GYSEL POWER DIVIDER

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Introduction

Microwave systems have played a significant role in the past century. They were used in different applications, especially in the field of communication through data and power delivery. Microwave systems have two types of components which are passive components and active components.

In this report, we will discuss more one of the passive circuits' applications in microwave systems which is the power divider/combiner. The growing demand for compact and low-cost components in RF and microwave systems is attracting more attention resulting in the development of the use of microwave transmission lines. The power dividers are one of the implementations of microwave circuits that focus on the signal division into two or more ports through the use of transmission lines. There are many types of power dividers for example, there is the Wilkinson power divider, Rat race, and the Gysel which will be discussed more in this report.

The Gysel power divider was developed by Ulrich Gysel and released in a paper published by IEEE in 1975. The Gysel was designed as a mixture between the Wilkinson power divider and the Rat race resulting in a unique combination with some great features. These features are the high isolation between the output ports through a shunted resistance, low insertion loss, and matched conditions at all ports.[1] These features make it a popular choice for high-frequency systems where signal quality and reliability are critical.

The gysel is used as an N-way power splitter (divider) that results in output signals that will be two equally divided signals at the output ports. This power divider is based on the principle of quarter wave transformers to transform the input impedances to the desired value.

We will be designing a Gysel for an antenna application that will be used to produce two equally divided signals on the output ports with high isolation between these two outputs in addition to input and output matching at 50 Ohms.

In this report we will start with the problem description and the main target then the proposed design through which we will elaborate on the design required to fulfill the power division the results through which all graphs and results will be attached.

Problem description

The theory behind gysel:

Gysel power divider looks like a cross between a branch line and a Wilkinson, but it is also closely related to the rat-race coupler. The solution of gysel power divider came up when they wanted to solve the main problem in Wilkinson. This problem is that the lumped resistor in Wilkinson limits the power handling capability because the adequate heat sinking of the lumped resistor is not possible. That is why the Wilkinson divider cannot be used in high-power applications. So gysel solved this by replacing the lumped resistor in Wilkinson with TLs network and 2 external loads. The Gysel allows the two external resistors to be measured in parallel, so it is easy to realize good thermal performance unlike Wilkinson the resistor is embedded into the network. [2] [3]

Description of process:

1. **Input signal:** The Gysel power divider receives a single input signal at one of its ports (the input port "TermG1").
2. **Impedance matching:** The input signal is impedance-matched to the characteristic impedance of the divider (which equals 50 Ω) to minimize reflections and optimize power transfer.
3. **Branching:** The input signal is then split into two branches, each of which is connected to one of the output ports. (The values are chosen to achieve equal power division)
4. **Resistive load:** A resistive load is connected to each of the output ports, it should be matched to the characteristic impedance of the divider and both loads have the same value (which equals 50 Ω) to divide the power equally among them.
5. **Phase adjustment:** A quarter-wave transmission line ($\lambda/4$) is added to one of the branches to adjust the phase of the output signals. The length of the transmission line is chosen to provide a 90-degree phase shift at the center frequency of operation which ensures that the output signals are in phase with each other.
6. **Output signals:** The Gysel power divider produces two output signals, each with the same power level as the power is divided equally among the two similar resistive loads.

<u>Proposed Design:</u>[2]

This design works at full efficiency at 2.4 GHz splitting power into two equal ports terminated at matched load 50 Ω.

Ideal transmission line:

We focused on a microstrip antenna application based on a (1:1) Gysel power divider and started the design in its ideal case using:

1. Frequency= 2.4 GHz.
2. S-parameters with start = 0 GHz, stop = 5 GHz, and step = 0.05 GHz.
3. Four Ideal transmission lines with 90 degrees (TL2 & TL3 = 50*sqrt (2) Ω) & (TL4 & TL7 = 50 Ω)
4. Two ideal transmission lines with 90 degrees (TL5 & TL8 = 50*sqrt (2) Ω).
5. Input and output ports of characteristic impedances= 50Ω.
6. Two matched loads of characteristic impedances= 50Ω.

