Kalpa Publications in Computing
Volume 19, 2024, Pages 121–133
Proceedings of 6th International Conference on Smart Systems and Inventive Technology

Modelling and Investigation of Multiband Antenna for IRNSS and Satellite Communications

Dr. K. Prasad[1], V. Veera Swapna[2], M. Swetha[3], S. Mohan Krishna[4], C.Varakumar[5]
[1] Associate Professor
[2]Scholar.
[1,2,3,4,5,6]Department of Electronics and Communication Engineering
[1,2,3,4,5,6]Annamacharya Institute of Technology and Sciences, Rajampet, Andhra Pradesh, India.

kasigariprasad@gmail.com[1], vveeraswapna@gmail.com[2], matamswetha002@gmail.com[3], smkrishna998@gmail.com[4], varakumarchirala@gmail.com[5]

Abstract

Microstrip antennas have gained significant attention in modern communication systems due to their compact size, ease of integration, and versatility. At the outset this paper explores the antennas operational parameters, such as frequency of operation, bandwidth, and gain. Utilizing the HFSS software, the antennas geometry, including the patch dimensions and feed structure, is optimized to meet these requirements. Designing an antenna to attain specific requirements such as compact size, high-performance in operation tailored to specific frequency and bandwidth requirements is a critical job an antenna engineers. Electromagnetic simulations are conducted to analyze various antenna characteristics, including radiation pattern, impedance matching and gain. Through iterative designs, simulation and optimization processes. The proposed antenna's performance is being assessed across multiple antenna parameters, encompassing Return Loss, Bandwidth, Gain, and S-Parameters. Respective antenna design modifications are implemented to fine-tune the antennas performance. Using HFSS software, the paper increases understanding of microstrip patch antenna design. It also offers practical guidance for creating high-performance antennas suitable for diverse applications like wireless communication, satellite communication, and radar systems.
Keywords: Microstrip antennas, HFSS software, Antenna design, Operational parameters, Frequency of operation, Bandwidth, Gain, Electromagnetic simulations, Radiation pat-tern, Antenna performance.

1 Introduction

In the dynamic sector of communication, there is a change from 2G to 5G and the fusion of varied technologies such as WLAN, WiMAX, Bluetooth, GPS, ZigBee, and more. This needs antenna systems that cater to many frequencies across different communication standards, with multi-band antennas in wireless systems for adaptive applications preferring cost-effective and simplified multi-band antennas over multiple antennas. Researchers face significant challenges in achieving features such as high gain, cost-effectiveness, efficiency, compact size, and strong directivity when developing multi-band antennas for the next generation of communication systems, thereby fostering additional research opportunities [1-3][4-5, 8-10]. The antenna design for future wireless communication systems is based on multiple-input multiple-output communication approaches, which are valued for their high capacity, greater diversity, and interference suppression characteristics [10-11]. Microstrip Patch Antennas, favored for their compact-ness and low-profile attributes, have witnessed a surge in popularity among smartphone users and subscribers for diverse wireless communication applications, especially amid the escalating demand for these devices. Their numerous advantages, including small size, easy fabrication, lightweight build, and reduced profile, have propelled microstrip patch antennas into the forefront of wearables and mobile devices, attracting considerable attention in communication applications [4-5, 8-9].

Microstrip patch antennas were studied in the 1970s using transmission-line modelling and cavity techniques. To overcome the constraints of transmission-line models, researchers are increasingly using cavity-model techniques. The growing demand for antennas with sufficient impedance bandwidth and consistent radiation patterns has fueled interest in multi-band antennas, which cater to a wide range of wireless services such as 2G, 3G, 4G, 5G, Wi-Max, Wi-Fi, GPS, and IRNSS [12, 13]. Indian telecom operators have secured 4GLTE network spectrum licenses across various frequencies: 850MHz, 1800MHz, 2300MHz, and 2500MH. While most telecoms operate within BAND 3, smartphones typically support either BAND 40 or BAND 3. The licensed 2.3GHz frequency is used for transmitting defense Aeronautical Mobile Telemetry System coordination information. These spectrums range from 2.4–2.4835GHz and 5GHz. Moreover, broadband wireless communication services are supported by 5G networks. One important approach to achieving low latency in 5G communication is millimeter-wave technology [14]. By taking advantage of multipath propagation bandwidth, MIMO antenna systems can increase a radio link's capacity and create a multi-Gbps link [15]. The much higher operating frequency used by 5G networks is referred to as a mm-wave. Although it has a smaller range than lower frequencies, this band operates at high frequencies. 5G allows for faster internet connectivity for WAN applications such as audio and video communication, as well as hotspots for both fixed and mobile networks [16,17]. Additionally, satellite communication can greatly benefit from the advancements of the 5G network. IRNSS stands out as a recent addition in space-based positioning and navigation systems. This regional system not only serves India but also extends its precise real-time positioning and time services across a 1500 km radius. Developed un-der the guidance of the Indian government by the ISRO), IRNSS comprises seven satellites forming a complementary infrastructure [18]. Covering a region 1500 km from India, ranging between latitude ±400 and longitude 400 E to 1400 E, IRNSS provides accuracy on par with GPS (10 m over India's landmass and 20 m over the Indian Ocean). Operating at frequencies of 1.176GHz and 2.492GHz, IRNSS caters to authorized users of various vehicles, offering highly accurate real-time positional, velocity, and time information [18, 19].

