Lab_1

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1 General

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- video recording
- lab1 desc

1.2 Terminology

DVM Digital Volt Meter

2 Theory

2.1 Surge Impedance

$$Z_0 = \sqrt{\frac{L}{C}} \tag{2.1}$$

Where L and C are the line capacitance and reactance. [1]

2.2 Electrical Length

This is effectively a measure of the amount of wavelengths of a particular frequency fit into a length of conductor. Electrical length is given by Equation 2.2.

$$\theta = \omega\sqrt{LC} \tag{2.2}$$

A value of $\theta = 2\pi$ would imply a single wavelength, however even for very long lines, typically values are $\ll 2\pi$.

2.3 Open Circuit Transmission line Voltage distribution

Voltage distribution along the line is given by Equation 2.3:

$$V(x) = V_s \frac{\cos\left(\theta(1 - x/a)\right)}{\cos\theta} \tag{2.3}$$

Where x is defined as the distance from the sending end, a is the line length, and V_s is the phasor voltage at the sending end. setting $x = a$ and expression is derived for the voltage at the receiving end.

$$V_r = V(x = a) = \frac{V_s}{\cos\theta} \tag{2.4}$$

Since we assume that typical values of angle are $\ll 2\pi$ we know that as θ grows we expect V_r to increase from being exactly equal to V_s to a value $\geq V_s$

2.4 Matched Impedance Transmission line Voltage Distribution

The voltage profile for a line terminated in a matched impedance Z_0 would yield a perfectly flat voltage distribution i.e. $V(x) = V_s = V_r$. For any impedance greater than the surge impedance (Z_0) the voltage will tend to rise at the end of the transmission line while lower load impedance will cause the voltage profile in the line to sag leading to lower V_r. [2]

[1] since this is given as a fraction it doesn't matter whether this is given as a per unit length value or as a total value

[2] this can be expressed also as higher voltage for loads lower than the surge load where *surge load* $\propto 1/Z_l$

2.4.1 Reactive Power Consumption

When the load impedance is matched to the surge impedance ($Z_0 = Z_l$), the reactive power consumption of the line is zero. When $Z_l > Z_0$ the line generates reactive power whereas when $Z_l < Z_0$ the line consumes reactive power.

3 Experiment

3.1 Line Parameters

Line parameters are given by Table 3.1:

Table 3.1: *Per section model transmission line parameters*

C_{Sect} (μ F)	C_{Tot} (μ F)	L_{Sect} (mH)	L_{tot} (mH)	$N_{Sections}$
0.02	0.2	7.29	72.9	10

3.2 Experimental Parameters

Table 3.2 shows the experimental parameters used in this lab.

Table 3.2: *Signal generator settings*

f (Hz)	ω (Rad/s)	V_{Src} (V_{pp})	V_{Src} (RMS)
700	4398.1	10	3.5355339

3.3 Surge Impedance (Part a)

Line surge impedance is calculated according to Equation 2.1 and the line parameters given in Table 3.1. Table shows the resulting surge impedance:

Table 3.3: *Calculated Surge Impedance based on Equation 2.1 and Line Parameters in Table 3.1*

Surge impedance Z_0 (Ω)
1.6563467e-3

3.4 Electrical length (Part b)

Electrical length is calculated from Equation 2.2 and the line total line parameters given in Table 3.1. The results of the Calculation are shown in Table 3.4.

3.5 Open Circuit Test (Part c)

3.5.1 Procedure

- Freq of signal gen set to 700Hz
- Output voltage set to $10V_{pp}$
- Oscilloscope range to 2V/Division

Table 3.4: *Model Transmission line calculated Electrical Length according to Equation 2.2 and Transmission line parameters in 3.1.*

θ (Rad)	θ (Deg)
0.5311	30.4307

- DVM used to measure RMS voltage along the line at the ten intervals
- phase angle of middle and end point measured

3.5.2 Voltage distribution - Open circuit Termination

The experiment results from the open-circuit measurement along with the theoretical voltage distribution calculated according to Equation 2.3 are tabulated in Table 3.5. The measured and actual voltage distribution on the line is shown in Figure 3.1.

