Design and Analysis of Coupler for Micro Strip patch Antenna Applications

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ABSTRACT

In this paper, the main aim is to design and analyses of coupler for micro strip patch antenna for wireless communication and to analyze various factors like gain, directivity, return loss, radiation intensity for the frequency of 2.5GHz. The simulation of this antenna is carried out in ANSYS HFSS v20201. Results like return loss, radiation pattern, 3D polar plot, sidelobe level, beamwidth, radiated power, accepted power have been obtained using HFSS v2021. This research on this antenna gives a great view on how it can be designed and used at 2.5GHz frequency has a peak gain of 1.42dB. The main advantage of this antenna is providing matching network to ensure proper impedance matching, which is essential for optimal power transfer.

Keywords : Coupler, Envelope correlation coefficient, return loss

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1. INTRODUCTION

1.1 INTRODUCTION TO COUPLER ANTENNA

Antenna is defined as an electromagnetic waves device or transducer that transforms an RF signal. It acts as a means of transmitting radio waves and receiving them. Antennas play a major role in wireless communications. The types of antennas include parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas. These types are unique in properties and usage. A type of telecommunication technology called an Micro strip patch antenna. Microstrip patch antennas have garnered significant attention in recent years due to their compact size, low profile, and ease of integration into various electronic devices. However, to harness the full potential of microstrip patch antennas, the development of advanced feeding and coupling mechanisms has become imperative.

1.2 DESIGN EQUATION

1) $$w = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

2) $$\varepsilon_{r_{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2}$$

3) $$L = \frac{\lambda}{2} - 2\Delta L$$

4) $$\frac{\Delta L}{h} = \left(\frac{\varepsilon_r+0.3}{\varepsilon_r-0.258}\right)\left(\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.8}\right)$$

1.3 ADVANTAGES OF RATRACE COUPLER ANTENNA

The antenna has wide applications and few are listed below

- Power division
- Beam forming
- Impedance matching
- High immunity to noise
- Low losses and cost effective

1.4 APPLICATIONS OF RAT RACE COUPLER ANTENNA

- Telecommunications: Ratrace couplers are used to combine or split optical signals in fiber optic networks to enhance data transmission and reception.

- Photonics: Ratrace couplers play a vital role in photonics applications, enabling efficient manipulation of light for various purposes, such as signal processing and laser systems.

- Fiber-optics: Ratrace couplers facilitate signal distribution and power splitting in fiber optic communication systems, ensuring reliable data transmission.

- Interferometry: In interferometry, ratrace couplers help merge and split light beams to create interference patterns, aiding in precise measurements and scientific research.

1.5 DISADVANTAGES OF RATRACE ANTENNA

Though antenna provides variety of applications it lags with few properties and are listed below

- Limited Splitting Ratio: Ratrace couplers are typically designed for specific splitting ratios, and it can be challenging to change this ratio without changing the physical device. This limitation can be a drawback when flexibility is required in power distribution..
- Wavelength Sensitivity: Some Ratrace couplers may be sensitive to specific wavelengths of light, which means they might not work optimally across a wide range of wavelengths. This can be a limitation in applications that require broadband or multi-wavelength operation.It still has the potential to interfere with existing systems since it uses a spectrum that is also allocated for various military, civilian, and commercial applications.
- Fabrication Complexity: Fabricating high-performance Ratrace couplers can be complex and may require precision manufacturing techniques, making them relatively costly to produce.

2.LITERATURE SURVEY

Zhengbin Xu etal.,[1] proposed and measured the performance of a fabricated 3-/6-GHz dual-mode ring coupler and found that it achieved good results in terms of gain, directivity, return loss, and efficiency. Specifically, the coupler had a gain of 3.6 dB at 3 GHz and 5.8 dB at 6 GHz, a directivity of greater than 15 dB at both frequencies, a return loss of less than -10 dB at both frequencies, and an efficiency of greater than 70% at both frequencies. The authors also used the dual-mode ring coupler to design and fabricate a 19-/38-GHz balanced frequency doubler. The doubler had a conversion loss of less than 8.9 dB with an input frequency ranging from 17 to 21 GHz, and a minimum conversion loss of 7.3 dB at 19 GHz.

Oguzhan Kizilbeyl etal.,[2] proposed,fabricated and tested a prototype of coupler.The coupler achieved a gain of 3 dB, a directivity of 15 dB, a return loss of 10 dB, and an insertion loss of 0.5 dB over a bandwidth of 2-5 GHz. These results demonstrate that the proposed coupler is a promising new technology for use in wideband communication systems. The authors used a variety of techniques to miniaturize the coupler without sacrificing performance. One technique was to use stepped impedance transformers. Stepped impedance transformers allow for a gradual change in impedance over a short distance. This is useful for miniaturizing circuits, as it allows for the use of smaller components. Another technique that the authors used was to optimize the layout of the coupler. They carefully placed the components on the PCB to minimize the overall size of the coupler. The authors also used a variety of techniques to improve the performance of the coupler. One technique was to use high-quality components. They also used a careful design process to ensure that the coupler was well-matched to its source and load impedances.