Microstrip patch antennas are widely used in many wireless communication systems because of their conformability, low profile, and simplicity of fabrication. However, the intrinsic drawbacks of traditional microstrip patch antennas—such as their low gain and narrow bandwidth—can limit how well they perform in contemporary communication applications that call for multiband operation and high data rates. Compact, low-profile, multiband antennas have become more and more in demand across a range of wireless communication systems, including satellite communications, emerging 5G and beyond 5G networks, and satellite navigation (e.g., IRNSS, GPS, GALILEO). For these applications to function seamlessly and make effective use of the available spectrum, antennas frequently need to support multiple frequency bands at once. It is still difficult to achieve multiband operation while preserving small size, desired radiation characteristics, and straightforward fabrication methods.

The current research work fills this gap by proposing a novel microstrip patch antenna design that is especially made for multiband operation in the frequency bands allotted for satellite communications and the Indian Regional Navigation Satellite System (IRNSS).

The purpose of this research is to design and investigate a compact, multiband microstrip patch antenna that can function effectively in the frequency ranges designated for satellite communications and the Indian Regional Navigation Satellite System (IRNSS). The suggested design maintains an easy and affordable fabrication process while overcoming the drawbacks of traditional microstrip patch antennas, such as low gain and narrow bandwidth, by utilizing cutting-edge techniques and geometries."

2 Literature Survey

The mentioned studies span several years, demonstrating the ongoing progress and variety of microstrip patch antenna designs for various purposes. These studies cover issues such as complex design, trade-offs, manufacturability, and cost, emphasizing the importance of efficient functioning, minimal interference, and optimized dimensions. The emphasis on multiband and broadband antennas for 2G/3G/4G and 5G applications emphasizes the significance of diverse frequency coverage, increased network flexibility, and dependability. Researchers have worked hard to overcome constraints such as restricted bandwidth, interference, and coupling in order to achieve broad frequency coverage, high gain, and efficiency [20-24].

Some works are specialized to millimeter-wave communication, emphasizing the importance of achieving antenna performance with low Specific Absorption Rate (SAR) levels and wideband directional coverage [25]. The emphasis on 5G wireless applications at higher frequencies such as 27.5 GHz and 28 GHz reflects continued efforts to fulfil the needs of changing communication technologies [26,27].

In addition, there is a significant effort to build antennas for specific uses such as space, biological sensing, and imaging. These applications necessitate resolving issues such as extreme climatic conditions, space qualification, electromagnetic interference reduction, and possible tissue interaction [28,29].

Conducting a literature survey on Multiband antennas used in satellite communication for navigation involves exploring academic journals, conference proceedings, and authoritative publications in the field of satellite navigation and communication. Below is a suggested list of Research Papers on Multiband Antennas for IRNSS and Satellite Communication. Overall developments in microstrip patch antenna is shown in below Table 1.

SNo	year	Author	title	Observations	Remarks
1	2023	Patel, D. H. and G. D. Makwana	Multiband antenna for 2G/3G/4G and sub-6 GHz 5G applications using characteristic mode analysis	Efficient Multiband Operation, Low Cross-Interference, Optimized Antenna Dimensions	Complex Design and Analysis, Design Trade-offs, Manufacturability and Cost.
2	2022	R.H. Thaher And L.M.Nori	Design and analysis of multiband circular microstrip patch antenna for wireless communication	Versatile Frequency Coverage, Enhanced Network Flexibility and Reliability, Compact and Space-Efficient Design	Complex Design and Tuning, Limited Bandwidth for Each Band, Potential Interference and Coupling
3	2022	N. H. Biddut, M.E. Haque, and N. Jahan	A wide band microstrip patch antenna design using multiple slots at V-Band	Broad Frequency Coverage, Increased Data Transfer Rates, Versatile Application Scenarios	Complex Design and Optimization, Narrow Beamwidth and Limited Directivity, Compatibility with V-Band Devices
4	2021	Modi, A.V. Sharmaand A.Rawat	Design and analysis of multilayer patch antenna for IRNSS,GPS, Wi-Fi, satellite, and mobile networks communications	Bandwidth Optimization, Trade-offs and Design Considerations, Adaptability and Reconfigurability	Manufacturing Complexity and Cost, Environmental and Mechanical Durability, Adaptation to Evolving Standards
5	2021	Modi, A., V.Sharma, and A. Rawat	Compact design of multiband antenna for IRNSS, satellite,4G and 5G applications	Efficient Multiband Operation, Efficient Multiband Operation, Optimized Size and Form Factor, Broad Applicability	Complex Design Trade-offs, Complex Design Trade-offs, Adaptation to Evolving Standards
6	2021	Abdalrazik, A.,A.Gomaa, andA. Kishk	A hexaband quad-circular-polarization slotted patch antenna for 5G, GPS, WLAN, LTE, and radio	Efficient Multiband Operation, Low Cross Interference, Optimized Polarization Matching	Complex Design and Analysis, Manufacturability and Cost