The design has satisfied the following:

1. Isolation between output ports using the isolated resistances R1 and R2 as shown in Fig.1
2. Input and output matching.

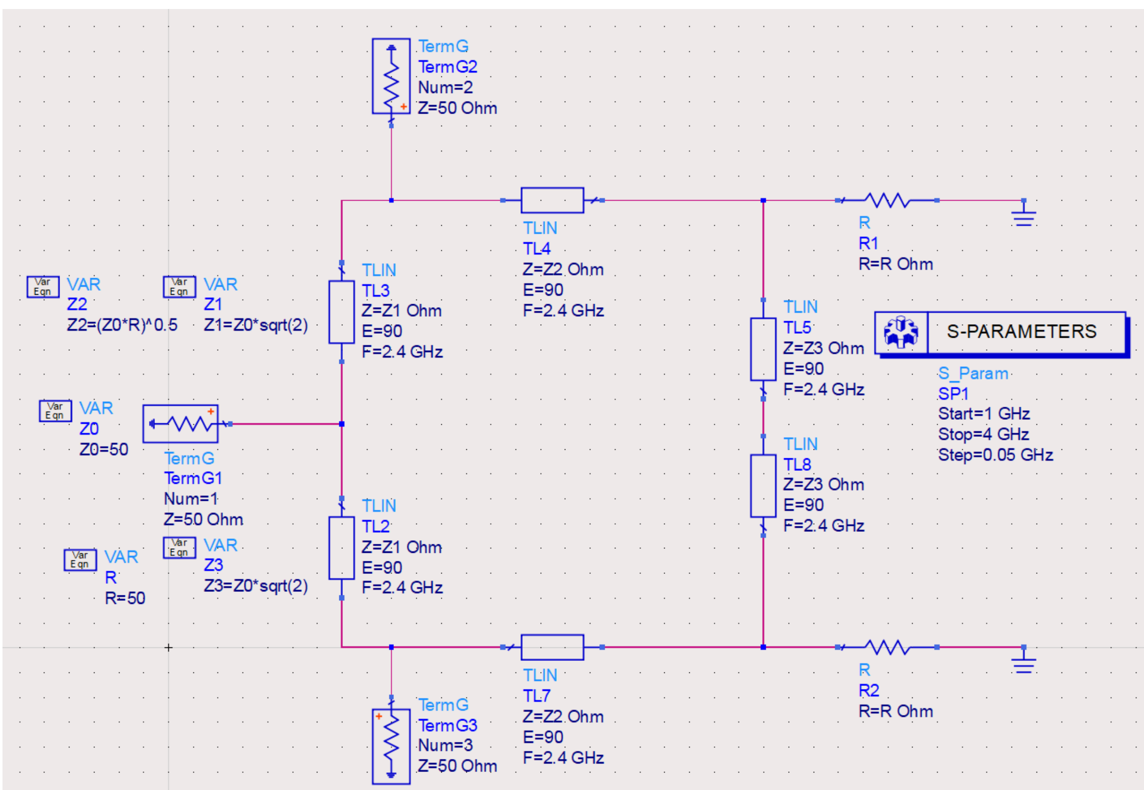

Fig 1 Ideal Schematic of Gysel power divider

Microstrip Implementation:

Then replace the ideal transmission lines with real microstrips based on Rogers 4003C substrate with the following parameters: [4]

H	0.41mm
ϵ_r	3.38
μ_r	1
conductivity	5.8e7
Hu	16.997mm
T	35u
TanD	0.0021

Table 1: Substrate parameters

Using:

1) 6 Non-Ideal TLs and we calculated their lengths and widths to satisfy specific impedances for each one as we used in the ideal case such that:
   (TL1 & TL2 =50*sqrt (2) Ω),
   (TL4 & TL5 =50 Ω)
   (TL6 & TL10 = 25*sqrt (2) Ω).
   So, the calculations done by the line calculator show that the lengths and widths are:
   - L=19.27mm, W=0.9mm for TL4 & TL5 as it as shown in Fig.2
   - L=19.8mm, W=0.48mm for TL1, TL2, TL6 & TL10. it as shown in Fig.3