Jae-du Yu etal.,[3] proposed and performed a comparative analysis of the performance of various six-port phase correlator structures. The structures considered are:

Structure 1: Three 90° hybrid couplers and a Wilkinson power divider.
Structure 2: One 90° hybrid coupler, two power dividers, and one 180° rat-race ring coupler.
Structure 3: Three 90° hybrid couplers and one 180° rat-race ring coupler.

The authors simulated the performance of the three structures at a center frequency of 2.5 GHz. The simulation results showed that Structure 2 had the widest bandwidth, while Structure 3 had the best gain flatness. Structure 1 had the smallest phase error. The gain and directivity values of a ring coupler vary depending on the specific design of the coupler. However, typical values for gain are 3-6 dB and for directivity are 15-20 dB. In the paper described in [1] achieved a gain of 3.6 dB at 3 GHz and 5.8 dB at 6 GHz, and a directivity of greater than 15 dB at both frequencies. The miniaturize wideband 180° hybrid ring coupler proposed in the paper "A Miniaturized Wideband 180° Hybrid Ring Coupler" by Oguzhan Kizilbeyl, Osman Palamutcuogullari, and Binboga Siddik Yarman achieved a gain of 3 dB, a directivity of 15 dB, and a return loss of 10 dB over a bandwidth of 2-5 GHz.

Eric S.Li etal.,[4] proposed two new designs for broad-band cavity-coupled microstrip directional couplers.The first design is a three-cavity coupler that uses a tapered coupling cavity to achieve a wide bandwidth.

The tapered coupling cavity gradually increases in width from the input port to the output port. This helps to reduce the dispersion of the coupler and extend the bandwidth.
The second design is a four-cavity coupler that uses two coupling cavities, one on each side of the main transmission line. The coupling cavities are coupled to the main transmission line through slots. The slots are designed to minimize the reflection loss of the coupler. Both of the proposed couplers were fabricated and tested. The three-cavity coupler achieved a bandwidth of 11.3 GHz at a center frequency of 18 GHz. The four-cavity coupler achieved a bandwidth of 12.1 GHz at a center frequency of 20 GHz. The author also measured the gain and directivity of the proposed couplers. The three-cavity coupler had a gain of 3.5 dB and a directivity of 20 dB. The four-cavity coupler had a gain of 4.2 dB and a directivity of 22 dB.

Kun-Hung Tsai etal.,[5] proposed and used synthetic coupled lines to create a directional coupler with two coupled ports and two isolated ports. The coupler is designed to have a high directivity, which is the ratio of the power coupled to the desired port to the power coupled to the undesired port.
The authors fabricated and tested a prototype of the proposed coupler. The coupler achieved a directivity of 28.5 dB at a center frequency of 24 GHz. This is significantly higher than the directivity of traditional directional couplers made in CMOS technology. The authors also measured the gain and insertion loss of the proposed coupler. The coupler had a gain of 3.5 dB and an insertion loss of 1.5 dB. These values are comparable to traditional directional couplers made in CMOS technology. Overall, the results presented in the paper demonstrate that the proposed coupler is a promising new technology for high directivity applications in CMOS technology.

Table 1 : Comparison table

Paper No	Cutoff Freqyency(GHz)	Gain(dB)	Directivity (dB)	Efficiency (%)	Return Loss(dB)
[1]	3-6	3.6	15	70	-10
[2]	2-5	3	15	50-70	-10
[3]	2.5	3-6	15-20	>50	-10
[4]	11	3.5	18-20	>75	-22
[5]	24	3.5	28.5	>60	-10

From the above Comparison table ,We have taken the structure from [1] as our base paper structure and designed the coupler for microstrip patch antenna.

2 . DESIGN METHODOLOGY

Multi-port coupler design can be made as follows: From the circle 180° rotated ports are designed. In between the 180° gap, another ports are placed as shown in Figure 1.

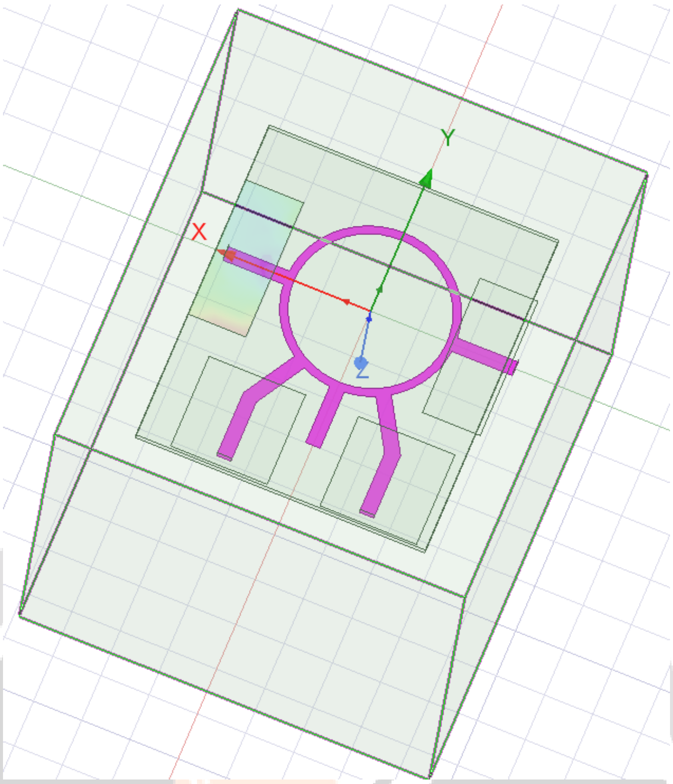


Fig 1 : Modeler window design in HFSS of the proposed antenna.

