ECE320: Fields and Waves

Lab 2 Report: Standing Waves and Waveguides

PRA106

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1 Introduction

This laboratory session was focused on investigating the voltage standing wave (VSW) pattern along a microstrip transmission line, as well as its depedance on the load impedance. Figure 1 shows the diagram of a microstrip line that sits on the PCB substrate at the bottom and free space (or air) above, due to which the voltage wave effectively travels through $\epsilon_{\text{eff}}\epsilon_0$. We measure the fringing electric field using a probe, acting as a monopole antenna, at the top of the strip. Since the measured, vertically oriented, electric field is proportional to the voltage at that position we are able to determine the VSW pattern along the line.

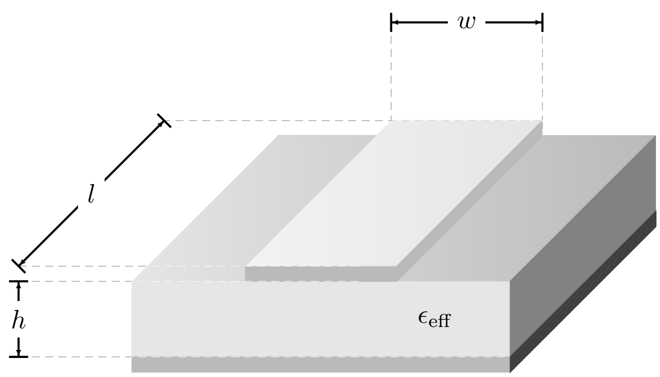


Figure 1: A microstrip transmission line

2 Measurement of Microstrip Line Characteristics

We know that since the wave travels in a compound medium – the PCB substrate and the air – we will have to consider an effective dielectric constant dependant on the geometry as well as the substrate parameters. It has been found that this is best described using a combination of conformal mapping and empiral formulae, which are:

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \left(\frac{\epsilon_r - 1}{2}\right)\left(1 + \frac{10}{s}\right)^{-xy}$$

where $s = \frac{w}{h}$ and

$$x = 0.56\left(\frac{\epsilon_r - 0.9}{\epsilon_r + 3}\right)^{0.05}$$
$$y = 1 + 0.02\ln\left(\frac{s^4 + 3.7\cdot 10^{-4}s^2}{s^4 + 0.43}\right) + 0.05\ln\left(1 + 1.7\cdot 10^{-4}s^3\right)$$

The characteristic impedance of a microstrip line can also be found using empiral formulae, such as:

$$Z_0 = \frac{60}{\sqrt{\epsilon_{\text{eff}}}} \ln \left(\frac{6 + (2\pi - 6)e^{-t}}{s} + \sqrt{1 + \frac{4}{s^2}} \right)$$

where

$$t = \left(\frac{30.65}{s} \right)^{0.75}$$

We measured the width of the microstrip line and used the above formulae to calculate the theoretical values of the characteristic impedance, effective dielectric constant, the phase velocity of the voltage wave, its wavelength at $f = 1$ GHz, the reflection coefficient at the short circuit load, and the voltage standing wave ratio (VSWR). The results can be found below in table 1.

Parameter	**Value**
w	0.3 cm
Z_0	48.697Ω
ϵ_{eff}	3.347
v_p	$1.639 \cdot 10^8$ m/s
λ	0.163 m
Γ_L	-1
VSWR	∞

Table 1: Theoretically calculated parameters of the microstrip transmission line

Using the vector network analyzer (VNA) in the lab, we sampled the magnitude of the electric field every 5 mm, starting at the location of the first minimum magnitude d_{min}. The experimental SWR pattern can be found in figure 2.

