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Innovative Approach in Teaching Microstrip Patch Antennas

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ABSTRACT

Microstrip patch antennas are playing a very critical role in 5G and 6G spectrum, especially because of their low profile, flexibility of shape, low cost, ease in fabrication, and compatibility with high frequency and sub Tetra Hertz T Hz for mobile applications. In our higher education system, the emphasis has been placed more on the theoretical concepts of learning and teaching. Keeping Viksit Bharat @ 2047 in mind, it is time for us to make some changes in our teaching and learning. It has become extremely important to bring the theoretical microstrip antenna concept into our classrooms in alliance with the industry-relevant applications. A shift is required from theoretical antenna and communication to 'work-ready' skills through project-based learning and more emphasis on learning through internships.

It is becoming extremely important to study and use more advanced materials. More research is to be brought to the classrooms to focus on metamaterial-inspired structures to improve antenna parameters for 6G applications. It is the need of time to use digital simulation tools. AI in antenna designs utilizes machine learning techniques to perfectly optimize antenna parameters for their best applications. Bluetooth application requires 5G and 6G spectrum usage. Hence, IoT (Internet of Things) devices become very promising. It has become very important to include the development of nano-antennas and compact antenna design for IoT devices and space applications, especially for CubeSats (miniature satellites, built using standard 10cm cubic units, 1U). Since it is small and affordable, it will allow the colleges, universities and researchers to become part of launch space missions.

With the change of lifestyle, it has become important to study and develop flexible and wearable antennas. These antennas are developed for smart clothing and medical on-body communication. These antennas are lightweight and flexible, to be the choice for our clothes. Smart clothing and medical on-body communication usually use polymer textiles and conductive materials. While designing these wearable antennas for wireless communication for on-body sensors and health monitoring, it becomes extremely important that these antennas are lightweight and capable of operating close to human bodies with minimum performance degradation.

*Keywords***:** microstrip antennas, metamaterial, IoT, wearable antennas, AI.

1. INTRODUCTION

Keeping Viksit Bharat @ 2047 in mind, wireless applications immediately take the front seat. Without any doubt, the microstrip patch antenna is the most suitable and innovative antenna technology used in wireless communication. Howell created the first microstrip patch antenna in 1970 [1]. A microstrip patch antenna consists of a planar resonant radiating patch on one side of a dielectric substrate and a ground plane on the other side [2, 3]. The radiating patch, together with the feed lines, is easily photoetched on a thin dielectric sheet on the ground plane. High demand for microstrip patch antennas is because of the rising need for personal and mobile communications, as well as the necessity for smaller and less expensive antennas. Microstrip patch antennas provide numerous advantages. They are easy to fabricate and utilize printed circuit technology. They are very light in weight, small in size and volume, can be made conformal and have shape flexibility: patches of any shape-square, rectangular, circular, semicircular, triangular, elliptical, annular ring, etc., can be used as radiators. Microstrip patch antennas are characterized through radiation/power patterns, gain, return loss, bandwidth, efficiency, and polarization. Rectangular patch antennas are the most common microstrip patch antennas. One of the core limitations that microstrip antennas have is their bandwidth, which can be increased by increasing the thickness of the substrate, but this reduces their efficiency because of higher power loss. This problem can be resolved by reducing the length of the patch; however, in doing so, impedance bandwidth is reduced and hence the radiation efficiency [4].

The designers have used various strategies, such as the use of high permittivity substrates to increase the impedance bandwidth of antennas. Ultra-wideband antennas are being designed by creating different slots in the ground plane. By including the capacitor/inductor, the microstrip patch antennas with higher gain are being achieved. Lens covering is being used as an alternative method for boosting the gain of these miniature antennas. Radiation from radiating elements is focused by lenses like elliptical, hemi-elliptical, and extended hemispherical lenses.

Partial substrate removal (micromachined patch antennas) [5] on a multi-layer dielectric substrate can also increase gain. The development of the microstrip patch antenna requires the employment of a more comprehensive and suitable methodology. The microstrip patch antenna's intended use and band designations are to be taken into account carefully.

2. 5G AND 6G WIRELESS COMMUNICATION:

It has become extremely important to include the study of 5G and 6G in the classroom curriculum, keeping 2047 Viksit Bhara in mind. It is essential because 5G establishes the foundation for ultra-low latency, massive connectivity, and high-speed data. 5G lays the foundation for 6G, which is expected around 2030 and shall merge physical, digital, and virtual worlds through AI-native systems, enabling autonomous systems, and 100x faster speeds [6-8]. We do not have a choice, and it's time to understand this evolution. Knowledge of 6G is necessary to anticipate technologies like holograms and intelligent networking.