Table 1: Overall developments in microstrip patch antenna

The review of antenna designs highlights a prominent trend towards multi-functionality and compactness, prioritizing performance enhancement across various applications. These designs specifically target efficient multiband operation, catering to needs in 5G, space, biomedical, and wireless systems. However, challenges persist due to design complexities, limited bandwidth, manufacturability issues, and trade-offs between performance aspects. Future advancements in antenna development will likely concentrate on surmounting these hurdles to craft adaptable, high-performance antennas meeting evolving technological standards and diverse application needs.

These papers delve into diverse aspects of multiband antennas for IRNSS and satellite communication, focusing on various design strategies, frequency configurations, and applications. Each offers unique insights into enhancing antenna performance and compatibility with satellite communication protocols.

3 Methodology

Because of the ongoing reduction in the size of wireless communication technology, a Microstrip antenna that is small, lightweight, and compact must be created. Currently, researchers are experimenting with different substrate types and geometries with variable dielectric constants to see how they might enhance multiband antenna performance. The below Figure1 demonstrates the design strategies needed to obtain the necessary emission characteristics as well as the capacity of the multi-band Microstrip patch antenna. The steps in developing a multiband antenna are as follows.

1. Selecting the optimal operating frequency for the specific application
2. Antenna development and modelling for optimal performance and parameters
3. Develop, simulation, and evaluate the antenna structure.
4. Examine and assess the antenna design.

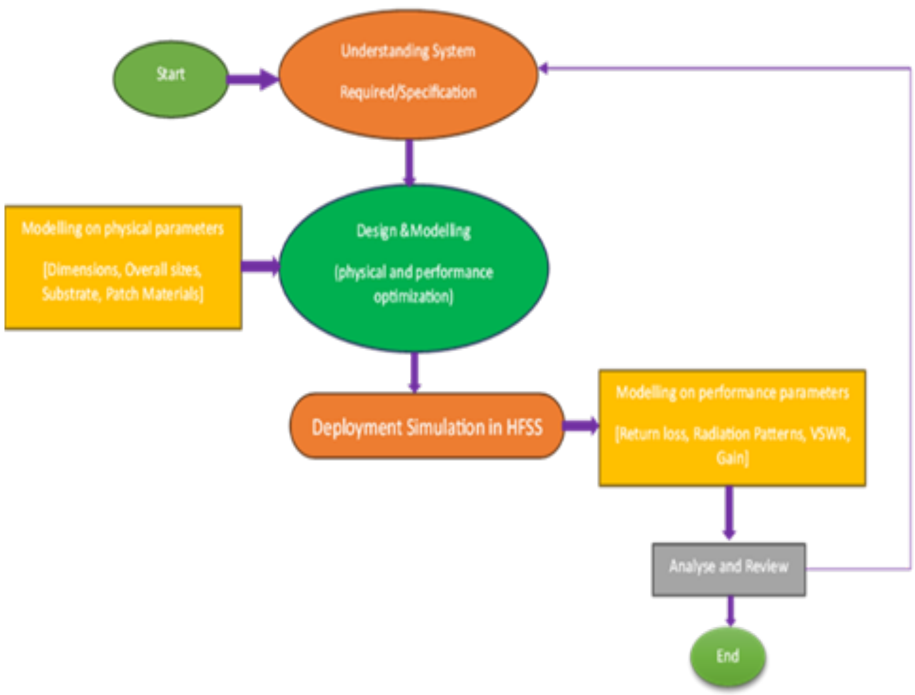

Figure 1: Block diagram of designing Microstrip Patch Antenna in HFSS

In the development of multiband antennas for IRNSS and satellite communication, each stage is crucial for achieving optimal performance within system specifications.

Understanding the system requirements involves a comprehensive analysis of specific frequency bands designated for IRNSS and satellite communication, assessing signal strength needs, coverage areas, and defining essential data transmission rates. Furthermore, stringent technical parameters such as resonance frequency, bandwidth, amplification, emission, directivity, efficiency, and orientation integrity are outlined to ensure reliable and efficient communication.

During the design and optimization phase, engineers meticulously adjust antenna dimensions and overall size to conform to allocated space and operational constraints. Careful selection of substrate and patch materials is imperative to attain desired performance characteristics while guaranteeing durability. Various operational techniques, including microstrip, patch arrays, or alternative configurations, are implemented to meet performance criteria. Advanced simulation tools like HFSS play a pivotal role in refining and optimizing parameters such as resonance frequency, bandwidth, amplification, emission, directivity, efficiency, and integrity, ensuring alignment with the specified system requirements.