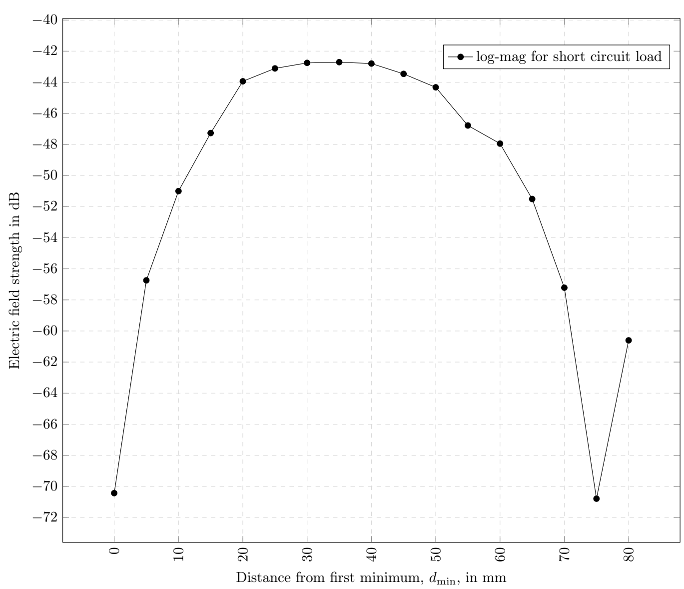


Figure 2: VSW pattern for a shorted load on the microstrip line

Using the data in figure 2, we know that

$$||\tilde{V}_{\text{max}}|| = k \cdot ||\tilde{E}_{\text{max}}|| = k \cdot 10^{-\frac{42.707}{20}} = k \cdot 0.00732$$

Similarly,

$$||\tilde{V}_{\text{min}}|| = k \cdot 10^{-\frac{70.430}{20}} = k \cdot 0.00030$$

Thus,

$$\text{VSWR} := \frac{||\tilde{V}_{\text{max}}||}{||\tilde{V}_{\text{max}}||} = 24.330$$

Although here the VSWR is large, it is still very small compared to the theoretical value of ∞. But to show that our measurements are still accurate, we can show that the corresponding value of reflection coefficient at the load, $||\Gamma_L|| = \frac{\text{VSWR}-1}{\text{VSWR}+1} = 0.921 \approx 1$ is close to the theoretical value of 1.

We also measured that two consecutive voltage minimums were ≈ 8 cm apart, thus giving us the wavelength of the voltage wave $\frac{\lambda}{2} = 8 \text{ cm} \implies \lambda = 16 \text{ cm} \approx 16.3$ cm, since the wavelength observed in the SWR pattern is half of the wave's wavelength. Using the above result for wavelength and the chosen frequency of 1 GHz, we get $v_p = 1.6 \cdot 10^8 \text{ m/s} = \frac{c}{\sqrt{\epsilon_{\text{eff}}}} \implies \epsilon_{\text{eff}} = 3.511 \approx 3.347$. Thus, our measurements do closely match the theoretical results for all the parameters.

3 Using Standing Wave Patterns for Load Calculations

Observed waveforms at different points on the transmission line can be found in Figure 5.

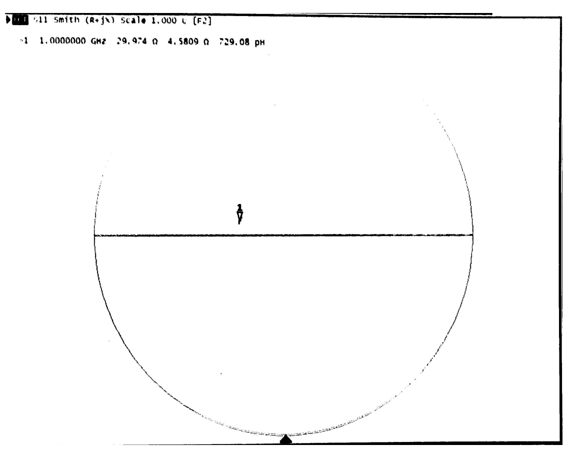


Figure 3: Transmission line terminated with load $Z_L = Z_0$

The connector length and impedance as well as it sticks out and is not a microstrip at the end. Thus, our calculations reveal a close, but slightly off impedance. It is on the same quadrant of the smith chart and close to the observed value.

