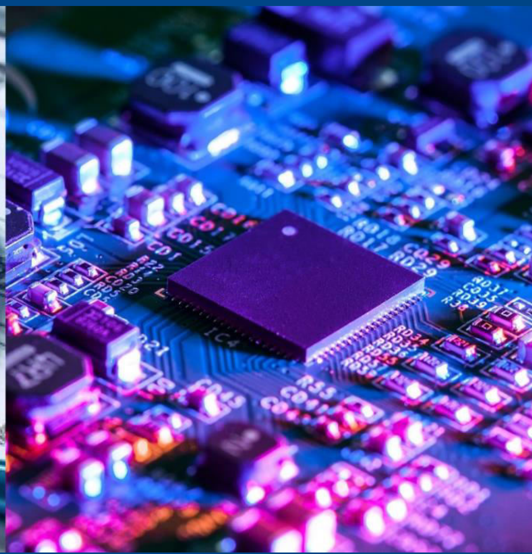
ISSN: 2582-7219





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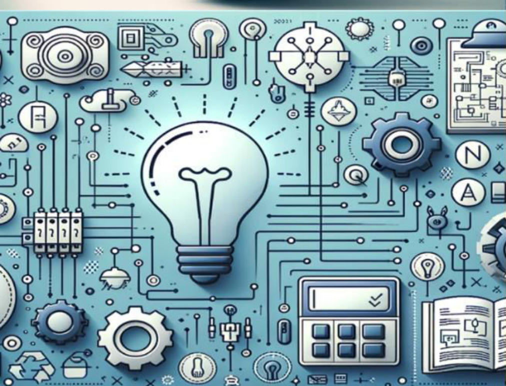

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Volume 8, Issue 5, May 2025

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International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

The Compact Triple-Fed Self-Triplexing Antennas using SIW

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ABSTRACT: A compact triple-fed high-isolation substrate integrated waveguide (SIW) based self-triplexing antennas. Unlike conventional designs that requires multiple antennas or external components for frequency divisions, this antenna integrates all necessary functionalities within a single compact structure. By utilizing a triple-fed SIW cavity, the antenna achieves good isolation greater than 20Db between the three frequency bands, ensuring minimal interference and optimal performance. Traditionally, complex diplexers or triplexers are employed to separate different frequency bands, leading to increased system complexity and size. This reduction in size and weight is particularly advantageous for portable and mobile devices where space is a premium. Beyond its compact size, this antenna exhibits remarkable performance characteristics such as radiation patterns, ensuring efficient signal transmission and reception. It is particularly well-suited for modern wireless communication systems. It can be integrated into 5G and beyond wireless devices to support high-speed data transfer and massive connectivity. Additionally, the antenna's compact form factor makes it ideal for wearable devices, Internet of Things (IoT) sensors, and other space-constrained applications. In conclusion, the miniaturized high-isolation triple-fed self-triplexing antennas using SIW demonstrates significant advancements in compact antenna design. The innovative use of SIW enables superior isolation between channels, making it ideal for multi-band and multifunctional communication system.

KEYWORDS: HFSS, SIW, High Isolation, Self triplexing.

I. INTRODUCTION

The rapid growth of wireless communications cannot wait for the emerging antennas that are small in size and multifunctional, or tuneable by frequency. Equipment in the area of smartphones, routers, and IoT nodes typically has to operate in multiple frequency bands with integrity of signal. Instead of external duplexers or filters usually found in traditional multi-band antennas, these device types have to rely on internal configurations.

The development of Substrate Integrated Waveguide (SIW) has opened new horizons in compact and high-performance microwave components. It has merits like low losses, high Q factor, and integration in planar circuits. Self-triplexing antennas that internally separate signals into distinct bands allow less complexity and reduce hardware.

In this paper, we present a new miniaturized SIW antennas structure with triple-feed and inherent triplexing behavior. Ingenious design of the SIW cavity and feeding configuration helped us realize a very high isolation between ports and strong resonance on three distinct frequencies.

II. LITERATURE SURVEY

Triplexing antennas, which are capable of functioning on three frequency bands, are gaining traction with the growing requirement for compact and multifunctional antenna designs for modern wireless systems. Due to yet another application for most such designs, Substrate Integrated Waveguide (SIW) technology would offer the possibility for crafting designs with low loss, compact size, and ease of integration. Most recent studies have been in the form of miniaturized SIW-based triplexing antennas with triple-fed structures, designed towards realizing high isolation between ports to improve performance and reduce mutual coupling. The introduction of various techniques such as defected ground structures, novel feeding networks, and compact layouts** have been published for isolation and efficiency improvements. The survey intends to review the significant advances in antenna design towards triplexing using the SIW approach with the obtained results for future trends and challenges that this proposed approach method addresses.

