

Experiment One

Fundamentals of Electromagnetics Lab

EECE2530/1

Michael BRODSKIY
Brodskiy.M@Northeastern.edu

October 4, 2023

Date Performed: September 27, 2023
Partners: Manas MAHAJAN & Priyam MODI
Instructor: Professor MARENKO-FUENTES
TAs: Nicolas CASILLI & Farah BEN AYED

Abstract

The goal of this laboratory experiment is to familiarize oneself with the functions of a vector network analyzer, while, at the same time, applying knowledge of transmission lines and Smith chart analysis. This is done by plugging various components into the vector network analyzer and analyzing their Smith charts and phases.

KEYWORDS: vector network analyzer, transmission line, Smith chart, phase

1 Equipment

Available equipment included:

- E5063A Vector Network Analyzer
- Type N Calibration Kit:
 - Open Circuit
 - Short Circuit
 - Matched Load ($50[\Omega]$)
- Type N to BNC Adapter
- Resistors, capacitors, and inductors

2 Introduction & Objectives

We started off this laboratory experiment by acquainting ourselves with the E5063A Vector Network Analyzer. We first established the correct settings for the network analyzer, after which the machine was tested with various calibration scenarios. Short, open, and matched loads were used to determine whether the network analyzer was well-calibrated. The results of the calibration can be seen in Figures 1-3 below.

Then, assuming the speed of light to be a constant $3 \cdot 10^8 [\frac{m}{s}]$, we determined the length of the transmission line inside of the network analyzer.

Finally, we connected various components, such as capacitors, resistors, and inductors, to determine whether the circuit components had expected behavior at all frequencies, then determining the wavelength in the cable and the dielectric constant.

3 Results & Analysis

First and foremost, the calibration kit yielded the following results:



Figure 1: Shorted Load Smith Chart

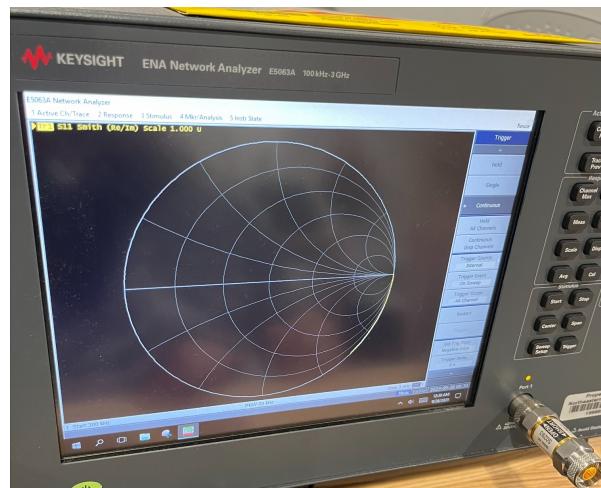


Figure 2: Open Load Smith Chart



Figure 3: Matched Load Smith Chart

Evidently, we see the behavior is exactly as expected; that is, the shorted load appears at the top left of the Smith chart, with slight variation, and the opened load appears at the bottom right, with some variation. The matched load, on the other hand, occurs right at the center of the chart, as it should when the impedance is matched.

We then used this data to estimate the length of the transmission line inside of the network analyzer, Δz , assuming the speed of light in the transmission line as c . As shown in Figure 4 below, the phase shift is roughly 67.87° — we rounded to 70° .¹

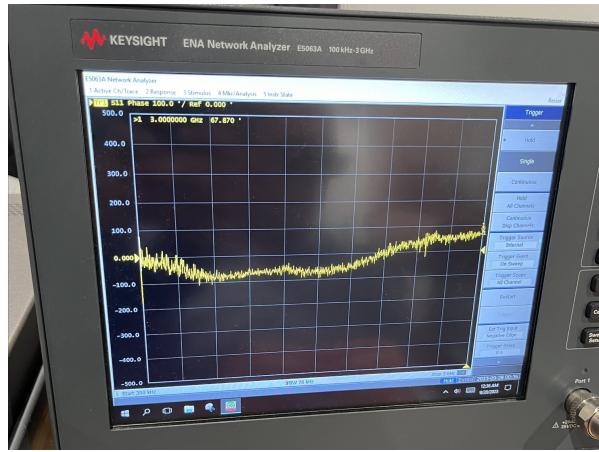


Figure 4: Phase for Matched Load

¹As a continuous sweep, the phase would jump from roughly 60 to 80 degrees; thus, 70 seemed an appropriate estimate