Table 1 Design specifications of coupler

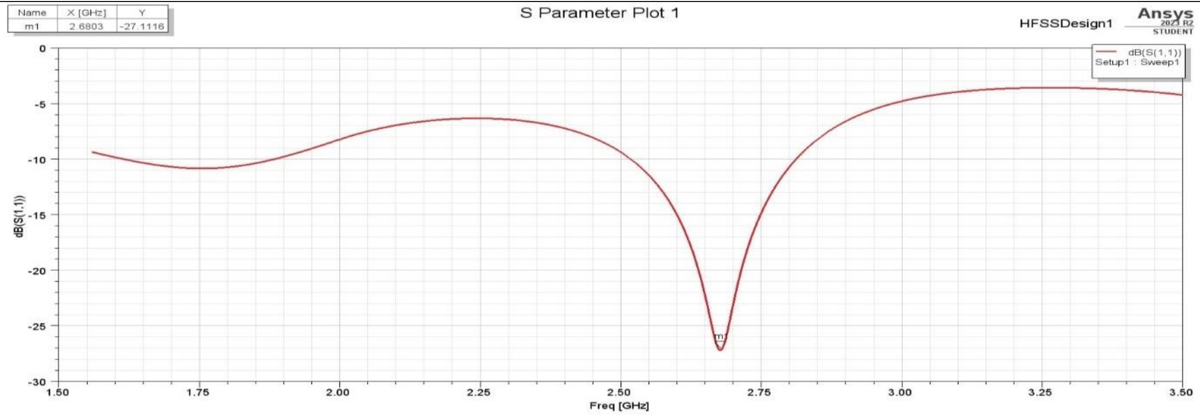
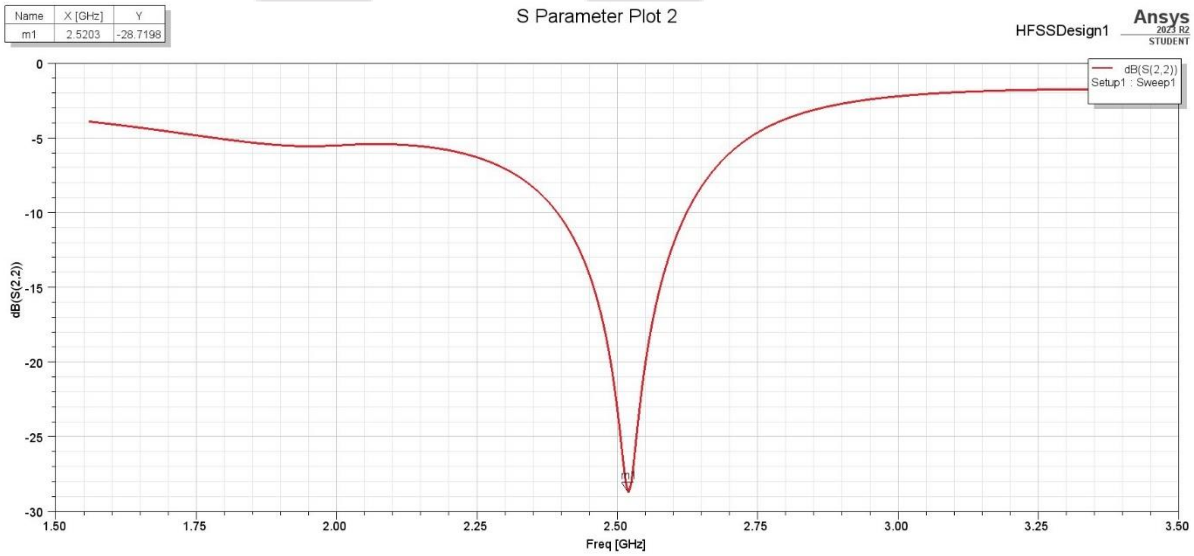
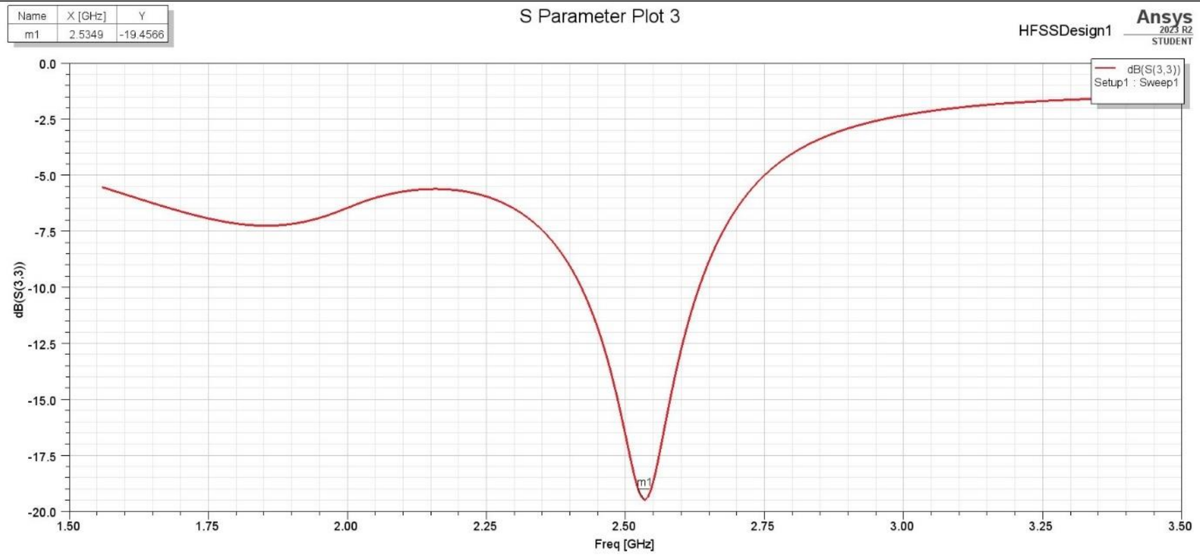
Design Parameters	**Value**
Operating Frequency (GHz)	2,5
Length of patch (1 and 4) ,(3 and 2) (mm)	30,20
Width of patch (1and 4),(3 and 2) (mm)	12,20
Height of Substrate (mm)	1.6
Dielectric Constant (ε_r)	4.4