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1.The Tunable Dual-Fed Self-Diplexing Patch Antenna is a compact antenna designed for transmitting and receiving functions. It offers compact size, frequency tunability, and cost-effectiveness, making it suitable for modern communication systems. However, it faces challenges like increased complexity, potential signal interference, and limitations in certain frequency ranges or systems.

2. The **"An Integrated SIW Cavity-backed Slot Antenna Triplexer"** is a compact, integrated antenna system that uses a SIW cavity-backed design and resonance control techniques. It eliminates the need for an external diplexer, resulting in high port-to-port isolation and efficient radiation performance. However, it has limitations like limited frequency flexibility, high fabrication precision, and increased design complexity, which must be managed carefully during implementation.

3.The **"Compact Dual-Band Substrate Integrated Waveguide Crossover with High Isolation"** design is a slot-based structure designed for efficient signal routing in compact microwave systems. It offers compact size, high efficiency, and cost-effectiveness, making it suitable for dense communication circuit layouts and multi-band systems. However, it has limitations like limited operational bandwidth and requires complex fabrication techniques for precise slot alignment.

4.The study **"Dual-Feed Dual-Polarized Patch Antenna with Low Cross Polarization and High Isolation"** proposes a dual-feed antenna design to improve performance. It aims to achieve high isolation between two polarization states while minimizing cross polarization, crucial in modern wireless communication systems. The design's advantages include low cross polarization and a compact structure, making it suitable for space-constrained systems. However, it faces challenges like a complex feed network, limited bandwidth, and high fabrication precision.

Thus, the proposed “miniaturized triple-fed high-isolation self-triplexing antennas using SIW” presents an effective answer to such needs for compact multi-band communication systems allowing simultaneous operation in three frequency bands. By employing Substrate Integrated Waveguide (SIW) technology, this design achieves high isolation, compact size, and low insertion loss, addressing specific issues related to traditional triplexing antenna structures. The use of a triple-feed arrangement combined with optimized SIW geometry not only provides good frequency separation but also guarantees low mutual coupling levels among the ports. Therefore, the proposed antennas fits readily into the mounting requirements of **contemporary wireless platforms** for which multi-band functionality, space efficiency, and high-performance isolation are critical.

III. PROPOSED METHODOLOGY

A special thing about the design of a Substrate Integrated Waveguide (SIW) antenna is its flexibility that permits many configurations to be adapted to specific applications involving wireless communications, radar, or satellite systems. Basic SIW antennas consist of three main components: the substrate, metallic vias, and top and bottom conductive plates. The substrate is a dielectric material, commonly Rogers RT/Duroid 5870, that is selected according to its dielectric constant (εr) and thickness to define the propagation characteristics of waveguide operation while facilitating high-frequency operation, that is within 4GHz to 10 GHz. The dielectric layer under consideration forms the medium through which electromagnetic waves travel and critically assists in impedance matching and bandwidth control.

A metallic via is a vertically drilled and metallized hole in the substrate. This via arrangement is conducted on the side edges of the waveguide path. Close spacing of these vias—typically, less than one-tenth of the guided wavelength ($\lambda g/10$)—is provided to suppress unwanted radiation leakage and effectively act as the waveguide solid walls. Finally, the top and bottom plates, usually of copper cladding, form the upper and lower boundaries of the waveguide, encapsulating the dielectric and providing proper confinement of the guided electromagnetic energy. Together, the design forms a compact, low-loss, and planar waveguide structure supporting high-quality transmission and making the SIW antennas especially attractive for integration into modern microwave and millimeter-wave systems.

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ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

