**ECE 6340**

**Fall 2016**

**CLASS PROJECT**

Version date: Oct. 24, 2016

**INSTRUCTIONS**

This project is due on Wednesday, Dec. 14, 2016 at 5:00 p.m. (please turn it in by slipping it under the instructor’s door). Please work individually on the project. Do not give or receive any material to/from anyone else. To do otherwise will be considered a violation of the UH Academic Honesty Policy.

You will be graded mainly on the accuracy of the results and the quality of the plots, but also on the discussion of the results and the grammar and writing style. There is no required length for your report. It is recommended that you make it long enough so that you are able to discuss all of the points that you find relevant, but do not try to make the report longer than it needs to be.

The calculations can be done in software package that you prefer (Matlab, Fortran, Mathcad, Mathematica, etc.) The project must be written on a word processor (using, e.g., Microsoft Word or something similar). The project should contain the sections listed below. The equations in the report should be done professionally, using e.g., MathType or something similar.

Please report any problems or typos that you notice to the instructor as soon as possible. Please watch the class Blackboard site for announcements regarding corrections. Please check periodically to make sure that your version of the project is the latest one (note the version date at the top of this page).

The project should have the following sections:

* Title page
* A brief Abstract
* An Introduction section
* An Analysis section
* A Results section
* A Conclusion section
* A Reference section (if any references are cited)

The analysis section should present all of the main formulas that are used for the calculation. However, you do not need to re-derive anything that was already derived in the class notes.

**PROJECT DESCRIPTION**

A semi-infinite RG-6/U (CATV) coaxial cable is attached to a signal generator at *z* = 0 as shown below. The signal generator provides an input voltage  that is a pulse given by

 ,

where  is  seconds. The output voltage is to be calculated at a distance  from the source, as shown in Fig. 1 below.

+

-

*z* = 



*z* = 0

-

+



Copper wire

Dielectric

Aluminum shield

Outer shield



Figure 1**.** A semi-infinite coaxial transmission line that is connected to a signal generator at one end. (a) Side view showing signal generator. (b) Cross-sectional view of coax.

The parameters of the coaxial cable are as follows.

*Z*0 = 75 [Ω] (characteristic impedance)

*a* = 0.512 [mm] (radius of inner copper wire)

*b* = 2.70 [mm] (outer radius of dielectric, or the inner radius of the aluminum shield)

*t* = 0.025 [mm] (thickness of aluminum shield)

 (real part of relative permittivity for the dielectric (foamed polyethylene))

tan *δ* = 0.001 (loss tangent of the dielectric)

[S/m] (conductivity of the inner copper wire conductor)

[S/m] (conductivity of the outer aluminum foil conductor)

**REQUIRED CALCULATIONS AND RESULTS**

The calculations and results listed below are a required part of the project. You are free (and encouraged) to include any others results that you wish.

1. Determine the Fourier transform of the input signal as a function of the transform variable *ω*. Use the transform definition that was used in class. Plot the magnitude of the Fourier transform versus *ω*. (Note: Examining the spectrum of the pulse might help to determine what the limits of integration should be in the numerical inverse Fourier transform integration for calculating the output voltage.)
2. Numerically evaluate and plot the output voltage  for = 0 [m]. This plot should be almost the same as that of the given input voltage , if your numerical evaluation of the integral is working correctly. Hence, this step is a validation of your numerical integration scheme.
3. Numerically evaluate the output voltage  for = 0, 1, 10, 100, and 200 [m] for the coaxial cable. Make a plot of the output voltage versus shifted time. The shifted time is defined as , where  (this is the speed of light in the dielectric, if it were lossless). This will allow for a clear examination of how the pulse has changed in both amplitude and shape during the transmission through different distances. Put all plots (different lengths) on the same figure if possible, for an easy comparison.
4. Consider a train of two digital “one” pulses with a “zero” level in between, so that the input signal is now given by

.

Repeat the previous step using this sequence of two digital pulses. This will allow for an examination of how a clear transition between the digital states “one” and “zero” in the input signal will degrade due to dispersion.

1. As a continuation of the previous step, assume now that the output pulse is amplified so that the maximum level of the output signal is always one volt. Assume that the transition from a “one” state to a “zero” state can only be recognized if the voltage level in the output signal falls below 0.5 V. Find the minimum distance  such that the transition in the digital state can no longer be recognized.

**DISCUSSION OF METHOD**

Use the RLCG formula to obtain the propagation constant *γ* for each value of *ω* in the inverse Fourier transform integration. To ensure that the results are as accurate as possible, account for the skin-effect resistance and the internal inductance that arises from the skin effect. In order to account for both low and high frequency effects, use the model proposed by Tesche for the series impedance per unit length. The differential length of transmission line is shown below in Fig. 2.

The series impedance per unit length *Za* corresponding to the inner wire is given by the circuit shown below in Fig. 3 [1], where “DC” means the DC values and “AC” means the high-frequency skin-effect values. A similar circuit holds for the outer conductor.

*C*

*Za*

*Zb*

*G*

*L*0

Δ*z*

Figure 2. A per-unit-length model of the coaxial cable. The impedance *Za* corresponds to the inner conductor (wire) and the impedance *Zb* corresponds to the outer conductor(s).



Figure 3. A circuit model for the series impedance per unit length *Za*. A similar circuit model holds for the series impedance per unit length *Zb*.

The capacitance and conductance per unit length (in [F/m] and [S/m], respectively) are given by the following formulas:



.

The external inductance per unit length *L*0 in [H/m] is given by the formula

.

The DC inductances (per unit length) in [H/m] are given by



,

where  is the outer radius of the aluminum shield. Note that the outer shield (the one that is outside of the aluminum shield) is being neglected here.

Remember that the DC inductances need to get multiplied by *ω* in order to obtain reactances at any given frequency *ω*.

The DC resistances (per unit length) in [Ω/m] are given by



.

The high-frequency (AC) skin effect formulas for the resistances and the reactances in [Ω/m] are



,

where *δ*1 is the skin depth associated with the inner copper wire (having conductivity *σ*1) and *δ*2 is the skin depth associated with the outer aluminum shield (having conductivity *σ*2).

When you take the square root to determine the propagation constant *γ*, make sure you choose the correct sign of the square root. (Note that *α* should always be positive.)

**ITEMS FOR DISCUSSION**

The following points would make good items for discussion within your report. You are free (and encouraged) to discuss any other items that you wish.

* + How was the shape of the pulse affected by the losses on the transmission line?
  + How is the peak amplitude of the pulse affected by the transmission down the line?
  + Can the leading edge of the pulse ever travel faster than the speed of light? Is this confirmed by your results?
  + How far do we have to go down the line before we lose signal integrity and can no longer reliably detect the transition between states in the digital pulse sequence?
  + Are there numerical issues that you encountered that are worth mentioning?

**REFERENCE**

[1] F. M. Tesche, “A simple model for the line parameters of a lossy coaxial cable filled with a nondispersive dielectric,” *IEEE Trans. EMC*, vol. 49, no. 1, pp. 12-17, Feb. 2007.