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Modelling of the Behavior of Lossless Transmission Lines

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ABSTRACT

The behavior of a lossless transmission line is investigated and modeled in this paper. Lossless transmission lines as the name implies are lines with little or no signal loss during signal flow. Certain factors are responsible for this condition and they are discussed in this paper. These factors which are applied to coaxial and two-wire transmission lines were modeled using MATLAB in this work; a Graphical User Interface was then incorporated to provide an interactive way of analyzing the effect they have on signal flow efficiency. The modeling results show why lossless transmission lines are the best choice for optimum transmission efficiency.

Keywords: *Behavior, lossless transmission lines, modeling, Matlab*

1. Introduction

A transmission line is any device designed to guide electrical energy from one point to another. Transmission lines are used for a variety of purposes such as connecting radio transmitters and receivers with their antennas, distributing cable television signals and connections in a computer network. For a transmission line to be efficient, there must be little or no attenuation (distortion) in the line during signal flow. Itshould not also radiate any of its signals as radio energy. Lines which radiate some of its signals are called lossy lines. Certain transmission line parameters such as reflection coefficient, attenuation and voltage standing wave ratio affects transmission line performance and are major determinants of the best type of line for optimal signal flow.

The objective of this paper is to model and investigate the responses of a lossless transmission line under three circuit conditions: short circuit, open circuit and matched load circuits.

Javan and Newman (2005), describes some of the important parameters of different transmission media, such as twisted pair, co-axial cables and fiber optics. Important line parameters such as characteristics impedance of the line, frequency dependent losses, radiation, and interference were identified and presented as tabulated results to assist communication system designers' select appropriate media for their applications.

Luyan and Zhengyu (2012) analyzed transmission line parameters of Coaxial cables, such as propagation delay, reflection coefficient, attenuation incoaxial cablesby simulationand verification of different types of coaxial cables, including lossless cables using MATLAB and MODELICA.

2. Theoretical Background

Generally, a transmission line has these four parameters: Resistance, Inductance, Capacitance and Conductance (McCammon, Roy, 2010) as seen in Figures 1 and 2.

The lossless transmission line model is made up of the series inductance Ldx and shunt capacitance Cdx only, while (x,t) represent the distance and time components of current and voltage (Naredo, 1995).
Applying Kirchhoff's voltage and current laws, we get;

$$\frac{d}{dx}V(x,t) = L\frac{d}{dt}I(x,t) \quad (1)$$

$$\frac{d}{dx}I(x,t) = C\frac{d}{dt}V(x,t) \quad (2)$$

Also, to obtain the second order Telegraphers' equation for voltage and current, we differentiate equations (1) and (2) respectively, with respect to distance (x) and time (t), we get;

$$\frac{d^2}{dx^2}V(x,t) = LC\frac{d^2}{dt^2}V(x,t) \qquad (3)$$

$$\frac{d^2}{dx^2}I(x,t) = LC\frac{d^2}{dt^2}I(x,t) \qquad (4)$$

Hence, the Telegraphers equations for voltage and current in a lossless transmission line are:

$$\frac{d}{dx}V(x,t) = L\frac{d}{dt}I(x,t) \qquad (5)$$

$$\frac{d}{dx}I(x,t) = C\frac{d}{dt}V(x,t) \qquad (6)$$

$$\frac{d^2}{dx^2}V(x,t) = LC\frac{d^2}{dt^2}V(x,t) \qquad (7)$$

$$\frac{d^2}{dx^2}I(x,t) = LC\frac{d^2}{dt^2}I(x,t) \qquad (8)$$

Attenuation and Phase Shift Coefficient

From the equation:

$$-(\alpha + j\beta) = \sqrt{[(R + j\omega L)(G + j\omega C)]}$$

For R=0, G=0

$$-(\alpha + j\beta) = \sqrt{[(0 + j\omega L)(0 + j\omega C)]} = \sqrt{(j^2 w^2 LC)}$$

The characteristic impedance for a lossless transmission line can be gotten from the telegrapher's equation and is given by the expression

$$Zo = \sqrt{\frac{L}{C}}$$

. The reflection coefficient (Γ) of a signal wave is the ratio of the reflected wave to the incident wave at any point along the transmission line. This is given as:

$$Z_o\frac{[1 + \Gamma]}{[1 - \Gamma]} = Z_l$$

Expansion gives us

$$[Z_o + Z_o\Gamma] = [Z_l - Z_l\Gamma]$$

Collecting like terms, and dividing through, the equation becomes :

