ElecEng 2CF3

ASSIGNMENT 6

Voltage and Current Traveling Waves in Transmission Line Equivalent Circuits

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Instructions and Objective

- Perform all exercises.
- For each exercise, there are instructions on what to include in a short report about your observations. The report also must contain the answers to the posed questions.
- For **EXERCISE #1**, you are required to submit: (i) MATLAB source-code (*.m), (ii) your final LTspice (*.asc) file and (iii) your short report (*.pdf) file. Submit to the respective Dropbox on A2L by the deadline. Do not include intermediate *.asc files. Failure to submit either file in the correct format will be penalized. If the current version of MATLAB cannot run the submitted file without errors, you will receive a grade of zero for this exercise. Make sure the file name extension of what you submit is not *.txt.
- For **EXERCISE #2**, you are required to submit: (i) your final LTspice (*.asc) files and (ii) your short report (*.pdf) file. Submit to the respective Dropbox on A2L by the deadline. Do not include intermediate *.asc files. Failure to submit either file in the correct format will be penalized.
- **Do NOT submit zipped folders** as this requires download to a local folder on the TA's computer, which the TAs have the right to refuse due to security reasons.
- Each exercise report (the PDF) must include (at the top of the first page) a suitable short title, your full name as it appears on Avenue to Learn, your student ID number, and your MacID login name.
- If you need help in using LTspice, please refer to LTspice *QuickStart Guide* PDF file on A2L. Help is also available from the TAs from 3:30 pm to 4:30 pm every day from Monday to Friday.
- There is a requirement to include SPICE netlists in the PDF report. Just copy-paste the netlist text from LTspice. Do not export or submit any netlist files.

The objective of this assignment is to practice the analysis of transmission lines under matched-impedance conditions and learn how to use circuit simulators for transmission-line analysis.

EXERCISE #1: LOW-LOSS TRANSMISSION LINE

A transmission line (TL) has per-unit-length (*PUL*) parameters R' (Ω/m), L' (nH/m), G' (mS/m), and C' (pF/m). Pick a set of *PUL* parameters based on the **last digit of your student number** from **Table I** (see the last page of this document). Write a MATLAB code to calculate complex propagation constant γ and plot: (a) the attenuation constant $\alpha = \mathrm{Re}\,\gamma$, (b) the phase constant $\beta = \mathrm{Im}\,\gamma$, (c) the phase velocity v_p, (d) the real part of characteristic impedance Z_0, and (e) the imaginary part of Z_0, all in the frequency range from 1 GHz to 10 GHz (with a step of 10 MHz). Provide one trace per plot for each part.

The TL is implemented as an equivalent LTspice circuit as shown in Fig. 1. Build this circuit in LTspice. The lossy transmission line is modelled with the `ltline` item, which you can find in the `Component` tool. Once you place the `ltline` component in the schematic, change its name from "LTRA" to "TL1" (while hovering over the component, right-click to open the `Component Attribute Editor`, then double-click in the "Value" of the attribute "Value"). You also need to include an LTspice directive for `TL1`. To this end, press the `s` key on your keyboard while your curser is in the schematic window to open the `Edit Text on the Schematic` window. Make sure the option `SPICE directive` is selected. Type in the directive

```
.model TL1 LTRA (L=***n C=***p R=*** Len=1)
```

wherein you must replace the asterisks with the values of L', C' and R' with those you used in your MATLAB code. Here, `Len = 1` sets the length of the TL to 1 unit of length, which is the unit used to define the *PUL* parameters (in our case, meter). Identify nodes `in` and `out` as shown in Fig. 1. Based on this, the voltages at nodes `in` and `out` are those at the input and the output of the TL, respectively.

Unfortunately, G' cannot be defined in this LTspice model. So, we include it as an additional shunt resistor as shown in Fig. 1. For a TL of length 1 m, $G = G'$ and $R = 1/G = 1/G'$.

Define $\mathbf{V}_s$ as a sinusoidal voltage source with amplitude of 1 V and frequency of 1 GHz. Choose transient analysis for your simulation. Suitable simulation parameters are:

```
.tran 0 10n 0 0.001n
```

Simulate your circuit and plot the voltage waveforms $v_{\text{in}}(t)$, $v_{\text{out}}(t)$ and $v_s(t)$ in a single plot. You will need the image of this plot for your report.

