**Project Report**

# A 180-degree hybrid coupler operating at 3 GHz with a characteristic impedance of 50 ohms using AWR Microwave Office

Submitted in partial
fulfillment of
the requirements of the degree of

Bachelor of Technology(Electronics & Communication Engineering)
ECE F314, EM Fields and Microwave Engineering

**BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE HYDERABAD CAMPUS**

**Submitted to:** **Submitted by:**

**Dr. Harish V Dixit** **Group 27**

**DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING**

**November, 2022**

# ECE F-314 Course Project

**Title: -** To design and implement a 180-degree hybrid coupler operating at 3 GHz with a characteristic impedance of 50 ohms using AWR Microwave Office

By


Shreya Muralikrishna Roll no 79

Sivaram Padmasola Roll no 80

Kolli Shanmukh Roll no 81


| **Member Name** | **Contributions** |
| --- | --- |
| Shreya Muralikrishna | Research, setting substrate values, calculations, Writing report |
| Sivaram Padmasola | Research, Tuning, Calculations, Writing report |
| Kolli Shanmukh | Research, Schematic, Calculations, Writing report |

# Abstract

This report comprises the design of a 3 dB 180-degree hybrid ring coupler using rat- race coupler design using AWR software. Hybrid Couplers serve the purpose of dividing or combining power. They play a vital role in wireless communications and in the design of microwave circuits. They have wide applications in RF and Microwave Engineering. The designed 180-degree hybrid coupler has an optimum operating frequency of 3 GHz. The hybrid coupler was made using FR-4 Substrate of thickness 0.8 mm. It was designed using microstrip lines in AWR Microwave Office Software. The dielectric constant $\epsilon_r$ is 4.4 and characteristic impedance $Z_0$ is 50 ohm.

# Table Of Contents

# List of Figures

# Chapter 1: Introduction

Ring couplers serve the utility of dividing or combining power. They are widely used owing to their ease of fabrication and affordability.

There are three types of hybrid couplers based on their phase shift:

- Zero phase shift hybrid coupler (Wilkinson Power Divider)
- 90-degree shift hybrid coupler
- 180-degree shift hybrid coupler

The 180-degree shift ring coupler, also known as the rat-race coupler, will serve as the main topic of this report. This coupler has four ports in its design. It is a bidirectional coupler which splits power equally between two output ports owing to it being a 3db coupler. The 180-degree shift ring coupler can also combine power.

The ring coupler design comprises of three lines of electrical length $\frac{\lambda}{4}$ and one line with electrical length of $\frac{3\lambda}{4}$. The four arms are connected at the junctions. This design results in a low voltage standing wave ratio (VSWR), good phase-amplitude balance, impedance matching and high output isolation.

The line calculations were conducted with the help of microstrip line formulae and verified it with the result given by the line calculator tool in AWR Microwave Office.

The rat-race coupler is used for splitting and combining signals in amplifiers, in switching circuits and in antenna beam-forming networks. These couplers are also used in RF and microwave circuits for combining and dividing power and for phase shifting.

Shown below is the hybrid coupler which was obtained after fabrication.

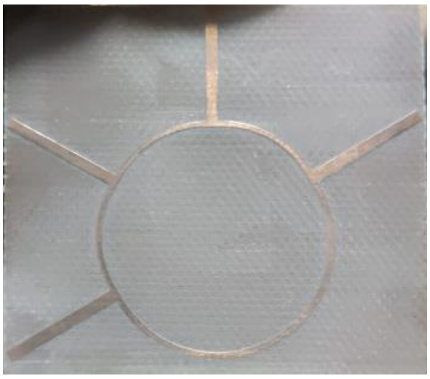


**Fig 1.1: Fabricated 180-degree hybrid coupler**

# Chapter 2: Theory Of 180-degree hybrid coupler

180-degree hybrid rat race couplers are four-port devices which are used for either power division or power combination. They can split an input signal or sum two signals. The output signals will be equally split with a 180-degree phase difference. They can also be operated such that the outputs do not have any phase shift.