As the world stands on the threshold of a new era in wireless communication, Viksat Bharat has to become one of the members in the global player list to lead the development of 5G technology and its successor, 6G technology and set the stage for the future of mobile communication. 6G technology is expected to revolutionize the concept of connectivity. It is expected to integrate various aspects of our daily life, giving us smart homes, autonomous vehicles, and, in true séance, the smart cities. Ultra-low latency, higher data rates, and the ability to connect billions of devices are expected to be achieved by these next-generation networks, thereby facilitating digital transformation in several vertical industries. 6G technology shall not only supersede 5G technology, but it shall also integrate and further improve the features of 4G LTE and other previous generation networks

To achieve our goals of Viksit Bharat, we have to actively work towards creating a roadmap for the deployment of 6G technology. We have to get involved in the development of a white paper that outlines the technical requirements and potential use cases for 6G technology.

Advanced wireless technologies, which include edge computing, artificial intelligence, and network slicing, are expected to be utilized in 6G technology. Edge computing will allow data processing to be done closer to the data source and, hence, will reduce latency. The complexity of 6G networks will be managed with the use of artificial intelligence, enabling automated network management and predictive maintenance.

Network slicing, which is a key feature of 5G technology, will also be enhanced in 6G networks, providing customized network services to meet the diverse needs of users and applications. The integration of these technologies in 6G networks is expected to bring significant improvements in the quality, performance, and efficiency of wireless networks.

3. ADVANCED MATERIALS FOR MICROSTRIP ANTENNAS

The limitations of traditional, low-frequency microstrip antenna designs at the high-frequency terahertz (THz) range (0.1–10 THz), critical for 6G, can be overcome by using advanced materials such as metamaterials, graphene, and specialized polymers. These materials improve 6G antenna performance by enhancing the gain, expanding its bandwidth, enabling beam steering for MIMO systems, and significant miniaturization of antenna to fit into compact, next-generation devices. The use of metamaterial structures like a split-ring resonator for a ground plane or patch enables the creation of high-impedance surfaces. Hence, surface wave propagation is reduced, and forward radiation is increased, leading to a much higher antenna gain up to 14.8 dBi. Radiation efficiencies often exceeding 90% in the THz band can be achieved by the use of Graphene-based patches and advanced substrates (like polyimide) that exhibit high conductivity and low dielectric loss.

High data rates critical for 6G can be achieved by the use of advanced materials, such as specific polymers (PMMA) or metamaterial-based resonant structures (slots), which enable the microstrip antennas to operate with an ultra-wide bandwidth (ranging from 1 THz up to 30 THz).In addition, metamaterials also allow for multiple resonances, allowing a single, small antenna to cover different frequency bands simultaneously. Silicon has high dielectric constants; when used as a substrate, it allows for drastic reductions in the physical dimensions of antennas while maintaining resonance at high frequencies.

Metamaterial-loaded antennas are expected to reduce physical size by up to 70–82% compared to conventional patch antennas. Graphene is a potent candidate in terms of tunable materials, in which the conductivity can be dynamically altered by changing its chemical potential (using voltage), allowing the antenna to change its operating frequency, radiation pattern, or polarization in real-time to adapt to 6G network demands [9]. Metamaterial-loaded antennas can be used for beam steering. These metamaterial microstrip antennas can produce main beam deflection up to 28° or even more, enabling beamforming without requiring massive, complex physical arrays.

Advanced materials like silicon decoupling walls or CSRR-based Metasurfaces are inserted between antenna elements to support massive MIMO in 6G. Thus, signal interference is prevented by achieving high isolation (>30 dB). These advancements are sure to ensure that microstrip antennas will effectively handle the high-data-rate, low-latency, and high-frequency requirements of 6G networks