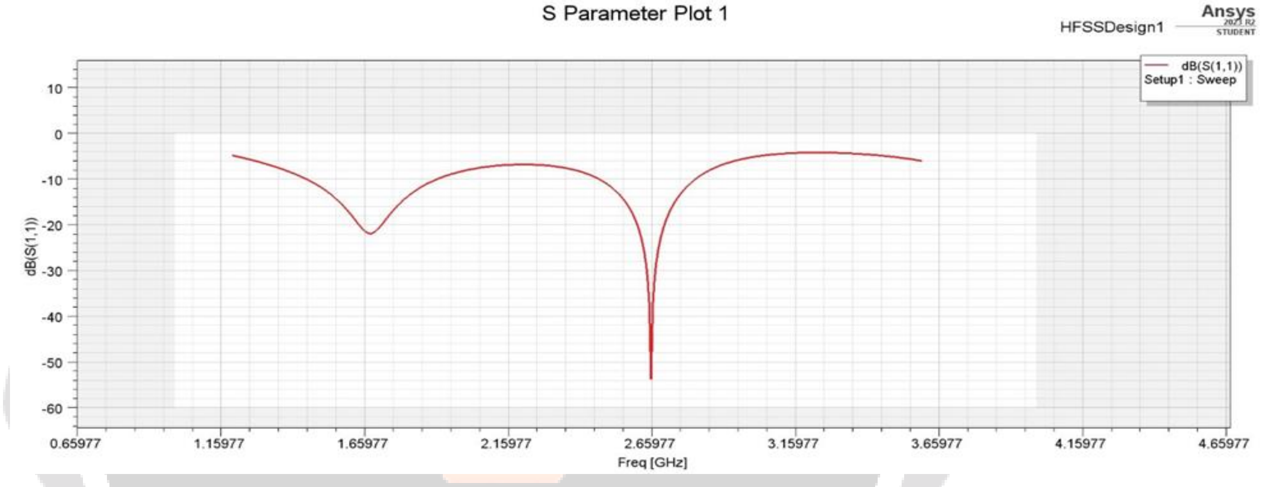
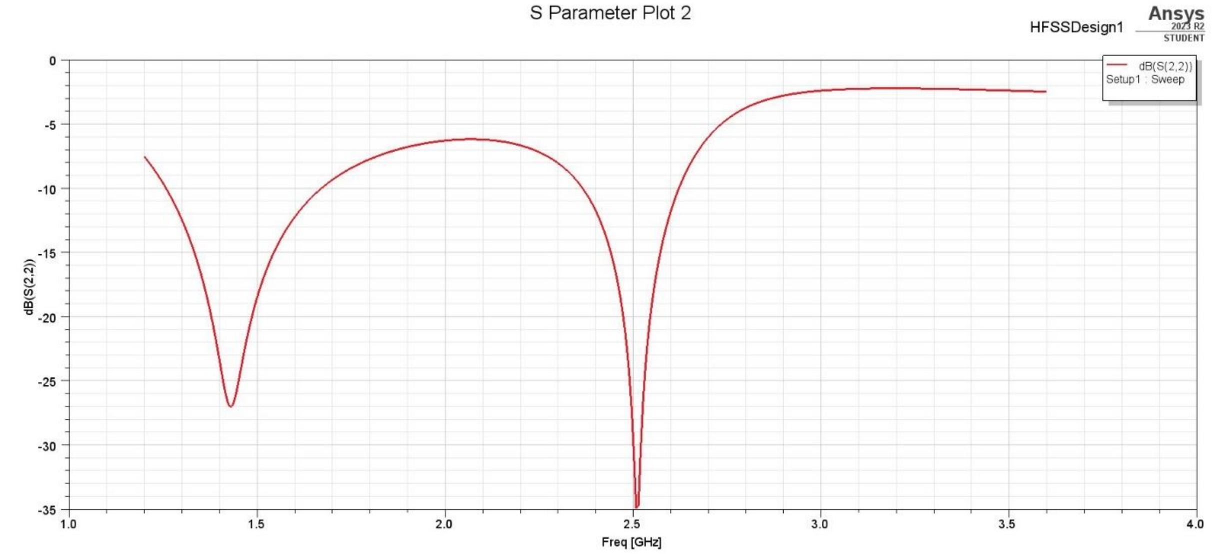
4. SIMULATION RESULTS

