Lab Write-up 1: Transmission Line Basics

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1 Role of Wavelength

1.1 Measured Data

$$R_1 = 2212\ \Omega$$
$$R_2 = 1808\ \Omega$$

Frequency	**Cable**	v_1 (V)	v_2 (V)	ΔT (ns)	$\Delta\varphi°$
$f_1 = 100$ kHz	12"	5.65	2.55	-16	-0.5
	180"	5.85	2.55	60	2.7
$f_2 = 100$ MHz	12"	4.35	0.133	1.48	50
	180"	3.35	0.116	1.48	50

Table 1: Voltage and phase measurements for varying signal frequency and cable length

1.2 Analysis

1.
$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}} \tag{1}$$

From Equation 1, frequency values from Table 1, and given $\varepsilon_r = 1.9$,

$$\lambda_1 = 2176.43\ m$$
$$\lambda_2 = 2.17643\ m$$

2.

Frequency	**Cable**	$l : \lambda$
$f_1 = 100$ kHz	12"	0.00168
	180"	0.0252
$f_2 = 100$ MHz	12"	1.68
	180"	25.21

Table 2: Ratio of l to λ for varying signal frequency and cable length

3.

Frequency	**Cable**	v_1 (V)	v_2 (V)	v_{out} (V)
$f_1 = 100$ kHz	12"	5.65	2.55	2.54
	180"	5.85	2.55	2.63
$f_2 = 100$ MHz	12"	4.35	0.133	1.96
	180"	3.35	0.116	1.51

Table 3: Comparison of measured voltage (v_2) and expected voltage (v_{out}) from basic circuit theory

4. For $f_1 = 100$ kHz, the computed v_{out} is almost identical to the measured v_2 in lab using the 12" cable and very similar using the 180" cable. There is a 0.39 % difference for the 12" cable and a 3.09% difference for the 180" cable. On the other hand, v_{out} is completely different from the measured v_2 in lab for $f_2 = 100$ MHz (Table 3).

5. As the ratio between the length of the cable and the wavelength in the circuit increases past 0.01, basic circuit analysis fails and we must use transmission line theory. If we do not, the phase delays of the signal and the interferences, constructive and destructive, on the line from the reflected wave become significant, causing in otherwise unexpected measurements.

1.3 Questions

1. I would expect that the output voltage of the RF signal source to be constant over the frequency range examined because the signal source was rated to be able to provide such a signal. However I did not observe and constant output voltage on channel 1 (Table 3). This is because there was a 24" BNC cable connecting the RF signal source to the oscilloscope. For the 100 MHz signal, this results in a 3.36 $l : \lambda$ ratio, so there is significant interference from the reflected wave and the line no longer acts as an ideal wire; it must be treated as a transmission line.

2. Which of

   (a) Integrated circuit (500 MHz –¿ 1 GHz)

   (b) Electrical lines in house

   (c) Electrical lines connecting cities by hundreds of km

   (d) VHF antenna from rabbit ear antenna to TV

3. A major assumption of a wire in DC analysis is that the signal travels instantly down the line. In fact, it is limited to the speed of light. Therefore, as the length of the line increases, the time delay from the moment the signal enters one end of a wire to the moment it reaches the other end of the wire increases. For a signal given by $A\cos(\omega t - \beta z)$, this time delay manifests itself as a phase shift of magnitude βz.

2 Standing Waves on the Slotted Line

2.1 Measured Data

2.1.1 Short Termination

Location	|v| (V)	**Position (mm)**
1^{st} minimum	0.020	116
1^{st} maximum	3.08	190
2^{nd} maximum	0.020	266

Table 4: Standing Waves - Measured Data

Resistive termination value = 10 Ω
Capacitive termination value = 39 (pF)

Table 5: Standing Waves - Loads

	Probe Position (λ)											Minimum	
Load	0	$\frac{\lambda}{20}$	$\frac{2\lambda}{20}$	$\frac{3\lambda}{20}$	$\frac{4\lambda}{20}$	$\frac{5\lambda}{20}$	$\frac{6\lambda}{20}$	$\frac{7\lambda}{20}$	$\frac{8\lambda}{20}$	$\frac{9\lambda}{20}$	$\frac{10\lambda}{20}$	Pos.	Vol.
Probe Position (mm)	116	131	146	161	176	191	206	221	236	251	266	X	X
Short	0.02	0.81	1.79	2.49	2.89	3.00	2.77	2.29	1.65	0.76	0.02	116	0.02
Open	2.75	2.59	2.19	1.59	0.736	0.032	0.643	1.53	2.21	2.61	2.73	193	0.02
Matched	1.42	1.42	1.43	1.45	1.45	1.46	1.45	1.43	1.42	1.4	1.39	266	1.39
Resistor	1.89	2.27	2.41	2.33	2.03	1.57	1.01	0.434	0.591	1.25	1.87	227	0.346
Capacitor	2.79	2.61	2.17	1.53	0.687	0.02	0.79	1.65	2.31	2.69	2.77	191	0.02

Table 6: Standing Waves - Loads

2.1.2 Loads

2.2 Analysis

1. Since the signal was 1 GHz and we are assuming $\varepsilon_r = 1$, $\lambda = 300\ mm$ (Eq. 1, pg. 1). Then, the distance between the minima is 266 mm - 116 mm = 150 mm or $\frac{\lambda}{2}$. This is equal to the theoretical value of $\frac{\lambda}{2}$.