4. AI LEARNING

Various antenna parameters like patch dimensions, resonant frequency, and hence, the gain, directivity, bandwidth, radiation/power patterns, return loss/VSWR, etc., are very accurately optimized using digital simulation tools combined with AI/Machine learning. These tools specifically include Neural Networks, Genetic Algorithms, and Particle Swarm Optimization. The use of AI and machine learning is transforming antenna design by automating the optimization of parameters of microstrip antennas. These methods ensure the accuracy and efficiency while drastically reducing design time, cost, and manual labour. Neural Networks (NN) work on the principle of training on datasets, often generated by HFSS or CST. NNs are primarily used for synthesis, i.e., finding physical dimensions for desired performance and analysis (predicting performance from dimensions) of patch antennas. The most common approach involves a 3-layer MLP network (input, hidden, output) trained using backpropagation to minimize error. NNs, specifically Multilayer Perceptrons (MLP) with back propagation, are capable of predicting antenna dimensions (length, width) from desired resonant frequencies, and vice versa, in seconds rather than hours [10, 11]. Training data is typically generated using numerical methods like the Method of Moments (MoM) or HFSS, with 50-5000+ samples used for training and testing. Neural Networks are optimized to achieve very high accuracy in predicting the resonant frequency and hence the bandwidth, and return loss. To handle high-frequency complexities as required in 6G, researchers use "knowledge-based" or regularized Neural Networks, which incorporate physical insights (e.g., spectral or derivative regularization) to enhance accuracy and reduce necessary training data. NN-based models allow for rapid, iterative optimization of microstrip antenna geometry to meet the required specific performance, often providing a ~99% accuracy level compared to traditional simulations. NNs in general use Python (scikit-learn), Ansys HFSS, CST Microwave Studio, and MATLAB as software.

In microstrip antennas, the key applications include optimization of the patch, optimization of substrate thickness, and dielectric constant for specific bandwidth and return loss requirements for their application in 5G/6G. Genetic algorithms and Particle Swarm Optimization (PSO) efficiently explore large, multi-dimensional design spaces to find optimized configurations. Deep Reinforcement Learning (DRL) adjusts microstrip antenna patterns dynamically for 5G and 6G, adapting to changing environmental conditions. Simulation Software Tools like Altair Hyper Study and FEKO use AI for design exploration, reducing the reliance on and time for manual iterative design for millimetre wave applications. Digital simulation tools and the use of AI in antenna designs (utilizes machine learning techniques) face some challenges as it requires large, high-quality datasets for training, high computational costs during initial stages, and potential compatibility issues with existing hardware. The benefit of faster design cycles, superior performance, and automated optimisation outweighs the above challenge [11-16].

5. NANO ANTENNAS AND COMPACT ANTENNAS FOR IOT

Nano-antennas and compact antenna designs are critical for IoT. So, it becomes important to first understand IoT. The Internet of Things (IoT is a network of physical objects (things). These objects/things are embedded with sensors/devices, software, user interfaces, and technologies that connect and exchange data with other devices through the internet (Wi-Fi, Bluetooth, cellular). Devices collect and share data, often enabling machine-to-machine (M2M) communication without human intervention. The use of IoT is expected to bring revolution in consumer smart home devices (Smart watches, smart thermostats, and connected appliances), industrial tools (Predictive maintenance, supply chain management, and enhanced safety), and smart cities (Infrastructure management for traffic and energy). IoT allows for automation, data collection, and analysis, with billion and billion devices using the upcoming 6G. IoT aims to enhance efficiency, improve decision-making, and automate tasks

Nano-antennas and compact antennas enable miniaturization, high-performance connectivity in devices such as wearables, sensors, and implants. Nano-micro strip antenna technologies include sub-wavelength patch, FPC (Flexible Printed Circuit), and UWB (Ultra-Wideband) antennas, with designs often utilizing evolutionary algorithms (e.g., GA-MAD) to optimize size and efficiency. The recent trends are MIMO for 5G, multi-band, and reconfigurable designs. MIMO Technology utilizing multiple antennas to increase data capacity and reliability in small devices. Nanoscale antennas are usually optical or terahertz and enable unprecedented miniaturization, ideal for biomedical implants, smart sensors, and advanced imaging. These antennas are very precise and have localized control of electromagnetic fields. They improve performance in complex environments and at higher frequencies, such as terahertz, where physically small dimensions become more difficult to manage.

These Nano-antennas are designed and fabricated using techniques like Genetic Algorithms for Miniaturizing Antenna Dimensions (GA-MAD). While designing these antennas, the engineer has to keep the bandwidth and efficiency into consideration while maintaining performance in a limited space via optimized design framework. To increase the efficiency of these small antennas, dielectric materials with high dielectric constants are usually used. For bandwidth improvement, slots or fractal shapes are often used. While designing, it is extremely important to keep the frequency band in mind that supports multi-band or reconfigurable (e.g., 2.4 GHz for Bluetooth, 5G frequencies) functionality.