This chapter deals with simulation results obtained from coupler design. Some parametric analysis also done with the design. Respective results are tabulated too in Table 2. It is proved that, when length of the ports is reduced by half, it can be designed to be operating in 2.4 GHz exactly with FR4 substrate.

Table 2: Return Loss

OPERATING FREQUENCY (in GHz)	**Return Loss**

2.5 S$_{11}$	
S$_{22}$	
S$_{33}$	

<table>
<tr><td>S_{44}</td><td>
</td></tr>
<tr><td>(Additional Innovations)
When port length varied from 3mm to 5mm at 2.5 GHz</td><td>
</td></tr>
<tr><td>When length of all patches reduce by half at 2.5 GHz.
S_{11}</td><td>
</td></tr>
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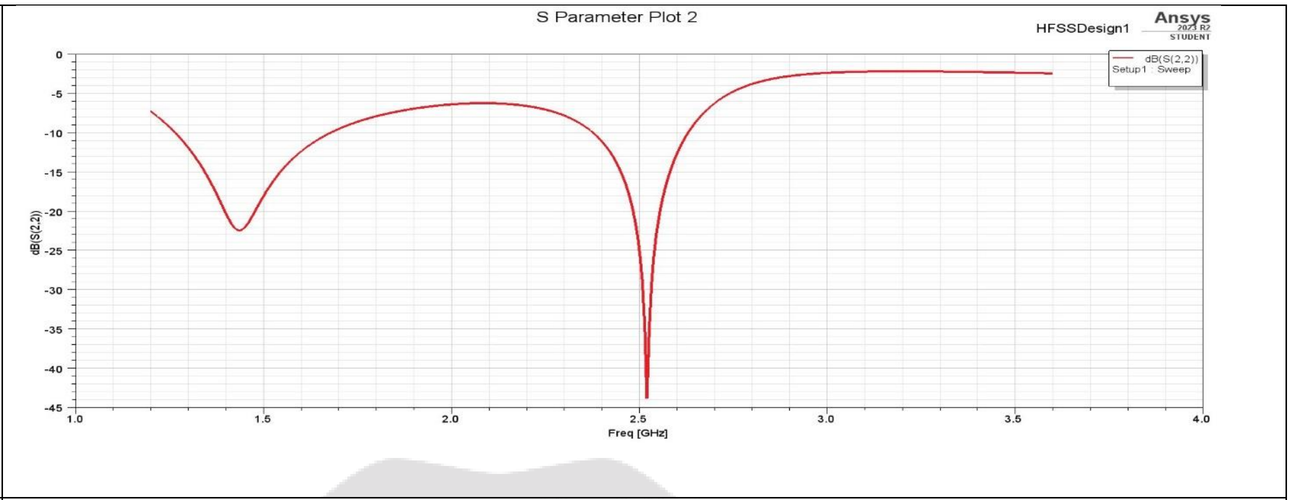
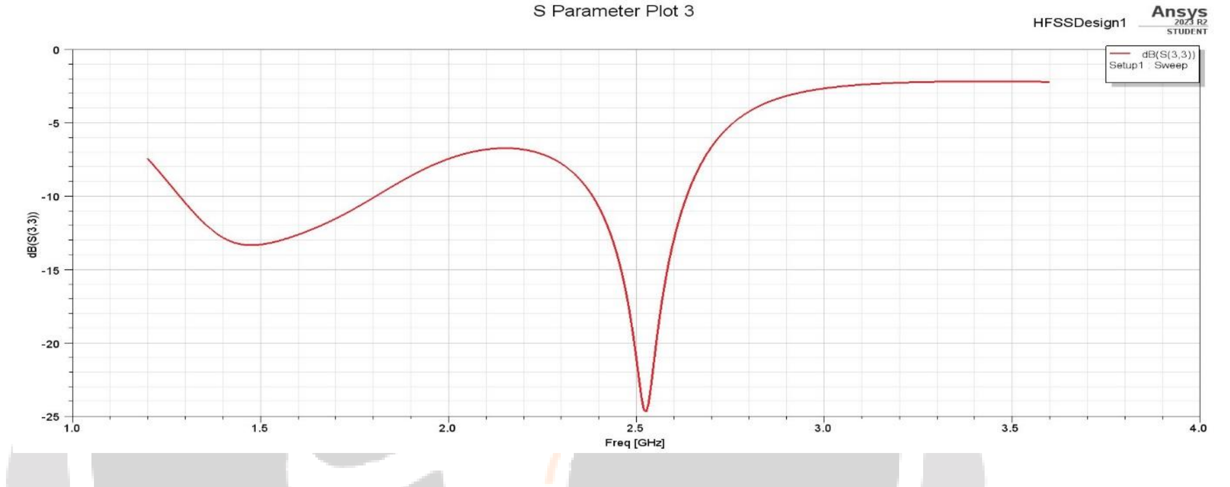
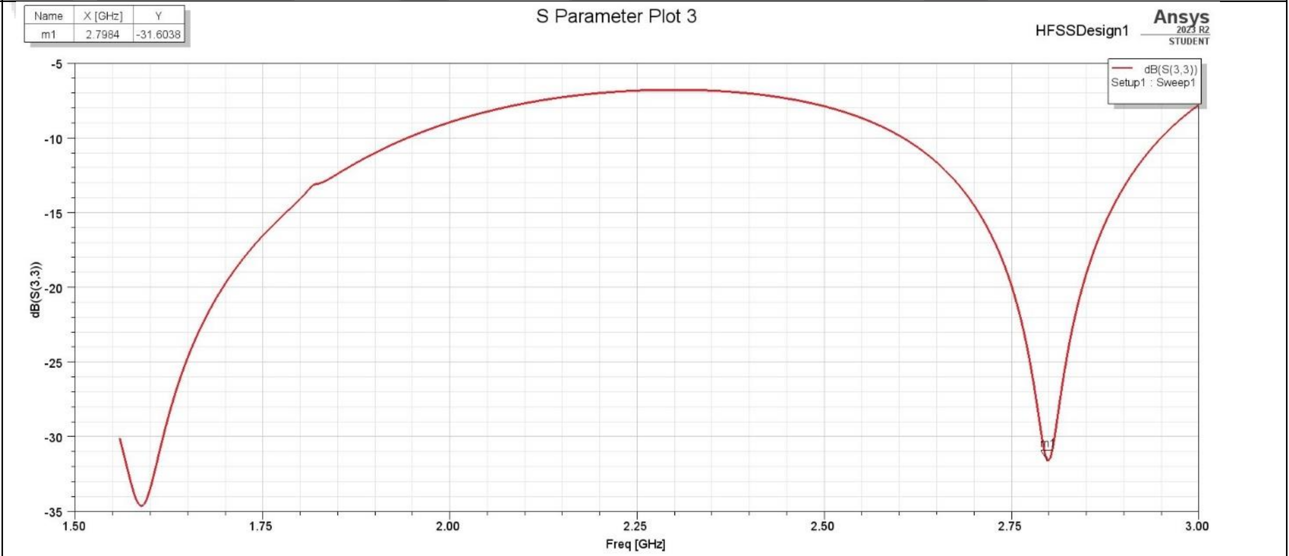
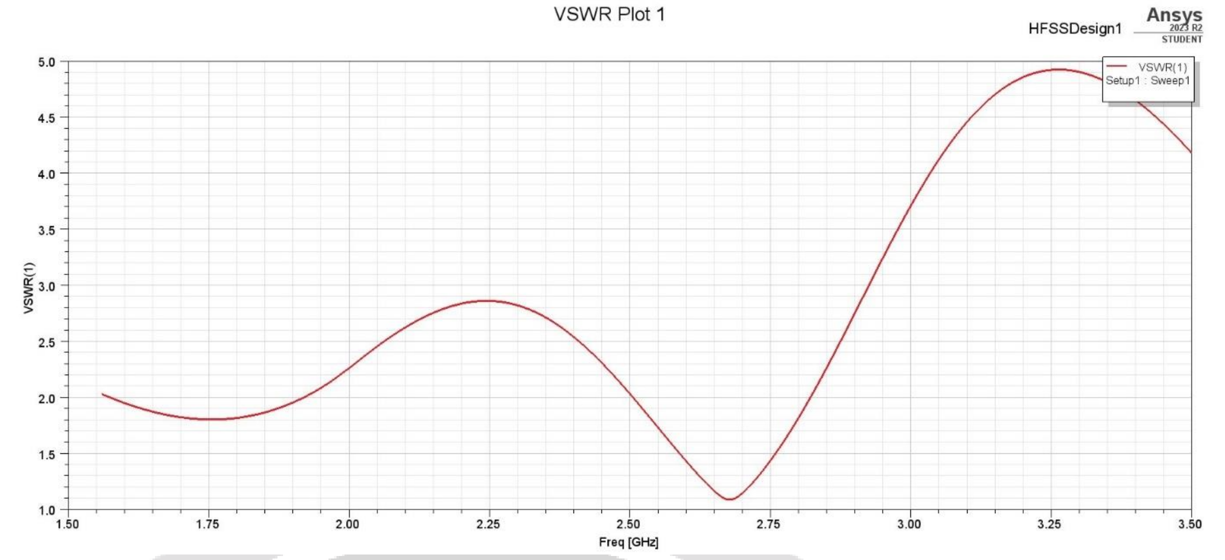
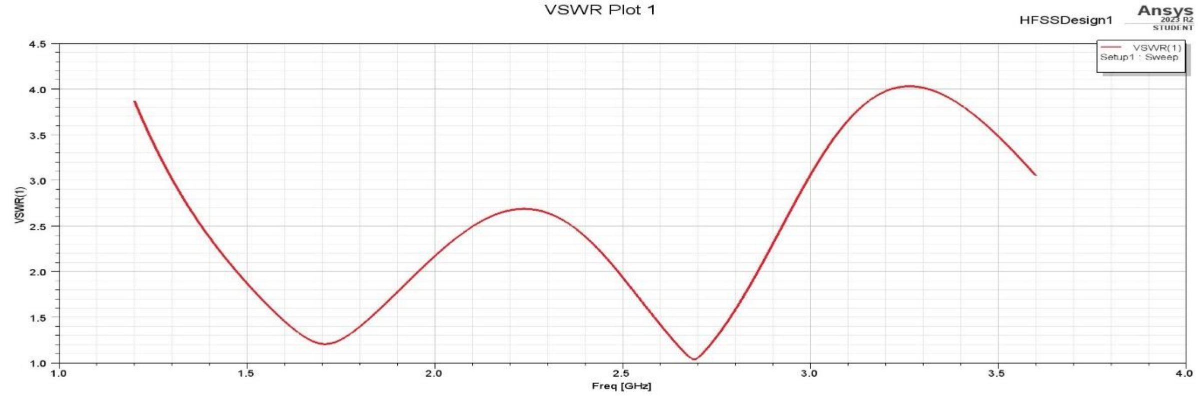
S_{22}	
S_{33}	
When Substrate Changed from Fr4 Epoxy TO Rogers	

