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Design of Impedance Matching Circuit

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Abstract:

This report explains the intuitive technique for designing the impedance matching circuit. Impedance is the opposition by a system to the flow of energy from a source. For constant signals, this impedance can also be constant. For varying signals, it usually changes with frequency. The energy involved can be electrical, mechanical, magnetic or thermal. The concept of electrical impedance is perhaps the most commonly known. Electrical impedance, like electrical resistance, is measured in ohms. In general, impedance has a complex value; this means that loads generally have a resistance component (symbol: R) which forms the real part of Z and a reactance component (symbol: X) which forms the imaginary part of Z . For maximum efficiency impedance matching is very essential.

1. Introduction

In electronics, impedance matching is the practice of designing the input impedance of an electrical load or the output impedance of its corresponding signal source to maximize the power transfer or minimize signal reflection from the load.

1.1. Maximum Power Transfer Theorem

Designing circuits involves the efficient transfer of the signals. In the early days of electric motors, it was found that to get the most efficient transfer of power from the battery (source) into the motor (load) required that the resistance of the different parts of the circuit be the same, in other words, matched; this is known as the maximum power transfer theorem. For DC circuits, maximum power will be transferred from a source to its load if the *load resistance* equals the *source resistance*. A simple proof of this theorem is given by the following example:

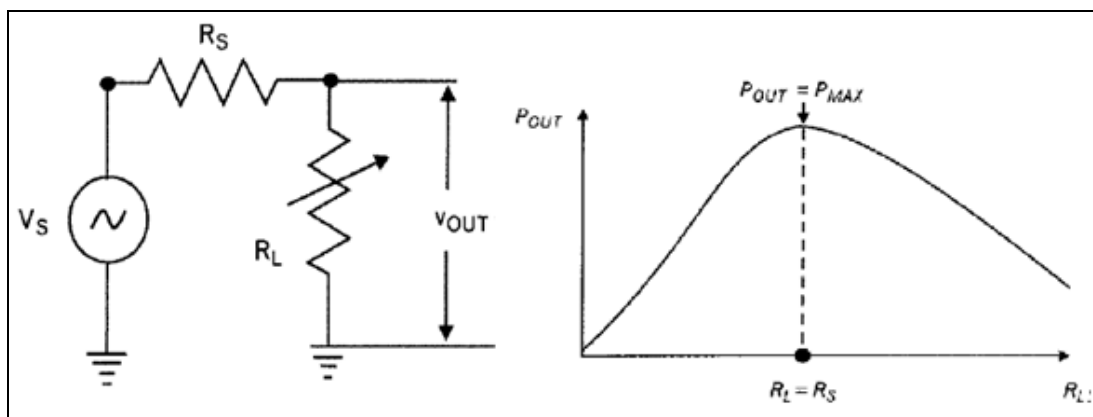


Figure 1: The circuit and graph to prove the condition for maximum power transfer.

$$v_{OUT} = \frac{R_L}{R_S + R_L} (v_S)$$

$$P_{OUT} = \frac{v_{OUT}^2}{R_L} = \frac{\left(\frac{R_L}{R_S + R_L}\right)^2}{R_L} (v_S^2)$$

$$= \frac{R_L}{(R_S + R_L)^2} (v_S^2)$$

2. Impedance Matching

Impedance Matching was originally developed for electrical power, but can be applied to any other field where a form of energy (not necessarily electrical) is transferred between a source and a load. The first Impedance Matching concept in RF domain was related to antenna matching. Designing an antenna can be seen as matching the free space to a transmitter or receiver. Impedance Matching is always performed between two specified terminations. The main purpose of Impedance Matching is to match two different terminations (R_{source} and R_{load}) through a specific pass-band, without having control over stop-band frequencies. We may assume that component losses are negligible but parasitic effects need to be considered.

The main role in any Impedance Matching scheme is to force a load impedance to “look like” the complex conjugate of the source impedance, and maximum power can be transferred to the load. When a source termination is matched to a load with passive lossless two-port network, the source is conjugated matched to the input of the network, and also the load is conjugate matched to the output of the network. Any reactance between R_s and R_L reduces the current in R_L and with it the power dissipated in R_L . To restore the dissipation to the maximum that occurs when $R_s = R_L$, the net reactance of the loop must be zero. This occurs when the load and source are made to be complex conjugates one of another, so they have the same real parts and opposite type reactive parts. If the source impedance is $Z_s = R + jX$, then its complex conjugate would be $Z_s^* = R - jX$.