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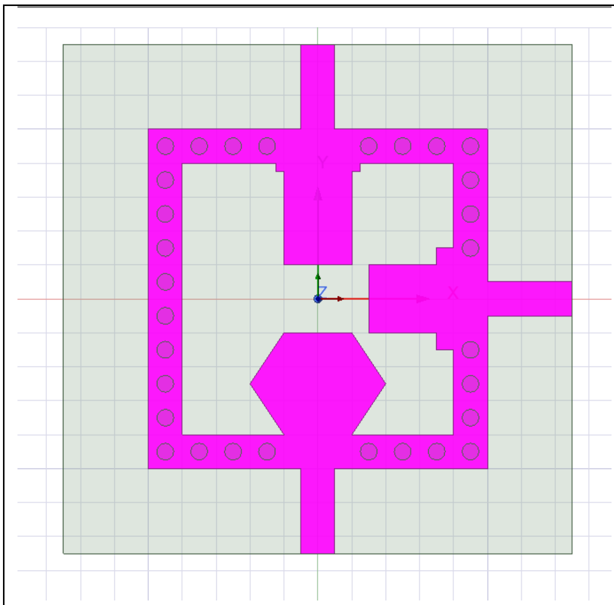
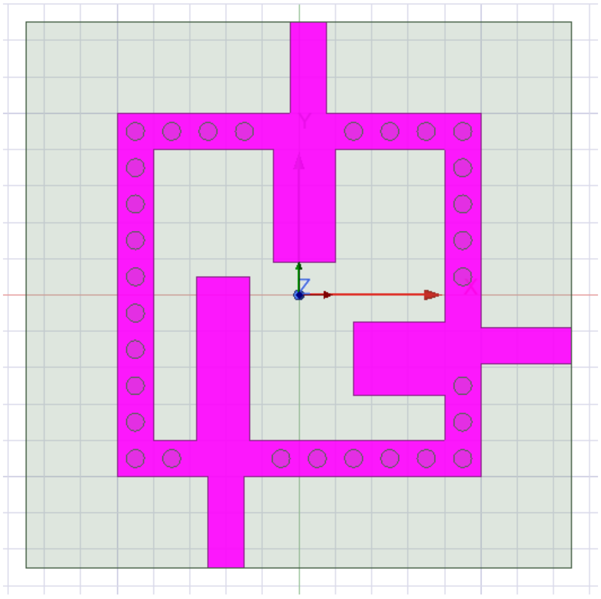
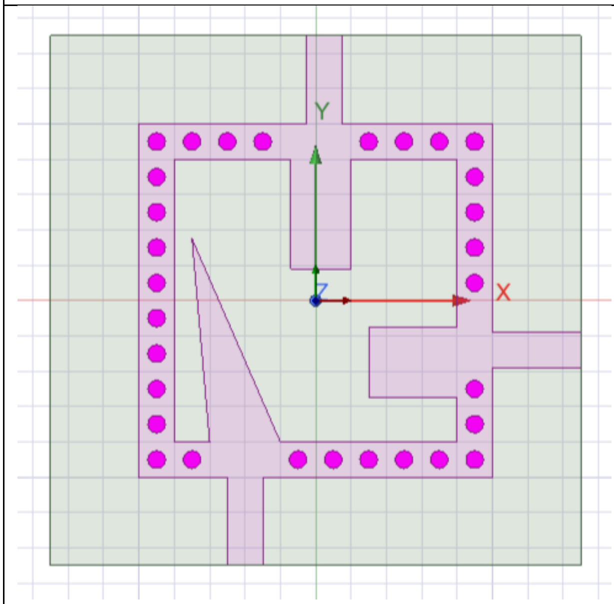


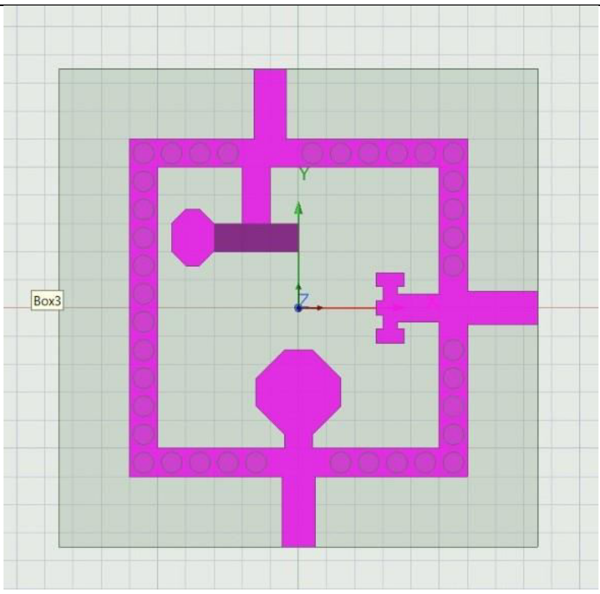
Design-1



Design-2



Design-3



Design-4

IV. RESULTS

Size of proposed antenna:

The overall size of the antenna is approximately;
Length :30mm/4.54 mm ~0.74 λo.
Width: 30 mm/40.54 mm ~0.74 λo.
Therefore, the overall size of antenna structure is approximately 0.74 λo x 0.74 λo.