## 2.1 Power division in hybrid coupler

If ports 1 and 4 are input ports, then ports 2 and 3 are the output ports. If a signal is sent into port 1, then it will be evenly split into two in phase components in ports 2 and 3, and port 4 will be isolated. If an input signal is sent into port 4 however, it will be split into two components with a 180-degree phase shift and the output will be observed in ports 2 and 3 again. In this case, port 1 is isolated.

## 2.2 Power combination in hybrid coupler

The hybrid coupler can also be used for the combination of two input signals, as suggested by its name. In this mode of operation, ports 2 and 3 are the input ports. The sum of the input signals is observed at port 1 while the difference of the input signals is seen at port 4. Therefore, port 1 is termed as the sum port and is denoted by $\sum$ while port 4 is called the difference port and is denoted by $\Delta$.

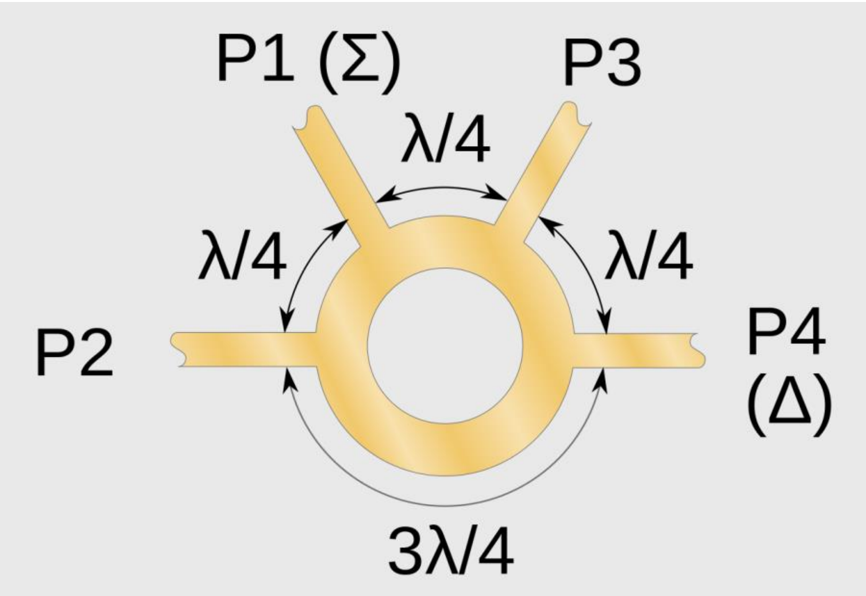



**Fig 2.1: Diagram representing the various ports and electrical lengths of hybrid coupler**

## 2.3 Scattering matrix

The scattering matrix for our hybrid coupler is given below. It is obtained from even-odd analysis, and it is used to describe the behavior of our hybrid coupler.

$$S = \frac{-j}{\sqrt{2}} \begin{vmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{vmatrix}$$

**Fig 2.2: Scattering matrix for 180-degree hybrid coupler**

# Chapter 3: Design process

There are four curved lines of the ring, three of which have an electrical length of $\frac{\lambda}{4}$ and one which has an electrical length of $\frac{3\lambda}{4}$. The intersection of these lines form junctions. There are four ports at the junctions. The characteristic impedance of the coupler's line is $\sqrt{2}Z_0$.

For power division, ports 1 and 4 are the input ports and ports 2 and 3 are the output ports. On the other hand, for power combination, ports 2 and 3 are the input ports and ports 1 and 4 are the sum and difference ports respectively.

## 3.1 Design process in AWR Microwave Office

In AWR Microwave Office, the coupler was designed using the schematic given below.