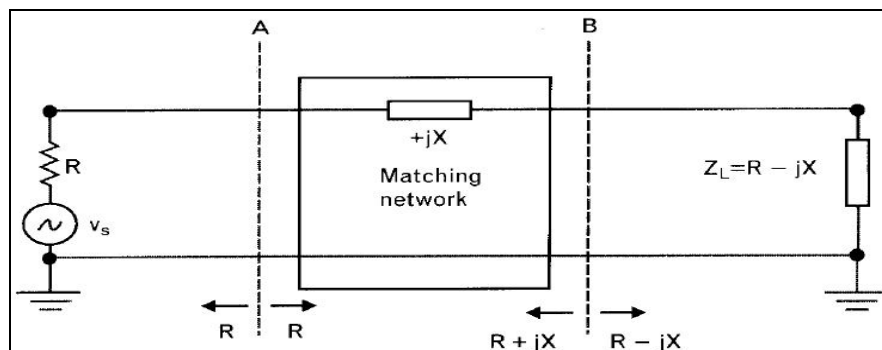


Figure 2: Impedance Matching of a resistive source and a complex load for maximum power transfer

Using only one series reactive element between two equal resistive terminations creates a voltage drop that reduces the voltage across the load. Impedance Matching can eliminate or minimize the unwanted reactance through a range of frequencies. The matching process becomes more difficult when real parts of the terminations are unequal, or when they have complex impedances. The second reason is device protection – If RF circuit is not matched we get reflected power. This reflected power builds standing waves on the transmission line between the source and load. Depending on the phase between the forward and reflected both waves can either subtract or add. Because of that on the line we can get places where the voltage is the sum of both voltages or eventually places where the voltage equals zero (maximum current). If the standing wave is positioned in such a way on the transmission line so that the maximum voltage or current is applied to the power FET's they can be destroyed.

2.1. Impedance matching using L-C Section

Any two resistive terminations can be simultaneously matched by adding two reactive elements between them.

If we need to match in a narrow frequency a source R_s and a load R_L , we can get almost the same performance by using a high-pass or low-pass network configuration. The pass-band performances near the matching frequency are very similar for both networks,

when the out-of-band characteristics of the low-pass and high-pass are different. A low-pass rejects signals at the high-end, and allow passing at low frequencies. The high-pass network does the opposite.

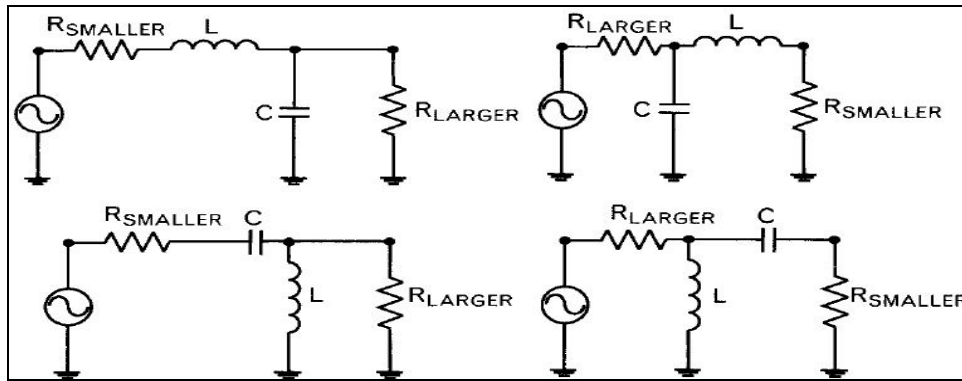


Figure 3: Four possible single matching L-C networks

2.2. Impedance matching with Transmission lines using Smith Chart

Smith Chart is a good choice when Impedance Matching is done using transmission lines.

- Cascading transmission lines always follow a clockwise rotation on the Smith Chart.
- Moving away from a termination on a transmission line, always follow a clockwise circular rotation on the Smith Chart.
- If the chart is normalized to the characteristic impedance of the transmission line, the rotation is a along a concentric circle.
- The radius of the concentric circle is determined by the normalized termination.

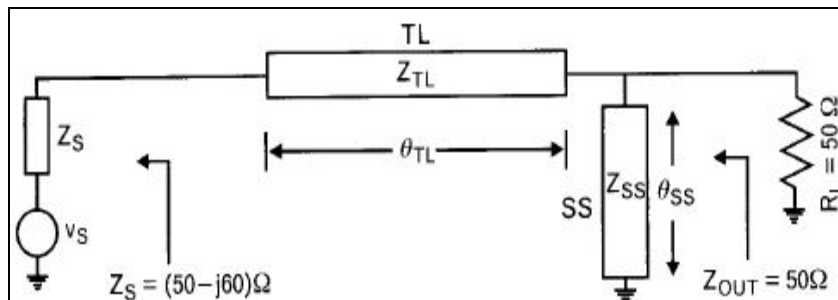


Figure 4: A complex source can be matched to the 50Ω load with a cascade series transmission line and a parallel short-circuited stub, there are 4 adjustable parameters: Z_{TL} , θ_{TL} , Z_{SS} , θ_{SS}

A parallel stub is treated as an equivalent parallel inductor or capacitor at specific frequencies, depending on what type of reactance it represents. If we use several cascade lines with different characteristic impedances, the Smith chart must always be renormalized to the appropriate impedance.

