PART II coursework

ELEC2229: Circuits and Transmission

Equivalent circuit model of transmission lines.

Extraction of equivalent circuit for transmission lines from full wave simulation

(This assignment carries 20% of the total mark)

This assignment requires you to build an equivalent circuit model of a coaxial transmission line.

This assignment uses:

- The Multisim circuit simulator to build and demonstrate the equivalent circuit model,
- Analytical models of transmission lines.

General remarks:

- All plots and screenshots must be of high enough resolution to be easily readable
- The report should be clearly structured into subsections with appropriate headings
- Please take a close look at the marking scheme

Before attempting this assignment read relevant sections in the recommended text-book [1] and [2]. Students are also adviced to use the notes and the information available in the lab EE56 – The Transmission Line as well as the other references suggested at end of this document.

1. Coaxial transmission line problem

You are asked first to calculate the characteristic line impedance and time delay (velocity ratio) of a coaxial transmission line. The geometry of the coaxial transmission line is schematically shown in figure 1. The diameter of the inner conductor is d = 0.58 mm, while the inner diameter of the outside conductor is D = 3.7 mm, the relative permittivity of the insulating medium is $\varepsilon_r = 2.2$ while the relative permeability of this medium is $\mu_r = 1$. For the length of the line assume 100 mm.

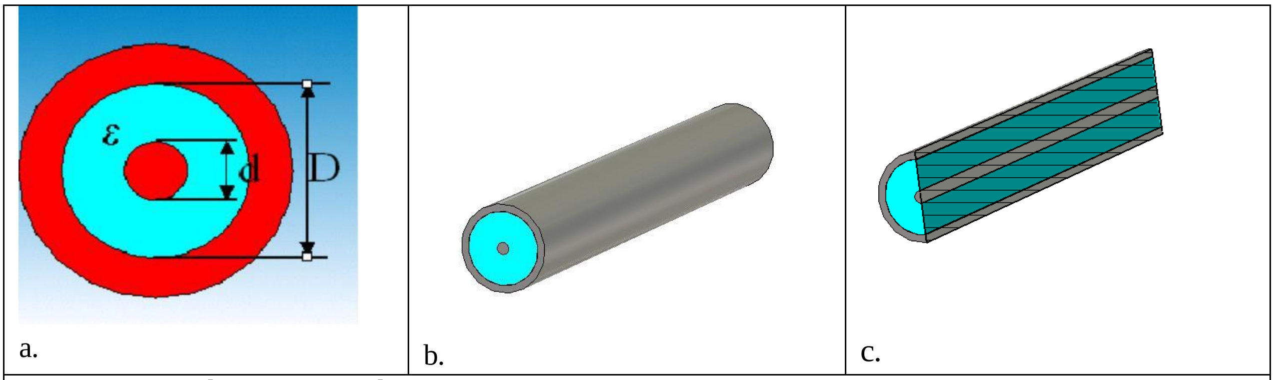

Figure1. Coaxial transmission line

The characteristic impedance of a loss free line can be calculated very easily if the inductance and capacitance per unit length of the coaxial transmission line are known. Calculate the value of the characteristic line impedance using your knowledge of electromagnetism that you have gained in ELEC2219. Also calculate the time delay of this transmission line and the velocity of the electromagnetic wave traveling along this line. Comment on the results obtained. *(Hint: in the ELEC 2219 tutorials calculation of the capacitance and inductance per unit length of a coaxial structure has been discussed).*

2. Equivalent circuit model of a transmission line

Usually the transmission lines are much longer than 100 mm. For example in your EE 56 – High Frequency Transmission Line lab the length of the transmission line is 32 meters. For such situations an equivalent circuit model is appropriate and efficient. Therefore in this part of the assignment you will be required to extract, build and simulate an equivalent circuit model able to reproduce the behaviour of a **32 meters long transmission line**.

For this part of the work you could use any decent circuit simulator. As you are familiar with Multisim you can use this tool to build, test and analyse your equivalent circuit models.
Using the results obtained in section 1 build up an equivalent model that correctly simulates a 32 meter coaxial transmission line with the same cross section geometry and material properties as described in section 1. Make sure that your model is capable of correctly simulating the coaxial transmission line up to **700MHz**. **Describe in your report a depiction of the circuit as well as the procedure that you have follow to build the equivalent circuit. Your discussion should include the reasons why you have followed this particular procedure.**
Although the model obtained by chaining together line sections that are electrically short represented by "Γ" LC circuits is correct it is still an approximation of a lossless transmission line (figure 6). Multisim as well as any other circuit simulator or SPICE based environment has an exact model of a lossless transmission line. This exact model is based on the work published by Branin, F., 'Transient Analysis of Lossless Transmission Lines', Proceedings of the IEEE, 55, November 1967, 2012–2013 and it has the equivalent model shown in figure 7.