2) 3 Non-Ideal TLs for the input and output ports of L=19.27mm, W=0.9mm to satisfy a characteristic impedance of 50 Ω.
3) 3 MTEE whose widths match that of the connected TLs to it as shown in Fig.4

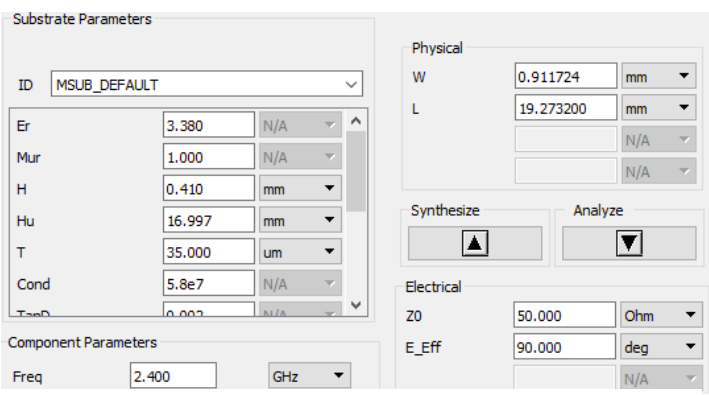

Fig 3 Line Calculator for 50 Ohms

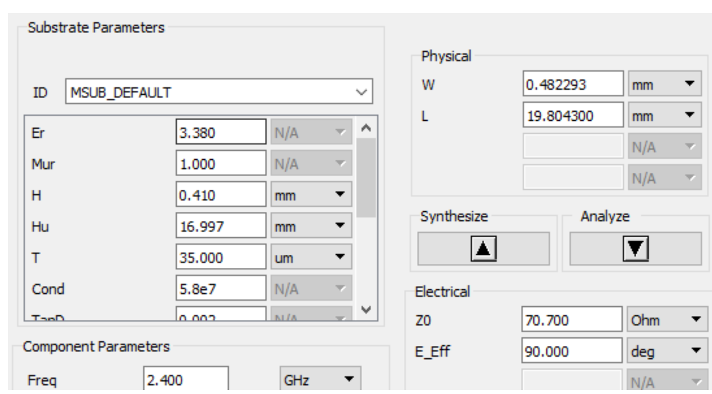

Fig 2 Line Calculator for 70.7 Ohms

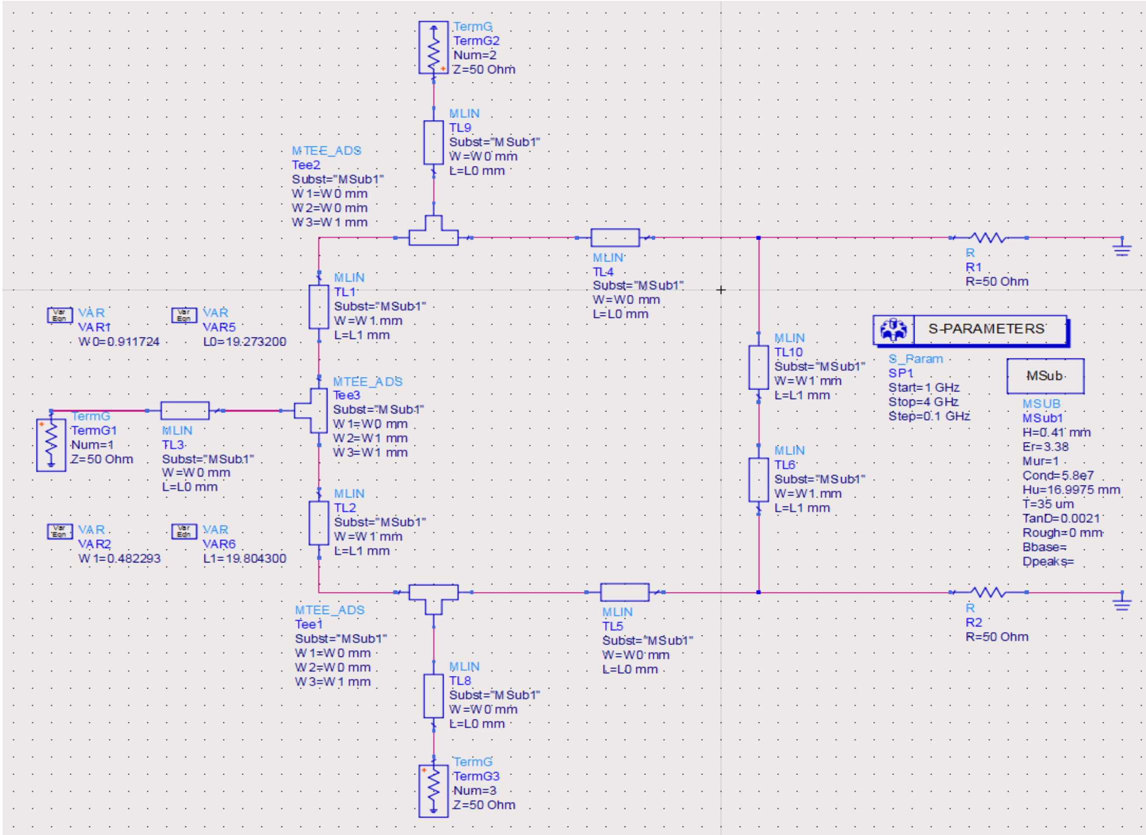

Fig 4 Non-Ideal Gysel power divider Schematic

Results

In this section we aim to investigate the performance of the Gysel power divider by representing the simulation results of the ideal transmission line and microstrip models.

Return loss:

We will establish a criterion for the accepted return loss, which should be greater than or equal to -15 db. This criterion serves as a threshold to determine whether