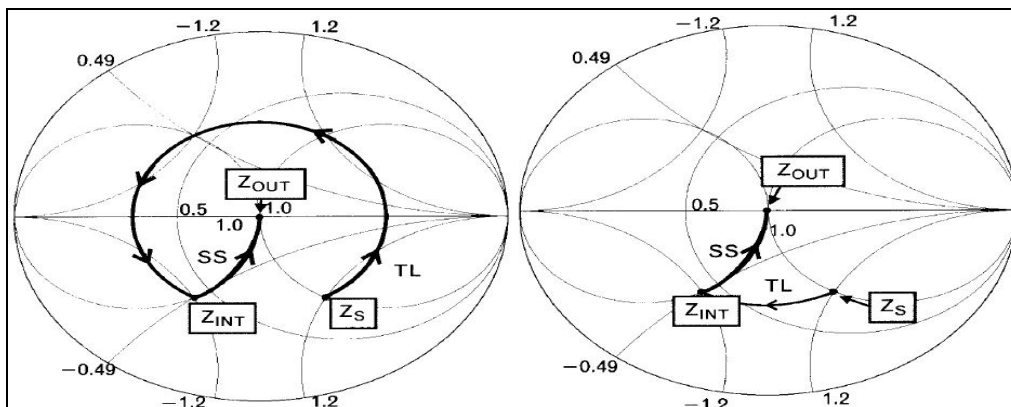


Figure 5: Smith Chart Alignment of Load And Source Impedance

Following a counter-clockwise rotation on the chart is equivalent to de-embedding, which is incorrect for this application. Moving away from any termination (source or load) with a transmission line, always leads to a clockwise rotation.

3. Basic Design Steps

1. Select the Smith Chart from Tools option. Then the following drop down menu will be displayed.

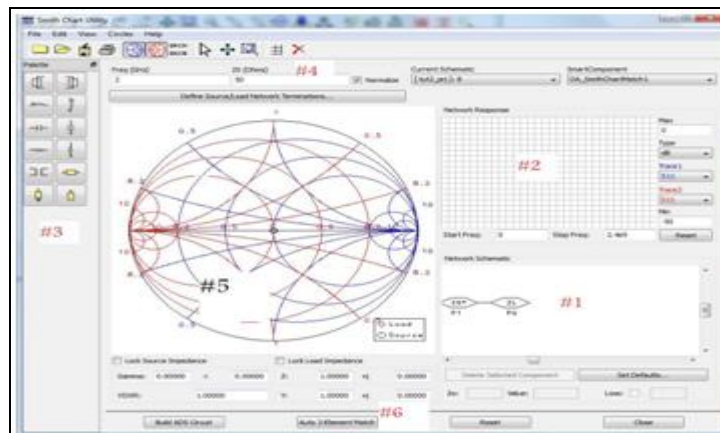


Figure 6: Smith Chart Utility Window

- This is the network schematic window.
- This is the plot window.
- These are the components we may add such as series inductor, series capacitor, etc.
- Main toolbar.
- The smith chart.
- This is where we set source and load impedance.

2. Select Z_s^* from #1 window and set the source impedance. Similarly, set the load impedance.

3. Now from window#3, add line length. This is a standard transmission line. Notice on the smith chart that your cursor draws the clockwise (toward the generator).

4. After selecting line length, make it almost half wavelength long. The cursor should draw almost a complete circle, and it should end up 'almost' back at the load.

5. Now, select an open circuit or short circuit stub, and again, make it long enough to draw out another, almost complete circle. Notice the path that cursor takes. Also, observe that our design (window#1) consists of load, line, stub, and source. Right now, your impedance is the pink square, but you want it to be at the center, to match the source.