Table 3.5: *Voltage Measurements along the model Transmission Line*

Measurement #	θ(1-x/a) (Rad)	Measured Voltage (V)	V/V_{Src}	V/V_{Src} Theory
0	0.5311	3.536	1.0001	1.0000
1	0.4780	3.618	1.0233	1.0298
2	0.4249	3.715	1.0508	1.0566
3	0.3718	3.802	1.0754	1.0805
4	0.3187	3.878	1.0969	1.1014
5	0.2656	3.944	1.1155	1.1191
6	0.2124	3.997	1.1305	1.1337
7	0.1593	4.040	1.1427	1.1451
8	0.1062	4.070	1.1512	1.1532
9	0.0531	4.089	1.1565	1.1581
10	0.0000	4.095	1.1582	1.1598

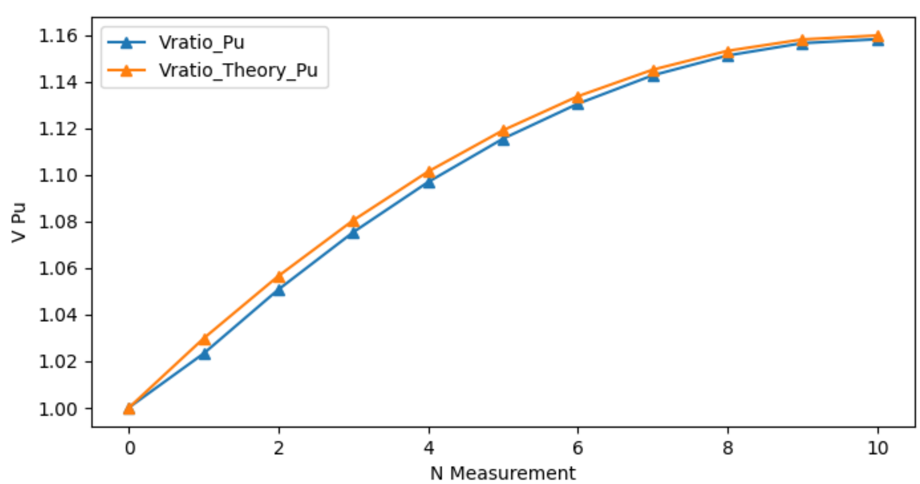

Figure 3.1: *Theoretical and measured voltage profile along the model transmission line Results Plotted from Table 3.5*

The theoretical and measured voltage distribution curves in Figure 3.1 match closely implying that the measurements are in agreement with Equation 2.3.

3.5.3 Phase change - Open circuit Termination

The measured phase-shift of the voltage along the transmission line relative to the sending end voltage for the centre and receiving end of the line are shown in Table 3.6.

Table 3.6: *Measured relative phase-shift and magnitude at receiving, middle and end of line (Normalised against sendig end magnitude)*

Measurement Point	Angle $\theta°$	Magnitude
receiving end	0	1.1582
mid-point	0	1.1155
Sending end	0	1

