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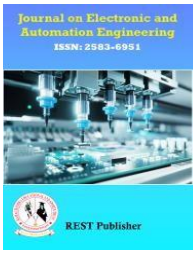

Design of Microstrip Patch Antenna Using Meta-Surface for Bandwidth Enhancement

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Abstract: *Microstrip patch antenna (MSA) operates in the microwave frequency range (13GHz-19GHz) and is commonly used in wireless communication systems. Known for their small size, low profile, directivity, and cost-effectiveness, MSAs are often referred to as "printed antennas". Miniaturization of MSAs plays a key role in improving their performance while maintaining their functionality. Techniques for miniaturization include material loading, reshaping, shrinking, and folding, as well as introducing slots and defects in the ground plane. Key design parameters include patch dimensions, ground plane, substrate, feeding method, and antenna performance characteristics such as bandwidth and aspect ratio. Bandwidth refers to the range of frequencies over which an antenna meets specific requirements such as gain and radiation pattern. The axial ratio, especially for circularly polarized (CP) antennas, typically has a smaller -3dB bandwidth compared to linearly polarized (LP) MSAs. Techniques such as adjusting the substrate, using multiple resonators, adding slots, and introducing parasitic couplings are used to improve the impedance bandwidth and axial ratio bandwidth (ABW). Recent studies have highlighted the growing demand for met surfaces due to their strong performance in improving antenna properties. When planar materials designed to control electromagnetic wave propagation, meta-surfaces offer improved impedance bandwidth, efficiency, gain, and ABW. In this project, meta-surface technology will be implemented to achieve improved antenna performance.*

Keywords: *Microstrip, Axial Bandwidth, Bandwidth Enhancement, Meta-surface.*

1. INTRODUCTION

A microstrip patch antenna is a type of antenna that operates in the microwave frequency range. They can be printed directly onto circuit boards and are low-profile. They consist of a radiating patch, usually made of conductive material, mounted on a dielectric substrate. A micro strip antenna is a type of antenna that consists of a thin conducting patch placed on top of a dielectric substrate, with a ground plane on the other side. It is one of the most widely used antenna types due to its low profile, light weight, and ease of integration into various devices. The antenna's patch is typically rectangular or circular in shape, but other geometries can be used depending on the design requirements. Micro strip antennas are particularly favoured in modern communication systems, such as mobile phones, GPS devices, satellite systems, and Wi- Fi networks, due to their compactness and low cost of production. The design simplicity of micro strip antennas is a key advantage, as they can be fabricated using standard printed circuit board (PCB) technology, which makes them both cost-effective and suitable for mass production. Additionally, their ability to be integrated directly into the surface of devices allows for space-saving solutions in systems where size is a constraint. However, micro strip antennas also have some limitations, such as narrow bandwidth, low efficiency, and lower gain compared to other antenna types. Despite these drawbacks, ongoing advancements in materials and design techniques, such as the use of Meta-surfaces, have significantly enhanced their performance, making micro strip antennas a preferred choice in many wireless and communication applications.

