise. [5] H. T. Chattha, M. K. Ishfaq, B. A. Khawaja, A. Sharif, and N. Sheriff, “Compact multiport MIMO antenna system for 5G IoT and cellularhandheld applications,” IEEE Antennas Wireless Propag. Lett., vol. 20,no. 11, pp. 2136–2140, Nov. 2021. With multiport configuration the system supports multiple input and output streams, enhancing data throughput and spectral efficiency crucial for 5G IoT and cellular applications. Only one potential limitation could be the trade-off between antenna size and performance. [6] M. Wagih, G. S. Hilton, A. S. Weddell, and S. Beeby, “Millimeter wavepower transmission for compact and large-area wearable IoT devicesbased on a higher-order mode wearable antenna,” IEEE Internet ThingsJ., vol. 9, no. 7, pp. 5229–5239, Apr. 2022.Central to the study is the introduction of a novel wearable antenna design leveraging higher order mode propagation, optimized for compactness and efficiency while maintaining performance. But, millimeter waves have limited penetration capabilities compared to lower frequency bands, which may result in challenges when developing wearable IoT devices.

EXISTINGMETHOD

A common-aperture sub 6GHz and millimeter wave antenna system[7] is related to the integrated microwave and mm-wave MIMO antenna module. Existing sub-6 GHz wireless communication technologies, i.e. 4G and Wi-Fi, are congested and only allow limited bandwidth and thus, are able to support only limited data rates. To enhance the data rates and improve the system capacity, the next generation of technology, which is known as 5G, must be deployed with a new mechanism of spectrum allocation that allows wider bandwidth. The mm-wave technology needs high gain antennas to compensate for high path loss. Since the gain is inversely proportional to the width of a radiation beam, high-gain antennas yield narrow beamwidth. Thus, beam scanning is required to improve space coverage. So, an integrated antenna system is proposed for sub-6 GHz and mm-wave applications. The key element of the design is a dipole antenna, which has dual-feature. Firstly, it works as a conventional dipole operating at 3.6 GHz and fed from a tapered slot. This tapered slot also operates as an end-fire high gain antenna at mm-wave band. Thus, it also has a dual-feature, i.e., used as a feeding component for the dipole at sub-6 GHz and as an antenna at mm-wave band. This feature of the structure provides an extremely large operating frequency ratio, which makes the design unique.

