

EE3109 Applied Electromagnetics

Lab 02

Design and Verification of the Single-Stub Impedance Transformer Network

Objectives

- i) To reinforce the concept of impedance transformer.
- ii) To design and verify an impedance transformer using transmission line and stubs.

Equipments Required

- i) Smith Chart or Online Smith Chart Tool
- ii) Microwave oscillator module
- iii) Power adapter 5VDC, 2A
- iv) RF Coaxial cable
- v) Termination board
- vi) 50 Ohm coaxial termination
- vii) N(f)-SMA adaptor(f)
- viii) Male-to-Male SMA adapter
- ix) Spectrum analyzer
- x) Copper foil tape
- xi) Scissors
- xii) Scale

Note: you should take the calculator and drawing compass by yourself.

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1. Introduction

In lab 2, You will receive a piece of PCB where a 50-ohm microstrip line is printed and loaded by a resistor. You are required to design a single-stub impedance transformer using the Smith-Chart and fabricate the practical circuit using the copper foil tape. Then, you need verify your design using ME1200 module and the spectrum analyzer.

2. Effect of Transmission Line on Impedance: Visualization on Smith Chart

Figure 1 shows an impedance Z_L (we shall call this the load impedance) connected with a short length of lossless transmission line with characteristic impedance Z_o and with physical length l . The phase constant of the transmission line is β

Note:

$\beta = \frac{2\pi}{\lambda}$, where λ is the wavelength of the corresponding electromagnetic wave guided by the transmission line

The impedance and reflection coefficient (with respect to Z_o) at the far end of the transmission line are also shown in Figure 1. The important equations in Figure 1 are listed below:

$$Z_s = Z_o \frac{Z_L + jZ_o \tan(\beta l)}{Z_o + jZ_L \tan(\beta l)} \quad (1)$$

$$\Gamma_s = \Gamma_L e^{-j2\beta l} \quad (2)$$

$$\lambda = \frac{v_p}{f} \quad (3)$$

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi f}{v_p} \quad (4)$$

In equation 3, the phase velocity (i.e., the speed at which the electromagnetic wave propagates in the transmission line) of the transmission line is dependent upon the material used and structure of the transmission line cross-section. Usually v_p can be worked out from the transmission line cross-section dimensions. Then knowing the operating frequency, we can find the wavelength λ . For a transmission line filled with air, the phase velocity is equal to speed of light, i.e., $v_p \approx 2.998 \times 10^8$ m/s. For transmission filled with other types of dielectric, v_p is usually between 40–70% of the speed of light. There are formulas to work out v_p for various types of transmission line, but that is not our focus here.

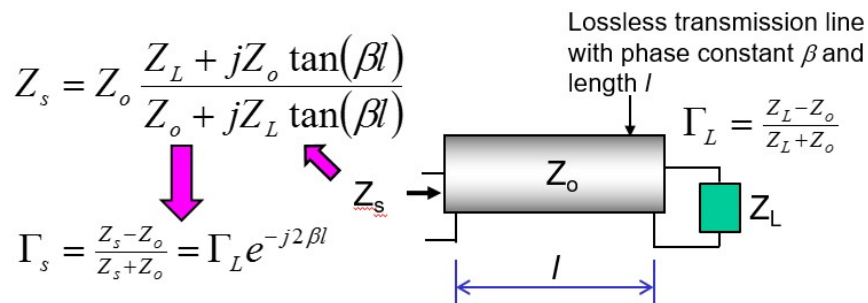


Figure 1 – A Section of Transmission Line Changes the Impedance or Reflection Coefficient of Z_L

Essentially having a transmission line in front of the load impedance modifies both its impedance and reflection coefficient. For instance, let $Z_L = 100$, $Z_0 = 50$. The reflection coefficient of Z_S at the far end of the transmission line is plotted on the Smith Chart in Figure 2 for various values of l . We can interpret this as the reflection coefficient 'moves' on the Smith Chart as a result of the presence of the transmission line. The locus traced by Γ_S as we increase the physical length l (remember β is fixed for a particular transmission line structure) is a clockwise circle centred at the origin of the Smith Chart. The radius of the circle is equal to $|\Gamma_L|$, and this circle is called the *Constant SWR (Standing Wave Ratio) Circle*.

