

A Simple Way of Simulating Transmission Lines Using Free Software. Application to a Quarter Wave Transformer

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Abstract A simple way to simulate a transmission line using a free software is developed. The line is simulated connecting in cascade a number of cells consisting of capacitors and inductors with appropriate values. This model was verified by reproducing numerical values of an example taken from the literature.

Keywords: Transmission Lines, Characteristic Impedance, Stationary Voltage Waves, Impedance Matching

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1. Introduction

In this paper, a simple method of simulating transmission lines is presented. Numerical results from a specific problem found in [1] were verified by the simulation.

Transmission line may be defined at a basic level as the device that transmits electromagnetic energy between two points in a controlled way. This transmission is guided through a physical medium formed by two conductors separated by an insulator material, from a source energy generator to a load, as shown in Figure 1. Ideally, all of the energy generated at the source would efficiently reach the load and be consumed by it. Unfortunately, this is hardly the case. The transmission line always suffers from losses due to the attenuation of the conductors, a topic that will not be studied here. Also, the energy reaching the load is generally not totally absorbed, producing unwanted reflections. The energy in a line is transmitted through voltage and current waves. Therefore, an energy reflection means that voltage and current waves are returning back to the generator. It is well known that, when two counter propagating waves interact, the result is a stationary wave pattern, which has maximum and minimum amplitude values. These extremes values remain at the same point in space. A stationary voltage wave in a transmission line may origin some problems; one of them is that the maximum voltage value of the wave, which is the sum of the incident and the reflected amplitudes waves, may damage the insulator material through dielectric breakdown, producing a short circuit in the line. Also, the energy returning back could damage the generator. For these reasons, methods to avoid energy reflections in

transmission lines are important topics in textbooks on electric engineering. When these reflections are not present, or were avoided using some technique, it is said that the line is matched to the load.

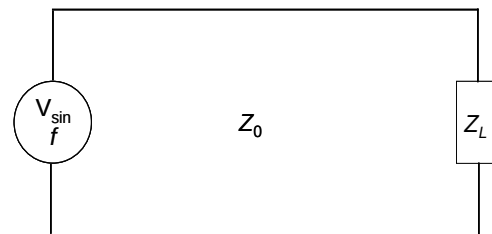


Figure 1. Schematic showing energy generator, transmission line and load

In this work, sinusoidal voltage waves will be considered, characterized by the amplitude, V_0 , and the frequency, f . With the values of the electric permittivity, ϵ , and magnetic permeability, μ , of the dielectric (insulator) medium of the line, the wavelength, λ , corresponding to the voltage wave can be determined by $\lambda = (\epsilon\mu)^{-1/2} / f$, see ref [2]. The quantity Z_0 is the characteristic impedance of the line, which is defined as the quotient between the voltage amplitude and the current amplitude of the respective waves propagating by the line, taking account the waves in just one sense of propagation. The quantity Z_L is the load impedance. The case of lines without losses will be studied, which implies that the value of Z_0 is real. The reflection of the voltage wave at the load can be quantified by the reflection coefficient of voltage, defined as the quotient between the amplitude of the reflected to the incident voltage wave [1], given by:

$$\rho_V = \frac{V_R}{V_I} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1)$$

Where V_R and V_I stands for the amplitudes of voltage waves reflected and incident, respectively, measured at the load. It can be seen from (1), that unwanted energy reflections are due to the dissimilar values of the characteristic impedance of the line and the load impedance.

In most of the textbooks treating on transmission lines, the quarter wave line, or quarter wave transformer, is presented as one of the main devices used to avoid unwanted energy reflection from a load. The characteristic impedance of such a line is given by [2]:

$$Z_{0\lambda/4} = \sqrt{Z_0 \cdot Z_L} \quad (2)$$

The physics length of this line is $\lambda/4$. This line must be connected between the transmission line and the load. Also, this line can be used to match the impedance between two lines of different characteristics impedances.

2. Example to be Analysed

It will be studied specifically the example given in [1], page 162, in which a quarter wave transformer is used to match two transmission lines of characteristic impedance of 100Ω and 400Ω . In this case, the characteristic impedance of the quarter wave transformer is: $Z_{0\lambda/4} = \sqrt{400 \times 100} = 200 \Omega$. A schematic diagram for this case is shown in Figure 2.

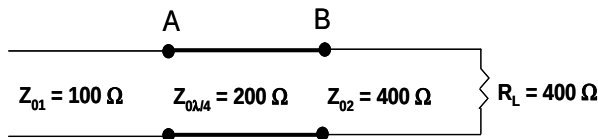


Figure 2. Schematic of the example studied in this work

The points marked as “A” and “B” at Figure 2 are the junctions, or interfaces (i.e., the points where the characteristics impedances change). The aim of the example is: giving a sin type continuous wave-front, of wavelength λ and amplitude V_0 (1V in the example), incident at point “A” from the left, determine the steady-state values of the amplitude’s voltage waves to the left of point “A” and to the right of point “B”. Ultimately, these values result to be 1V and 2V respectively, and this is what is intended to found in the simulation. At this point, to gain full insight on this matter, it may be interesting that the reader also checks a detailed analytical solution of that problem in [3].