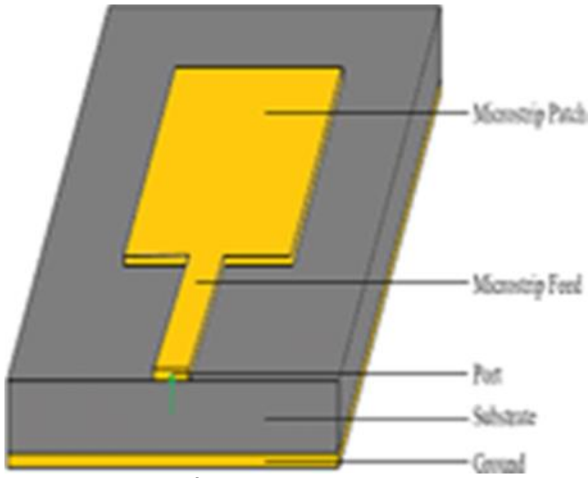

FIGURE 1. Diagram of a Micro strip Patch Antenna

In telecommunication, a microstrip antenna (also known as a printed antenna) usually is an antenna fabricated using photolithographic techniques on a printed circuit board (PCB). It is a kind of internal antenna. They are mostly used at microwave frequencies. An individual microstrip antenna consists of a patch of metal foil of various shapes (a patch antenna) on the surface of a PCB, with a metal foil ground plane on the other side of the board. Most microstrip antennas consist of multiple patches in a two-dimensional array. The antenna is usually connected to the transmitter or receiver through foil microstrip transmission lines. The radio frequency current is applied (or in receiving antennas the received signal is produced) between the antenna and ground plane. Microstrip antennas have become very popular in recent decades due to their thin planar profile which can be incorporated into the surfaces of consumer products, aircraft and missiles; their ease of fabrication using printed circuit techniques; the ease of integrating the antenna on the same board with the rest of the circuit, and the possibility of adding active devices such as microwave integrated circuits to the antenna itself to make active antennas Patch antenna. Based on its origin, microstrip consists of two words, namely micro (very thin/small) and is defined as a type of antenna that has a blade/piece shape and is very thin/small. Enhanced bandwidth refers to the increase in the range of frequencies over which a device, such as an antenna, can effectively operate. In simple terms, it means the ability of a system to handle a wider spectrum of frequencies while maintaining good performance, such as low signal loss, high efficiency, and consistent radiation patterns. To achieve enhanced bandwidth in antennas, several effective techniques can be employed. One of the most common methods is slotting the patch, which involves adding slots into the patch to create multiple resonant modes, thereby widening the frequency range. Increasing the substrate thickness also helps by lowering the antenna’s quality factor, thus expanding the bandwidth, although care must be taken to balance efficiency. Multilayer or dual-frequency designs are another technique, allowing the antenna to operate at multiple frequencies simultaneously, and further broadening its bandwidth. Incorporating parasitic elements like directors or reflectors can also improve bandwidth by shaping the radiation pattern and minimizing losses. Aperture coupling is another useful method, enhancing impedance matching and increasing bandwidth. Using low-dielectric constant materials can improve bandwidth by reducing the antenna’s resonant frequency, leading to wider operational ranges. Additionally, larger ground planes can help reduce impedance mismatches, further enhancing the bandwidth. Lastly, fractal geometries have been shown to provide increased bandwidth by utilizing self-similar patterns that optimize the antenna’s performance over a wider range of frequencies. These techniques, when carefully implemented, can significantly improve the bandwidth of antennas, making them more versatile for modern communication applications. Nowadays, microstrip antennas are widely used for military and civilian applications such as broadcast radio, television, mobile systems, radio-frequency identification (RFID) system, vehicle guidance system, a global positioning system (GPS), vehicle collision avoidance system, multiple-input multiple-output (MIMO) systems, radar systems, determination of direction, surveillance systems, biological imaging, and missile systems.

Literature Survey: Meta-surface is a simpler two-dimensional version of meta-material. It may alter the amplitude and phase of the light source at any point on the wave plate by adjusting the resonance strength and the abrupt phase induced by resonance, to regulate the propagation, polarization, and form of the light beam. A meta-surface antenna is a type of antenna that uses a two- dimensional array of engineered structures to manipulate electromagnetic waves. These structures, called meta-surface, are made up of unit cells that are designed to interact with waves in specific ways [1]. The meta-surface substrate is a highly effective method for enhancing antenna performance in terms of gain (2 db to 10 db gain improvement depending on metasurface structure and antenna type), and bandwidth (20-50% bandwidth enhancement, depending on metasurface design and frequency range). This makes it an ideal solution for modern communication systems requiring compact, high-performance antennas [2].

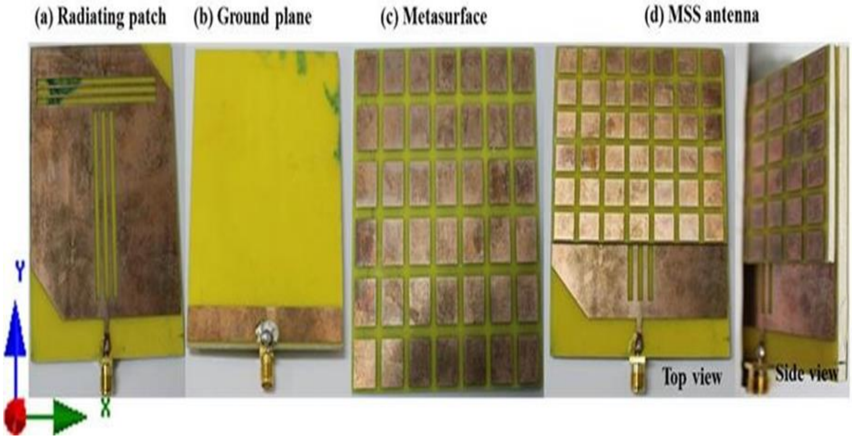

FIGURE 2. Photograph of fabricated prototype of (a) radiating patch; (b) ground plane; (c) met surface; and (d) meta-surface substrate loaded antenna.