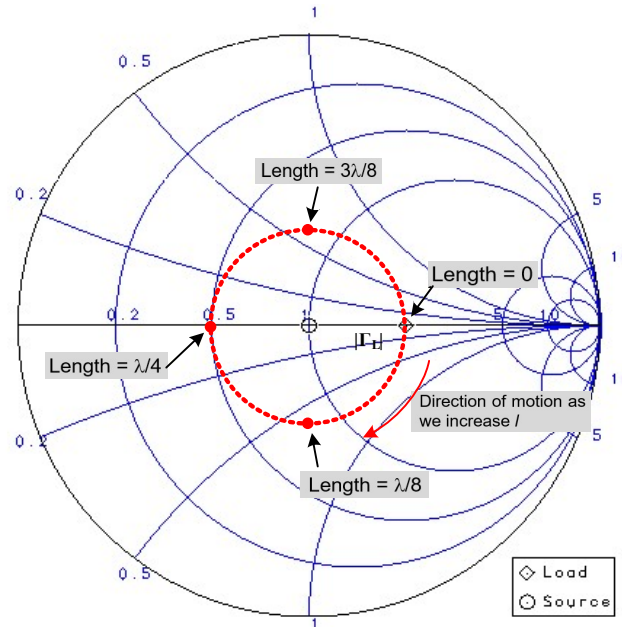


Figure 2 – How Z_S 'Moved' Across the Smith Chart as the Physical Length of the Transmission Line Changes: the Constant SWR Circle

3. Single-Stub Impedance Transformer Design

In the last section, we have seen that adding a transmission line section allow us to change a load impedance Z_L value such that it moves in a circle (the constant SWR circle) on the Smith Chart. This movement is one dimensional, or one degree of freedom. By adding element jB to near end of the transmission line, we increase the degree of freedom for the network to two. To be able to move (for example, transform a given Z_L or Γ_L) an impedance arbitrarily on the surface of the Smith Chart, which is a two-dimensional surface. Note that a minimum of two degrees of freedom is needed for an arbitrary impedance transformation. This type network is called the *Single-Stub Impedance Transformer*. The element jB is represented by the *stub* which could be open-ended or short-ended stub.

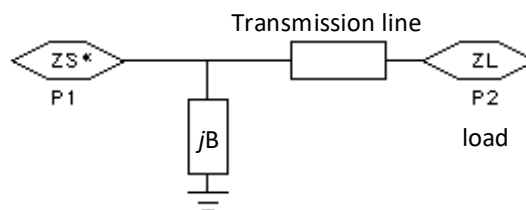


Fig.3 schematic diagram of the Single-Stub Impedance Transformer

As an illustration, suppose we wish to transform $Z_L = 220 + j0$ at 2500 MHz to $Z_S = 50 + j0$, using a transmission line with a characteristic impedance Z_0 at 2500 MHz. We will not be concerned with the physical structure of the transmission line at the moment except its physical length. We assume we have a transmission line where the electromagnetic wave guided by the line has a wavelength of 65.82 mm or $\beta = 2\pi/\lambda \cong 95.46$.

The first approach (short-ended stub, inductive stub): the transformation is shown in Figure 3. First, we move Z_L along the constant SWR circle to an intermediate value of $Z = 13.8 - j22.4$ by adding a transmission line with a length of 11.78 mm. Then we add a short-ended stub with a length of 5.8 mm, Z moves to Z_S anticlockwise along the admittance circle.

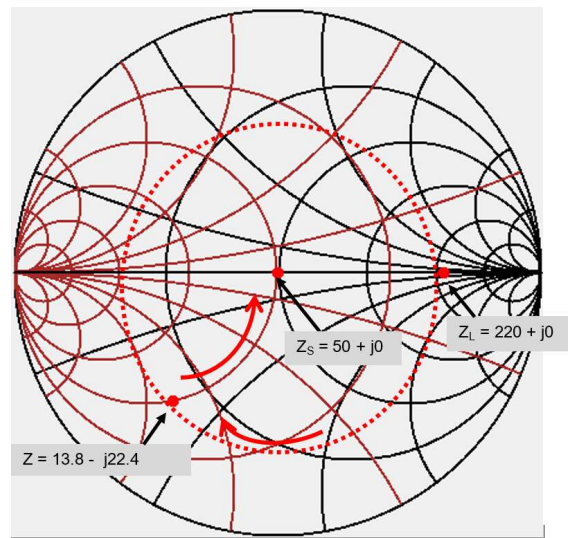


Figure 3 –Transforming $Z_L = 220 + j0$ at 2500 MHz to $Z_S = 50 + j0$: Movement on the Smith Chart (Solution Approach 1)