3. Simulation and Results

In order to reproduce the results of the example, a simulation using free software LTspice [4] was performed. As a font of the sin-type voltage waves, it was used an electrical generator, with a frequency f of 13,4 Mhz. To simulate the transmission line, a cascade of cells consisting of inductors (connected in series) and capacitors (connected in parallel) were assembled, as shown in the schematic in Figure 3.

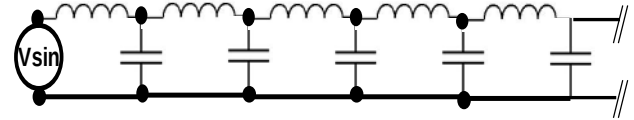


Figure 3. Transmission line as simulated in LTspice

The characteristics impedance of the line, Z_0 is given by [2]:

$$Z_0 = \sqrt{\frac{L}{C}} \quad (3)$$

Where L and C are the inductance and capacitance per unit of length, respectively. In this particular case, it was simulated the transmission line with a $Z_0 = 100 \Omega$, connecting forty-six cells, each consisting in a series inductance (L) of $0.53 \mu\text{H}$ and a parallel capacitance (C) of 52.1 pF . In the context of the simulation, this values of inductance and capacitance are actually the values of inductance and capacitance per “unit of length”, which can be defined as the longitudinal length of one cell. Assuming this unit of length to be meter, the value of L and C should be chosen also in order to keep the velocity of propagation of the voltage waves to a value physically realistic. This velocity is given by [2]:

$$v = \sqrt{\frac{1}{LC}} \quad (4)$$

With the values of L and C used in this example, the velocity calculated using (4) is $1.91 \times 10^8 \text{ m/s}$, which is a realistic value for a transmission line. In this way, the transmission line has a length of 46 m and the values of L and C are per unit of length (m). Of course, it can be assumed another unit of length for the individual cells, and the values of L and C should have the appropriate values, in order that (4) gives a physically realistic value of v . With the values of v and f , the wavelength, λ , of the tension wave propagating on this line can be calculated trough the well-known relation:

$$\lambda = \frac{v}{f} \quad (5)$$

and has the value $\lambda \cong 14,3 \text{ m}$.

Now, the quarter wave line must be designed. As already seen, the characteristic impedance for this line must be $Z_{0\lambda/4} = 200 \Omega$. The values of inductance and capacitance per unit of length for this line were chosen to be $L_{\lambda/4} = 0.93 \mu\text{H/m}$ and $C_{\lambda/4} = 23.32 \text{ pF/m}$, respectively. To calculate the appropriate length of this line, the value of $\lambda_{\lambda/4}$ must be known. It can be calculated by first estimating the velocity, using the values of $L_{\lambda/4}$ and $C_{\lambda/4}$ in (4), and then using (5). The result is $\lambda_{\lambda/4} \sim 16$ units of length, or 16 m. Then, to simulate the quarter wavelength line, there must be placed four cells of inductances and capacitances with the values $L_{\lambda/4}$ and $C_{\lambda/4}$.

In order to not complicate the simulation, the line of $Z_0 = 400 \Omega$, can be replaced by the load, $R_L = 400 \Omega$, with no difference in the final results (we are not expecting reflections from R_L , as it is effectively matched with Z_{02}).

It was simulated a temporal window of 700 ns. The results of the simulation are shown in Figure 4.

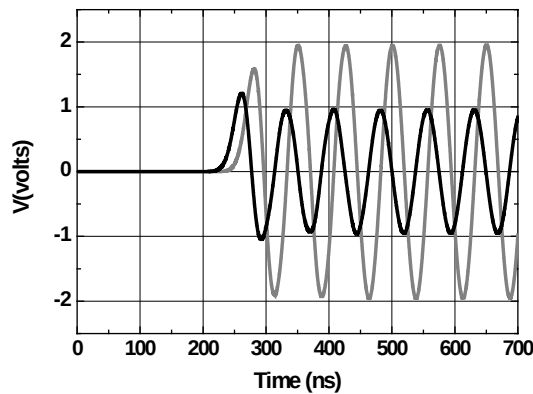


Figure 4. Voltage waves obtained in simulation. Black trace: voltage at point A (see Figure 2); grey trace: voltage at point B

The voltage waves shown in Figure 4 were obtained at point "A" (shown in Figure 2), in black trace, and at point "B", in grey trace. Note the delays of ~ 220 ns and 250 ns for both the traces, indicating the time the waves took to travel from the generator to points "A" and "B", respectively. It also can be seen, in Figure 4, that the amplitude voltage values obtained in the simulation are slightly lesser than expected, i.e., 1V and 2 V for traces black and grey, respectively. This is due to the fact that the inductor used in the software has a default series resistance of $1\text{ m}\Omega$, which produce this potential drop.

4. Conclusions

In this work it has been shown how to simulate a transmission line using a free software. The line can be designed by connecting, in cascade, individual cells consisting in a series connected inductor and a parallel connected capacitor. The values of each component should be chosen so as to give the desired characteristic impedance. Also, it should be assumed, for each cell, a unit of length that reproduces a physically realistic value for the velocity of the electromagnetic interaction. The correctness of this model has been verified by reproducing stationary values of tension at both sides of a quarter wavelength, in an exercise taken from an example of well-established literature.

The author has no competing interests

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