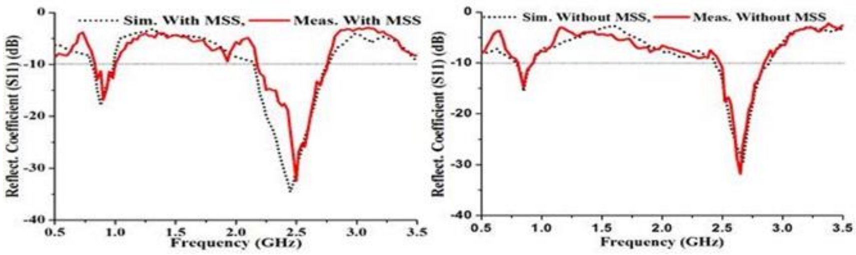

FIGURE 3. Simulated and measured reflection coefficient of the proposed antenna.

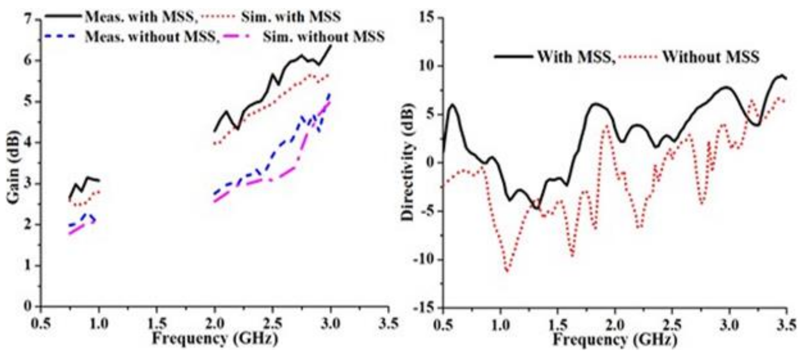

FIGURE 4. Gain and directivity of the proposed antenna with MSS and without MSS.

A miniaturized microstrip patch antenna loaded on a ring shape meta-material is proposed. This antenna is designed to work at Wi-Fi band of 5.725-5.825 GHz. Miniaturization of 68% with good radiation efficiency of 72% is achieved. Which consists of a 4-cell ring shape meta-material under patch, is presented. The presented patch antenna design resulted in a miniaturization percentage of 68%, 72% radiation efficiency and 5.8% bandwidth, which is the result of meta-material loading in the substrate of the antenna [3]. A low-profile, high-gain, and wideband meta-surface (MS)-based filtering antenna with high selectivity is [2] investigated in this communication. The planar MS consists of non-uniform metallic patch cells, and it is fed by two separated microstrip-coupled slots from the bottom. The prototype with dimensions of 1.3 λ0 × 1.3 λ0 × 0.06 λ0 has a 10-dB impedance bandwidth of 28.4%, an average gain of 8.2 dBi within passband, and an out-of-band suppression level of more than 20 dB within a very wide stop band [4].

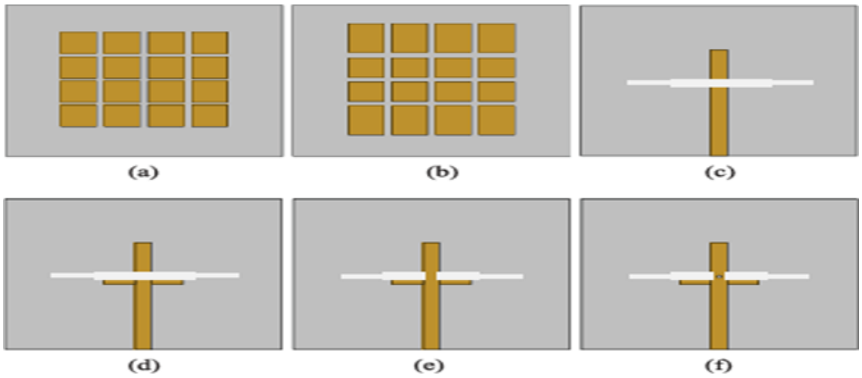

FIGURE 5. Antenna configurations. (a) Reference Antenna I: uniform MS fed with a straight- microstrip coupled slot. (b) Reference Antenna II: nonuniform MS fed with a straight- microstrip coupled slot. (c) Feeding circuit for reference Antennas I and II. (d) Reference