2. The distance between the first minimum and maximum is 190 mm - 116 mm = 74 mm or 0.247λ. This is very similar to the theoretical value of $\frac{\lambda}{4}$.

3. Insert Plotssssszzsss

	Probe Position (λ)										
Load	0	$\frac{\lambda}{20}$	$\frac{2\lambda}{20}$	$\frac{3\lambda}{20}$	$\frac{4\lambda}{20}$	$\frac{5\lambda}{20}$	$\frac{6\lambda}{20}$	$\frac{7\lambda}{20}$	$\frac{8\lambda}{20}$	$\frac{9\lambda}{20}$	$\frac{10\lambda}{20}$
Probe Position (mm)	116	131	146	161	176	191	206	221	236	251	266
Short	0.0065	0.26	0.58	0.81	0.94	0.97	0.90	0.74	0.54	0.25	0.0065
Open	0.89	0.84	0.71	0.52	0.24	0.010	0.21	0.50	0.72	0.85	0.89
Matched	0.46	0.46	0.46	0.46	0.46	0.47	0.47	0.46	0.46	0.45	0.45
Resistor	0.61	0.74	0.78	0.76	0.66	0.51	0.33	0.14	0.19	0.41	0.61
Capacitor	0.91	0.85	0.70	0.50	0.22	0.0065	0.26	0.54	0.75	0.87	0.90

Table 7: Analysis 2.3

2.3 Questions

1. What would you expect

2. Why was it acceptable

3 Network Analyzer

3.1 Measured Data

3.1.1 Reflection Coefficients

3.1.2 Scanner Antenna SWR

3.2 Analysis

1. **FINISH ME**

Load	$\mid \Gamma \mid$	$\Delta\Gamma^{\circ}$
Short (uncal)	0.751	97.872
Short (cal)	1	173.25
Open	1	-7.425
50 Ohm (matched)	0.001	26.735

Table 8: Network Analyzer - Reflection Coefficients

Frequency of SWR minimum	170.5 MHz
Minimum SWR value	1.513
Lower Frequency of 2.5 SWR	156.7 MHz
Higher Frequency of 2.5 SWR	222.7 MHz

Table 9: Nework Analyzer - Scanner Antenna

2. Using Eq. XXX for the reflection coefficient and the fact that $Z_0 = 50\ \Omega$,

$$\Gamma = \frac{Z_L - Z_0}{Z_l + Z_0} \tag{2}$$

The theoretical values for Γ are shown in Table XXX. Furthermore, by converting our measured data from the network analyzer from the dB scale to the linear scale using Eq. XXX,

$$|\Gamma|_{linear} = 10^{|\Gamma|_{dB}/20} \tag{3}$$

Load	$\lvert\Gamma\rvert_{dB}$	$\lvert\Gamma\rvert_{linear}$	$\lvert\Gamma\rvert_{theoretical}$
Short (uncal)	0.751	1.09	1
Short (cal)	1.00	1.12	1
Open	1.00	1.12	1
50 Ω (matched)	0.001	1.00	0

Table 10: Analysis 3.2

3. The equation relating the standing wave ratio S and the reflection coefficient Γ is:

$$S = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{4}$$

Since Γ can be assumed to be real, $\Gamma = |\Gamma|$. Thus, Eq. XXX can be rewritten as:

$$\Gamma = \frac{S - 1}{S + 1} \tag{5}$$

By substituting the measured $S_{min} = 1.513$, it follows that $\Gamma = 0.204$. By solving Eq. XXX for Z_L, again using the fact that $\Gamma = |\Gamma|$:

$$Z_L = Z_0 \frac{1 + \Gamma}{1 - \Gamma} = Z_0 S \tag{6}$$

Finally, using Eq. XXX and the fact that $Z_0 = 50\ \Omega$, it follows that $Z_L = 75.65\ \Omega$ at the frequency where the SWR minimum was measured, 170.5 MHz.

3.3 Questions

1. **FINISH ME**
2. Since $Z_L = 75.65\ \Omega$ and using Eq. XXX and XXX
   (a) A 50 Ω transmission line system is what the antenna was tested with and results in $S = 1.513$ at 170.5 MHz. Thus, the antenna works well with this system.
   (b) A 75 Ω transmission line system is nearly matched and results in $S = 1.009$ at 170.5 MHz. Thus, the antenna works well with this system.
   (c) A 300 Ω transmission line system results in $S = 3.965$. Thus, the antenna does not work well with this system.