The calculation performed began with the formula

$$e^{-j\theta} = e^{-2j\beta\Delta z}$$

$$\theta = 2\beta\Delta z$$

$$\Delta z = \frac{\theta}{2\beta}$$

In terms of radians, we found θ as:

$$\frac{70 \cdot 2\pi}{360} = 1.2217[\text{rad}]$$

We know $\beta = 2\pi/\lambda$, and $\lambda = c/f$. Substituting gives us:

$$\Delta z = \frac{\theta c}{4\pi f}$$

Using the values we have, we get:

$$\Delta z = \frac{(70)(3 \cdot 10^8)}{4\pi(3 \cdot 10^9)} = 9.97 \cdot 10^{-3}[\text{m}] \approx 1[\text{cm}]$$

We now connect the BNC adapter. With an open-circuit BNC, we obtain the Smith chart shown in Figure 5:



Figure 5: Open Load with BNC Adapted

We can see that the output immediately becomes more lossy than the open circuit calibration connector. This can be explained by the fact that the BNC adapter adds length to the transmission line. In doing so, more of the same wavelengths can fit, which means the wave travels farther. Thus, more of the current and voltage is lost.

We know plug in various components with the BNC, as described in Figures 6-8:

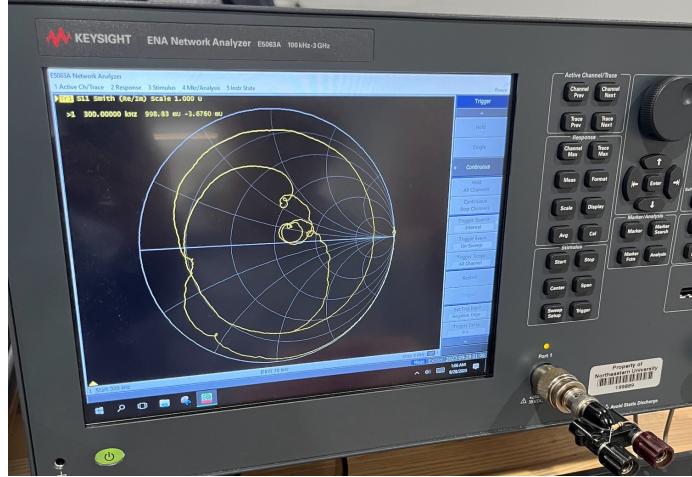


Figure 6: BNC with Resistor

The resistor more or less looks as it should; that is, it starts with no impeding component; however, as the frequency increases, significant loss occurs.

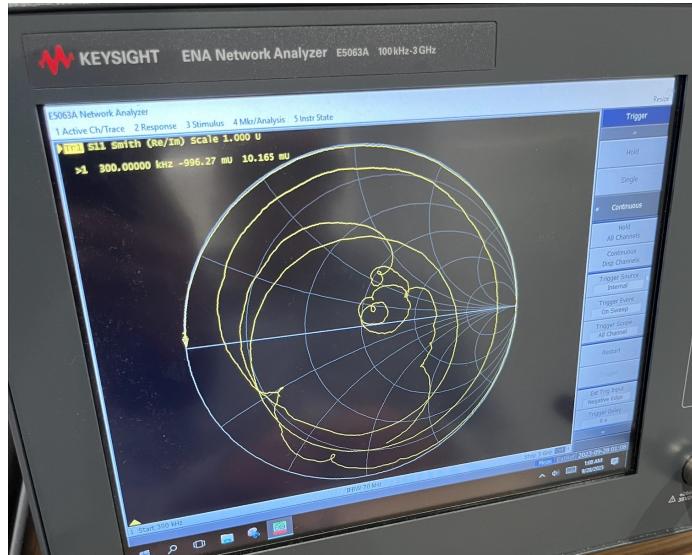


Figure 7: BNC with Capacitor

At lower frequencies, the capacitor appears as it should — it is following an impedance proportional to $-\frac{j}{\omega C}$. As the frequency increases, however, a loss occurs, as indicated by the spiral. This can be explained by the fact that capacitors begin as open circuits,

but, at high frequencies, capacitors act as short circuits.

