Transmission Lines and Time-domain Reflectometry

Overview: This document is a preparation for lab 2. It is due at the beginning of the lab session.

Equipment: Matlab® software is needed to complete this pre-lab.

For more information: Contact the teacher assistants or class instructor. See website for details: www.ece.utah.edu/~ece3300

Objectives:
- Learn about different types of transmission lines including coaxial cable, two wire lines, and microstrip.
- Measure the effect of external materials on capacitance and therefore impedance of a line.
- Understand the meaning of characteristic impedance $Z_0$ and how it differs from impedance $Z(z)$.
- Understand step function voltage transients on transmission lines.

Background:
Students should understand before the lab:
- Lumped element (RLGC) model for transmission lines (TL) and how to calculate the RLGC parameters for a variety of transmission lines.
- How to make bounce diagrams and calculate the voltage at a point on the line as a function of time.
Pre-lab:

1. **RLGC Model of Transmission Lines:**

Write a Matlab\textsuperscript{TM} code that will calculate the values of $R$, $L$, $G$, $C$, $\alpha$, $\beta$, velocity of propagation, and $Z_0$ for a coaxial transmission line, two wire line, and parallel plate transmission line. The following information is from [1].

![Coaxial line](image1)

(a) Coaxial line

(b) Two-wire line

(c) Parallel-plate line

(d) Strip line

(e) Microstrip line

### TEM Transmission Lines

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coaxial</th>
<th>Two Wire</th>
<th>Parallel Plate</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R'$</td>
<td>$\frac{R_s}{2\pi} \left( \frac{1}{a} + \frac{1}{b} \right)$</td>
<td>$\frac{R_s}{\pi a}$</td>
<td>$\frac{2R_s}{w}$</td>
<td>$\Omega/m$</td>
</tr>
<tr>
<td>$L'$</td>
<td>$\frac{\mu}{2\pi} \ln(b/a)$</td>
<td>$\frac{\mu}{\pi} \ln \left[ (d/2a) + \sqrt{(d/2a)^2 - 1} \right]$</td>
<td>$\frac{\mu d}{w}$</td>
<td>$H/m$</td>
</tr>
<tr>
<td>$G'$</td>
<td>$\frac{2\pi \sigma}{\ln(b/a)}$</td>
<td>$\frac{\pi \sigma}{\ln(b/a)} \ln \left[ (d/2a) + \sqrt{(d/2a)^2 - 1} \right]$</td>
<td>$\frac{\sigma w}{d}$</td>
<td>$S/m$</td>
</tr>
<tr>
<td>$C'$</td>
<td>$\frac{2\pi \varepsilon}{\ln(b/a)}$</td>
<td>$\frac{\pi \varepsilon}{\ln(b/a)} \ln \left[ (d/2a) + \sqrt{(d/2a)^2 - 1} \right]$</td>
<td>$\frac{\varepsilon w}{d}$</td>
<td>$F/m$</td>
</tr>
</tbody>
</table>

Notes: (1) Refer to Fig. 2-4 for definitions of dimensions. (2) $\mu$, $\varepsilon$, and $\sigma$ pertain to the insulating material between the conductors. (3) $R_s = \sqrt{\pi \mu / \sigma_c}$. (4) $\mu_c$ and $\sigma_c$ pertain to the conductors. (5) If $(d/2a)^2 \gg 1$, then $\ln \left[ (d/2a) + \sqrt{(d/2a)^2 - 1} \right] \simeq \ln(d/a)$. 

---

Test your code on the following transmission lines, and bring the code to lab with you:

**RG58 Coaxial Line (cable type is printed on the side of the cable)**
- The frequency is 1 GHz.
- The inner radius \( a = 0.445 \text{ mm} \), and the outer radius \( b = 1.765 \text{ mm} \).
- The conductor is copper (\( \sigma_c = 5.8 \times 10^7 \text{ S/m}, \mu_r = 1.0 \)).
- The insulation between the coaxial lines is polyethylene (PE) (\( \varepsilon_r = 2.25, \sigma = 0.0001 \text{ S/m} \)). Unless a material is clearly magnetic (ferrite materials), assume \( \mu_r = 1.0 \).

Answers for coax:
- \( R = 3.6947 \text{ ohms/m} \)
- \( L = 2.7557 \times 10^{-7} \text{ H/m} \)
- \( G = 4.5602 \times 10^{-4} \text{ mohs/m} \)
- \( C = 9.1164 \times 10^{-11} \text{ F/m} \)
- \( \alpha = 0.0461 \text{ Np/m} \)
- \( \beta = 31.4923 \text{ rad/m} \)
- \( v_p = 1.9951 \times 10^8 \text{ m/s} \)
- \( Z_0 = 54.9796 - 0.0368i \text{ ohms} \)

**Parallel Plate Line**
- The frequency is 1 GHz.
- The polyethylene substrate has a thickness of 1 mm.
- The top and bottom are made of copper.
- The width of the line is 6 mm.

**Twin Lead**
- The frequency is 1 GHz.
- The radius of the wires is 2 mm, and the distance between the wires is 6 mm.
- Assume they are separated by polyethylene.

Answers for twin lead line:
- \( R = 1.3131 \text{ ohms/m} \)
- \( L = 3.8497 \times 10^{-7} \text{ H/m} \)
- \( G = 3.2643 \times 10^{-4} \text{ mohs/m} \)
- \( C = 6.5256 \times 10^{-11} \text{ F/m} \)
- \( \alpha = 0.0211 \text{ Np/m} \)
- \( \beta = 31.4923 \text{ rad/m} \)
- \( v_p = 1.9951 \times 10^8 \text{ m/s} \)
- \( Z_0 = 76.8071 + 0.0097i \text{ ohms} \)
2. Voltage Step Function Response:

Sketch Voltage Reflection Diagrams (Bounce Diagrams) for a 50 Ω RG58 coaxial line connected to the following terminations. Assume P = 1m and d = 2m. Use the velocity of propagation calculated in the previous section for polyethylene-filled coaxial line. Sketch the voltage at the sampling probe P as a function of time. Also calculate and show on your plot the steady state voltage (from Ulaby equation 2.159).

a) Matched Load (50 Ω)
b) Open Circuit
c) Short Circuit
d) Resistor = 100 Ω
e) Resistor = 25 Ω
f) 75 Ω transmission line that is 0.8 meters long and open at the end (connected to the 50 Ω line where \( R_T \) is shown). This creates tandem transmission lines, which are discussed in Agilent Application Note 1304-2.
g) Inductor (qualitative drawing is sufficient), also discussed in the application note.
h) Capacitor (qualitative drawing is sufficient), also discussed in the application note.

Questions:
2.1) Explain the concept of “step function response” of a system. See your circuits book if you do not remember.
2.2) Explain how the bounce diagrams and their related voltage vs. time plots relate to the step function response.
References