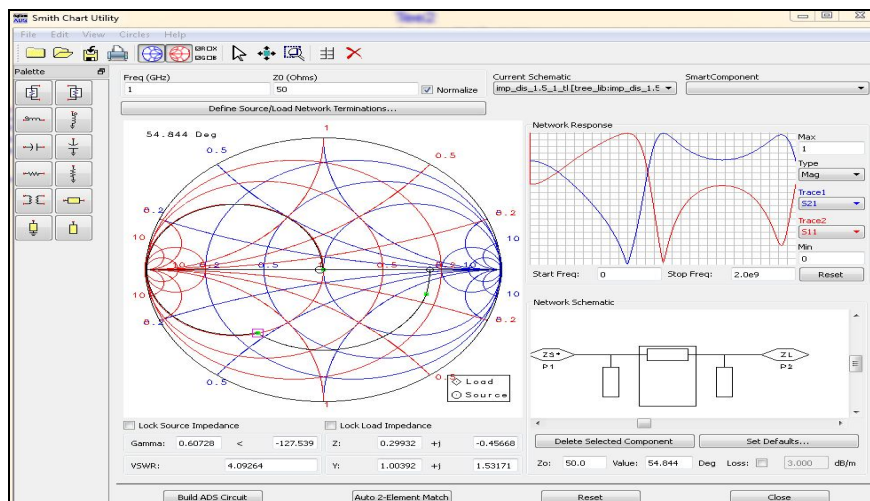


Figure 7: Smith Chart Utility Window with open stubs

6. In window #1, select the t-line. Now you can manipulate its length, either numerically below window #1, or graphically on the chart. As you change length, the circle drawn out by the stub moves along with the termination of the line. Reduce the t-line length until the 'circle' passes thru the origin. Like so:

7. Now, select the stub and reduce its length until you end up at the origin.

8. Using the LineCalc tool the length and width of corresponding transmission line is determined.

9. Now, using these values we draw the schematic of the impedance matching circuit. And then corresponding layout and graph can be eventually obtained.

4. Design Specifications for Different Impedance Matching Circuits

For $F_c = 1.5 \text{ GHz}$:

Source Impedance = 50 Ohms, Load Impedance = 200 Ohms (using MLOC):

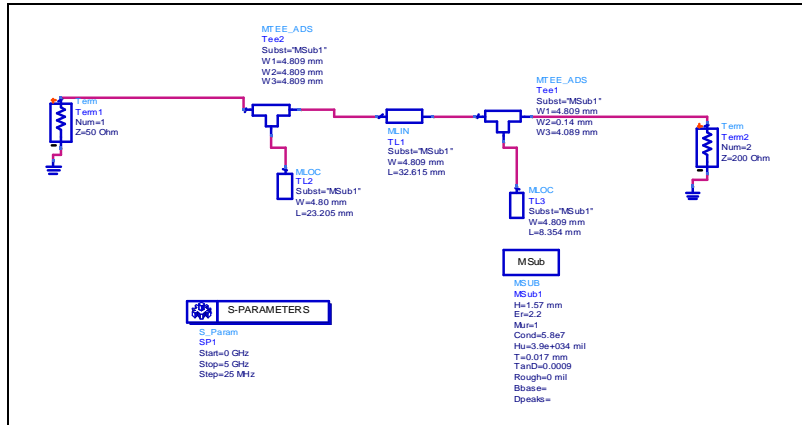


Figure 8: Schematic View

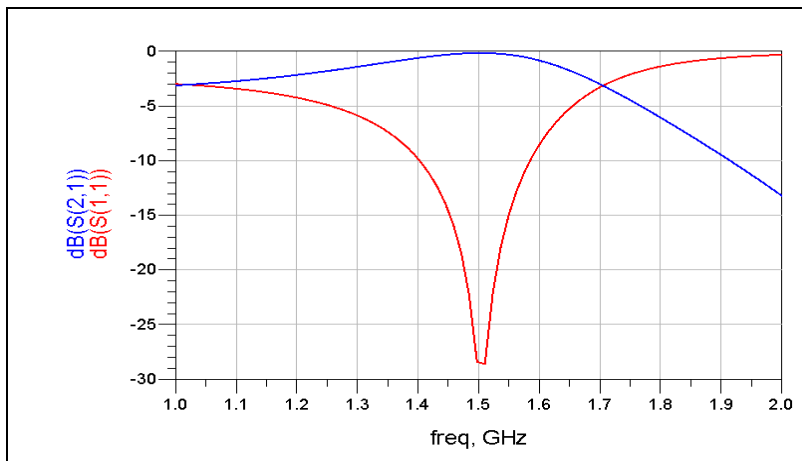


Figure 9: Output Graph

Source Impedance = 50 Ohms, Load Impedance = 200 Ohms (using MLSC)