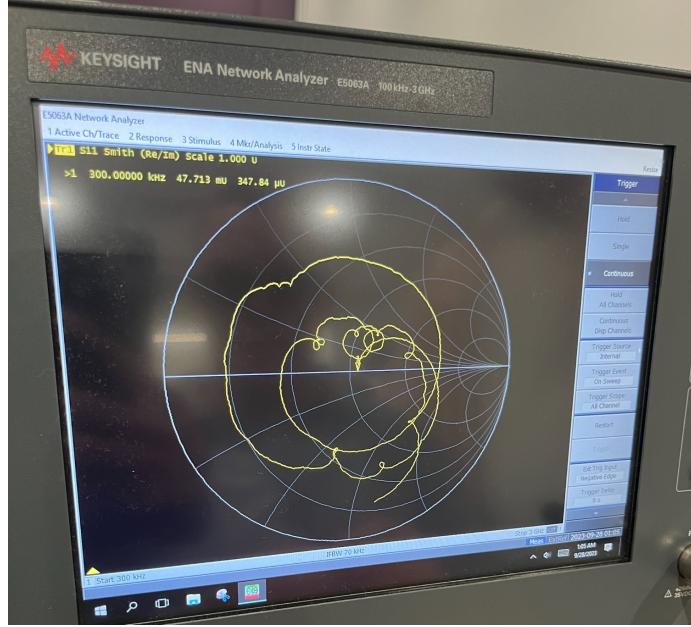


Figure 8: BNC with Inductor

In the picture above, the inductor doesn't behave exactly as expected; this is most likely because it was not coiled tight enough. We do see, however, a tendency for lossiness as the frequency increases.

After this, we plug in a short and long wire, as shown in Figures 9 and 10:

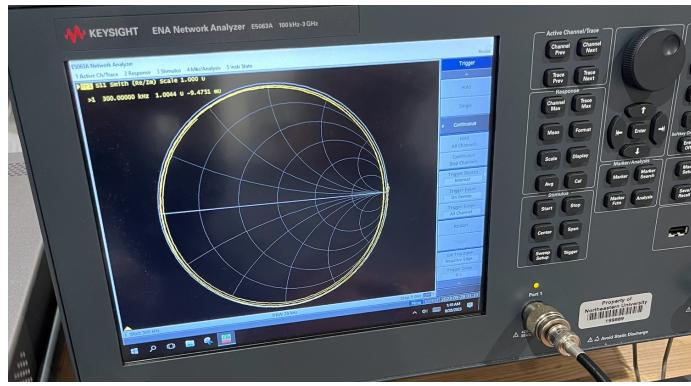


Figure 9: The Short Wire

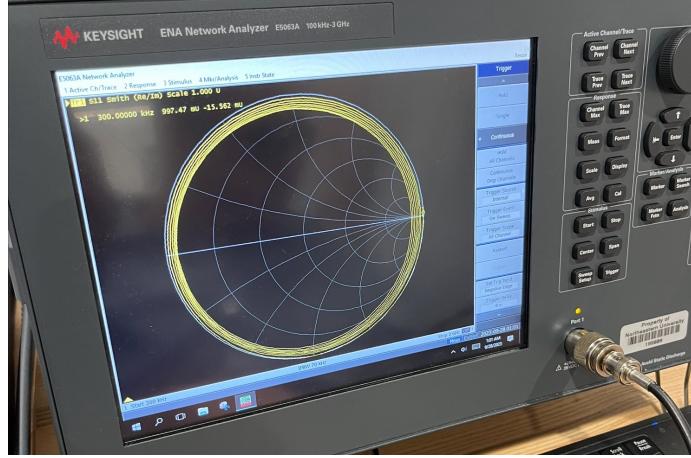


Figure 10: The Long Wire

We see that, with the longer cable, the Smith chart has more “rings” or loops. Logically, this makes sense. We know that a single “loop” is one phase/360 degrees. As a wire gets longer, it will fit more phases/wavelengths in it, and, thus, display more loops in a Smith chart. Both wires show increasing losses, as the circles spiral into the center. The length of the cable was measured as approximately 23.5[cm]. We can then calculate the dielectric constant:

$$\epsilon_r = \left(\frac{\lambda_o \theta_m}{4\pi \Delta z} \right)^2$$

Using the values we obtained for the longer wire, we get:

$$\begin{aligned} \epsilon_r &= \left(\frac{(.)(7.5 \text{ cycles})}{4\pi(.235 + .01)} \right)^2 \\ \epsilon_r &= \left(\frac{(.)(47.124[\text{rad}])}{4\pi(.245)} \right)^2 = 2.34 \end{aligned}$$

Now analyzing the amplitude, phase, and Smith outputs for a matched load, we find the outputs shown in Figures ??-??:

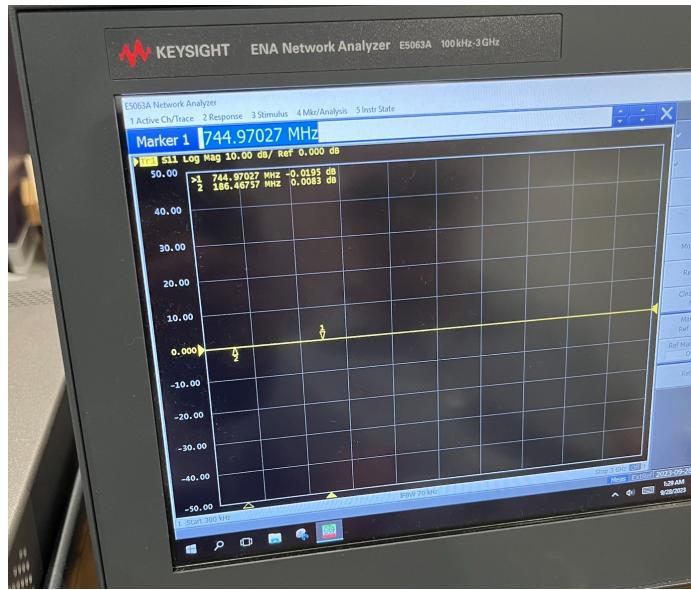


Figure 11: The Amplitude Display with Log Magnitude

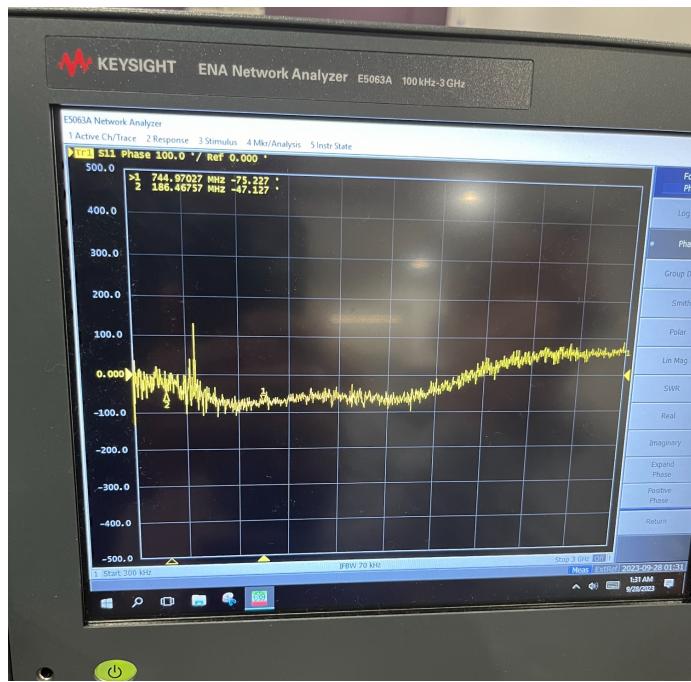


Figure 12: The Phase Display

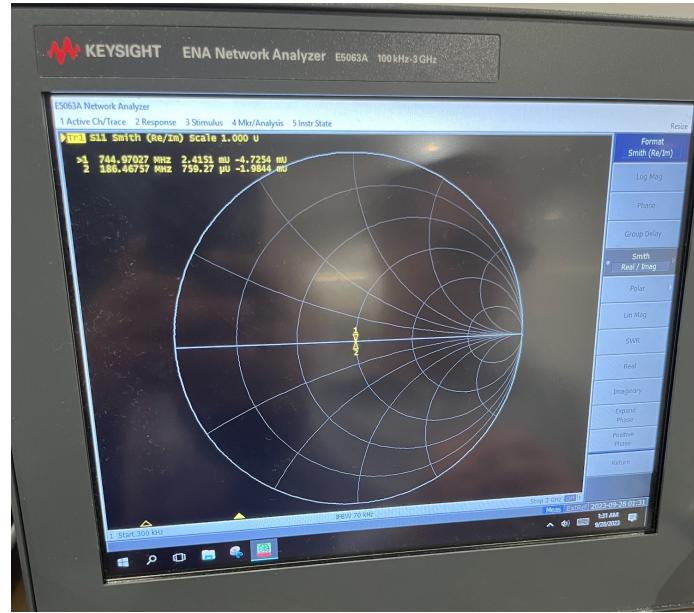


Figure 13: The Smith Chart Display

Overall, the most graphically concise (that is, most information in simplest format) chart seems to be the Smith chart. Though it depends on exact purpose (like, sometimes, the phase display can more easily show the phase angle), the Smith chart seems the best tool.

4 Conclusion