3.5.4 Phasor Plot

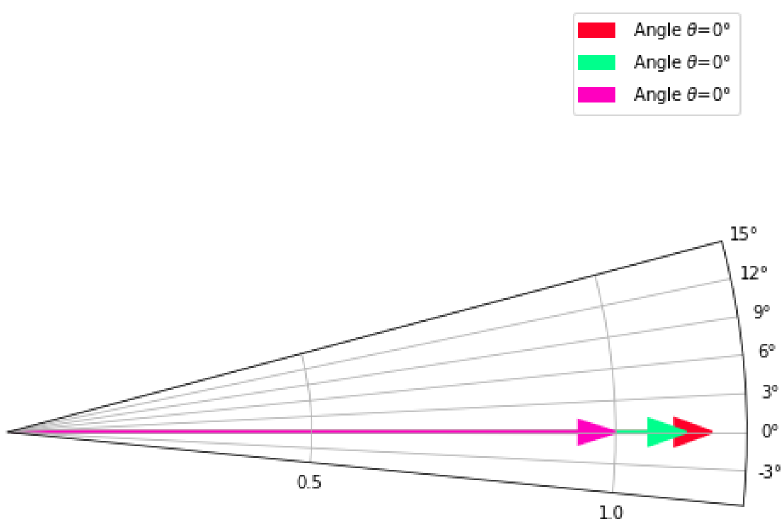

Figure 3.2: *Matched Impedance Phase shift of mid point and receiving end relative to sending end*

3.6 Surge Impedance Load Test (Part d)

3.6.1 Procedure

- Matched impedance load Z_0 attached at the end of the transmission line.
- DVM Measurements of voltage distribution taken
- Oscilloscope measurements of phase for the mid point and end taken.

3.6.2 Voltage distribution - Matched termination

Measurements are again taken in then equally spaced increments along the length of the transmission line, results are tabulated in Table 3.7 and plotted against measurement point in Figure 3.3.

Table 3.7: *Voltage distribution along the model transmission line with a matched termination*

Measurement #	Measured Voltage (V)	V/V_{Src}
0	3.536	1.000
1	3.509	0.992
2	3.505	0.991
3	3.502	0.991
4	3.500	0.990
5	3.496	0.989
6	3.492	0.988
7	3.489	0.987
8	3.486	0.986
9	3.483	0.985
10	3.479	0.984

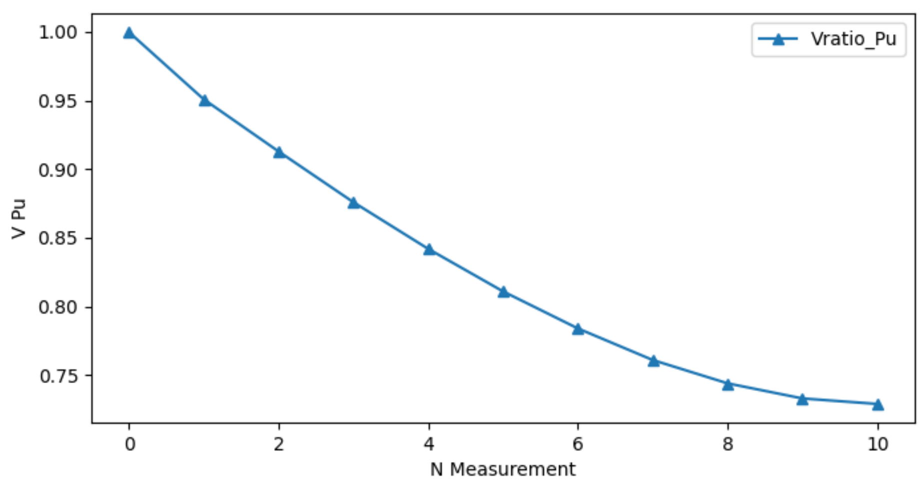

Figure 3.3: *Transmission line voltage profile terminated with a matched impedance and normalised against sending end voltage.*

From Figure 3.3 we see that the voltage distribution along the line is indeed very flat deviating to a maximum of ≈2% deviation from the sending end voltage. In theory there should be no deviation from the sending end voltage however this deviation may be due to the terminating impedance being slightly lower than the sending end due to tolerance. The outlier

3.6.3 Phase change - Matched termination

Phase angle for the model line with matched termination is shown in Table 3.8. These are measured relative to the sending end voltage. Taking the sending end voltage as the origin, with the measurements of phase angel shown below it can be seen that the phase angle along the line varies linearly with the electrical length since the measurement point of the end point is by definition twice the electrical length of the mid point and has twice the phase-shift. It is also noted that the total phase shift along the line is roughly equal to the electrical length of the line.