The most common microstrip antennas used in GPS and IoT are the patch antennas due to their low profile and ability to be integrated directly onto PCBs. Another type of antenna is the Flexible Printed Circuit (FPC) microstrip antenna. These are lightweight and can fit inside curved, small IoT device enclosures by using adhesive mounting. Compact microstrip antennas also include Ultra Wide Band (UWB) Monopole antennas. These are wide-bandwidth antennas (e.g., 15 mm × 17 mm) that support high-speed data for IoT applications. After correctly designing these Nano/compact antennas, integration is done. The antennas are integrated directly into the chip package (Antenna-in-Package, AiP) for further reduction of size.

6. NANO ANTENNAS AND COMPACT ANTENNAS FOR CUBESAT

Nano antennas and compact antenna technologies are very crucial for CubeSat (nanosatellite) missions, where volume (typically 1U-16U) limitations and weight constraints restrict the use of large, traditional antennas. To overcome the risks of mechanical deployment failures, modern CubeSat designs emphasize on small size, low-profile, low cost, high-gain, and integrated microstrip antennas with operational frequencies in the range of S-band and X-band [20, 21].

CubeSats are miniature low-cost satellites used as models, typically measuring 10x10x10 cm (1U) and weighing approximately 1.333 kg/Unit. Their size can vary as 1.5, 2, 3, 6, 12 and 16 U. These are used as models and are developed for education and space research purposes. They often use standardized, commercial off-the-shelf (COTS) components. CubeSats are launched as secondary payloads in clusters, thus significantly reducing launch costs. These are basically used for various missions such as scientific research, demonstrations of technology, and the observation of planet Earth. They often operate in constellations for higher performance. They operate in Low Earth Orbit (LEO) and sometimes may operate in higher orbits too, and have a lifespan of 2-5 years before re-entering the atmosphere. They are deployed from dispensers on rockets. Because they are relatively inexpensive, hence, allows the universities, schools, and smaller organizations to participate in space exploration

For the usage in deep-space CubeSat missions has to very strictly abide by weight and volume constraints, and at the same time, the antennas on these CubeSats should have high gain, efficiency and bandwidth. Keeping this in mind, the microstrip antennas used in CubeSats are slot antennas, cavity-backed antennas, foldable dipole and monopole antennas, 3D printed or ceramic antennas

7. FLEXIBLE AND WEARABLE ANTENNAS

With the change of lifestyle, it has become important to study and develop flexible and wearable antennas. These antennas are developed for smart clothing and medical on-body communication. These antennas are lightweight and flexible, to be the right choice for our clothes. Smart clothing and medical on-body communication usually use polymer textiles and conductive materials. While designing these wearable antennas for wireless communication for on-body sensors and health monitoring, it becomes extremely important that these antennas are lightweight and capable of operating close to human bodies with minimum performance degradation [17-19].

Flexible and wearable antennas are compact, lightweight, and conformal devices designed to operate on curved surfaces, using flexible substrates like polydimethylsiloxane PDMS) and silicone rubber, which provides the required flexibility and strength. Commonly used textiles are cotton, denim or polyester. Antennas on this fabric are conformal in nature. These antennas can be fabricated on the textile by screen printing or by inkjet printing. They can also be installed on the fabric with the help of embroidery using conductive thread/copper foil. It is important to note that they must be able to withstand daily wear, including bending, washing, and ironing.

Key applications include medical and health care monitoring, detection of disease well in advance, and detection of tumours with the help of these body-centric wireless body area networks (WBAN)/antennas. Flexible antennas are used in smart clothing so that they can be easily worn on the human body. These IoT flexible antennas commonly operate in 2.45 GHz and 5.8 GHz bands.

8. CONCLUSION

The advent of 5G/6G technologies presents a plethora of opportunities and challenges in the field of wireless communication. As we stand on the precipice of a new era in wireless communication, the importance of AI learning in classrooms for communication systems cannot be overlooked. We have to boost the teachings in advanced technologies like AI and machine learning, which will play a crucial role in building Viksit Bharat @2047, addressing many challenges and realizing the full potential of the next generation.

Collaborative testing allows for a more comprehensive and accurate evaluation of 5G/6G networks, addressing key challenges related to interoperability, performance, and security. By bringing together diverse entities with diverse expertise and perspectives, it allows for a more holistic understanding of the network's performance and behaviour. Moreover, the usage of AI and machine learning in co-operative testing permits more predictive analysis and accurate testing, enabling proactive measures to be taken to prevent potential issues. The theoretical microstrip antenna concept in our classrooms has to be brought in line with the industrially relevant applications. A shift is required from theoretical antenna and communication to 'work-ready' skills through project-based learning and more emphasis on learning through internships. The incorporation of AI studies in our basic education system is a big step towards Viksit Bharat @ 2047

9. REFERENCE

- Howell, J. Q. (1975). Microstrip antennas. *IEEE Transactions on Antennas and Propagation*, *23*, 90–93.
- Kumar, G., & Ray, K. P. (2003). *Broadband microstrip antennas* (2nd ed.). Artech House.