the device meets our requirements. We will focus on the optimal frequency of 2.4 GHz and measure the return loss at this frequency. Additionally, we will observe the bandwidth that satisfies the desired return loss. This bandwidth, which fulfills the required return loss, will be defined as the return loss bandwidth. The scattering parameter **S_{11}** will represent the return loss value. The graph shown in Fig.5 shows the comparison between ideal and non-ideal simulation.

Return loss $_{dB}$= S_{11}

	Ideal	**Microstrip implementation**
Return loss bandwidth	2.1=>2.7 GHz	2.09 => 2.7 GHz
Return loss @ 2.4 GHz	325 dB	51.29 dB

Table 2: Return loss bandwidth for ideal and microstrip implementation.

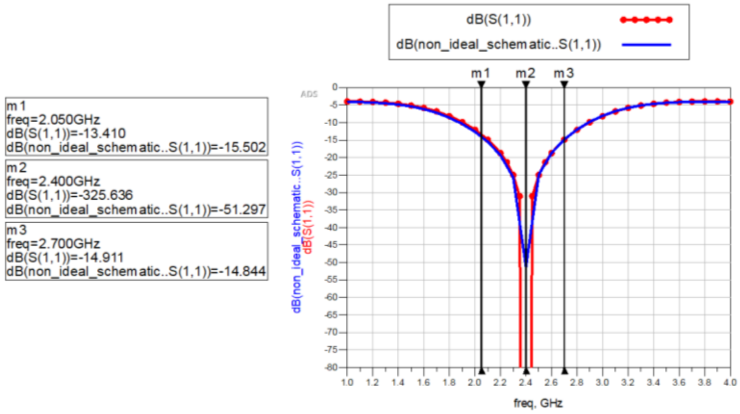

Fig 5 Return loss for Ideal and microstrip implementation.