This work explores the design, development, and performance enhancement of miniaturized metasurface antennas aimed at achieving wideband operation with reduced physical size [5]. Surface impedance can be varied and manipulated by patterning the metasurface unit cells, which has broad applications in surface wave absorbers and surface waveguides. They also enable beam shaping in both transmission and reflection. Meta-surfaces are also investigated in optical and micro wave frequencies for imaging applications [6]. The wide band low-profile CP slot antenna is achieved with numerical optimizations and parameter studies. Both simulations and measurements are performed to demonstrate the proposed antenna, and good agreements are obtained. Such results will open the path for polarization conversion meta-surfaces used in the CP antenna area. The proposed antenna exhibits a measured impedance matching bandwidth of 32% and an AR bandwidth of 20% centered at 5.6 GHz [7]. The antenna is an octagon with a side length of 32.3 mm and a height of 5.6 mm. The metasurface consists of two stacking layers, and both layers contain a 4×4 copper patch array. The antenna is excited by an aperture coupled structure made of an anomalous microstrip line and a narrow slot etched in the ground plane [8].

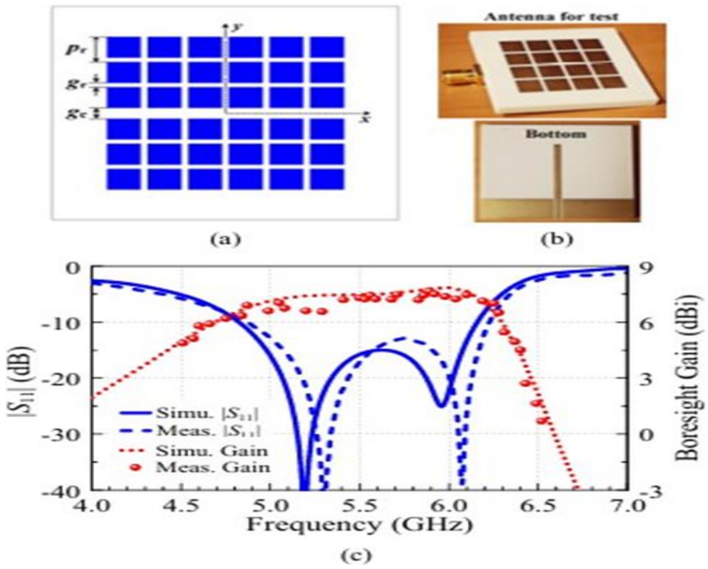

FIGURE 6. Dual-layer meta-surface antenna: (a) variation of the lower layer of the meta-surface, (b) Photos of the antenna prototype, (c) simulated and measured |S11| and realized foresight gain.

A multi-beam modulated meta-surface antenna for 5G backhaul applications at K- band (18-27 GHz). Integration of such antennas can significantly improve 5G backhaul performance, ensuring reliable, high-speed connectivity in urban and dense environments [9]. The resonant meta-surface antenna with resonant apertures demonstrates significant improvements in bandwidth, polarization control, and compactness, making it a promising solution for dual-polarized, broadband applications. The integration of characteristic mode analysis provides valuable insights for optimizing antenna performance while maintaining a low-profile design [10]. A meta-surface based circularly polarized patch antenna presented in this study exhibits substantial improvements in bandwidth (Wideband design, 10% - 30% of the centre frequency), gain (High gain, typically 8-12 dB or higher), and polarization characteristics compared to normal patch antenna's. The integration of meta-surface layer enables precise control over the electromagnetic wave propagation, leading to wider operational bandwidth and higher directivity [11].