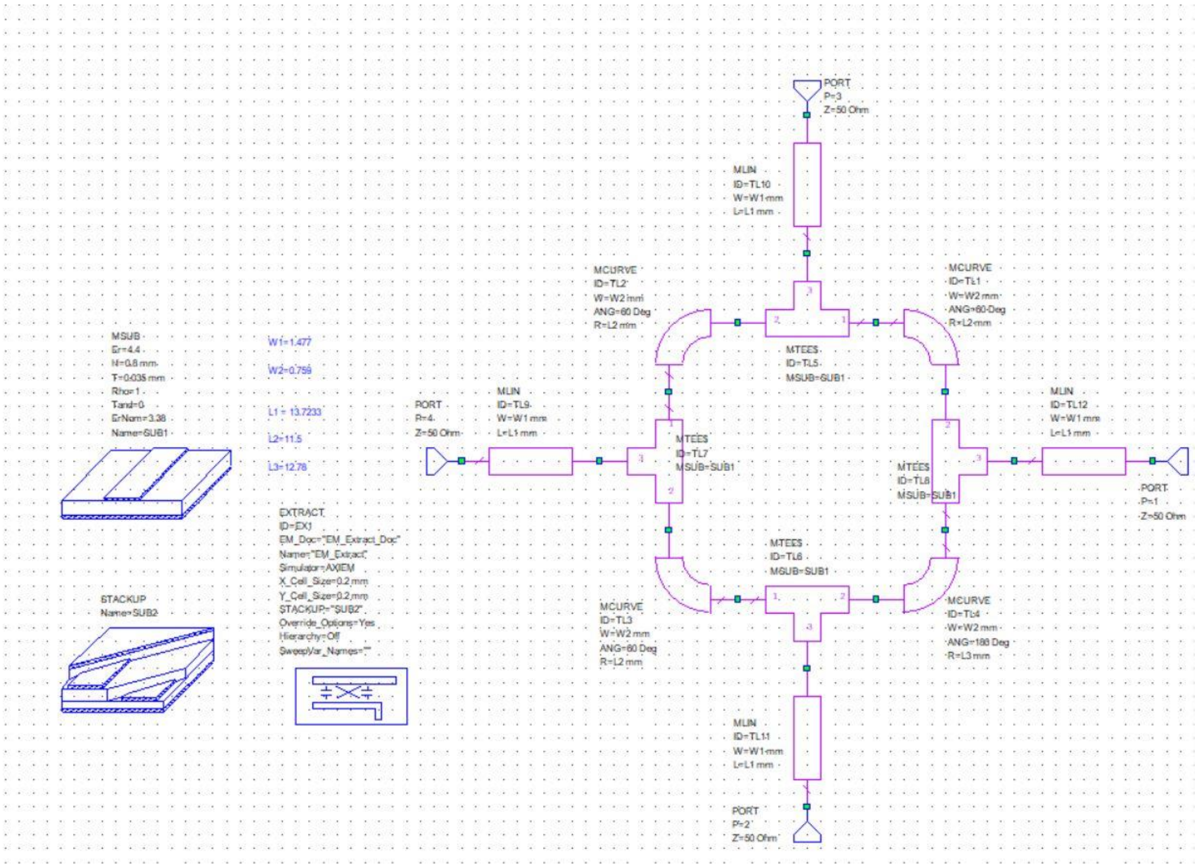



**Fig 3.1: Schematic of 180-degree hybrid coupler**

As can be seen from Fig 3.1,

- MCURVE is used to make the curved microstrip lines used in the ring which have a characteristic impedance of $\sqrt{2}Z_0$ = 70.7 ohm. Three of the MCURVE lines have a radius R = L2 mm while the fourth has a radius R = L3 mm. All of the MCURVE lines have the same width W2 mm.

- PORT is used for the ports. All the ports have a characteristic impedance of 50 ohm.
- MTEE$ is used for the junctions. The $ indicates that the software will automatically detect the widths and therefore it is not required to specify the widths for each junction
- MLIN is used to make the microstrip lines near the ports with the characteristic impedance $Z_0$ = 50 ohm. All the MLIN lines have a width of W1 mm and a length of L1 mm.
- MSUB is the substrate used. In this project, FR-4 substrate of thickness H = 0.8 mm is used. The dielectric constant $\epsilon_r$ is taken to be 4.4. The other specifications can be seen in the above figure.
- STACK UP is used to make the physical environment of the device such as creating the layers of dielectric or properties of the dielectric of the substrate.
- EM EXTRACT block helps us to make EM simulation easy as the properties required to start EM simulation were already included in it.
- Finally, during the simulation process, the following model for our rat race coupler was obtained.