The second approach (open-ended stub, capacitive stub): the transformation is shown in Figure 5. First, we move Z_L along the constant SWR circle to an intermediate value of $Z = 13.8 + j22.4$ by adding a transmission line with a length of 21.12 mm. Then we add an open-ended stub with a length of 10.66 mm, Z moves to Z_S clockwise along the admittance circle.

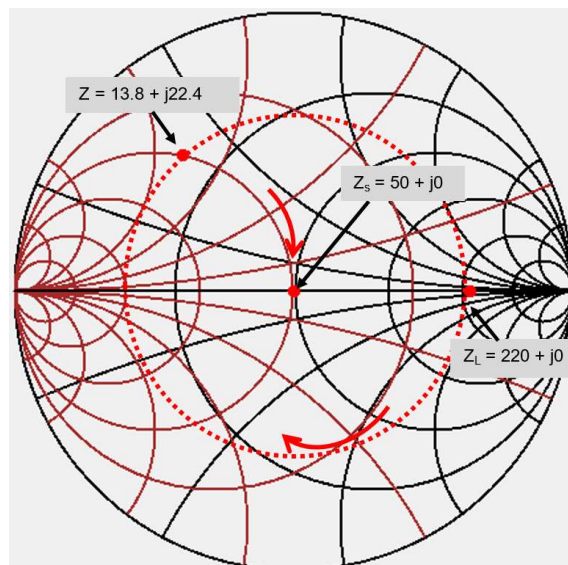


Figure 5 – Transforming $Z_L = 220 + j0$ at 2500 MHz to $Z_S = 50 + j0$: Movement on the Smith Chart (Solution Approach 2)

4. Design and fabricate your own single-stub matching circuit

Note: since the open-ended stub can be fabricated more easily, this approach is suggested in this lab.

You shall receive a PCB sample as shown in Fig.6. The transmission line has a characteristic impedance of 50 ohm and is loaded by a resistor in the far end. A female SMA connector is soldered in the near end for the electromagnetic wave injection. Values of loaded resistors include 22 ohm, 150 ohm, 270 ohm. You shall get one from them. Parameters of the microstrip transmission line is shown in Fig.7. With the given parameters, one can calculate the effective dielectric constant and wavelength guided by the microstrip transmission line using formula (5) and (6). where $c \cong 2.998 \times 10^8$ m/s.

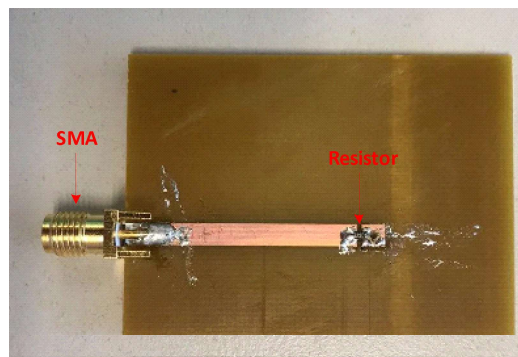


Fig.6 – 50ohm microstrip transmission line loaded by the resistor.

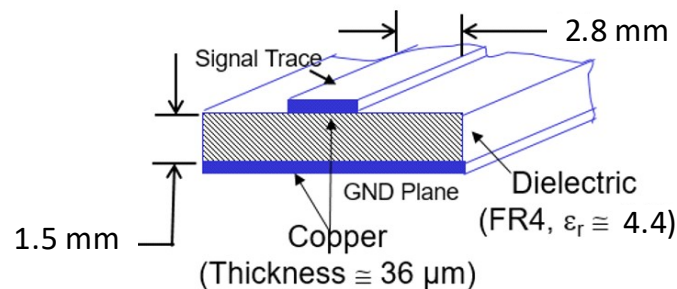


Fig.7 – 50ohm microstrip transmission line.

$$\epsilon_{eff} = \left[\frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + \frac{12h}{w}}} \right] \right] \quad (5)$$

$$\lambda = \frac{c}{f} \cdot \frac{1}{\sqrt{\epsilon_{eff}}} \quad (6)$$

1. Calculate the wavelength for 2500 MHz wave travelling in the provided microstrip transmission line. Also calculate the propagation constant β .