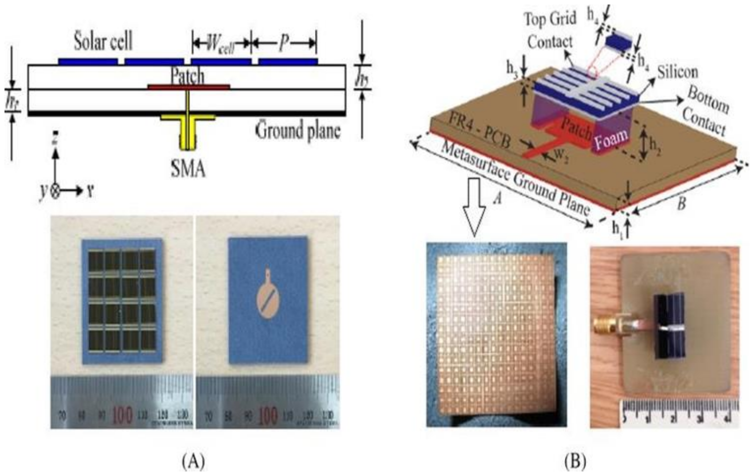

FIGURE 7. Meta surface integrated MSA

The impact on parameters like radiation patterns and polarization control: By leveraging these advanced materials, significant improvements in antenna performance are achievable, benefiting a range of applications, from communication to sensing technologies [12]. The proposed antenna demonstrates efficient circular polarization at both bands, making it suitable for applications such as satellite communication and wireless systems [12]. This suggests an advanced antenna design that combines a Low-profile Wideband, and circularly polarized met surface structure. By applying characteristic mode analysis, this design can optimize the antenna's resonant mode and supress those that could negatively Impact its performance, such as those that may cause polarization distortion or reduce bandwidth [13].

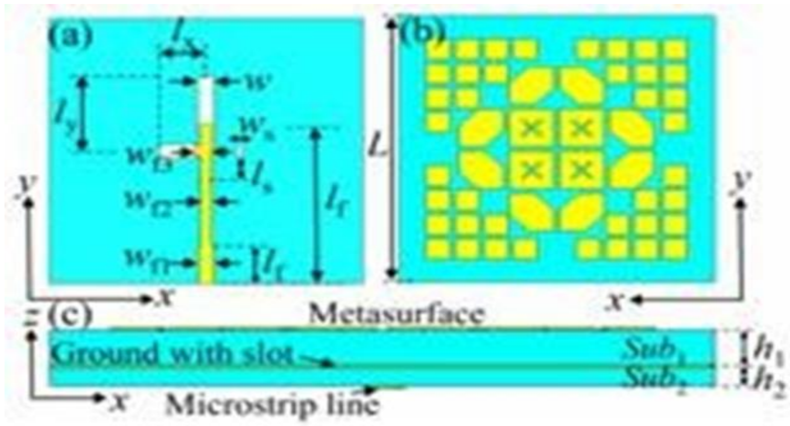

FIGURE 8. Configuration of the MS antenna. (a) Back view of microstrip line and L-shaped slot. (b) Top view of the proposed MS with suppression. (c) Side view.

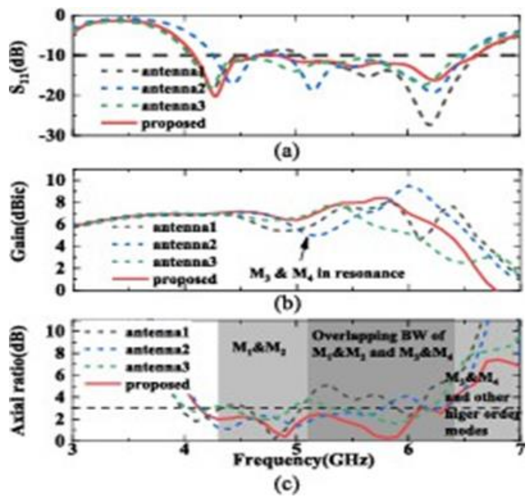

FIGURE 9. Comparison of (a) reflection coefficients (S11), (b) gain, and (c) AR of the antennas with different MS arrays.

The met surface is composed of no uniform truncated corner square patches arranged in two different arrangements. The central part of the met surface is a 2 × 2 array, while the outer part is surrounded by an additional 16unit cells. The antenna is analysed using characteristic mode analysis, revealing that it can expand its impedance and axial ratio bandwidth by exciting three modes [14]. Simulations demonstrate high polarization control and efficient wave manipulation, making it suitable for dual-band communication, radar, and sensing applications. The simple, cost-effective structure offers significant potential for next- generation met surface technologies [15].