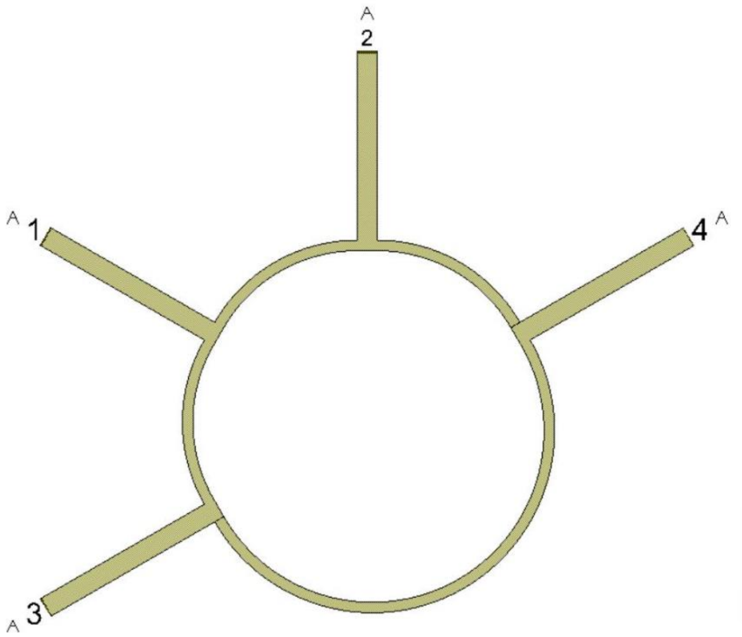



**Fig 3.2: Model of hybrid coupler obtained during simulation**

### 3.2 Line calculations

In AWR Microwave Office, there is a line calculator tool, so that was used that to get the values for the microstrip lines for this project. The line calculator tool uses the following equations to calculate the dimensions of the microstrip line.

1. The width for MLIN ( $Z_0$ = 50 ohm) and width for MCURVE ( $Z_0$ = 70.7 ohm) can be calculated using the formula
$$\frac{W}{h} = \frac{8e^A}{e^{2A}-2} \quad for \ \frac{W}{h} < 2$$
where
$$A = \frac{Z}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}(0.23 + \frac{0.11}{\epsilon_r})$$
Thus, our required W1 and W2 values are obtained.
2. The effective dielectric constant $\epsilon_{e1}$ for MLIN and $\epsilon_{e2}$ for MCURVE is calculated using the formula
$$\epsilon_e = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{1+\frac{12h}{W}}}$$
3. The wavelength is calculated with the formula
$$\lambda_0 = \frac{c}{f}$$
Here,
$$c = 3\text{x}10^8 m/s; f = 3\ GHz$$
Now,
$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{e2}}}$$
4. The radius of the MCURVE is calculated using
$$R = \frac{3\lambda_g}{4\pi}$$
5. The electrical length of microstrip line is calculated using
$$l = \frac{\theta}{\sqrt{\epsilon_e}k_0} \quad where \quad k_0 = \frac{2\pi f}{c}$$

Thus the following values are obtained. (Note that these are the values before tuning.)

| Parameter | Value |
|---|---|
| W1 | 1.49192 mm |
| W2 | 0.768724 mm |
| L1 | 13.7233 mm |
| L2 (R) | 13.5 mm |
| L3 | 14.805 mm |

Here, a different value for L3 was used, which is the radius of the MCURVE of electrical length $\frac{3\lambda}{4}$, since the ring formed gaps during the simulation process.

After tuning, the values obtained are shown in the table below.

| Parameter | Value |
|---|---|
| W1 | 1.477 mm |
| W2 | 0.759 mm |
| L1 | 13.7233 mm |
| L2 | 11.5 mm |
| L3 | 12.78 mm |

The tuning was done due to the optimum operating frequency not being the required value of 3 GHz initially.

# Chapter 4: Results

The results of the hybrid coupler comprise of the performance at or near the required operating frequency. The desired results should be

- Low reflection
- Low VSWR
- Equal splitting of input signal when used as a power divider
- Accurate sum and difference when used as a power combiner

The obtained results are given below.