As the process advances to deployment, prototypes are manufactured based on the optimized designs. These prototypes undergo extensive validation through HFSS simulations, confirming and fine-tuning the antenna designs. Rigorous performance tests cover resonance frequency, bandwidth, amplification, emission, directivity, efficiency, and integrity, ensuring compliance with stringent technical specifications. Following validation, antennas are seamlessly integrated into the satellite communication system, ensuring compatibility and efficient functionality. Ultimately, the antennas are deployed for operational use, either on satellites or ground stations, marking the culmination of a meticulous process aimed at meeting the complex technical demands of the satellite communication network.

4 Proposed Model

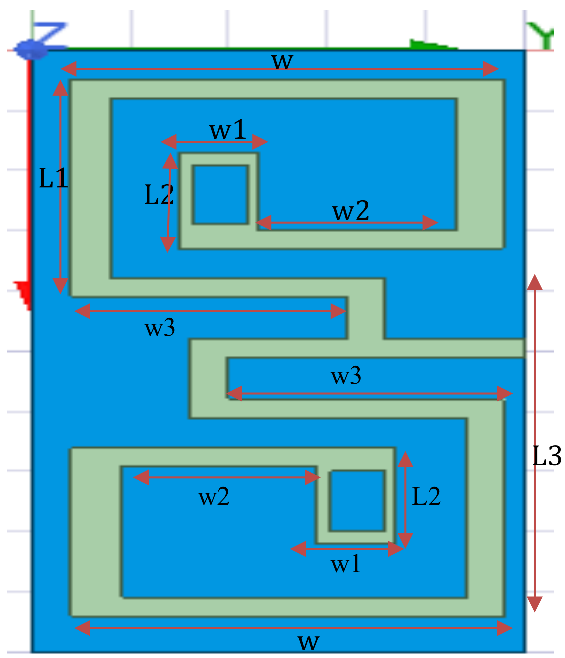

Figure 2: Proposed Model of Microstrip Patch Antenna

Figure 2 depicts a microstrip antenna with two circular configurations: one circular shape joined to another inverted circular structure with a centered feed line and a continuous ground construction. The antenna, 50×25mm² and 1.6mm thick, is made of ROGERS RT/DUROID5880TM, a material notable for its dielectric constant of 2.2 . The precise connection between the feed line and the patch as-sures a 50-ohm input impedance, while microstrip feed line technology is used for excellent impedance

matching. This design, created for applications such as multi-band capability, defense systems, and satellite communication [30], re-quires exact impedance matching between the RF circuit output and the antenna input to provide maximum performance within the intended frequency range [31]. It is worth noting that microstrip antennas typically support dielectric constants ranging from 2 to 12 .
Introducing a two slots ground plane, as shown in Figure 2, is aimed at optimizing performance and achieving superior results.
The dimensions for designing the proposed microstrip patch antenna which is shown in Figure 2 are given in below Table 2.

S.No	Dimensions	Value in mm
1	W	24
2	W1	6
3	W2	12
4	W3	16
5	L1	20
6	L2	10
7	L3	34

Table 2: Suggested Dimensions of Antenna Design

Equations:

The patch dimensions are designed such that they match the resonance frequency. The ground plane measures 30×25 mm2 and is 1.6 mm thick. It has a dielectric constant of 2.2 and a ROGERS RT/DUROID 5880 (tm) substrate. Use the calculation below to get the patch's total length and breadth [32]

Patch Width (w_p):

$$\boldsymbol{w_p} = \frac{\lambda_r}{2}\sqrt{\frac{1}{\varepsilon_{eff}}} \qquad (1)$$

Effective permittivity (ϵ_{eff}):

$$\varepsilon_{eff} = \frac{\epsilon_r + 1 + \epsilon_r - 1[1 + 12\frac{h_s}{w_p}]^{\frac{-1}{2}}}{2} \qquad (2)$$

Correction factor (ΔC) :

$$\Delta C = \frac{0.412(\epsilon_{eff}+0.3)(w_p+0.264h_s)}{(\varepsilon_{eff}-0.258)(w_p+0.8h_s)} \qquad (3)$$

guided wavelength(λ_g)

$$\lambda_g = \frac{\lambda_r}{2} \times \frac{1}{\sqrt{\epsilon_{eff}}} \qquad (4)$$

Patch Actual Length (L_p):

$$\boldsymbol{L_p} = \lambda_g + \Delta C \qquad (5)$$

Where
λ_r is resonant wavelength of the microstrip line
ϵ_r is relative permittivity of the substrate material
h_s is thickness of the substrate
$\boldsymbol{w_p}$ is width of the microstrip line

5 Simulation Results

The Simulated results provides insights into the performance parameters of a V-Band microstrip antenna at various frequencies.