4 Notes

All images taken during the lab were post-processed in a batch using a custom script that bit-wise inverts the pixels and binarizes the resulting image based on a custom threshold. No adjustments or modifications were made to the readings, for which the measurements on the VNA are also shown alongside the waveforms. All scripts and related work can be found at `github.com/pranshumalik14/ece320-labs`.

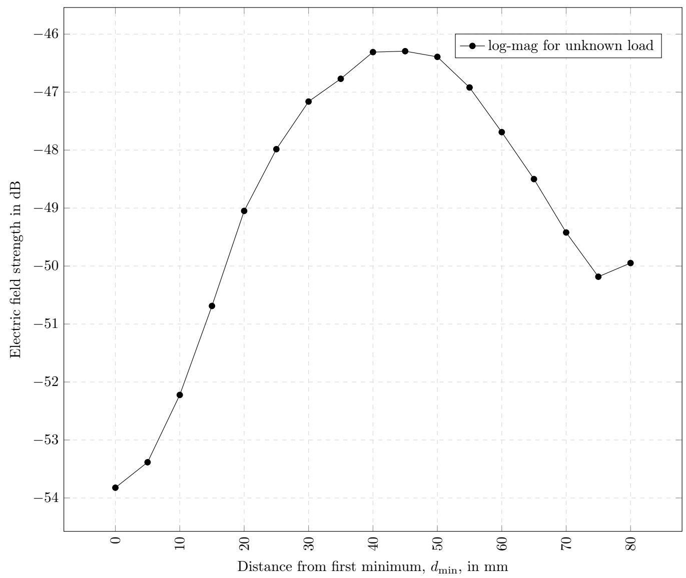


Figure 4: VSW pattern for an unknown load on the microstrip line

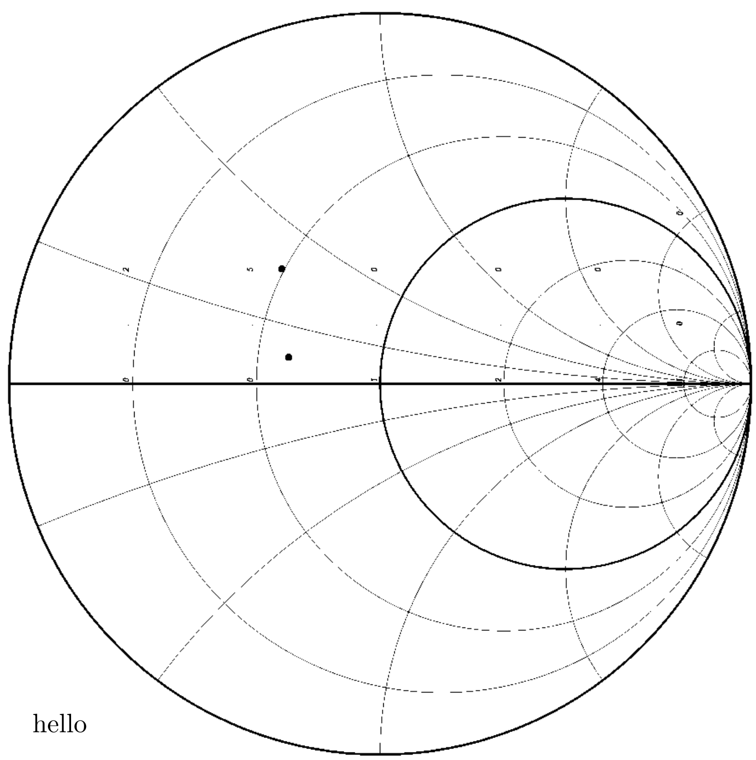
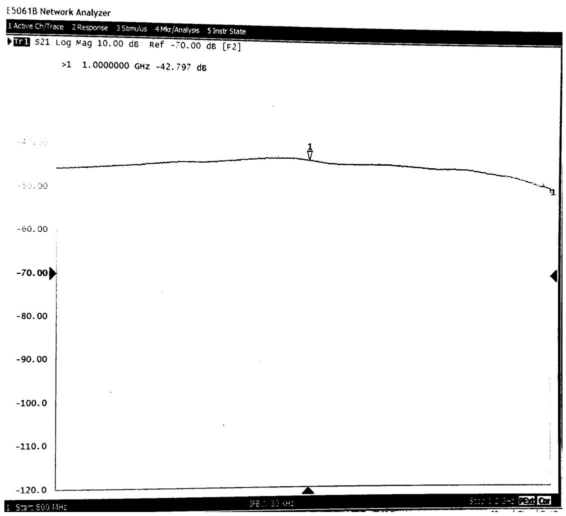
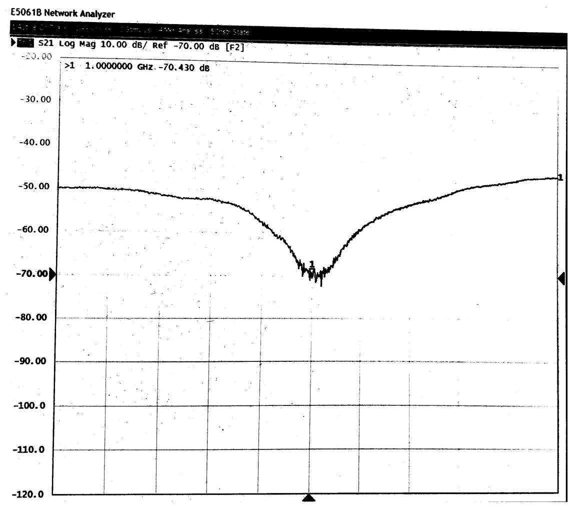