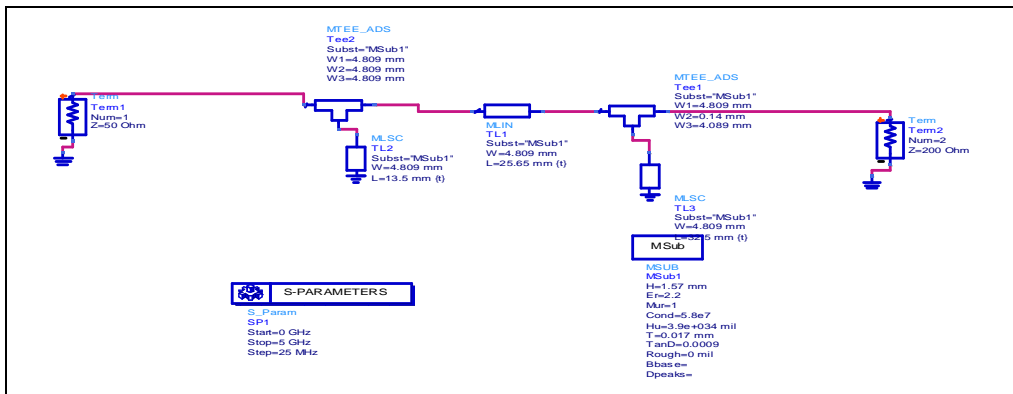


Figure 10: Schematic View

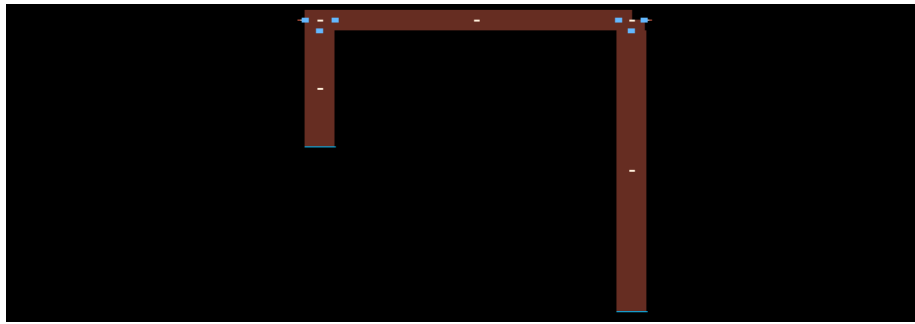


Figure 11: Layout View

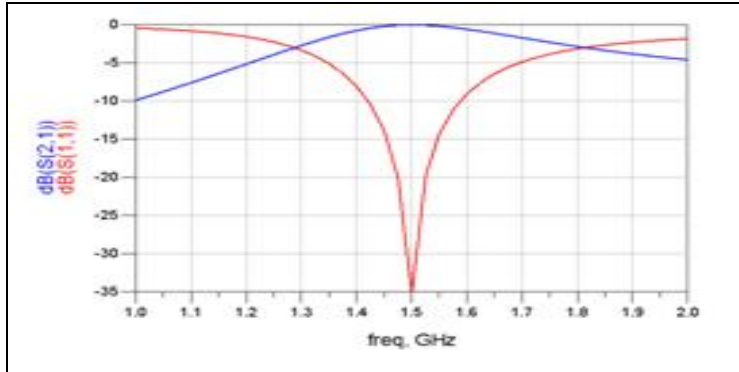


Figure 12: Output Graph

Source Impedance = 50 Ohms, Load Impedance = $120 + j \cdot 90$ Ohms (using MLOC)

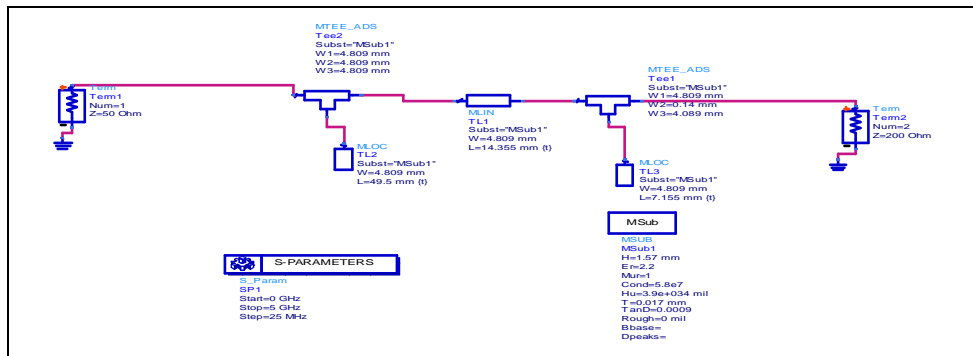


Figure 13: Schematic View

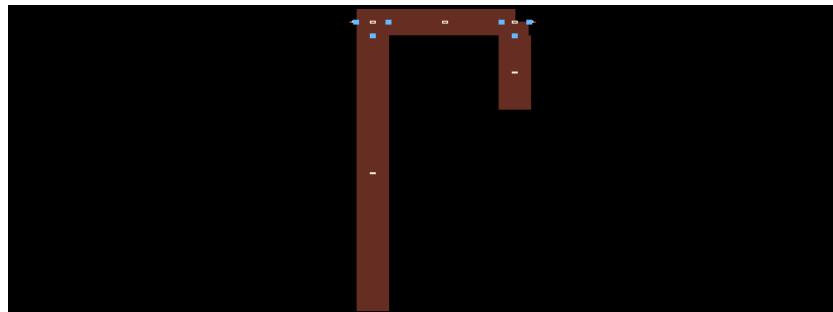


Figure 14: Layout View

Source Impedance = 50 Ohms, Load Impedance = $120 + j \cdot 90$ Ohms (using MLSC)