Table 3.8: *Measured Relative Phase-shift along Model transmission line measured relative to sending end*

mid-point angle $\theta°$	receiving end angle $\theta°$
15	30

3.7 Less than Matched Impedance (Part e)

3.7.1 Voltage Distribution - Less than Matched

The recorded voltage profile for a termination impedance « z_0 is presented in table 3.9. The voltages normalised against sending end are plotted against 1 point in Figure 3.4. Here the voltage again tends to fall along the line similar to the closed-circuit case, however with a significantly lower magnitude. The voltage profile seems to display an exponential decay.

Table 3.9: *Voltage Distribution Measurements for termination with less than matched impedance*

Measurement #	Measured Voltage (V)	V/V_{Src}
0	3.536	1.000
1	3.364	0.951
2	3.227	0.913
3	3.097	0.876
4	2.976	0.842
5	2.867	0.811
6	2.772	0.784
7	2.692	0.761
8	2.632	0.744
9	2.593	0.733
10	2.577	0.729

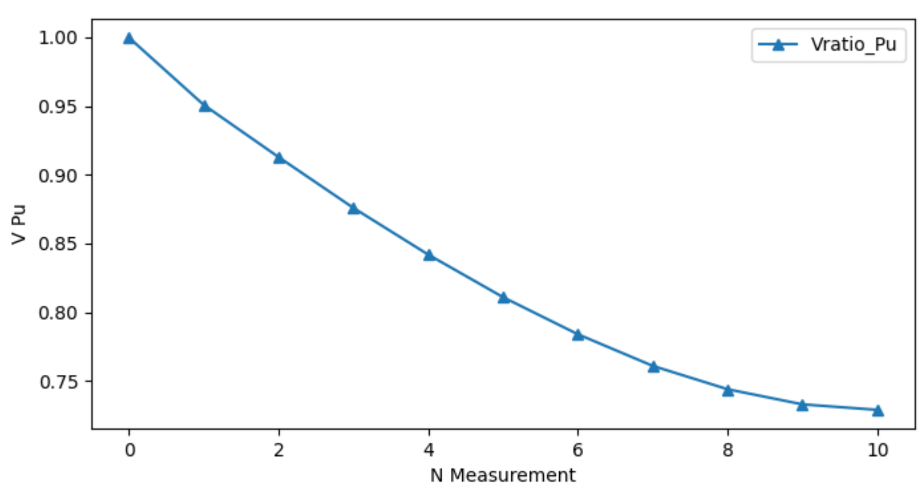

Figure 3.4: *Transmission line voltage profile terminated with in impedance less than the surge impedance and normalised against sending end voltage.*

3.7.2 Phase Change - Less than Matched

Phase angle measurements for a line terminated with less than the characteristic impedance at them middle and end of the line are shown in Table 3.10. In this case the relationship between the electrical length along the line again seems to be relatively linear, However the absolute phase difference is substantially larger than the matched or open circuit tests.

Table 3.10: *Measured Relative Phase-shift along Model transmission line measured relative to sending end*

mid-point angle $\theta°$	receiving end angle $\theta°$
22	50

3.7.3 TODO Reactive Compensation

3.8 Open circuit on double length line (Part f)

3.8.1 Double Electrical Length Calculations

1. Experimental Parameters Table 3.11 shows the experimental parameters with the modified excitation frequency used in this section.

Table 3.11: *Signal generator settings with modified excitation frequency*

f (Hz)	ω (Rad/s)	V_{Src} (V_{pp})	V_{Src} (RMS)
1400	8796.2	10	3.5355339

2. Electrical Length Electrical length is again calculated for a double length line.

Table 3.12: *Model Transmission line calculated Electrical Length according to Equation 2.2 and Transmission line parameters in 3.1 excited with a frequency of 1400Hz.*

θ (Rad)	θ (Deg)
1.0621	60.8556

3.8.2 Voltage Distribution

The line was exited with the same voltage magnitude as section C however with twice the excitation frequency of the prior experiment (1400Hz). The measurements of voltage along with the theoretical voltage distribution calculated according to Equation 2.3 are tabulated in Table 3.13. The measured and actual voltage distribution on the line is shown in Figure 3.5.