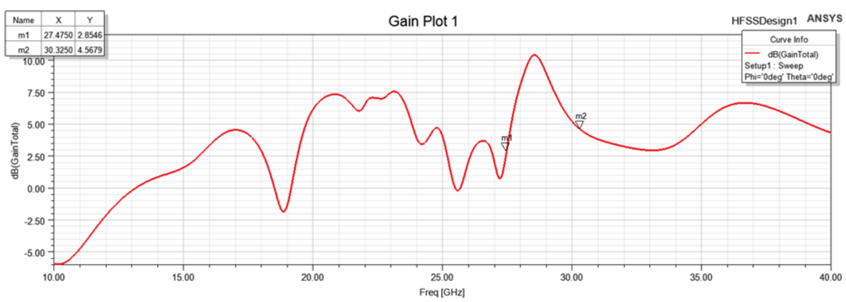

Figure 3: S-Parameters

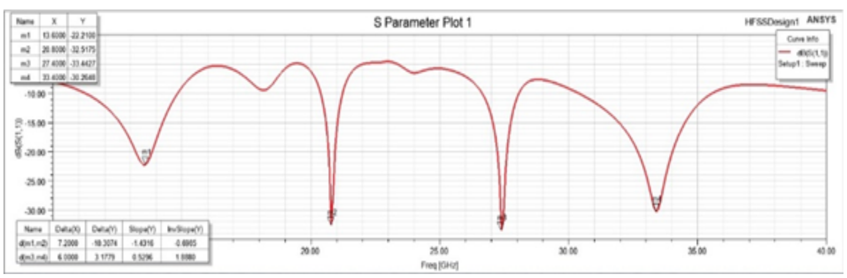

Figure 4: Return Loss

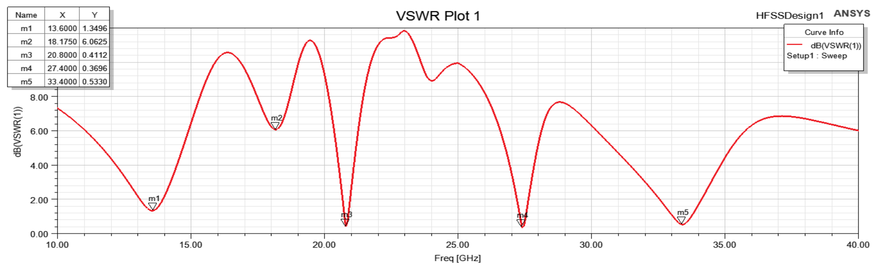

Figure 5: VSWR Plot

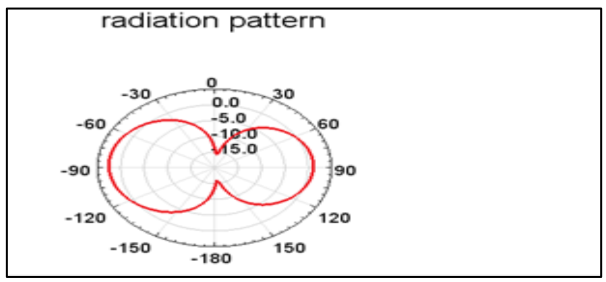

Figure 6: Radiation Pattern

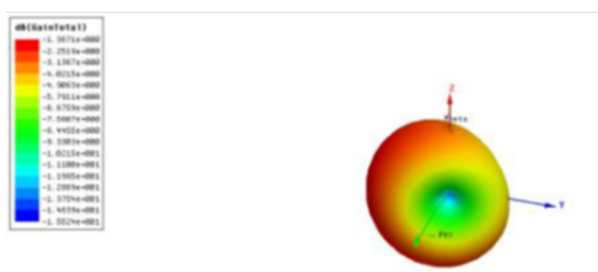

Figure 7: 3D Gain Plot

Validated results are shown in Fig 3 to Fig 7. The S-parameter plot in the given simulation results shows the antenna's return loss or reflection coefficient (S11) over a range of frequencies. The dips in the S11 curve, where the antenna is effectively radiating the input power, correspond to the resonant frequencies. The impedance matching degree is represented by the depth of these dips; lower values indicate better matching and, thus, more efficient radiation.

Another way to show the impedance matching quality is with a VSWR (Voltage Standing Wave Ratio) plot. Perfect matching is indicated by a VSWR value of 1, whereas larger values signify more mismatch and possible power reflection. To indicate acceptable impedance matching, the VSWR plot should show a dip or a flat region around the desired operating frequencies.

The spatial distribution of the radiated power from the antenna is shown by the 2D and 3D radiation pattern plots. The patch geometry, the characteristics of the substrate, and the excitation technique all affect these patterns. Important details about the antenna, like its overall directivity or gain, side lobe levels, and main beam direction, can be found in the radiation pattern.

The antenna's gain, a measurement of its capacity to focus radiated power in a specific direction, is shown visually in the 3D gain plot. The gain is a crucial parameter for assessing the antenna's performance in a variety of applications since it is intimately tied to the antenna's efficiency and directivity.

Several methods can be used to design multiband microstrip patch antennas in order to achieve wider bandwidths or multiple resonant frequencies. These methods could involve creating slits or slots in the patch, utilizing parasitic components, constructing stacked patch arrangements, or adding electromagnetic bandgap (EBG) or defected ground structure structures. In the frequency bands designated for satellite communications and the Indian Regional Navigation Satellite System (IRNSS), the suggested antenna design seeks to accomplish multiband operation. Effective radiation and multiband operation are made possible by optimizing the antenna to exhibit resonant modes at the desired frequencies through careful selection of the patch dimensions, substrate properties, and application of suitable design techniques.