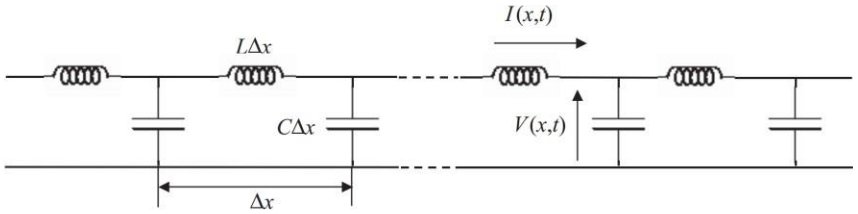

Figure 6. Representation of a lossless transmission line by lumped parameters consisting of cells of length Δx having per unit length inductance L and per unit length capacitance C

The equivalent circuit from figure 7 is an exact solution of transmission line equation in the case of a uniform lossless transmission line; The model has two resistances equal to the characteristic impedance of the line Z_0 and two dependent-voltage sources $e_i(t - T_D)$ and $e_o(t - T_D)$ at the source and load ends. $e_i(t - T_D) = V(l, t - T_D) - Z_0 I(l, t - T_D)$ and $e_o(t - T_D) = V(0, t - T_D) + Z_0 I(0, t - T_D)$.

The controlled source $e_i(t - T_D)$ is produced by the voltage and current at the load end of the line at a time equal to the line delay time T_D earlier than the present time. Similarly, the controlled source $e_o(t - T_D)$ is produced by the voltage and current at the line input at a time equal to the line delay time T_D earlier than the present time. T_D the line time delay represents the time necessary for a signal to travel along the line represented by this equivalent circuit. The Multisim model will need the characteristic impedance of the line Z_0 and the time delay T_D to be specified. Note that the time delay can be also specified in terms of phase difference between the input and output.

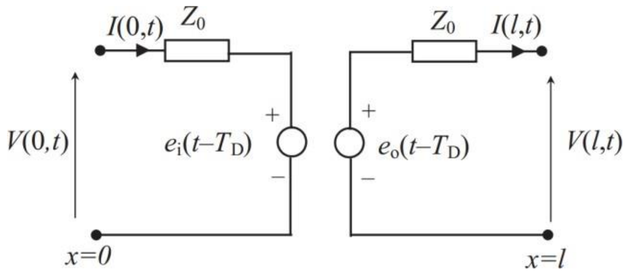

Figure 7. Exact distributed model of a lossless transmission line

Excite your model with a step voltage function with a time rise of 0.5 ns and a maximum voltage of 5 V and study the following test cases:

a. 75 Ω load for the transmission line.
b. Open circuit load.
c. Short circuit load.
d. 10 Ω load.

Observe the **input voltage** and **load voltage** for the cases listed above and comment on your observation. **Voltages, currents, reflection coefficient (etc) plots should be provided as a proof of your comments and observations.** As you (should) have two equivalent circuits for the 32 m transmission line – one based on the calculated per unit length capacitance and inductance (figure 6) and another one based on the available Multisim model (figure 7) – **simulate the cases listed above with both models and compare the results. Comment and explain your observations**.

Using the same circuit models, now change the excitation from a step voltage source to an AC voltage source. Use a 5 V amplitude and a frequency of 1 MHz, 10 MHz and 30 MHz and repeat the load conditions listed above (a., b., c., and d.). **Once more observe the input and load voltages. Explain your observations.**

As this line is lossless when there is no load (open circuit condition) it should have an infinite input impedance when the line length is $l = \frac{\lambda}{2}, \lambda, 3\frac{\lambda}{2}, 2\lambda$ ... and zero input impedance when $l = \frac{\lambda}{4},\ 3\frac{\lambda}{4}, 5\frac{\lambda}{4}$ .... When the line is short circuited the complementary behaviour is observed. What is the frequency of the voltage source that you need to set-up such that the line has a zero input impedance when the load is left open?

Demonstrate these situations using your equivalent circuit model (the LC chain model) as well as the model based on exact model of a lossless transmission line available in Multisim. Comment on your observations.

(Suggestion: There are some important aspects that should be carefully considered when the equivalent model of the transmission line is build and simulated. First consider carefully the fact that the model you are trying to build should behave like a 32m coaxial line anywhere within the bandwidth of interest. This mean that the physical length of the line has to be emulated in your circuit model, also you need to consider that the electrical length of your model changes with frequency. Second aspect that you should consider is the source that you are going to use in your simulations. Once more you are trying to produce a model that emulates reality, any real source will have an internal impedance, please consider this aspect when you set-up your model.)