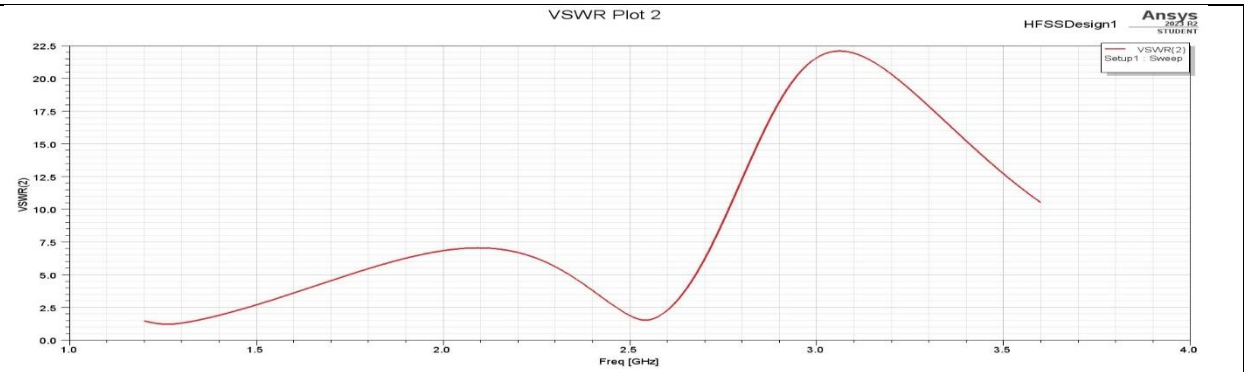
4.2 VSWR

The VSWR obtained by our proposed antenna at the frequency 2.5GHz is 1.34

Table 4.2VSWR plot for different frequencies

OPERATING FREQUENCY (in GHz)	**VSWR**

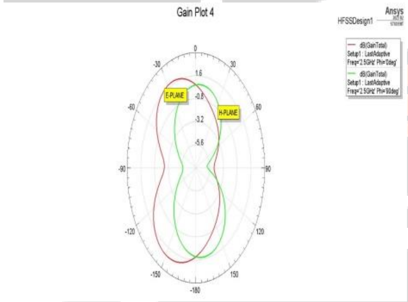
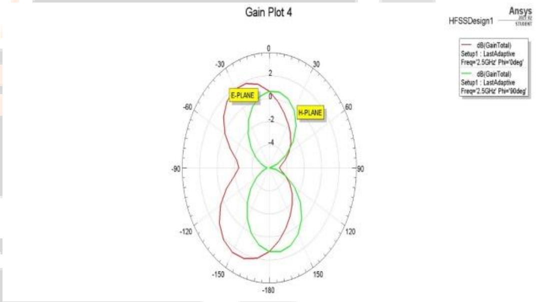
2.5 GHz Port-1	
Reduced length structure 2.5GHz	
Additional Innovations(Patch Size reduced by half)	

Port length increased twice	

Radiation pattern

Graphical representation of the relative field strength that the antenna transmits or receives is called radiation pattern. It is indicated with side lobes and back lobes. An antenna's radiation pattern can be defined as the locus of all points in which power emitted per unit surface is equal. The reference in this depiction is usually the best emission angle. The directive gain of the antenna may also be represented as a function of direction.

Table 4 Radiation Pattern for different frequencies

OPERATING FREQUENCY (in GHz)	**WITH E FIELD (Phi =0 degree)**	**WITH H FIELD (Phi=90 degree)**
2.5 GHz		

From the above graphs, it is inferred that directivity increases with Patch Size.