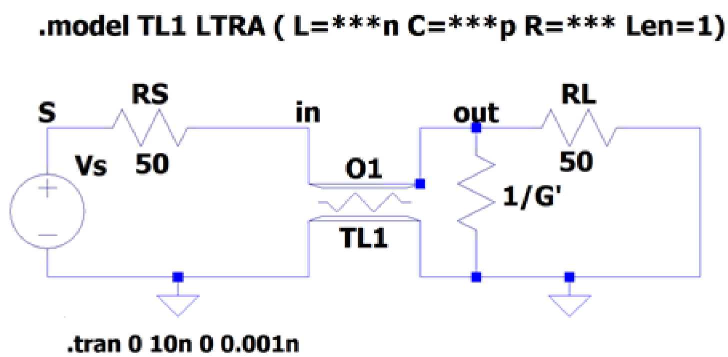

Fig. 1: Equivalent circuit of a transmission line in LTspice.

For the Report

1. Include your MATLAB code.
2. Include the following MATLAB-generated plots: (a) $\alpha = \operatorname{Re}\gamma$, (b) $\beta = \operatorname{Im}\gamma$, (c) phase velocity v_p, (d) ReZ_0 (real part of Z_0), (e) ImZ_0 (imaginary part of Z_0), all versus frequency. Each trace has to be plotted on a separate plot.
3. Include the complete LTspice schematic (screenshot or image export).
4. Include the complete LTspice netlist (`View→SPICE Netlist`).
5. Include the LTspice (*.asc) file, named properly, e.g., Exercise1.asc.
6. Include the plot of the $v_{\text{in}}(t)$, $v_{\text{out}}(t)$ and $v_s(t)$ waveforms resulting from the LTspice simulation (single plot).
7. How does the magnitude of $v_{\text{in}}(t)$ compare to the magnitude of $v_s(t)$? Explain your observation.

Hint: To read a value from a curve in a plot, double click on the curve's label that you can find above the plot. Two orthogonal lines (crosshairs) appear. Move these lines toward the peak of the trace to read out its value.

8. How does the magnitude of $v_{\text{out}}(t)$ compare to the magnitude of $v_{\text{in}}(t)$? Explain your observation.
9. Calculate the attenuation constant α (in Np/m) of the TL using the peak values of $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ that you determined in Questions 7 and 8. Does this value agree with the value obtained with your MATLAB code?

EXERCISE #2: LOSSY TRANSMISSION LINE

In this Exercise, you will use again the circuit in Fig. 1 with the *PUL* parameters modified so that the TL losses change.

First, consider loss-free TL. In this case, you have to define R' in the TL model to be zero and you have to remove the shunt resistor $1/G'$.

Define $\mathbf{V}_s$ as a digital source (pulse source) with the following specification:

```
PULSE(0 1 0 10e-16 10e-16 0.5n 1n)
```

Simulate the circuit and observe the $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ waveforms in a single plot. You will need the image of this plot for your report.

Second, increase R' in the TL model so that it is 10 times greater than the value of the low-loss TL in **EXERCISE #1** (i.e., 10 times greater than the value in **Table I**). You will not need a shunt resistor, i.e., G' will remain zero. Define $\mathbf{V}_s$ in the same way as in the case of the loss-free TL circuit. Simulate the circuit and observe the voltage waveforms $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ in a single plot. You will need the image of this plot for your report.

For the Report

1. Include the complete LTspice schematic for both loss-free and lossy TL (screenshot or image export).
2. Include the complete LTspice netlist for both loss-free and lossy TL (`View→SPICE Netlist`).
3. Include the LTspice (*.asc) file for both loss-free and lossy TL, named properly, e.g., `Exercise2_lossfreeTL.asc` and `Exercise2_lossyTL.asc`.
4. Include the plot of the $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ waveforms from the loss-free TL simulation (single plot).
5. Include the plot of the $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ waveforms from the lossy TL simulation (single plot).
6. Compare the magnitude of $v_{\text{out}}(t)$ in the loss-free TL compared to the magnitude of $v_{\text{out}}(t)$ in the lossy TL. Based on these two values, calculate the attenuation of the lossy TL in dB/m. You do <u>not</u> need to compare this calculation with analytical calculations.
7. What is the time delay t_{d} between $v_{\text{in}}(t)$ and $v_{\text{out}}(t)$ in the lossy TL?
8. Calculate the phase velocity v_{p} in the lossy TL using the time delay t_{d} found in Question 7. The length of the TL is 1 m.
9. Compare the so obtained phase velocity v_{p} with the analytical value, which you can compute using your MATLAB code at the repetition frequency $1/T$ where $T = 1$ ns. The analytical calculation of v_{p} <u>must</u> take the losses into account, i.e., you cannot use the low-loss approximation. Include your analytical value of v_{p} in the report. Is there good agreement? Please, state clearly the values of the simulation-based and the analytical phase velocities.

TABLE I

VERSIONS OF *PUL* PARAMETERS

Last Digit in Student ID	**R' (Ω/m)**	**L' (nH/m)**	**G' (mS/m)**	**C' (pF/m)**
Zero or Even	1.35	322	0.77	129
Odd	1. 8	286	0.65	115