## 4.1 Results obtained during simulation

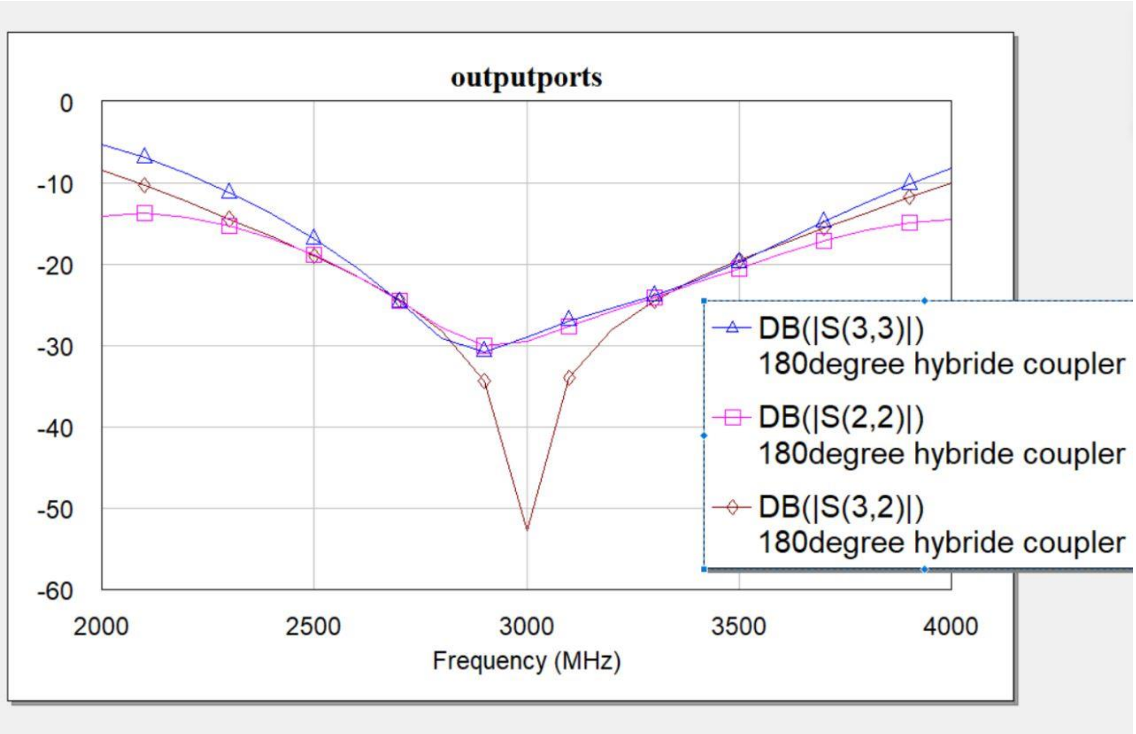



**Fig 4.1: Gain values of output ports**

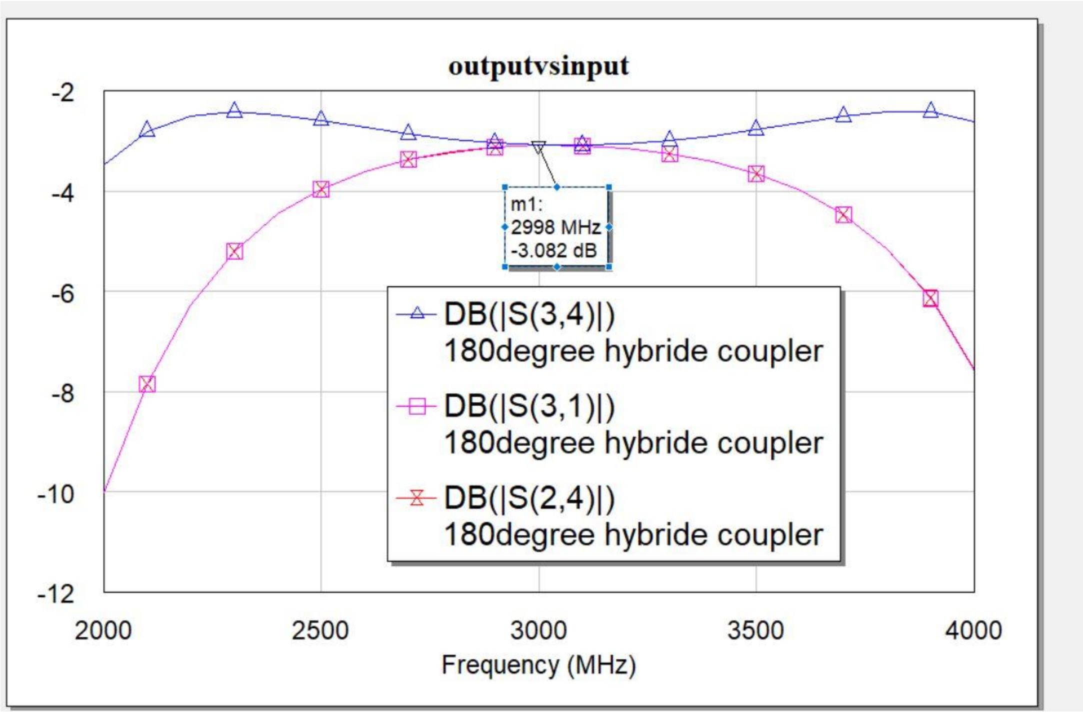



**Fig 4.2: Input v/s output gain values**

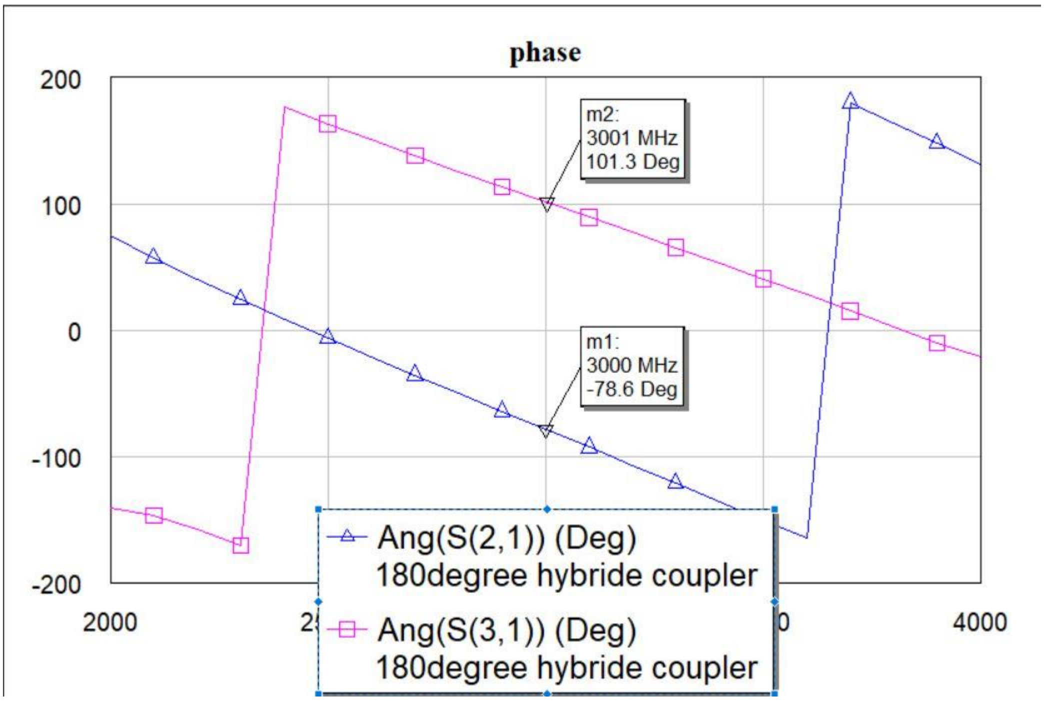



**Fig 4.3: Phase difference of output ports**

## 4.2 Results obtained after fabrication


**Fig 4.4**

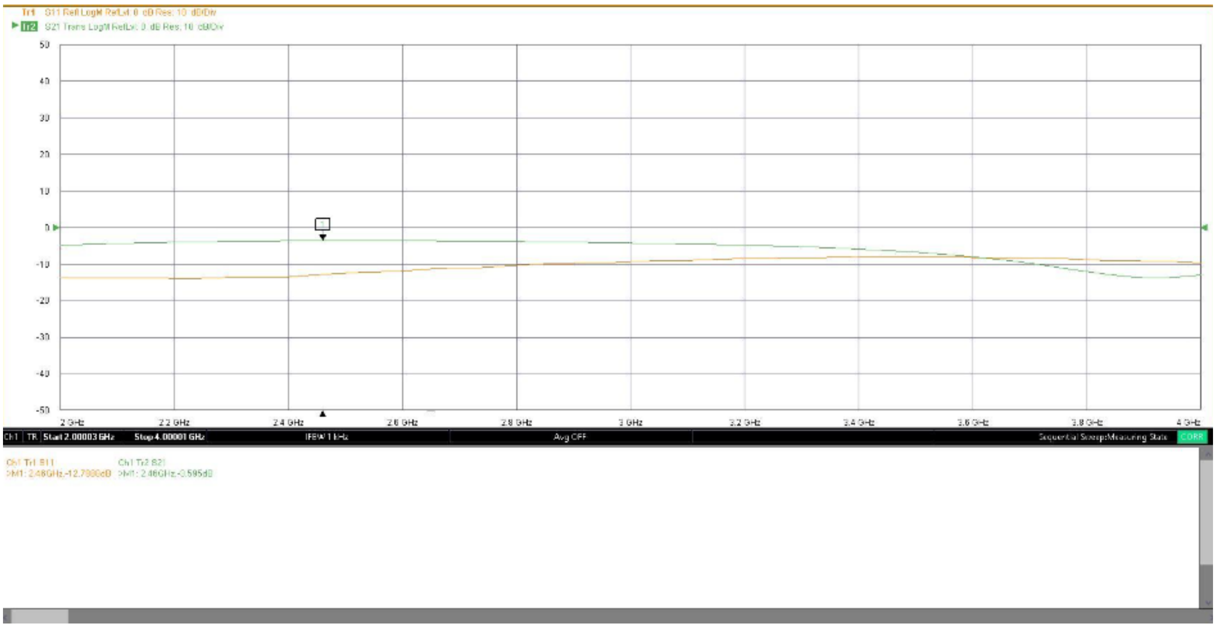



**Fig 4.5**

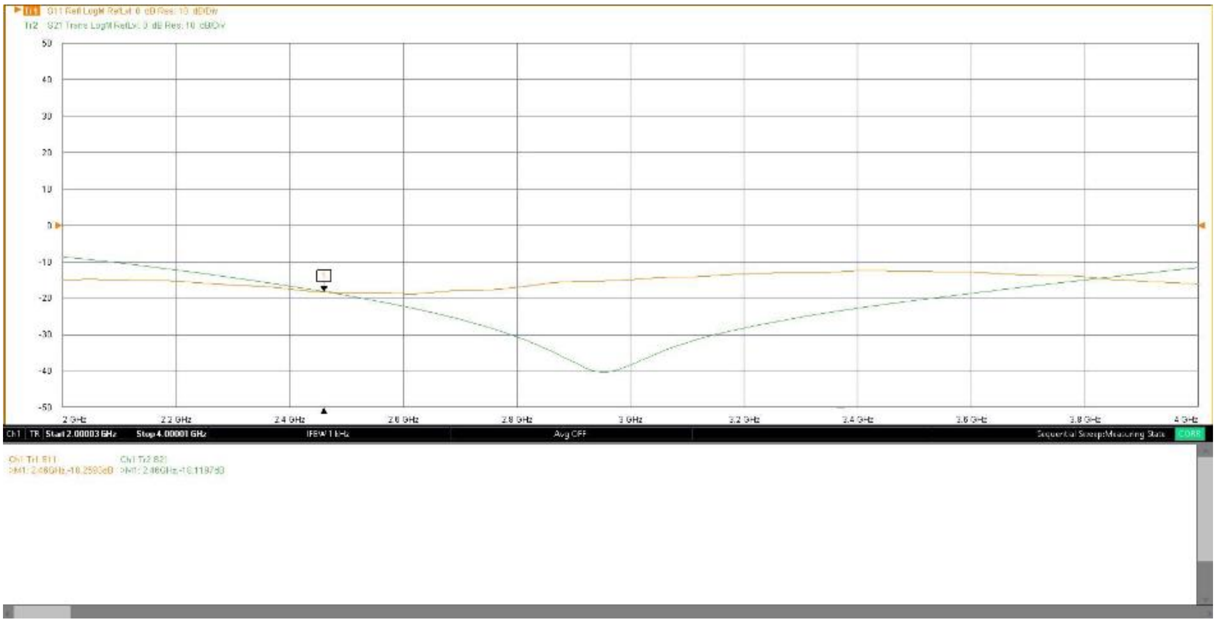



**Fig 4.6**

## 4.3 Significance of the obtained results

As can be seen in the above graphs, there is very less reflection but high transmittance. This is what is required because there should be no loss of power. Most of the power is being transmitted from the input ports to the output ports.

There are especially satisfactory results at 3 GHz, which is our operating frequency. In the input v/s output graph (Fig 4.2), the gain at 3 GHz is -3 dB, which shows that the power is being split equally across the output ports. In the