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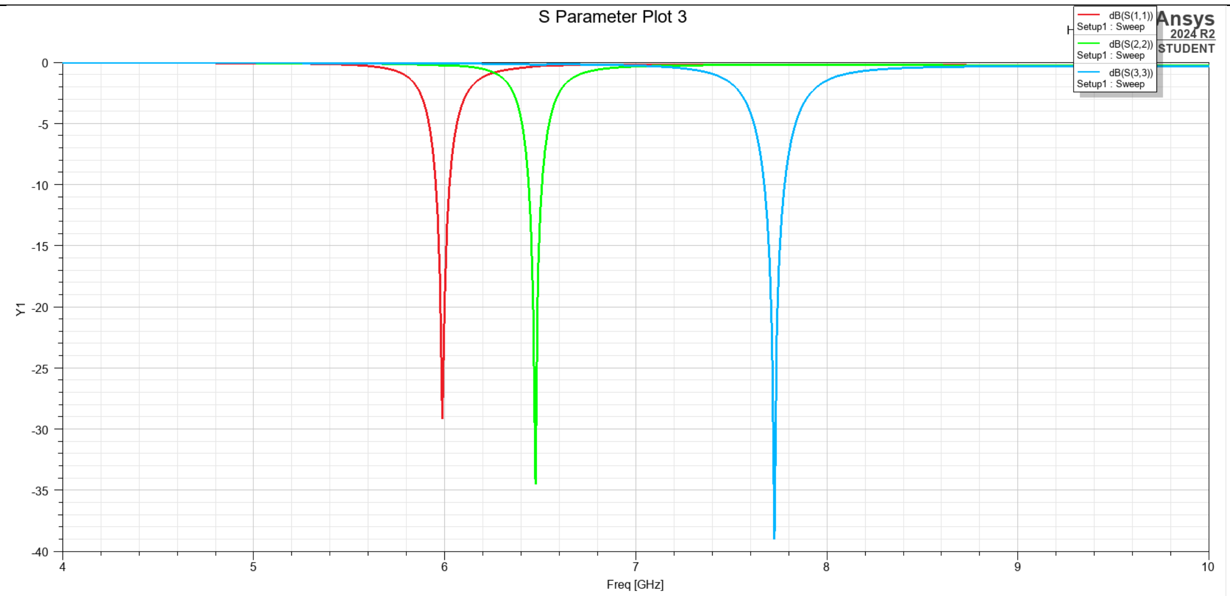
S- Parameters:
Scattering parameter or S-parameter (the element of a scattering matrix or S-matrix) describe the electrical behaviour of linear electrical networks when undergoing various steady state simulate by electrical signal. Scattering refers to the way travelling currents or voltage are affected when they meet a discontinuity in a transmission line

Return Losses:
Within the figure are shown the S-parameters (and, more specifically, return loss in dB) of the three-port microwave device simulated with Ansys HFSS (Student version 2024 R2). Each colored trace from left to right represents the reflection coefficient S11, S22, and S33 within the frequency range of 4 to 10 GHz.

The sharp dips of the curves correspond to the resonance frequencies wherein energy is transmitted or absorbed rather than reflected, with S11(red) having its resonance at around 7.4 GHz, S22 (green) around 8.73 GHz and S33 (blue) at around 9.58 GHz. These deep nulls (i.e., below −25 dB) imply good impedance matching at the respective frequencies and indicate that the structure is well-tuned for minimum reflection at each of its ports.This is achieved by using perfect slot and patch shape with accurate dimensions.

- For design[1] S11 is having its resonance at around 5.9 GHz, S22 (green) around 6.5 GHz and S33 (blue) at around 7.7 GHz.
- For design[2] S11 is having its resonance at around 4.8 GHz, S22 (green) around 6.3 GHz and S33 (blue) at around 7.4 GHz.
- For design[3] S11 is having its resonance at around 5.2 GHz, S22 (green) around 6.3 GHz and S33 (blue) at around 7.5GHz.
- For design[2] S11 is having its resonance at around 4.98 GHz, S22 (green) around 8.96 GHz and S33 (blue) at around 6.4 GHz