2. PROJECT OVERVIEW

Flowchart

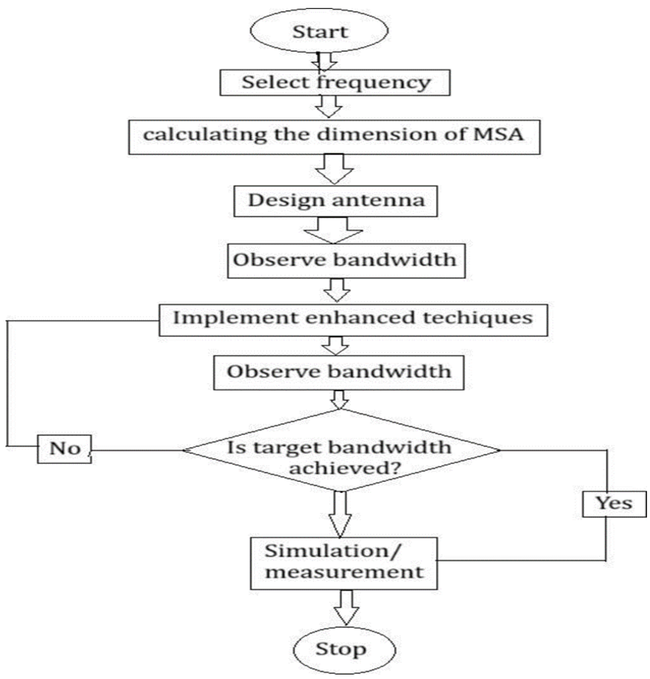

FIGURE 10. Flowchart

The work of this project focuses on designing a microstrip patch antenna (MSA) using meta-surfaces to improve bandwidth for modern wireless applications. The process begins by selecting the desired operating frequency based on application requirements such as 5G, satellite or IoT communication. Using this frequency, the dimensions of the patch are calculated using standard antenna design formulas, taking into account factors such as substrate type and dielectric constant. Once the initial MSA is designed with a patch, ground plane and feed mechanism, it is evaluated using parameters such as S11 (reflection coefficient) to determine its bandwidth performance. If the initial bandwidth of the antenna is low, meta-surface structures are introduced to improve it. Meta-surfaces, which are composed of engineered sub-wavelength elements, modify the electromagnetic wave propagation, reduce surface wave losses and improve impedance matching. Their geometry and structure are optimized to improve radiation properties and increase bandwidth. The performance of the antenna with the meta-surface is reanalyzed, and the improvements in bandwidth are compared with the initial design. If the target bandwidth is not met, iterative adjustments are made. Once the desired performance is achieved, full-wave simulations are performed using software such as HFSS or CST and practical measurements are carried out with a VNA. After validation, the final MSA design is complete and ready for real-world use.

3. SOFTWARE DESCRIPTION

Software Used

In the design and simulation of microstrip patch antennas using meta-surfaces for bandwidth enhancement, two major electromagnetic simulation software tools are commonly used—CST Studio Suite and HFSS (High-Frequency Structure Simulator). Both are powerful and widely adopted in academia and industry for designing high-frequency structures such as antennas, waveguides, and filters.

CST: Computer Simulation Technology

CST Studio Suite is the flagship product of Dassault Systèmes and a leading electromagnetic simulation software. It is particularly useful for designing and analyzing 3D electromagnetic devices and systems. CST offers a variety of solutions, including time-domain and frequency-domain solutions that can handle high-frequency, low-frequency, static, and thermal simulations. CST is widely used in industries such as telecommunications, aerospace, medical devices, and consumer electronics. CST's intuitive interface and powerful modeling tools allow users to simulate complex geometries with relative ease. The software supports the simulation of S-parameters, electric and magnetic fields, radiation patterns, and more. It is often preferred for fast, full-wave simulations and supports both planar and non-planar structures. CST is also known for its efficient mesh generation, which enables accurate results with optimized computational resources.

HFSS: High-Frequency Structure Simulator

Developed by Ansys, HFSS is a premier simulation tool that uses the finite element method (FEM) to solve electromagnetic field problems. It is widely used in the design and analysis of RF and microwave components. HFSS excels at modeling complex, high-frequency devices and provides excellent accuracy for simulations involving complex geometries and high-resolution results.
HFSS includes the following features:

- Accurate calculation of S-parameters and full-wave electromagnetic fields.
- Adaptive meshing with precision-driven solutions.
- Broadband velocity frequency sweep.
- Calculation of far-field radiation patterns.
- Parameterized 2D and 3D models.
- Advanced material support and extensive model libraries.
- Robust post-processing tools for visualizing electrical performance.

These features make HFSS well-suited for optimizing designs where accuracy is critical, such as in aerospace, telecommunications, and defense applications.
However, HFSS requires significant computing resources to produce fine-resolution results. A typical setup requires at least 8GB of RAM and a processor speed of at least 1.7GHz, although higher specifications are recommended for efficient simulation.