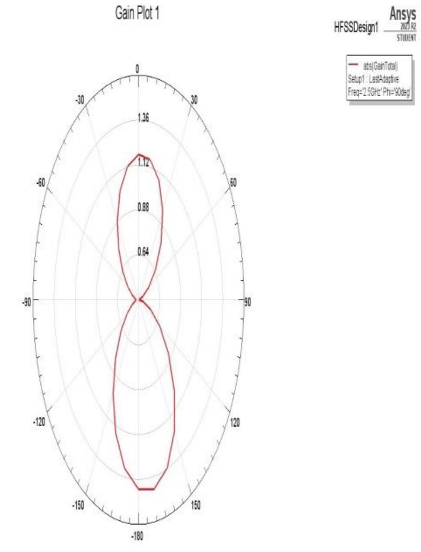
Antenna gain

The directionality of the antenna is measured by a factor called Antenna Gain or Gain of an Antenna. In particular, power gain is defined in terms of ratio of radiated intensity of an antenna in a particular direction at a random distance to the radiated intensity by an isotopic antenna at the same distance. A high gain antenna is normally unidirectional or emits radiation in a specific direction on the other hand the low gain antenna emits radiation equally in all directions. Gain is a dimensionless quantity.

Gain can also be given by,
Gain = Directivity × Efficiency
If the gain is higher, then in that particular direction the signal strength is higher

$$G=\frac{(P/S)_{ant}}{(P/S)_{iso}}$$

Table 5. Antenna gain for different frequencies

Operating Frequency- 2.5 GHz	**Radiation Plot(Step size -10)** **Pi- 90 to 90 ,Theta- 0 to 360.**
Structure-1	

From the above graphs, it is inferred that gain increases with the change in patch size.

4.5 Directivity

Directivity of an antenna is given by the ratio of the maximum intensity of radiation to the average intensity of radiation. Maximum intensity of radiation means power per unit solid angle and average intensity of radiation means average over a sphere. Directivity is given by

$$D = 4\pi U/P_{radiated}$$

where, $P_{radiated}$ is the power radiated by the antenna.

Directivity for a real antenna can be as small as 1.76 dB but can never be less than 0dB in principle. Normally for an antenna due to low efficiency or losses, the peak gain is low. Electrically smaller antennas usually have gain lesser than -10 dB, also there will be no loss because of impedance mismatch. They are inefficient antennas.

Table 6: Directivity pattern

Operating Frequency- 2.5 GHz	**Radiation Plot(Step size -10)** **Pi- 90 to 90 ,Theta- 0 to 360.**

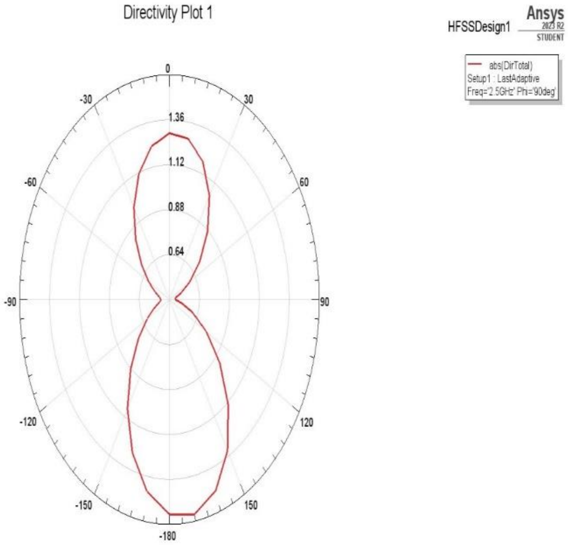
Radiation	

Table 7 shows the Performance of the Coupler antenna operating at the frequency of 2.5 GHz. Envelope Correlation coefficient is also tabulated in Table 8.

Table 7. Parameters of antenna for 2.5GHz frequency

PARAMETER (2.5GHz)	**VALUE**
Peak directivity(dB)	1.56
Peak gain(dB)	1.71
E-Field (V/m)	1802.2
H-Field (A/m)	18.698
Radiation efficiency	91.67%
System efficiency (%)	77.5%
Radiated Power(mW)	742.37
Accepted Power(mW)	813.19

Table 8. Correlation Coefficient Table

Frequency 2.5 GHz	
Port	Value
1,2	0.0248
1,3	0.1039
1,4	0.258
2,1	0.0258

2,3	0.00150
2,4	0.184
3,1	0.103
3,2	0.001502
3,4	0.507
4,1	0.258
4,2	0.184
4,3	0.105

CONCLUSION

The ratrace coupler antenna is mainly used to efficiently and evenly split or combine optical signals with low loss and high uniformity. It is used in wireless telecommunication systems. It is used in military telecommunications. This antenna is simulated in Ansys HFSS v2021. Return Loss is high at modified structure with -47 dB. The antenna gives good results at 2.5 GHz. The Dirctivity (2.21dB) and gain(2.06dB) increased by inserting the slot in structure. Thus the optimization of the antenna properties is done successfully over the HFSS Platform.

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