Return losses of Design-1

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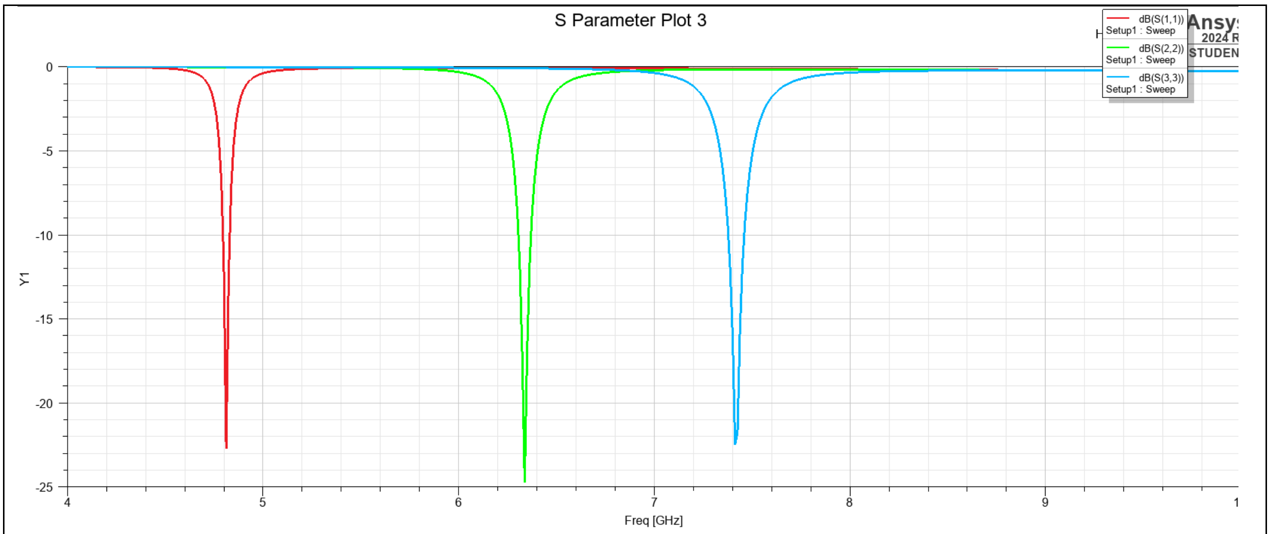
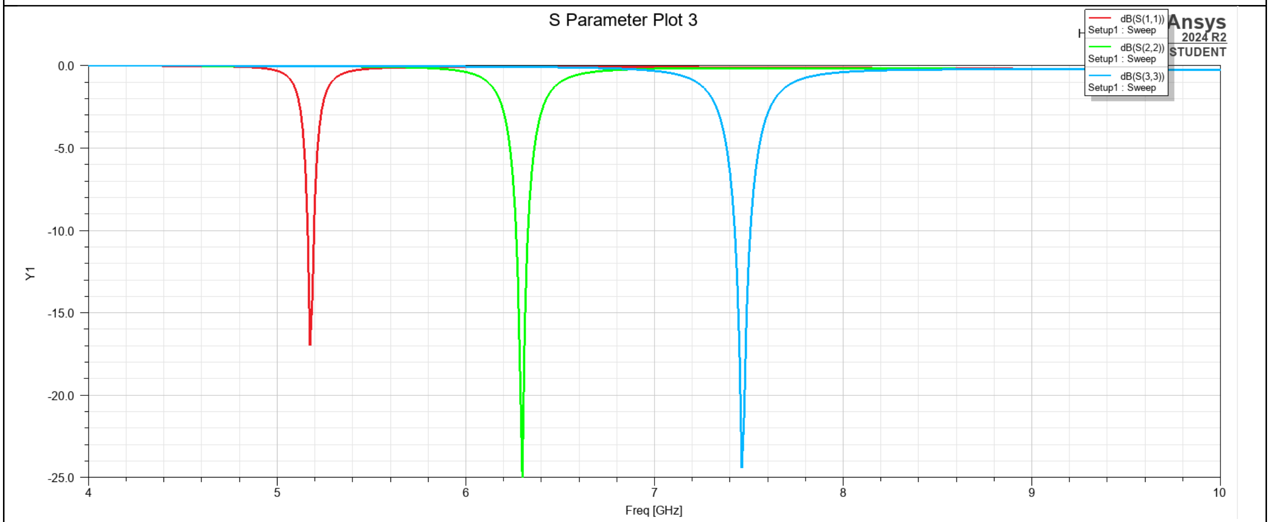


Return losses of Design-2



Return losses of Design-3

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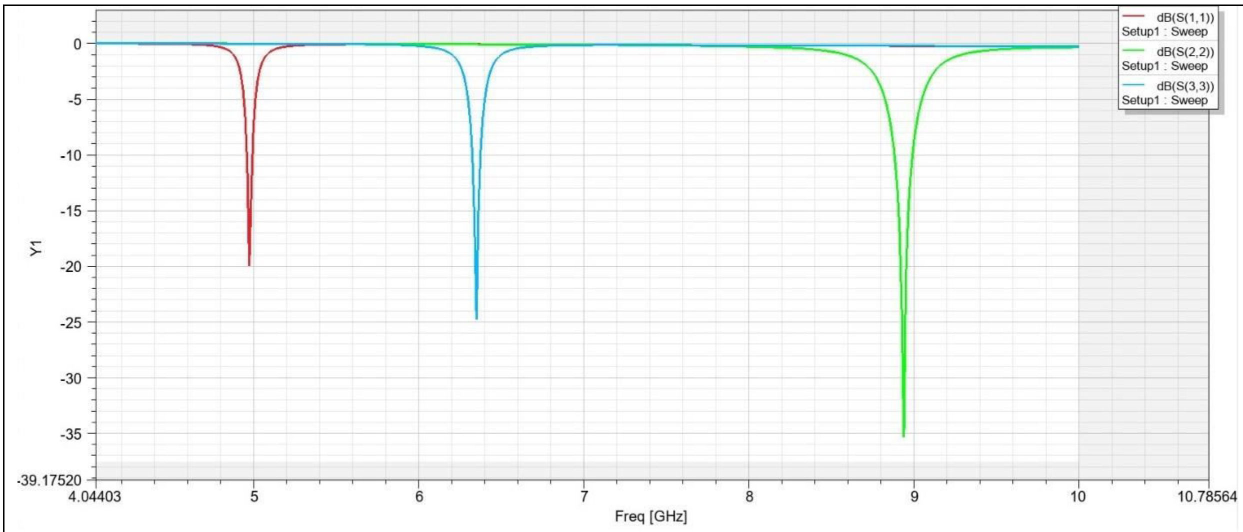