Comparison and Licensing Costs

While both CST and HFSS are robust tools for electromagnetic simulations, HFSS is often considered superior for complex high-frequency simulations due to its adaptive meshing, accurate FEM solver, and better handling of resonant structures. Additionally, HFSS integrates seamlessly with other Ansys tools, enabling a multidisciplinary simulation approach across mechanical, thermal, and electromagnetic domains. In terms of licensing and cost, both CST Studio Suite and HFSS are premium software tools. A single-user license for CST typically ranges from $10,000 to $30,000, depending on the modules and solver packages included. An HFSS license also falls in a similar range, costing approximately $20,000 to $40,000 for a standard package. Academic institutions often receive significant discounts, and subscription-based pricing is available for increased flexibility.

4. PROPOSED DESIGNS AND ANALYSIS

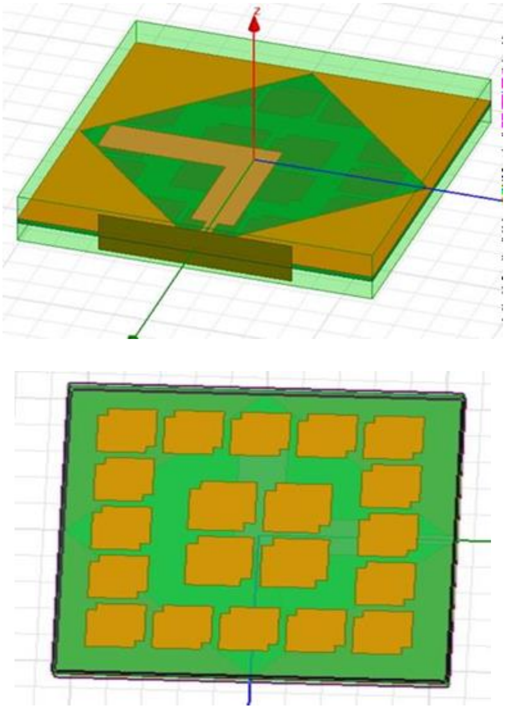

FIGURE 11. L shaped Margin wide band cp antenna.

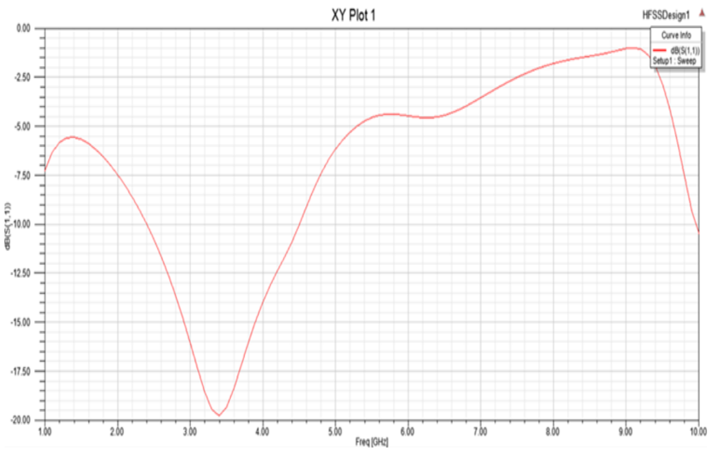

FIGURE 12. Simulated and measured results of S11 and efficiency

5. APPLICATIONS

Applications of Microstrip Patch Antennas

Microstrip patch antennas have become a foundational technology in modern wireless communication systems due to their compact design, cost-effectiveness, and ease of integration. Their low profile and compatibility with printed circuit board (PCB) manufacturing make them suitable for a variety of applications, from consumer electronics to advanced aerospace systems. With continued research into performance enhancements - particularly the use of meta-surfaces - these antennas are increasingly being used in high-performance situations requiring optimal gain, bandwidth, directivity, and polarization. Below are the main application areas of microstrip patch antennas:

1. Wireless Communication Systems

One of the most widespread applications of microstrip patch antennas is in wireless communication systems. Due to their small size and planar structure, these antennas are well suited for smartphones, tablets, laptops, routers, and Wi-Fi access points. They are capable of supporting multi-band and wideband operations, enabling seamless connectivity across various communication standards such as 3G, 4G, 5G, and Wi-Fi (2.4 GHz, 5 GHz, etc.).

Their adaptability in terms of frequency tuning and radiation pattern design makes microstrip antennas particularly valuable in crowded spectrum environments where interference and signal degradation are concerns. These antennas also support Multiple Input Multiple Output (MIMO) technology, a key component of 5G systems, which increases network capacity and data throughput.