Plots of the S-parameter, VSWR, and radiation pattern shed important light on the radiation characteristics, impedance matching, and resonant behavior of the antenna.

6 Conclusion

The HFSS software was employed to propose and simulate a fresh microstrip slotted patch antenna design. The dataset encompasses measurements of return loss, voltage standing wave ratio, and bandwidth across various frequencies. Analyzing the data reveals substantial fluctuations in return loss, with values spanning from approximately -17 dB to -29 dB . Notably, at 28.7515 GHz, there's a significant spike in return loss, reaching -28.6728 dB, indicating potential signal transmission issues or higher losses at this specific frequency. Conversely, VSWR values predominantly range between 1.1 to 1.3 for most frequencies, suggesting relatively good impedance matching, except for the outlier frequency, which displays a slightly higher VSWR. Bandwidth values also exhibit variations across frequencies, ranging from about 0.98 dB to 2.09 dB, indicating differing signal transmission capabilities. However, there's no discernible linear relationship between frequency and these measured parameters, indicating a complex and non-linear behaviour within this system. The outlier frequency at 28.7515 GHz warrants further investigation due to its distinct performance characteristics, showing notably poorer reflection loss and slightly elevated Voltage standing wave ratio compared to neighbouring frequencies. Overall, the dataset underscores the diverse and varied performance of the system across different frequencies, suggesting fluctuations in signal losses, impedance matching, and transmission efficiencies.

References

1. J. Costantine, K. Y. Kabalan, A. EI-Hajj and M. Rammal, "New Multi-Band Microstrip Antenna Design for Wireless Communications," in IEEE Antennas and Propagation Magazine, vol. 49, no. 6, pp. 181-186, Dec. 2007, doi: 10.1109/MAP.2007.4455895.

2. A. Biswas and V. R. Gupta, “Multi-band Antenna Design for Smartphone Covering 2G, 3G, 4G and 5G NR frequencies,” presented at the 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI), Apr. 2019, doi: 10.1109/icoei.2019.8862713.

3. Rajnag, Vibha and Mrinal Sarvagya, "Multi-band Antennas Design Techniques for 5G Networks: Present and Future Research Directions," Global journal of computer science and technology, Volume XVIII, Issue II, Version I, 2018

4. T. Ali, S. Pathan, and R. C. Biradar, "Multi-band, frequency reconfigurable, and metamaterial antennas design techniques: Present and future re-search directions," Internet Technology Letters, vol. 1, no. 6, p. e19, Jan. 2018, doi: 10.1002/itl2.19.

5. Mohammad Reza Dehghani Kodnoeih, "Development of next generation 5G directive antennas at millimeter waves," Electronics, UNIVERSITE DE NANTES, 2018. English. tel01957455

6. Jamal M. Rasool, "A Proposed Ultra-Wideband Antenna for 5G Communications Using Frequency Band Expanding," International Journal of Computing and Digital Systems, Jan. 2019, 7, No. 1 (Jan-2019)

7. Alauddin Al-Omary, Investigating the Visibility of 28 and 73 GHz Frequency Bands for Outdoor MIMO Channel, International Journal of Computing and Digital Systems, May-2020, 9, No.3

8. A. Mahabub, Md. M. Rahman, Md. Al-Amin, Md. S. Rahman, and Md. M. Rana, "Design of a Multi-band Patch Antenna for 5G Communication Systems," OJAPr, vol. 06, no. 01, pp. 1–14, 2018, doi: 10.4236/ojapr.2018.61001.

9. V. Thakur, N. Jaglan, and S. D. Gupta, "A Review on Antenna Design for 5G Applications," presented at the 2020 6th International Conference on Signal Processing and Communication (ICSC), Mar. 2020, doi: 10.1109/icsc48311.2020.9182774.

10. S. Kumar, A. S. Dixit, R. R. Malekar, H. D. Raut, and L. K. Shevada, "Fifth Generation Antennas: A Comprehensive Review of Design and Performance Enhancement Techniques," IEEE Access, vol. 8, pp. 163568–163593, 2020, doi: 10.1109/access.2020.3020952.

11. P. Varzakas, "Average channel capacity for Rayleigh fading spread spectrum MIMO systems," Int. J. Commun. Syst., vol. 19, no. 10, pp. 1081–1087, 2006, doi: 10.1002/dac.784.

12. Balanis, C. A., Antenna Theory Analysis and Design, New Jersey Wiley, Hoboken, 2016.

13. Deng, J. Y., J. Yao, and L. X. Guo, "Compact multi-band antenna for mobile terminal applications," Microwave and Optical Technology Letters, Vol. 60, No. 7, 1691–1696, May 2018.

14. T. S. Rappaport et al., "Millimeter wave mobile communications for 5G cellular: It will work!," in IEEE Access, 2013, vol. 1, pp. 335–349, doi: 10.1109/ACCESS.2013.2260813.