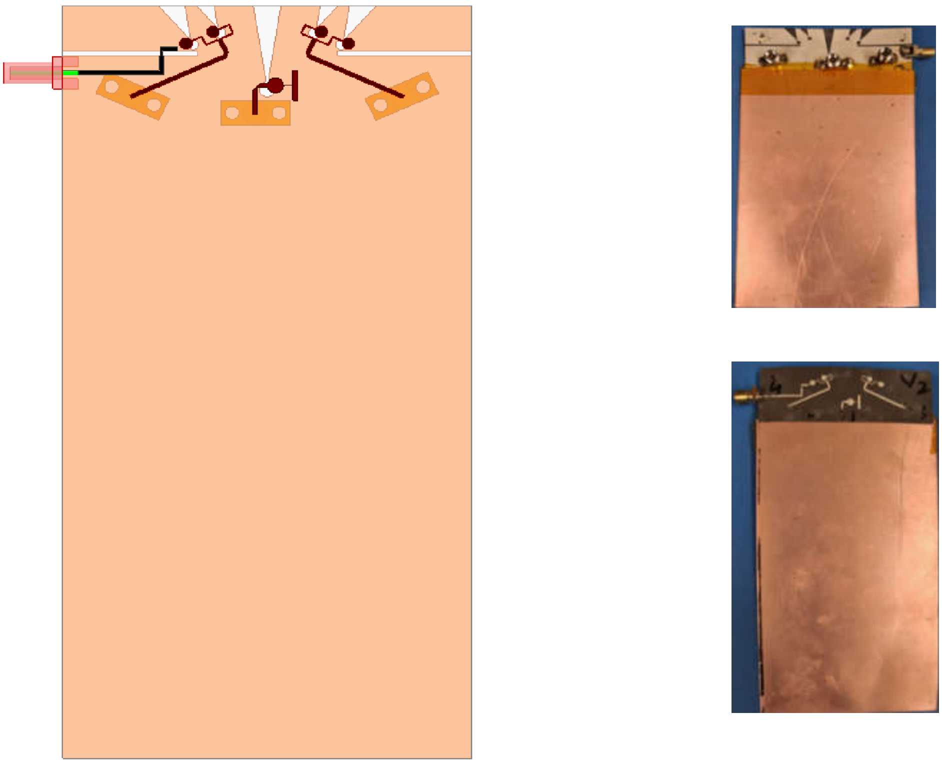

Fig-1: The geometry of the design with large ground plane and top, bottom views

PROPOSEDMETHOD

[9] The antenna consists of five metallic stubsconnected to the triangular monopole at its front, while twostubs are connected to it at its backside through shoring vias.The antenna is designed on ahigh-frequency Rogers-5880 substrate*(εr*= 2.2*,* tan *δ* = 0.0009*)*. The front metallic stubs act as a quarter-wavelength monopoles to provide multiple resonancesat 2.5, 3.5, 5.5, 7.5, and 28 GHz. At the same time, thestubs at the backside connected to the main radiator throughshorting pins are employed for the bandwidth improvements at2.5- and 3.5-GHz bands. The length of each stub is optimizedto get resonances at microwave and mm-wave bands. This single element antenna is the converted into 4-port MIMO antenna by creating a duplicate first and then rotating along the required axis.

THE DESIGN PROCEDURE

The design procedure primarily involves the designing of a single element antenna. This is commenced with a basic triangular monopole that featured a partial ground plane operating at a resonating frequency of 8.5GHz.

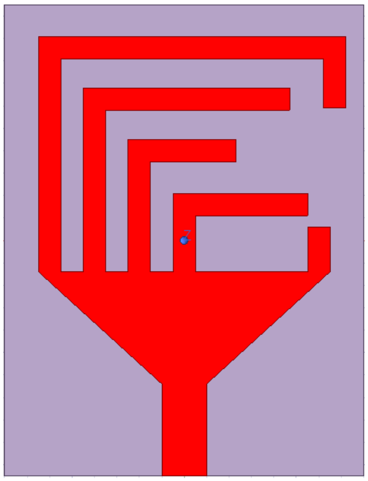

Fig-2: Front side of single element antenna

Initially a partial ground plane is designed which is of 16 x 3mm. On this ground plane a feed of length 4.1mm and width 2mm is created. Four polylines a combined to form an inverted triangle whose dimensions are 5x13mm. On to this monopole each stub is added one-by-one which is designed to resonate at a specific frequency. The first stub which is also the left most stub is designed by combining three rectangular monopoles which are lengths 10.5, 13.7 and 3.2mm. The resonating frequency of this stub is 2.5GHz. The second stub which is second from the left is used to resonate at 3.5GHz and is designed with the lengths of 8.2 and 9.2mm. Third stub is of length 5.9 and 4.8mm and the resonating frequency of the stub is 5.5GHz. The fourth stub is designed with the lengths 3.5 and 5mm and its frequency is 7.5GHz.

As this antenna is composed of many stubs the limited bandwidth can raise questions on the usage of the antenna.[9] To overcome this problem two additional stubs are connected at the backside of the antenna through shorting pins. The fourth stub which is the rightmost stub at the backside of the antenna is designed with the dimensions 10.5 and 14.2mm and used to improve the bandwidth at

2.5GHz bands. The sixth stub at the backside is of 8.2 and 9.2mm and the frequency band at which it improves the bandwidth connectivity is 3.5GHz. The last stub which is rightmost stub at the front is of 2mm long and the resonating frequency is 28GHz i.e., it is used to resonate at mm-wave frequency.

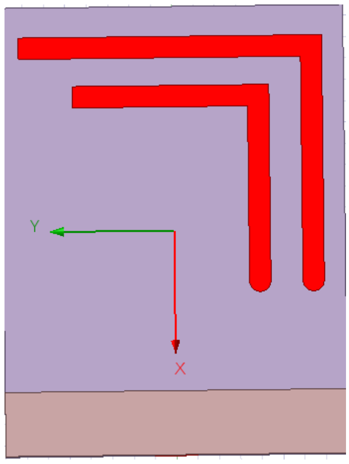

Fig-3: Backside of the antenna

Now this single element antenna is converted into 4-port MIMO antenna by creating a duplicate along the axis and then rotating it 90-degrees along the X-axis and Y-axis.