2. Satellite Communication

Microstrip antennas are widely used in terrestrial and space-based satellite communication systems. Their lightweight and flat form factor make them ideal for integration into satellite payloads and ground stations where space and weight are very constrained. Depending on the application, they operate in satellite-specific bands such as L-band, S-band, C-band, X-band and Ku-band. Whether in satellite TV dishes, weather satellites or high-throughput communication satellites, microstrip antennas provide the performance required for reliable data transmission and reception. Furthermore, microstrip antennas are preferred in satellite-on-the-move systems used on ships, aircraft and military vehicles - due to their low aerodynamic profile and mechanical simplicity.

3. Radar systems

Radar applications benefit significantly from microstrip patch antennas, especially in grid-array configurations. Grid-array radar systems use multiple microstrip antenna elements to electronically steer the radar beam, improving target detection and tracking. In military applications, microstrip antennas are used in surveillance, missile guidance, and airborne radar due to their performance and structural advantages. Civilian radar systems, such as weather radar and air traffic control radar, also use these antennas for their ability to provide directional control and high-frequency operation in a compact package.

4. Global Navigation Satellite Systems (GNSS)

Microstrip antennas are commonly used in GNSS receivers such as GPS, GLONASS, Galileo, and BeiDou. These systems rely on accurate and continuous signal reception from multiple satellites. Microstrip antennas are particularly suitable due to their ability to operate in the L1, L2, and L5 bands and their compatibility with multi-star and multi-frequency GNSS systems. Applications include vehicle navigation systems, handheld GPS units, drones, and survey equipment. The low-profile design enables seamless integration into consumer electronics, automotive systems, and even wearable technology.

5. Wireless Body Area Networks (WBANs) and Medical Applications

In medical and healthcare applications, microstrip antennas play a key role in enabling wireless communication in WBANs. These systems monitor a patient’s vital signs in real-time using body-mounted or implantable sensors. Microstrip antennas are used in these sensors to transmit the collected data to external monitoring systems or mobile devices. The biocompatibility, low power consumption, and miniaturization capabilities of microstrip antennas make them ideal for wearable medical devices, smart bandages, pacemakers, and ingestible sensors.

6. CONCLUSION AND FUTURE SCOPE

We designed a microstrip patch antenna using Meta-surfaces for bandwidth enhancement proves to be an effective solution for addressing the bandwidth limitations typically faced by conventional microstrip antennas. The integration of Meta-surfaces, with their sub-wavelength structured elements, plays a significant role in controlling electromagnetic wave propagation, leading to a notable increase in operational bandwidth. This enhancement is achieved by reducing the antenna’s Q-factor, improving impedance matching, and minimizing surface wave losses, which results in better overall performance. Additionally, the Meta-surface contributes to improved radiation efficiency and pattern by managing surface wave propagation, thus leading to more desirable directional radiation. Moreover, the design allows for antenna miniaturization while preserving high performance, making it particularly suitable for applications in compact devices and modern communication systems, such as 5G, IoT, and satellite communications. The ability to fine-tune the Meta-surface elements further offers flexibility in optimizing the antenna for specific frequency responses. Overall, this approach provides a promising pathway toward the development of high-performance, wideband antennas capable of meeting the demands of next-generation wireless communication technologies.

Future Scope: The design of a microstrip patch antennas using Meta-surfaces for bandwidth enhancement presents a promising solution to address the inherent bandwidth limitations of conventional microstrip antennas. Meta-surfaces are engineered materials that consist of sub-wavelength elements designed to manipulate electromagnetic waves in ways that traditional materials cannot. By incorporating Meta-surfaces into the design of microstrip patch antennas, the effective impedance matching, radiation characteristics, and frequency response of the antenna can be significantly improved. The Meta-surface can be designed to increase the antenna's effective aperture and enhance the coupling between the antenna and the radiated waves, leading to broader bandwidth and better overall performance. This approach allows for the creation of microstrip patch antennas that can operate over wider frequency bands without the need for complex tuning or additional components. The scope of this design extends to various applications, including wireless communication, radar, and satellite systems, where higher bandwidth is essential to accommodate increasing data rates and more efficient signal processing. Additionally, Meta-surfaces provide flexibility in optimizing the antenna's size, gain, and directivity, which makes them suitable for compact and high-performance communication systems. The integration of Meta-surfaces with microstrip patch antennas opens the door to next- generation antenna designs, where bandwidth enhancement, miniaturization, and multi-functionality can be achieved simultaneously.

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