3. Lossy Line

Build a 32 meter long transmission line in Multisim which includes these losses in a similar way as you have done for the no loss case. Load your transmission line with a 75 Ω load. Excite this model as before with a voltage source that has peak value of 5 V and a frequency of 1 MHz, 10 MHz and 30 MHz respectively.

Assume that ε"=2 x 10^{-9} and R=0.2 ohm/meter at 1 MHz, R=0.6 ohm/meter at 10 MHz and R=0.8 ohm/meter at 30 MHz.

Compare your results with the no loss case for different frequencies. Record and comment on your observations. What are the observations and conclusions of this work?

Report

Each student must submit an individual report on the work undertaken to solve this assignment. Your report should contain:

- A detailed description of the analytical extraction of the static capacitance and inductance per unit length of the coaxial transmission line.
- Full explanation of the equivalent circuit model extraction for the coaxial transmission line.
- Results obtained from equivalent circuit time domain simulation – step voltage and AC voltage case (for different frequencies) – with discussions and explanations of the results.
- Extraction of the resistance and conductance per unit length for the lossy equivalent circuit representation of the coaxial transmission line.
- Time domain simulation results obtained for the lossy case and comparisons with the lossless cases.
- General comments and conclusions.

When marking the final report, credit will be particularly given for interesting comments and observations, especially if they demonstrate that a thorough investigation has been conducted and additional information through independent study has been acquired. Make sure that your **graphs are readable and relevant to the results** that need to be presented.
A detailed marking scheme is attached; this should give you an idea about what is expected in your report. You will note that critical analysis of results, thorough investigations, relevant observations and meaningful conclusions are essential to achieve a good mark. Achieving a correct and useful model will also require careful implementation of the fundamental concepts.

<u>Very important note</u>*: The report should be written using a* ***standard IEEE format****. You can download a template of this format from https://www.ieee.org/conferences/publishing/templates.html*
<u>Your report should not exceed 6 pages (double sided, three A4 sheets, including appendices if you need them). If the report is not formatted in the above format and exceeds the limit stated above it will not be considered which will result in zero (0) mark.</u>

References

[1] A.H. Morton, Advanced Electrical Engineering, Longman Scientific and Technical, 1996.
[2] David. M. Pozar, Microwave Engineering, (fourth edition), Wiley, 2012.
[3] Microwaves101.com
[4] Robert A. Chipman, Schaum's outline of theory and problems of Transmission Lines, McGraw-Hill (1968)
[5] S. Caniggia and F. Maradei, Signal Integrity and Radiated Emission of High Speed Digital Systems, Wiley, 2008
[6]https://www.youtube.com/watch?v=dxwYEPT3rjc

Deadline

Please note that you are expected to complete your work by week 2 and 'hand in' your report by **4pm on Friday the 17 March 2023**. Any delay in handing in the report will incur a penalty in the form of reduced final mark (at a rate of 10% reduction for each working day of late submission, up to 5 working days, no submission is allowed after that; extension requests must be made in advance). The report should be submitted electronically through the "Handin" system.

Appendix A: Marking scheme

Assessment Criteria	Outstanding	Good	Poor	Absent
Analytical calculation and modeling with Multisim*:*				

Set up of the equivalent circuit model – loss free – using the extracted LC parameters and the available Multisim TL element *Calculate and built the equivalent circuit model of the transmission line for the loss free coax line*	**3.5**	**2**	**0.5**	**0**
Set up the of the equivalent model – lossy case *Calculation of the equivalent circuit components that represent the loss of the coaxial line*	**3**	**2**	**0.5**	**0**
Analytical calculation *Calculation of the equivalent circuit components using fundamental electromagnetic field theory*	**3**	**2**	**0.5**	**0**
Studies and analysis*:* *Time domain study and analysis of the equivalent circuit model (loss free) under step voltage excitation – including the comparison between the LC circuit model and Multisim TL element*	**3**	**2**	**0.5**	**0**
Time domain study and analysis of the equivalent circuit model (loss free) under harmonic (AC) voltage excitation - including the comparison between the LC circuit model and Multisim TL element	**2.5**	**1.5**	**0.5**	**0**
Time domain study and analysis of the equivalent circuit model (lossy case) under step voltage excitation	**1**	**0.5**	**0.25**	**0**
Time domain study and analysis of the equivalent circuit model (lossy case) under harmonic (AC) voltage excitation	**1**	**0.5**	**0.25**	**0**
Conclusions*:* *General conclusions and comments on the calculations, errors and implementation*	**3**	**1**	**0.5**	**0**
Total Mark	**out of 20**			