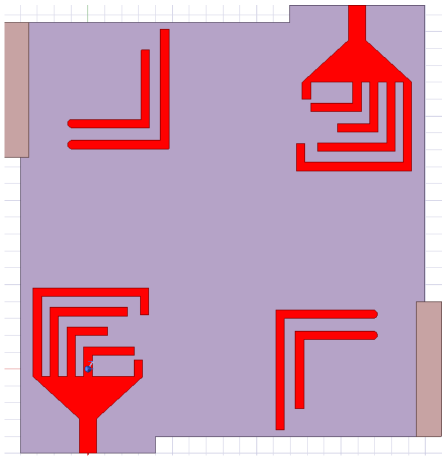

Fig-4 Four port MIMO antenna

RESULT ANALYSIS

The entire antenna is designed using the HFSS (High Structure Software Simulator) software. When each stub is added, prior to that the S-parameter plot and the VSWR plot. The final 4-port antenna is simulated and graphs are observed.[10]

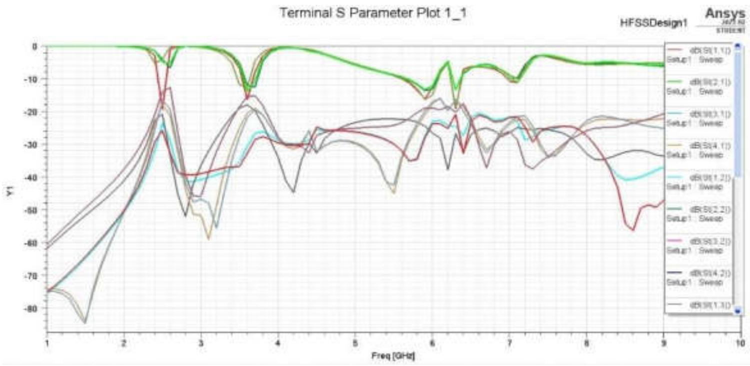

Fig-5: S-parameter plot

CONCLUSION

The integration of microwave and mm-wave band antenna in a single design for multistandard IoT system achieves enhance coverage, capacity and reliability, crucial for supporting the IoT devices. We developed a multiband 4-port MIMO antenna operating at microwave bands(2.5/3.5/5.5/7.5-GHz bands) and mm-wave bands offering high isolation and pattern diversity for 5G applications. This antenna has the advantages of good isolation and pattern diversity for 360degree space coverage for full-duplex operations to provide seamless connectivity for modern devices and sensors. This MIMO antenna technology represents a pivotal step towards realizing the full potential of 5G IoT, leading to an era of connected intelligence and transforming the way we interact with our environment.

REFERENCES

1. A. Gupta and R. K. Jha, “A survey of 5G network: Architecture andemergingtechnologies,” *IEEE Access*, vol. 3, pp. 1206–1232, 2015.

2. L. Chettri and R. Bera, “A comprehensive survey on Internet ofThings (IoT) toward 5G wireless systems,” *IEEE Internet Things J.*,vol. 7, no. 1, pp. 16–32, Jan. 2020.

3. J.Lan, Z. Yu, J. Zhou, and W. Hong, “An aperture-sharing array for (3.5, 28) GHz terminals with steerable beam in milli-meter-wave band,” IEEE Trans. Antennas Propag., vol. 68, no. 5, pp. 4114–4119, May 2020.

4. Y. Liu, Y. Li, L. Ge, J. Wang, and B. Ai, “A compact heptaband mode-composite antenna for sub (6, 28, and 38) GHz applications,” IEEE Trans. Antennas Propag., vol. 68, no. 4, pp. 2593–2602, Apr. 2020.

5. H. T. Chattha, M. K. Ishfaq, B. A. Khawaja, A. Sharif, and N. Sheriff, “Compact multiport MIMO antenna system for 5G IoT and cellular handheld applications,” IEEE Antennas Wireless Propag. Lett., vol. 20, no. 11, pp. 2136–2140, Nov. 2021.

6. M. Wagih, G. S. Hilton, A. S. Weddell, and S. Beeby, “Millimeter wave power transmission for compact and large-area wearable IoT devices based on a higher-order mode wearable antenna,” IEEE Internet Things J., vol. 9, no. 7, pp. 5229–5239, Apr. 2022.

7. M. Ikram, N. Nguyen-Trong, and A. M. Abbosh, “Common-aperturesub-6 GHz and millimeter-wave 5G antenna system,” IEEE Access,vol. 8, pp. 199415–199423, 2020.
8. Nimat Hussian, Nam Kim, “Integrated microwave and mm-Wave MIMO antenna module for with 360-degree pattern diversity for 5G Internet of Things”, IEEE INTERNET OF THINGS JOURNAL, VOL. 9, NO. 24, 15 DECEMBER 2022.

9. M. Wu and M. Chuang, “Multibroadband slotted bow-tie monopoleantenna,” IEEE Antennas Wireless Propag. Lett., vol. 14, pp. 887–890,Apr. 2015.

10. Y. Cao, Y. Cai, L. Wang, Z. Qian, and L. Zhu, “A review of substrateintegrated waveguide end-fire antennas,” IEEE Access, vol. 6,pp. 66243–66253, 2018.