Return losses of Design-4

Radiation pattern:

The radiation pattern of an antenna is a mathematical or graphical representation of the variation of emitted power with direction; it represents radiated energy spatially, more often than not in polar or Cartesian plots, with respect to directions in which the antenna is set to radiate or receive power. The pattern consists of the main lobe (the direction of maximum radiation), the side lobes, and the back lobes. From the radiation pattern, the parameters beamwidth, directivity, and front-to-back ratio can be derived. An understanding of the radiation pattern is important for antenna design, allowing the designer to efficiently direct energy to places where it is required while minimizing interference into places where it is undesired.

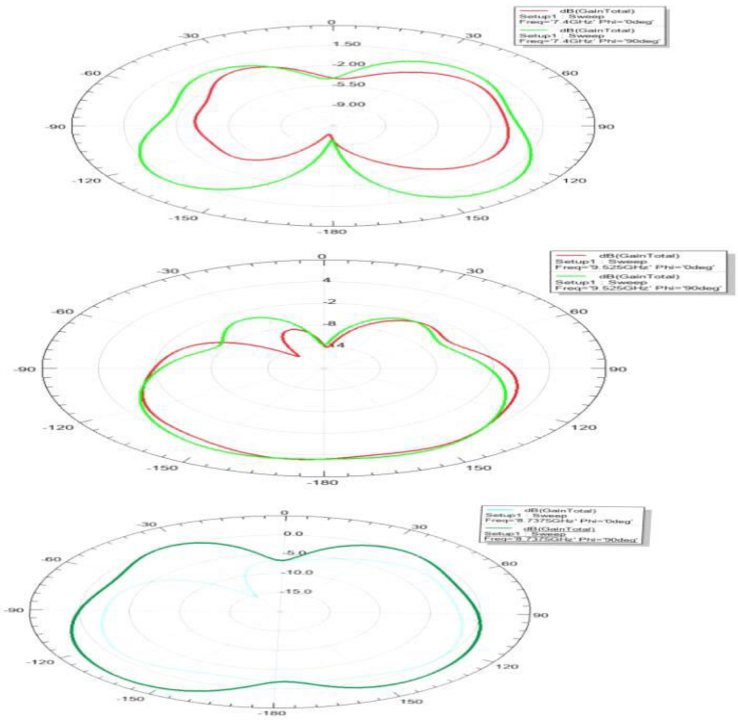

Figure:Radiation pattern

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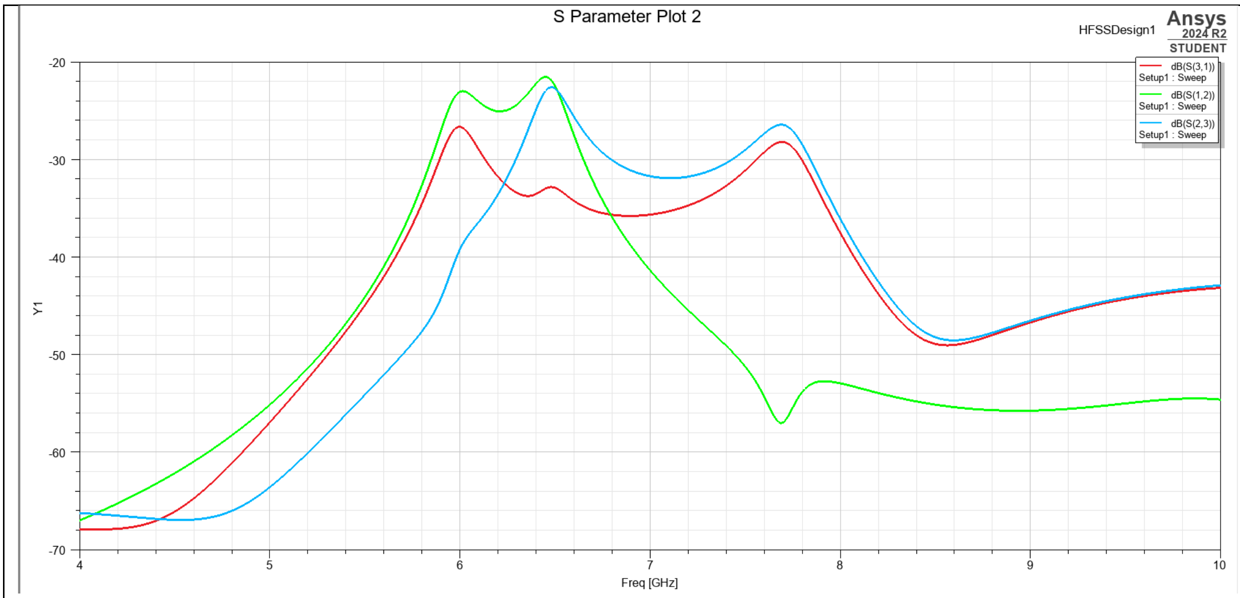