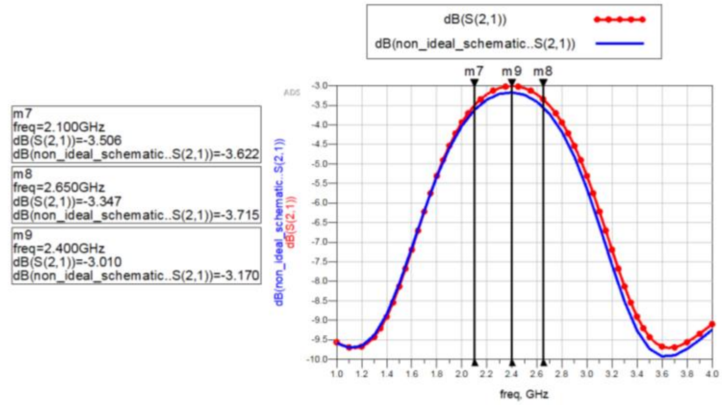

Fig 6 Insertion loss for Ideal and microstrip implementation

Insertion loss:

The primary function of this device is to evenly distribute power across its two output ports. In our application, we expect an ideal insertion loss of 3dB. However, due to the inherent losses associated with the microstrip implementation, the actual insertion loss will be higher, to ensure the acceptable performance of the power divider, we establish a criterion for the insertion loss. It should be greater than or equal to 3.5dB. This criterion serves as a threshold for determining whether the device meets our requirements, we will focus on the optimal frequency of 2.4 GHz and measure the return loss at this frequency. Additionally, we will observe the bandwidth that satisfies the desired insertion loss. This bandwidth, which fulfills the required return loss, will be defined as the insertion loss bandwidth. The scattering parameters $\mathbf{S_{21}}$, $\mathbf{S_{31}}$ will represent the insertion loss value.

Insertion loss $_{\mathbf{dB}}$= $\mathbf{S_{21}}$

	Ideal	**Microstrip implementation**
Insertion loss bandwidth	2.1 => 2.7 GHz	2.14 => 2.64 GHz
Insertion loss @ 2.4 GHz	3.01 dB	3.17 dB

Table 3: Insertion loss bandwidth for ideal and microstrip implementation

From Fig. 6 we have estimated the insertion loss at 2.4 GHz and the insertion loss bandwidth for ideal case and microstrip implementation as in Table 3.

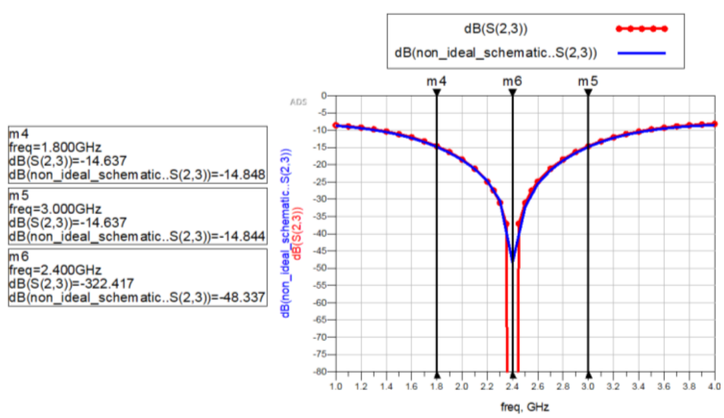

Fig 7 Isolation loss for Ideal and microstrip implementation

Excess loss:

We will examine the concept of excess loss in relation to the insertion loss and the ideal splitting loss, which is 3dB. Excess loss is defined as the difference between the insertion loss and the ideal splitting loss. Based on the defined acceptable value of the insertion loss, which is 3.5dB, we can establish that an acceptable value for the excess loss would be 0.5dB

Excess loss $_{dB}$= S_{21} - 3dB

Isolation loss:

Two shunt resistors are used to isolate the output ports, we will test the output port isolation performance by establishing a criterion for the accepted Isolation, which should be greater than or equal to 15 dB, the spectrum of frequencies which satisfy the criterion will be defined as Isolation bandwidth.

Isolation $_{dB}$= S_{23}

	Ideal	**Microstrip implementation**
Isolation loss bandwidth	1.8 => 2.98 GHz	1.8 => 3 GHz
Isolation loss$_{@2.4GHz}$	322.42 dB	48.33 dB

Table 4: Isolation loss bandwidth for ideal and microstrip implementation

From Fig. 7 we have estimated the isolation loss at 2.4 GHz and the isolation loss bandwidth for ideal case and microstrip implementation as in Table 4.