- Carver, K. R., & Mink, J. W. (1981). Microstrip antenna theory. *IEEE Transactions on Antennas and Propagation, 29*, 2–25.
- Bahl, I. J., & Bhartia, P. (1980). *Microstrip antennas*. Artech House.
- Yook, J. G., & Katehi, L. P. B. (2001). Micromachined microstrip patch antennas with controlled mutual coupling and surface waves. *IEEE Transactions on Antennas and Propagation, 49*(9), 1282–1289. https://doi.org/10.1109/8.951350
- *ICT Express*. (2024). Edge computing in future wireless networks: A comprehensive evaluation and vision for 6G and beyond. *ICT Express, 10*(5), 1151–1173. https://doi.org/10.1016/j.icte.2024.08.007
- Scindia, J. (2025, July 12). India is aiming to contribute 10% of the global 6G patents. *The Times of India*.
- Scindia, J., & Budhiraja, R. (2025, July 12). *India aiming to contribute 10% of global 6G patents* [Press release]. The Times of India.
- Abdul Kareem, Z. J., Hamad, T. K., & Elwi, T. A. (2025). Reconfigurable metasurface based on graphene ribbons for beam focusing applications. *Journal of Theoretical and Applied Physics, 19*.
- Author, A. (2025). AI empowered 6G technologies and network layers: Recent trends, opportunities, and challenges. *Expert Systems with Applications, 267*, Article 125985. https://doi.org/10.1016/j.eswa.2024.125985
- Cui, Q., et al. (2025). Overview of AI and communication for 6G network: Fundamentals, challenges, and future research opportunities. *Science China Information Sciences*. https://doi.org/10.1007/s11432-024-4337-1
- Gomathi, T., Panigrahi, S., Rajendran, N. K., Savita, & Jadhav, Y. (2025). Edge AI for ultra-reliable low-latency communication (URLLC) in 6G networks. *National Journal of Antennas and Propagation, 7*(1), 54–61. https://doi.org/10.31838/NJAP/07.01.09
- Matin, M. A., Goudos, S. K., Wan, S., et al. (2023). Artificial intelligence (AI) and machine learning (ML) for beyond 5G/6G communications. *EURASIP Journal on Wireless Communications and Networking, 2023*, Article 22. https://doi.org/10.1186/s13638-023-02212-z
- NVIDIA introduces an AI-powered 6G research platform. (2024, March 18). *Reuters*.
- NVIDIA seeks to advance 6G wireless through AI. (2024, March 18). *Barron's*.
- Wen, T., Jianglei, M., Peiying, Z., & Yan, C. (2024, December). 6G and AI: Bridging the physical and digital worlds through connected intelligence. *RS-OJICT*. https://doi.org/10.46470/03d8ffbd.b810ef97
- Al-Haddad, M. A. S. M., Jamel, N., & Nordin, A. N. (2021). Flexible antenna: A review of design, materials, fabrication, and applications. *Journal of Physics: Conference Series, 1878*(1), Article 012068. https://doi.org/10.1088/1742-6596/1878/1/012068
- Zhang, K., Soh, P. J., & Yan, S. (2020). Meta-wearable antennas—A review of metamaterial-based antennas in wireless body area networks. *Materials, 14*(1), 149. https://doi.org/10.3390/ma14010149
- Chen, Y.-S., & Ku, T.-Y. (2016). A low-profile wearable antenna using a miniature high impedance surface for smartwatch applications. *IEEE Antennas and Wireless Propagation Letters, 15*, 1144–1147. https://doi.org/10.1109/LAWP.2015.2495272
- Mishra, B., Verma, R. K., Yashwanth, N., & Singh, R. K. (2021). A review on microstrip patch antenna parameters of different geometries and bandwidth enhancement techniques. *International Journal of Microwave and Wireless Technologies, 14*, 652–673. https://doi.org/10.1017/S1759078721000670
- Przesmycki, R., Bugaj, M., & Nowosielski, L. (2020). Broadband microstrip antenna for 5G wireless systems operating at 28 GHz. *Electronics, 10*, 1. https://doi.org/10.3390/electronics1001000