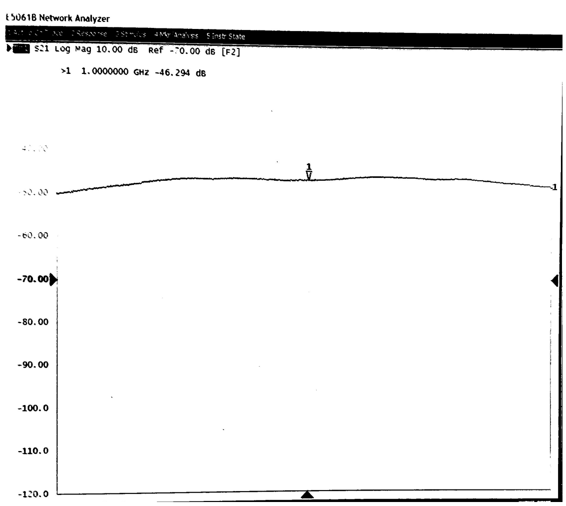
Figure 5: Comparison of measured and calculated imepedance



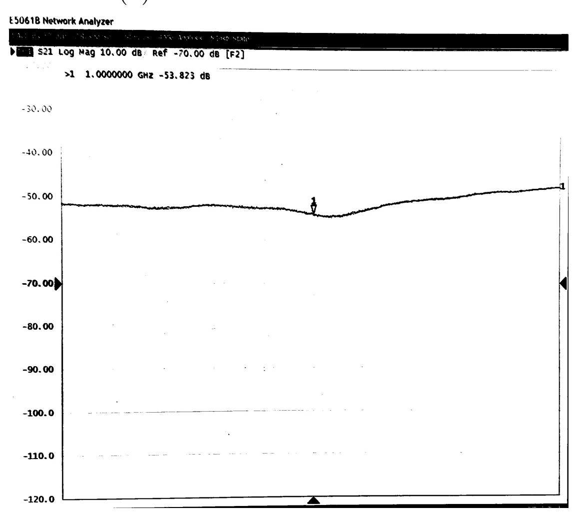
(a) Short circuit load maximum



(b) Short circuit load minimum



(c) Unknown load maximum



(d) Unknown load minimum

Figure 6: Snapshots for measurement of maximum and minimum values of VSW pattern on the VNA