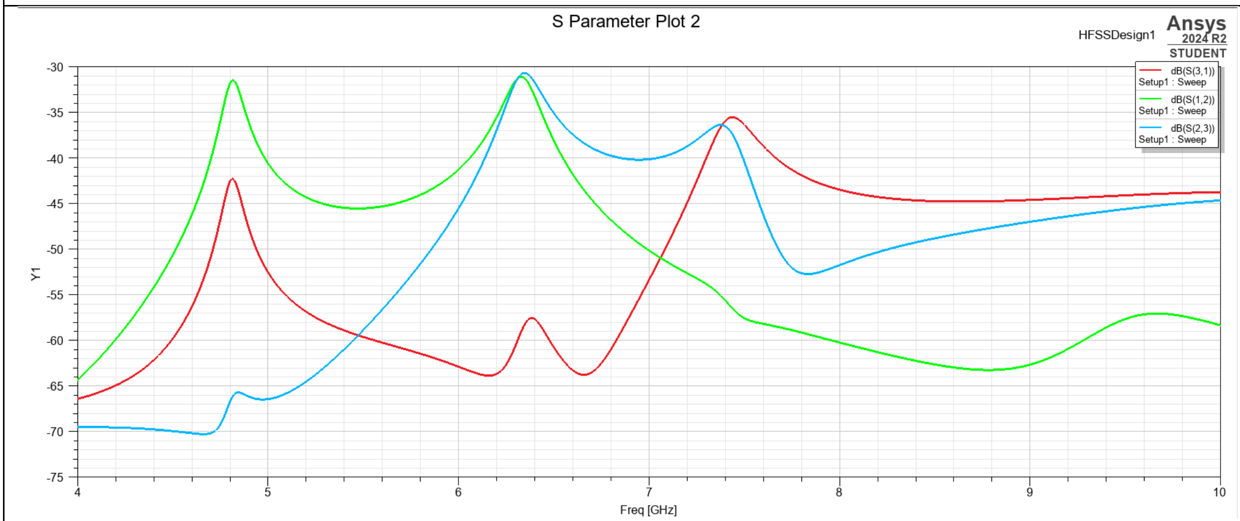
Isolation:

Isolation is defined as the efficiency with which the ports of an antenna or microwave device are separated in terms of the signal transmission considering the minimum signal leakage between them. Isolation is usually measured in terms of S-parameters such as S12, S13, S23 etc., which describe the power transferred from one port to another. The lower these parameters are, –25 db or below for instance, the better the isolation would be, which means there is very little signal leaking between the ports. High isolation is extremely helpful in improving the overall system performance, minimizing electromagnetic interference, and providing reliable operation of different signals or frequencies in applications such as MIMO systems and multi-band antennas.This can be achieved by off-centering th port 1 from origin.