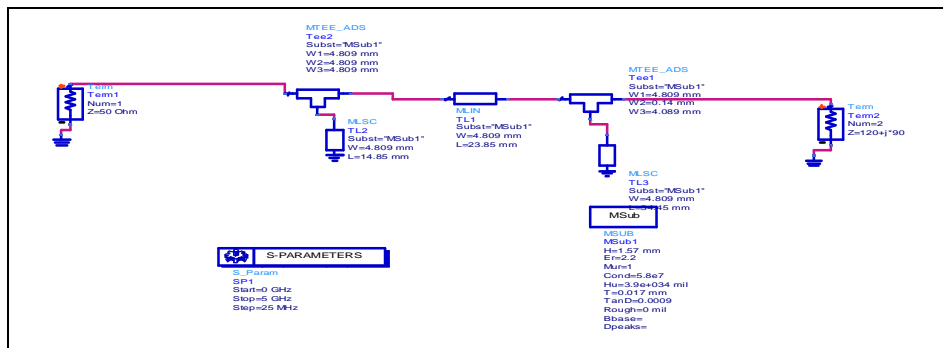


Figure 15: Schematic View

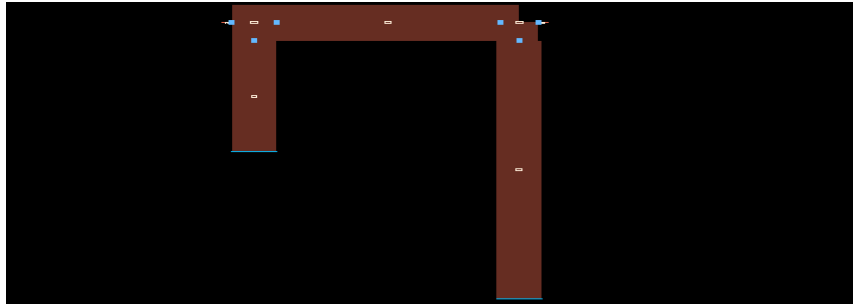


Figure 16: Layout View

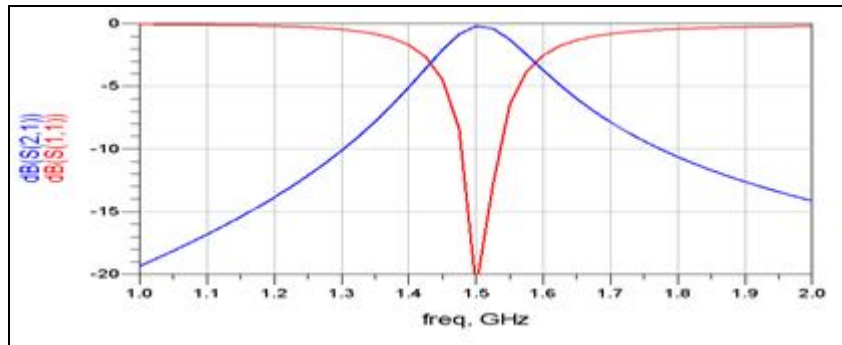


Figure 17: Output Graph

Source Impedance = 50 Ohms, Load Impedance = $141-j*12$ Ohms (using MLOC)

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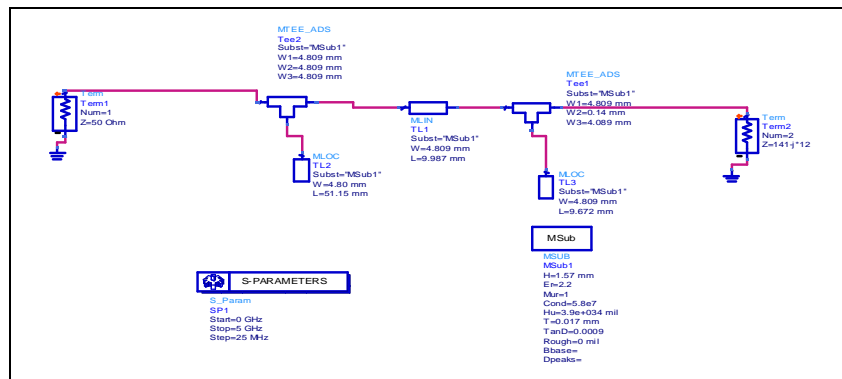