Bandwidth:

The overall bandwidth that will achieve the Gysel power divider requirements, will be the intersection of the return loss bandwidth, the insertion loss bandwidth, and the Isolation loss bandwidth, this will ensure that the device will perform properly at this bandwidth.

From Table 2, 3, 4 we can conclude that the overall bandwidth for the ideal case equals 2.1=> 2.7 GHz and for microstrip implementation equals 2.14 => 2.64 GHz

Summary of results:

@2.4 GHz	**Bandwidth**	**Return loss**	**Excess loss**	**Isolation loss**
Ideal transmission line	2.1 => 2.7 GHz	325 dB	0.01 dB	322.42 dB
Microstrip schematic	2.14 =>2.64 GHz	51.29 dB	0.17 dB	48.33 dB

Table 5: Summary of results

The acquired bandwidth in Table 5 will achieve a Return loss, Isolation loss > 15dB and an Excess loss < 0.5dB

Conclusion:

The designed Gysel power divider utilizing the microstrip technology of Rogers 4003C has demonstrated exceptional performance. The obtained results exhibit a remarkable level of comparability to the ideal case.

The designed Gysel power divider proves to be particularly well-suited for applications operating at 2.4 GHz, such as the even power splitting to two microstrip antennas. Its optimized performance in this frequency range makes it an ideal choice for such applications.

Layout:

A detailed documentation will be added to the report, regarding the performance of the designed layout, An EM Simulation will be made, so a more practical and accurate results will be approached.