From Figure 3.5 we see a very similar curve to section C (Figure 3.1) however this time the receiving end voltage has risen in to ~2.11× the sending end voltage, while for the half length line this was only ≈1.15×. This finding shows the nonlinearity in the relationship between electrical length θ and received voltage eluded to in Equation 2.3. As is section C the voltage distribution predicted by Equation 2.3 match the measured results closely.

Table 3.13: *Voltage measurements along the model transmission line terminated in open circuit and excited at 1400Hz.*

Measurement #	θ(1-x/a) (Rad)	Measured Voltage (V)	V/V_{Src}	V/V_{Src} Theory
0	1.0621	3.536	1.0001	1.0000
1	0.9559	4.202	1.1885	1.1845
2	0.8497	4.848	1.3712	1.3556
3	0.7435	5.436	1.5375	1.5114
4	0.6373	5.961	1.6860	1.6502
5	0.5311	6.417	1.8150	1.7704
6	0.4248	6.795	1.9219	1.8707
7	0.3186	7.095	2.0068	1.9499
8	0.2124	7.313	2.0684	2.0071
9	0.1062	7.442	2.1049	2.0417
10	0.0000	7.485	2.1171	2.0532

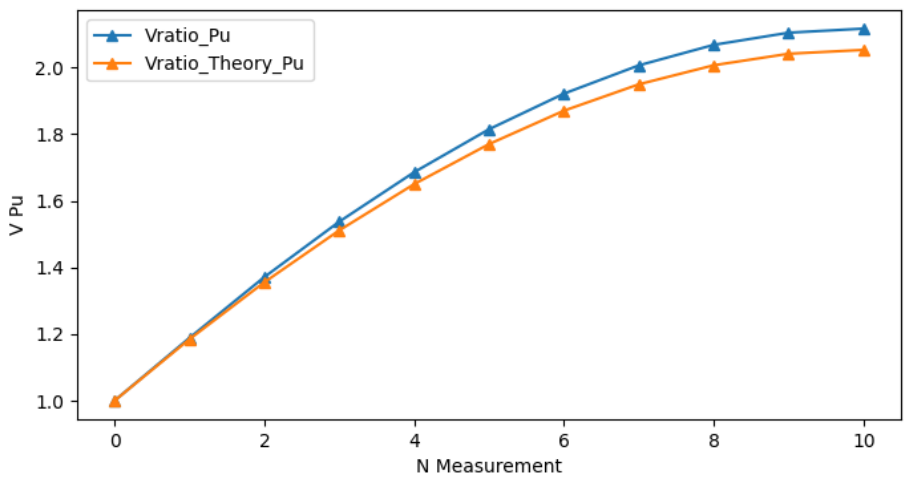

Figure 3.5: *Theoretical and measured voltage profile along the model transmission line terminated in open circuit and excited at 1400Hz results plotted from Table 3.13.*

The theoretical and measured voltage distribution curves in Figure 3.1 match closely implying that the measurements are in agreement with Equation 2.3.

3.8.3 Phase change along the line

The measured phase-shift of the voltage along the transmission line relative to the sending end voltage for the centre and receiving end of the line are shown in Table 3.14. As with section C there is no phase-shift observed along the line.

3.8.4 TODO Reactive Compensation

test

Table 3.14: *Measured relative phase-shift and magnitude at receiving, middle and end of line (Normalised against sending end magnitude) for line excited at 1400Hz.*

Measurement Point	Angle $\theta°$	Magnitude
receiving end	0	1.1582
mid-point	0	1.1155
Sending end	0	1