Isolation between ports for Design-1



Isolation between ports for Design-2

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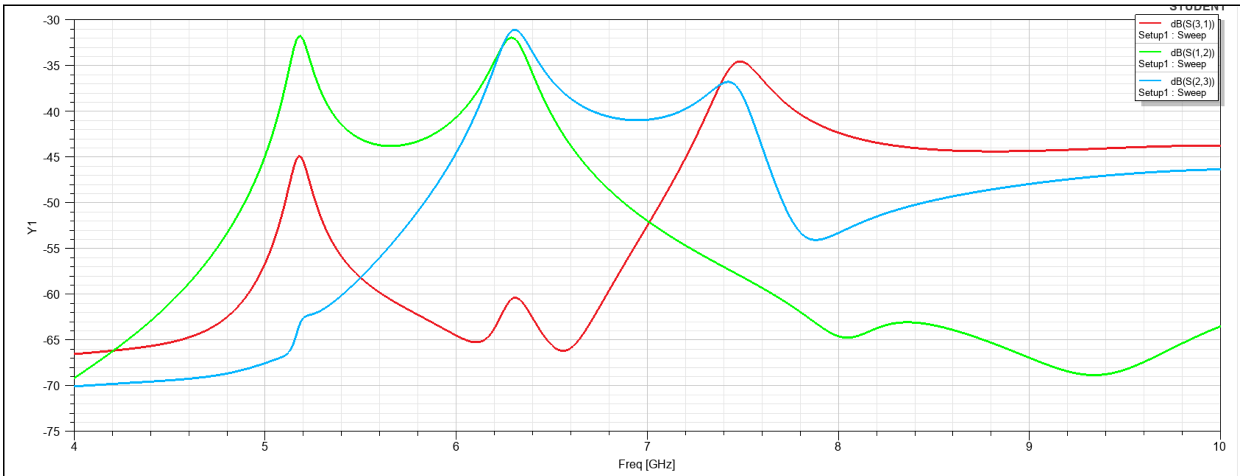
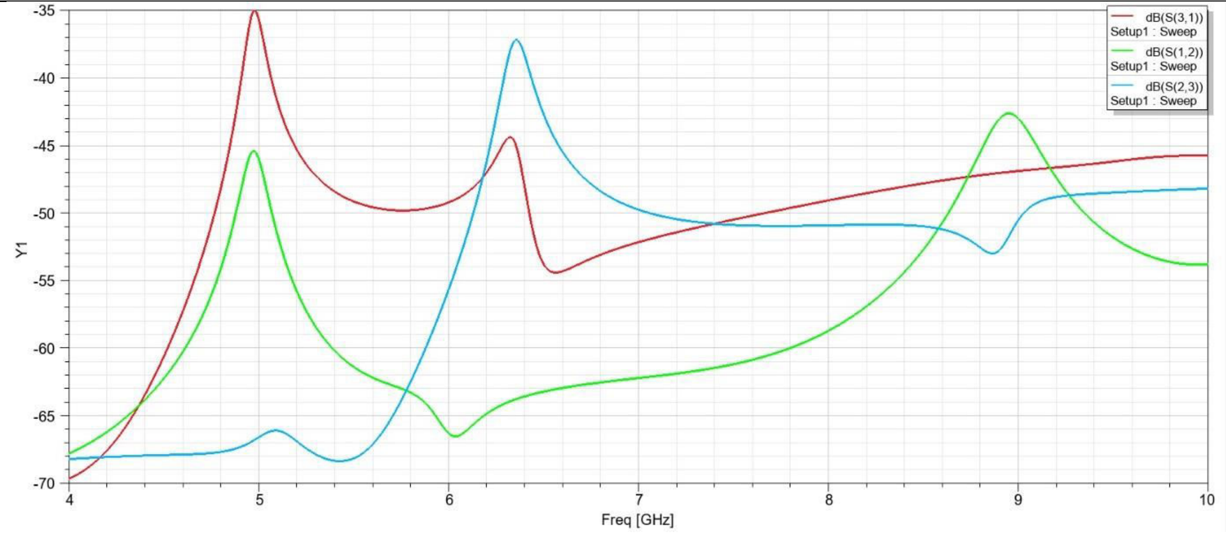


Isolation between ports for Design-3



Isolation between ports for Design-4

Figure: Isolation between ports

Dimensions of Antenna

Object	X-size	Y-size
Substrate	30	30
Ground	30	30
Patch	20	20
Diameter of via	0.5	-
Slot	16	16

All dimensions are in mm

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V. CONCLUSION

According to the available design and simulation results, miniaturized triple-fed high isolation SIW (Substrate Integrated Waveguide) self-triplexing antenna is actually an effective performance in key areas of triplexing operation. The layout reveals a compact structure with three different feed ports integrated into a common radiating element, surrounded by via fences which indicate the SIW boundaries. The S-parameter plots confirm that the antenna operates in three well-isolated resonant frequencies centered at ~7.4, ~8.73, and ~9.58 GHz; with deep return loss (S11, S22, S33 < -25 dB), thereby demonstrating excellent impedance matching. Furthermore, the transmission parameters, S21, S31, and S32, demonstrate strong isolation and selective coupling, with distinct peaks for each feed path, thus keeping in view the self-triplexing functionality. In conclusion, the design meets the demand for miniaturization, frequency selectivity, and high port isolation, thereby being a promising candidate for multi-band communication systems such as modern wireless or radar applications.

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