Extra Diagrams and Graphs

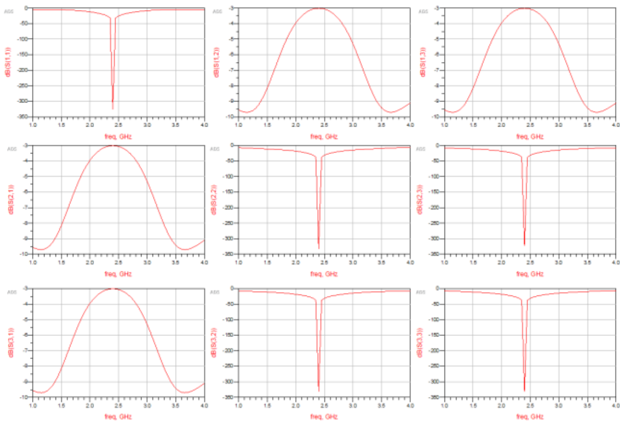

Fig 9 S parameters Matrix simulation for Ideal schematic

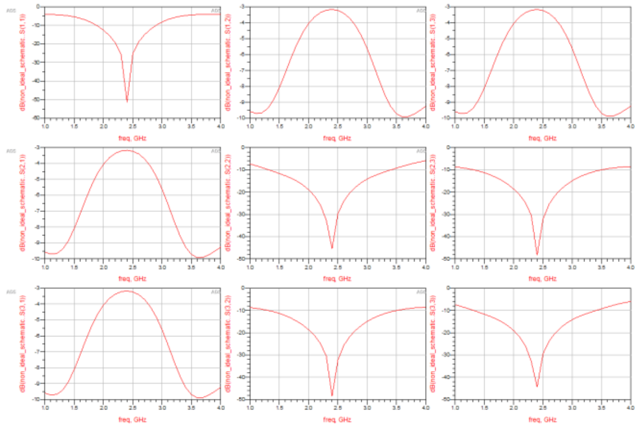

Fig 8 S parameters Matrix simulation for non-Ideal schematic

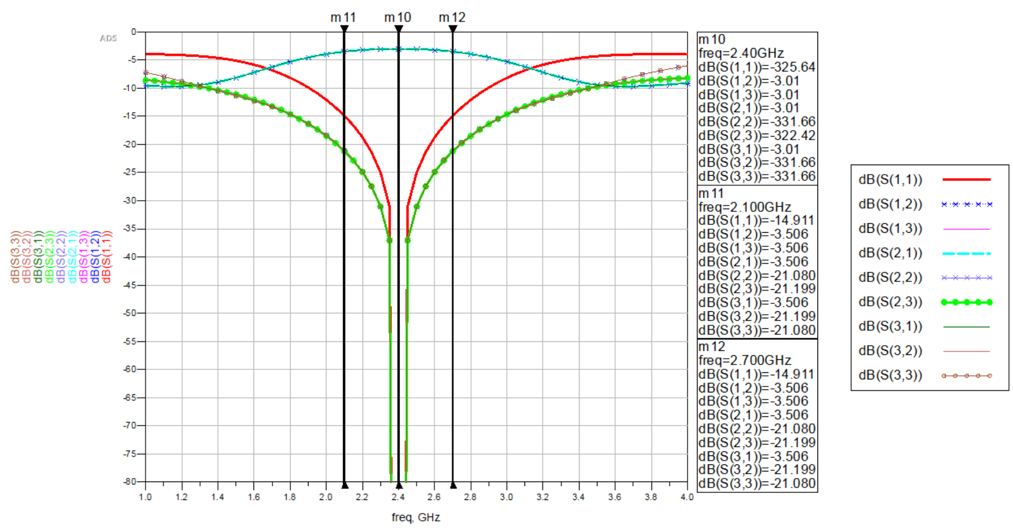

Fig 10 S parameters simulation for ideal schematic

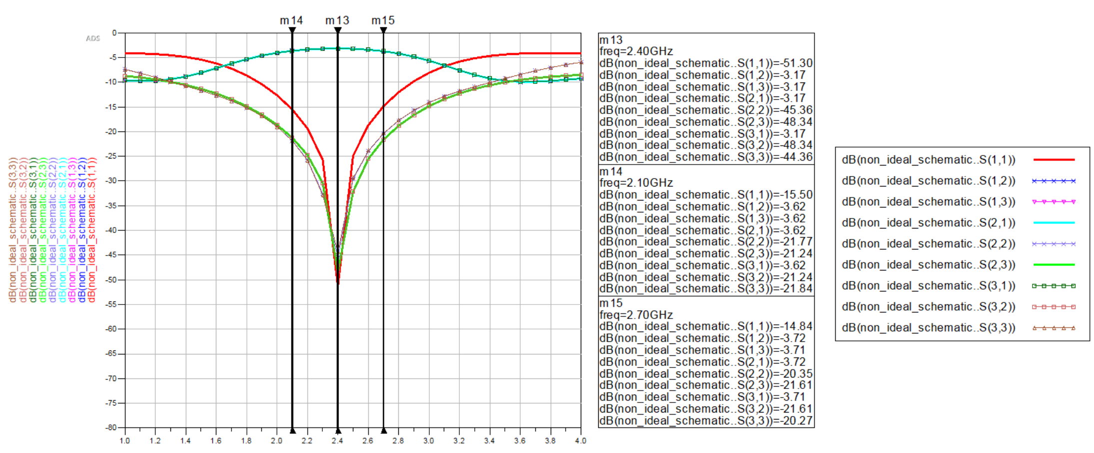

Fig 11 S parameters simulation for non-ideal schematic

References

[1] Ulrich Emanuel Gysel, "A New N-Way Power Divider/Combiner Suitable for High-Power Applications," *IEEE*, May 1975, doi: https://doi.org/10.1109/mwsym.1975.1123301.

[2] "Microwaves101 | Gysel Power Splitter," *Microwaves101.com*, 2019. https://www.microwaves101.com/encyclopedias/gysel-power-splitter

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[4] "RO4000® Series High Frequency Circuit Materials." Accessed: May 21, 2023. Available: https://www.rogerscorp.com/-/media/project/rogerscorp/documents/advanced-electronics-solutions/english/data-sheets/ro4000-laminates-ro4003c-and-ro4350b---data-sheet.pdf