preceding graph (Fig 4.1), it can be observed that there is low reflection. From Fig 4.3, it is observed that the phase difference between the output ports is indeed 180 degrees. In the graphs obtained after fabrication, it is observed the hybrid coupler is working as intended, with low reflection and high transmittance.

# Chapter 5: Summary and Conclusions

The concept of hybrid coupler was understood through the course of this project. The reasoning behind the name "180-degree phase shift coupler" was made clear. The other concepts that were understood were power division, combination and isolation of ports and the advantages and applications of the rat-race coupler in the real world.

The scattering matrix was obtained using even-odd analysis to describe the hybrid coupler's behavior.

The coupler was then designed on AWR Microwave Office. The software's line calculator tool was utilized to arrive at the microstrip line parameters (length and width of the microstrip lines). The values matched the calculations made using the microstrip line formulae. The results were obtained post simulation.

The coupler was then fabricated with the help of a PCB machine manufactured by MITS Electronics. The fabrication was completed in 30 minutes. After fabrication, four connectors were soldered to the coupler to serve as its four ports. The ports were connected to a 43.5 GHz Vector Network Analyzer (model: MS46524B) manufactured by Anritsu Results to obtain results.

In the results, low reflection and VSWR, equal splitting of input signal (when used as a power divider), and an accurate sum and difference (when used as a power combiner) were expected.

As expected, it was concluded from the results of both post simulation and post fabrication that there was less reflection, but high transmittance, leading to no loss of power from the input to output ports. The input v/s output graph showed that the gain was 3 dB at 3 GHz frequency indicating an equal split of power between the output ports.

# Chapter 6: Literature Cited

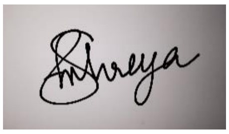

1. David Pozar, “Microwave Engineering”, 4th edition, John Wiley & Sons, 2012
2. Samuel Y. Liao, “Microwave devices and circuits” 3rd ed., PHI 2008
3. Annapurna Das and Sisir Das, “Microwave Engineering,” TMH 2009
4. De Ronde F.C. (1970), “A new class of microstrip directional coupler”, IEEE Int. Microwave Symp. Dig., pp.184 -189
5. Geoff H. Bryant, Principles of Microwave Measurements, Institution of Electrical Engineers, 1993

## Declaration of the Student

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources.

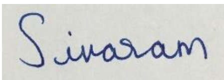
I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission.

I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Signature of the student 

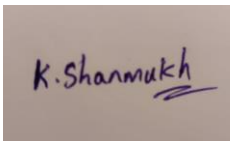

Shreya Muralikrishna

Roll no 79

Signature of the student 


Sivaram Padmasola

Roll no 80

Signature of the student 


Kolli Shanmukh

Roll no 81

Date: 30.11.2022