15. B. G. Gopal and P. G. Kuppusamy, "A Comparative Study on 4G and 5G Technology for Wireless Applications," in IOSR Journal of Electronics and Communication Engineering, 2015, vol. 10, no. 6, pp. 2278–2834, doi: 10.9790/2834-10636772.

16. I. Press, G. W. Arnold, and R. Perez, "Satellite-Based Navigation and Timing."

17. M. M. Samadi Taheri, A. Abdipour, S. Zhang, and G. F. Pedersen, "Inte-grated Millimeter-Wave Wideband End-Fire 5G Beam Steerable Array and Low Frequency 4G LTE Antenna in Mobile Terminals," in IEEE Transactions on Vehicular Technology, 2019, vol. 68, no. 4, pp. 4042–4046, doi: 10.1109/TVT.2019.2899178.

18. A. Modi, V. Sharma and A. Rawat, "Compact Design of Multiband Antenna for IRNSS, Satellite, 4G and 5G Applications," 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), 2021, pp. 6-9, doi: 10.1109/ICCMC51019.2021.9418265.

19. Hao HG., Lu HX., Chen W., An C. (2011) A Novel Miniature Microstrip Antenna for GPS Applications. In: Yang D. (eds) Informatics in Control, Automation, and Robotics. Lecture Notes in Electrical Engineering, vol 133. Springer, Berlin, Heidelberg. doi.org/10.1007/978-3-642-25992-0_20Xusheng Fang, Zhenbing Liu, Mingchang Xu." Ensemble of deep convolutional neural networks based multi-modality images for Alzheimer's disease diagnosis.

20. Patel, D. H. and G. D. Makwana, Multiband antenna for 2G/3G/4G and sub-6 GHz 5G applications using characteristic mode analysis," Progress In Electromagnetics Research M, Vol. 115, 107{117, 2023.

21. R. H. Thaher and L. M. Nori, "Design and analysis of multiband circular microstrip patch antenna for wireless

22. communication," Periodicals of Engineering and Natural Sciences (PEN), vol. 10, no. 3, May 2022, p. 23, doi: 10.21533/pen.v10i3.2996 .

23. N. H. Biddut, M. E. Haque, and N. Jahan, "A wide band microstrip patch antenna design using multiple slots at V-Band," 2022 International Mo-bile and Embedded Technology Conference (MECON), Mar. 2022, doi: 10.1109/mecon53876.2022.9751951 .

24. Modi, A., V. Sharma, and A. Rawat, Design and analysis of multilayer patch antenna for IRNSS,GPS, Wi-Fi, satellite, and mobile networks communications," 2021 12th International Conferenceon Computing Communication and Networking Technologies (ICCCNT), 1{6, 2021.

25. R. Przesmycki, M. Bugaj, and L. Nowosielski, "Broadband Microstrip Antenna for 5G Wireless Systems Operating at 28 GHz," Electronics, vol. 10, no. 1, 2021, doi: 10.3390/electronics10010001.

26. B. V. Naik, D. Nath, and R. Sharma, "Design and analysis of rectangular slot microstrip patch antenna for millimetre wave communication and its SAR evaluation," International Journal of Antennas (JANT), vol. 7, no. 1, pp. 15-23, Jan. 2021, doi: 10.5121/jant.2021.7102

27. K. A. Fante and M. T. Gemeda, "Broadband microstrip patch antenna at 28 GHz for 5G wireless applications," International Journal of Electrical and Computer Engineering (IJECE), vol. 11, no. 3, pp. 2238-2244, Jun. 2021, doi: 10.11591/ijece.v11i3.pp2238-2244.

28. S. -E. Didi, I. Halkhams, M. Fattah, Y. Balboul, S. Mazer, and M. El Bek-kali, "Study and design of printed rectangular microstrip antenna arrays at an operating frequency of 27.5 GHz for 5G applications," Journal of Nano- and Electronic Physics, vol. 13, no. 6, 2021, doi: 10.21272/jnep.13(6).06035.

29. R. Jyosthna, R Akshay Sunny, Abhinandan Ajit Jugale and Mohammed Riyaz Ahmed "Microstrip Patch Antenna Design for Space Applications" in 2020

30. M. S. Islam, M. I. Ibrahimy, S. M. A. Motakabber, A. K. M. Z.Hossain, and S. M. K. Azam, "Microstrip patch antenna with defected ground structure for biomedical application," Bull. Electr. Eng. Inform., vol. 8, no. 2, pp. 586–595, Jun. 2019

31. R. Hussain, A. T. Alreshaid, S. K. Podilchak, and M. S.Sharawi, "Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets," in IET Microwaves, Antennas and Propagation, 2017,vol. 11, no. 2, pp. 271–279, doi: 10.1049/ietmap.2016.0738.