Figure 18: Schematic View

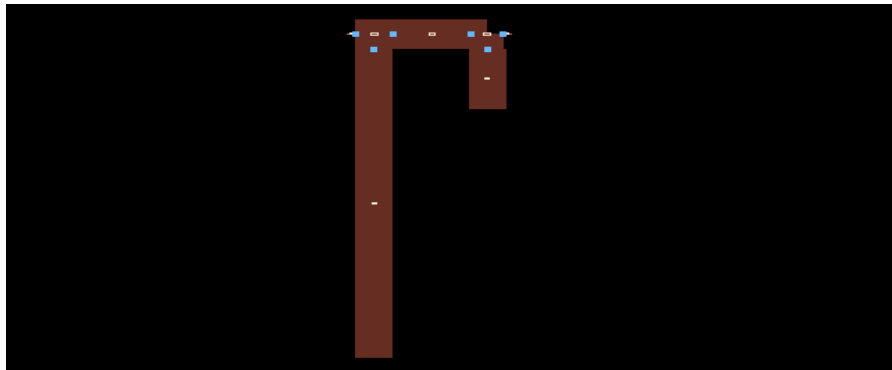


Figure 19: Layout View

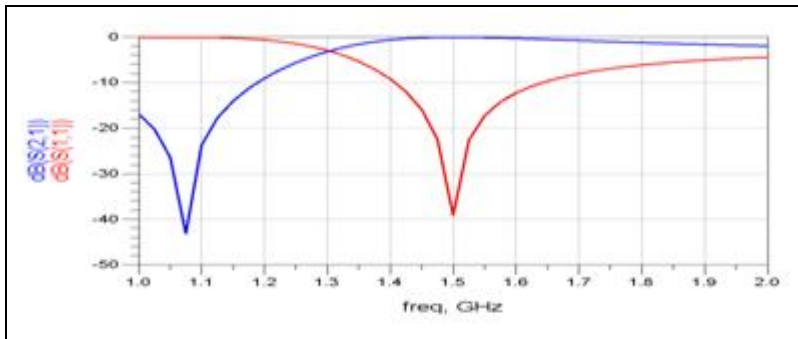


Figure 20: Output Graph

Source Impedance = 50 Ohms, Load Impedance = $141-j*12$ Ohms (using MLSC)

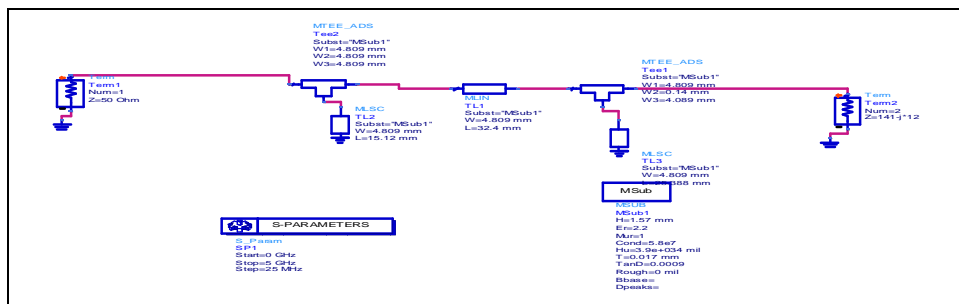


Figure 21: Schematic View

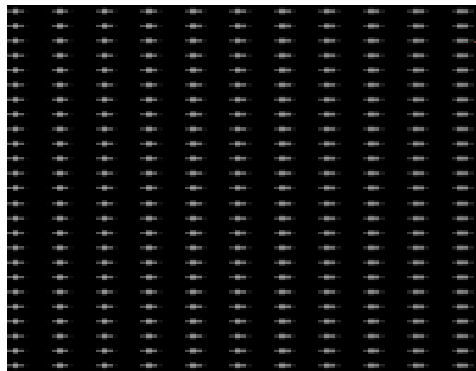


Figure 22: Layout View

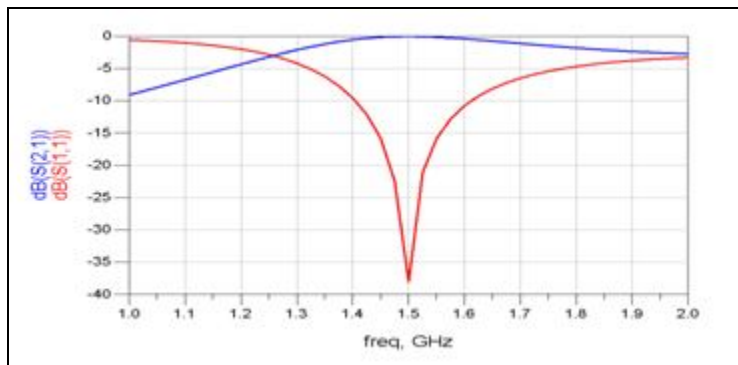


Figure 23: Output Graph

Source Impedance = $59+j*28$ Ohms, Load Impedance = $10-j*180$ Ohms (using MLOC)