2. Finish your Single-Stub Impedance Transformer design using Smith-Chart and mark the key points and routes. **Note: The Smith Chart is available on canvas and some paper copies will be provided during the lab.**

3. Draw your Single-Stub Impedance Transformer circuit below and give the key parameters (physical length).

4. Fabricate your Single-Stub Impedance Transformer design using the copper foil tape. Take a photo of your sample and stick it below.

Note: make sure a good electrical connection between the transmission line and the copper foil tape.

5. Verification Using ME1200

We can use the ME1200 microwave source to verify that the impedance looking into the SMA connector is close to $50 + j0$ at 2500 MHz. Connect the single stub impedance transformer to the ME1200 using a male-to-male SMA adapter as shown in Figure 8, and connect the electric field probe to the RF IN port of the spectrum analyzer.

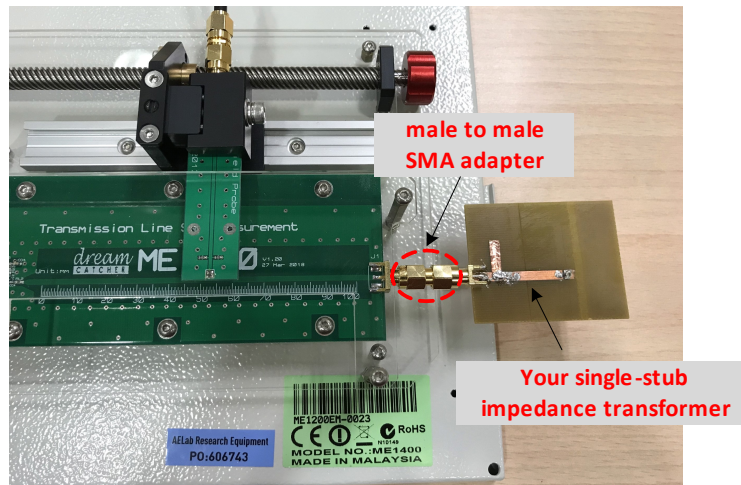


Figure 8 – Setup for Verification of the Single-Stub Impedance Transformer Network at 2500 MHz

1. Power up the oscillator on the ME1200 transmission line board with a 5 V power adapter and set the output frequency to 2500 MHz. Make sure that the indicator LED on the oscillator lights up. Connect the RF IN port of the spectrum analyzer to the electric field probe.
2. Configure your spectrum analyzer using the following parameters:

Centre Frequency	2500 MHz
Frequency Span	100 MHz
RF Attenuation	5 dB
Resolution Bandwidth (RBW)	100 kHz

3. Slowly move the tip of the electric field probe from the 16-mm position to the 86-mm position with a step of 2 mm. As you move the electric field probe, use the marker on the spectrum analyzer to search for the peak value and record the data in Table 1. Repeat this procedure twice: once for with the single stub tuner, and another time with the stub removed (i.e. no stub tuner).
4. If the Single-Stub Impedance Transformer circuit works well, i.e. the impedance looking into the SMA connector is close to $50 + j0$ at 2500 MHz, what should you observe (or expect) in step 3? Why?
5. Compare the two measurements. Is the difference what you expect to see? Why / why not?

5. Modify your design and repeat step 3 until you get an expected result.
6. Based on the data you get in table 1, make a plot of the power versus distance on a graph paper.