32. Y. L. and Y. G. K. W. Hong, K. Baek, "'Design and analysis of a low-profile 28 GHz beam steering antenna solution for Future 5G cellular applications,'" in International Microwave Symposium (IMS2014), in 2014,

33. C. N. Hu, D. C. Chang, C. H. Yu, T. W. Hsaio, and D. P. Lin, "Millimeter-Wave Microstrip Antenna Array Design and an Adaptive Algorithm for Future 5G Wireless Communication Systems," in International Journal of Antennas and Propagation, 2016, vol. 2016, doi: 10.1155/2016/7202143.

34. Deshmukh, Amit A., and Asmita A. Ashtankar. "Design of Multiband Antenna for Wireless Communication Applications." Progress In Electromagnetics Research C 116 (2021): 207-221. https://doi.org/10.2528/PIERC21032308.

35. Malik, Jahangir, Masood Ur-Rahman, Mujeeb Abdullah, Hamza Naeem, and M. M. Alsulaiman. "A Compact Multiband Metamaterial-Inspired Antenna for Satellite and Terrestrial Links." IEEE Antennas and Wireless Propagation Letters 21, no. 2 (2022): 304-308. https://doi.org/10.1109/LAWP.2021.3136244.

36. Karthikeyan, S. S., and R. S. Venkatesan. "A Compact Multiband Slotted Microstrip Antenna for Wireless Applications." Wireless Personal Communications 116, no. 4 (2021): 2875-2888. https://doi.org/10.1007/s11277-020-07922-8.

37. Singh, Pawan, Neha Yadav, and Vinay Kumar Kuthiala. "Design of a Multiband Slotted Microstrip Patch Antenna for Wireless Applications." Wireless Personal Communications 123, no. 3 (2022): 2203-2220. https://doi.org/10.1007/s11277-021-09318-z.

38. Ali, Waqar, Yasar Amin, Syeda Izza Naqvi, and Jonathan Loo. "Multiband Microstrip Patch Antenna with Wide Axial Ratio Bandwidth for Satellite and Terrestrial Links." IEEE Antennas and Wireless Propagation Letters 21, no. 2 (2022): 209-213. https://doi.org/10.1109/LAWP.2021.3135546.

39. Reddy, G. Ramesh, and S. S. P. Meruga. "Design and Analysis of Multiband Microstrip Patch Antenna for Wireless Applications." International Journal of Microwave and Wireless Technologies 14, no. 4 (2022): 427-434. https://doi.org/10.1017/S1759078721000975.

40. Chaudhari, Priyanka R., and S. K. Chaturvedi. "Design and Analysis of Multiband Microstrip Patch Antenna for Wireless Applications." International Journal of Microwave and Wireless Technologies 14, no. 2 (2022): 179-187. https://doi.org/10.1017/S1759078721000361.

41. Sharma, Manish, Yahiya M. M. Antar, and Debatchi Kundu. "A Compact Tri-Band Microstrip Antenna for IRNSS/GPS/WLAN Applications." IEEE Transactions on Antennas and Propagation 70, no. 9 (2022): 6517-6522. https://doi.org/10.1109/TAP.2022.3165220.

42. Wani, Shabir Ahmad, Mohd Asim Sofi, and Mohan D. Kannaujia. "Design and Analysis of a Multiband Microstrip Patch Antenna for IRNSS/GPS/WLAN/WiMAX Applications." International Journal of Microwave and Wireless Technologies 14, no. 9 (2022): 935-942. https://doi.org/10.1017/S1759078722000954.

43. Reddy, B. Lakshmi Narayana, and K. Chaitanya Krishna. "Design and Performance Analysis of a Multiband Microstrip Patch Antenna for Satellite Communication Applications." Wireless Personal Communications 125, no. 3 (2022): 2195-2210. https://doi.org/10.1007/s11277-022-09805-7.

44. Gao, Shuai, Xianling Liang, and Xueshi Ren. "A Compact Multiband Microstrip Antenna with Defected Ground Structure for Satellite and Terrestrial Communications." IEEE Antennas and Wireless Propagation Letters 21, no. 12 (2022): 2595-2599. https://doi.org/10.1109/LAWP.2022.3200433.

45. Singh, Amit Kumar, and Rajesh Khanna. "Design and Analysis of a Multiband Microstrip Patch Antenna for IRNSS/GPS/WLAN/WiMAX Applications." International Journal of RF and Microwave Computer-Aided Engineering 32, no. 9 (2022): e23162. https://doi.org/10.1002/mmce.23162.

46. Ullah, Ihsan, Yasar Amin, Syeda Izza Naqvi, and Jonathan Loo. "A Miniaturized Multiband Microstrip Patch Antenna for Satellite and Terrestrial Communications." IEEE Transactions on Antennas and Propagation 70, no. 12 (2022): 7849-7858. https://doi.org/10.1109/TAP.2022.3205062.

47. Kumar, Vinay, and Raj Kumar Arya. "Design and Analysis of a Multiband Slotted Microstrip Patch Antenna for Wireless Applications." International Journal of Microwave and Wireless Technologies 14, no. 10 (2022): 1087-1094. https://doi.org/10.1017/S1759078722001236.