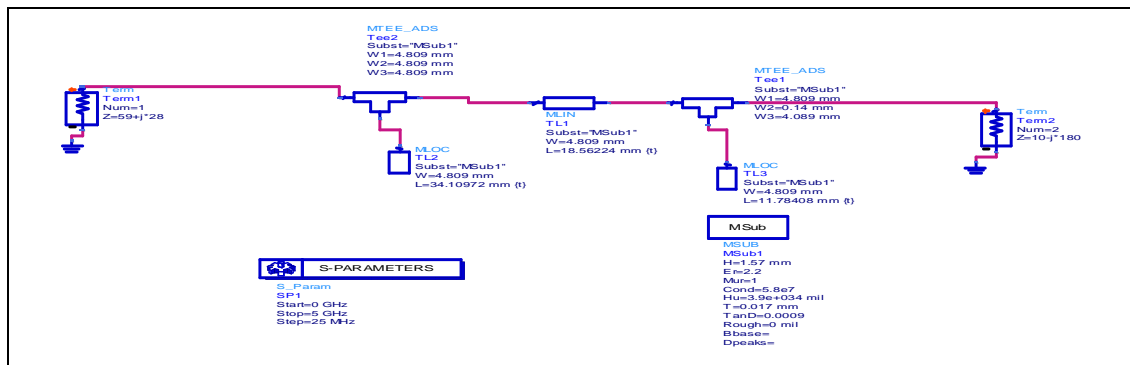


Figure 24: Schematic View

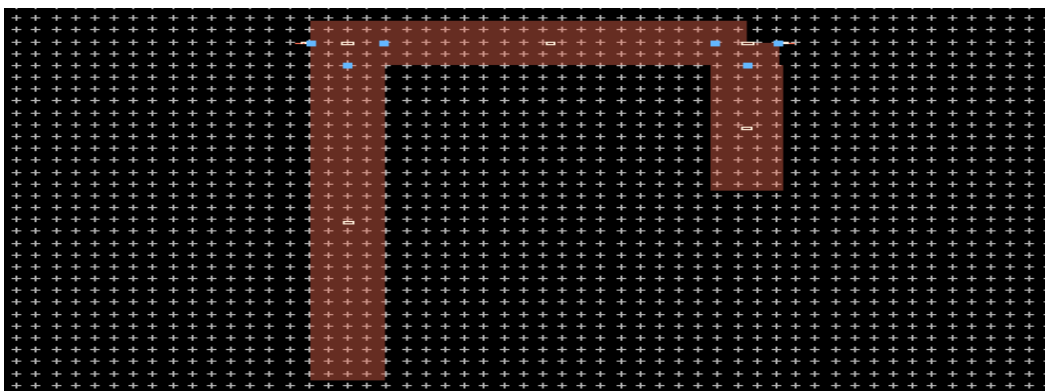


Figure 25: Layout View

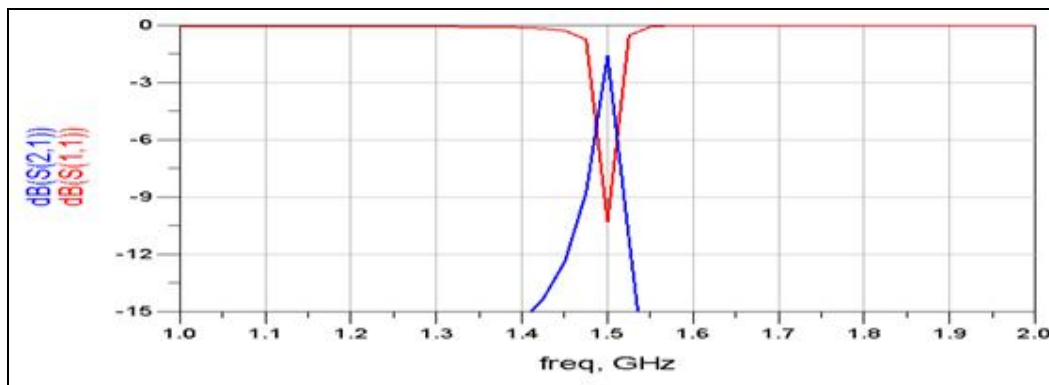


Figure 26: Output Graph

5. Conclusion

In this report, we have discussed the techniques of impedance matching circuit at different frequencies. We also discussed the design of impedance matching circuits using smith chart. Design specification for different impedance matching circuit is also discussed in detail. Impedance matching with Transmission lines using Smith Chart also encompasses various methods for impedance matching.

6. References

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