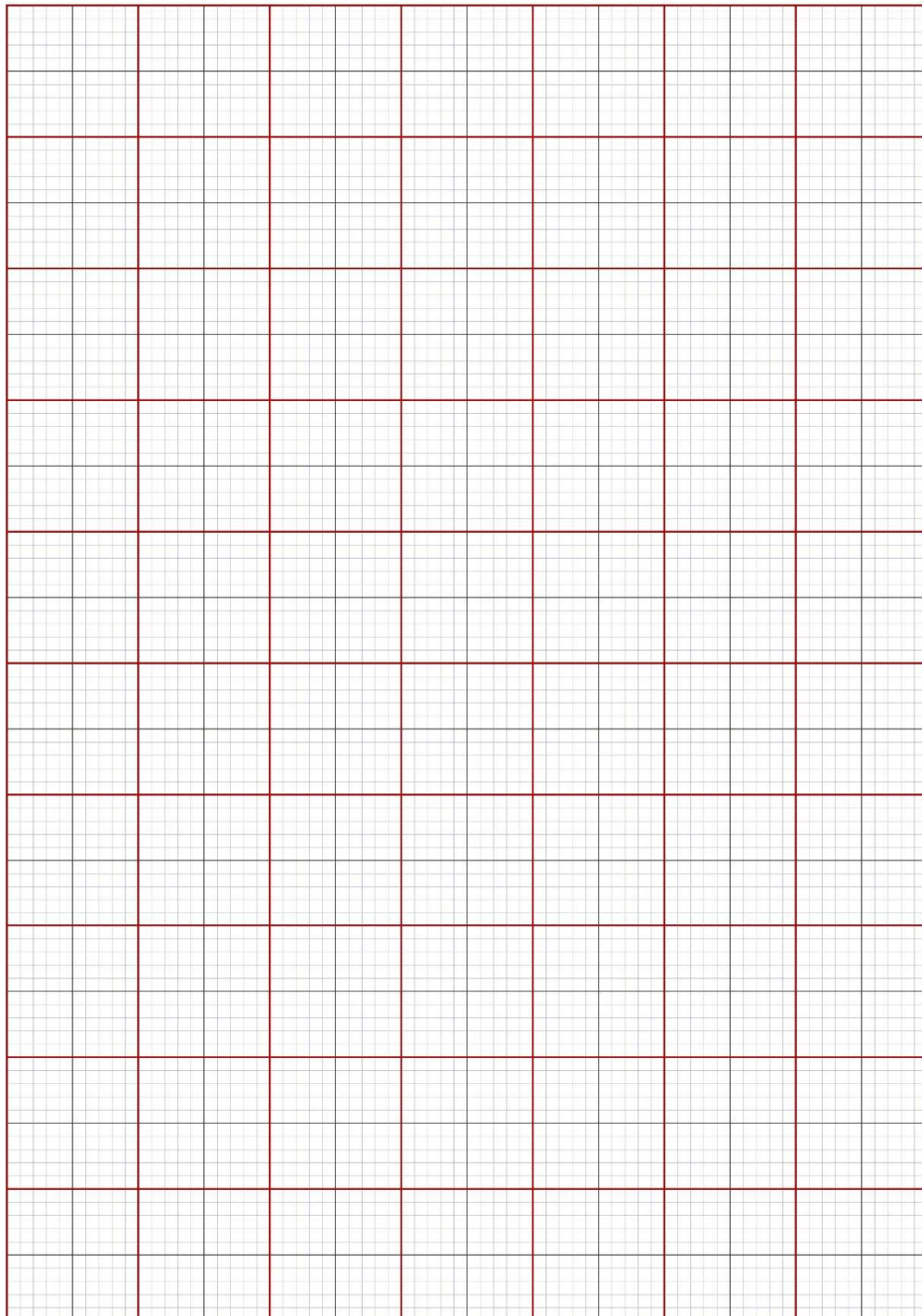
Note: you can also draw the plot by the Office Excel or any other tool.

Observation, discussion and conclusion:

7. Optional Exercise 1: consider to use a short-ended stub (the first approach in section 3), give the single-stub matching circuit design. Namely, draw the layout and mark the key microstrip dimensions.

Table 1 – Results for Section 5

Distance from the oscillator (mm)	No-stub Power (dBm)	Single-stub Z-transformer Power (dBm)	Unused for this version of the Lab
16			
18			
20			
22			
24			
26			
28			
30			
32			
34			
36			
38			
40			
42			
44			
46			
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86			



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