$$\Gamma = \frac{Z_l - Z_o}{Z_l + Z_o} \qquad (9)$$

- **For a matched case**, where $Z_o = Z_l$, $\Gamma = \frac{Z_l - Z_l}{Z_l + Z_l} = \frac{0}{2Z_l} = 0$, implying no reflection on the line.
- **For an open-circuit case**, where $Z_l = \infty$, $\Gamma = \frac{\infty - Z_l}{\infty + Z_l} = \frac{\infty}{\infty} = 1$, this implies total reflection of the input signal back along the line from the load end.
- **For a short-circuit case,** where $Z_l = 0$, $\Gamma = \frac{0 - Z_o}{0 + Z_o} = \frac{-Z_o}{Z_o} = -1$,. Hence the signal undergoes an 180˚ phase shift before it is totally reflected back along the line from the load end.

Mathematically, VSWR is given as

$$VSWR = \frac{|V_{incident}| + |V_{reflected}|}{|V_{incident}| - |V_{reflected}|} \qquad (10)$$

VSWR can also be related to the reflection constant $VSWR = \frac{\frac{|V_{incident}|}{|V_{incident}|} + \frac{|V_{reflected}|}{|V_{incident}|}}{\frac{|V_{incident}|}{|V_{incident}|} - \frac{|V_{reflected}|}{|V_{incident}|}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$

Reflection constant (Γ) can also be expressed as a function of the voltage standing wave ratio (VWSR).

$$|\Gamma| = \frac{(VSWR-1)}{(VSWR+1)} \quad (11$$

- **For a matched case, $|\Gamma| = 0$,** VWSR=$\frac{1+|0|}{1-|0|}$= **1.**
- **For an open-circuit case, $|\Gamma| = 1$,** VWSR=$\frac{1+|1|}{1-|1|}$ = ∞
- **For an short-circuit case, $|\Gamma| = 1$,** VWSR=$\frac{1+|1|}{1-|1|}$ = ∞

Lossless Transmission Line Modeling

In this paper, the lossless transmission lines was modelled based on different types of input voltages: Phasor voltages (AC), Square wave input and DC input voltages (John, 1950).
The input data considered for the lossless cable has the following parameters in Table 1.

3. GUI Modelling of Transmission Line Parameters

The program has two main functions (calculation and graph plotting) so it represents two independent systems. lossless transmission lines was considered under three main conditions: Open circuit, Short circuit and a matched load case.

For the open circuit case, a load impedance far greater than the characteristic impedance of the line was used.

For the short circuit case, a load impedance far less than the characteristic impedance of the line was used.
For the matched case, a load impedance that matches the characteristic impedance of the line was used. Figure 3 shows the GUI for the transmission line simulator.

The Input data used for the GUI simulation are shown in Table 2,3 and 4.

4. Results and discussion

Table 5 shows the output of lossless cable model

The outputs of the Graphical User Interface (GUI) under the cases previously stated are shown Figures 4, 5 and 6. The output of the GUI model is shown in Table 6. The output of the GUI model is shown in Table 7. The output of the GUI model is shown in Table 8.

As shown by the output results above, when the transmission line load is matched to its characteristic impedance, no reflected signal occurs..

The quantity measured, such as voltage, can be expressed as a sinusoidal phasor (AC), a DC or sine wave input. The phase of the sinusoid varies with distance which contributes the propagation constant being a complex number, the imaginary part being caused by the phase change.

Reflection Coefficient and Standing Wave Analysis

A simple lossless coaxial was used as an example; and the cable was considered when it is terminated in some typical conditions such as an open circuit, short circuit and when the load is matched to the characteristic impedance of the line. Figures 10, 11 and 12 show the Matlab Results obtained.

The first figure shows the out-of-phase reflection that occurs for voltage on a shorted line, due to the presence of reflected waves which are reflected back The second figure shows a 3D plot of the Voltage standing wave pattern. At the load end, the incident wave is extended past the load 180˚ out of phase and then folded back to provide the reflected wave.

The first figure shows the reflection that occurs for voltage on an open circuit line. At the end of a transmission line terminated in short circuit, the current is maximum and the voltage is zero. The second figure shows a 3D plot of the Voltage standing wave pattern. At the load end, the incident wave is 90 ˚out of phase with the reflected wave

When the transmission line is linked to its characteristic impedance, no reflected signal occurs and the power is transferred outward from the source until it reaches the load at the end, where it is completely absorbed. In the 3D plot of the Voltage standing wave pattern, there are no standing waves as only the incident wave from the source to the load can be seen. This is because, since the load is matched to the characteristic impedance of the line, all power is absorbed at the load end and nothing is reflected back along the line..

5. Conclusion

From this work, it was observed that the optimum condition of no reflection along the lossless transmission line occurs when the load is purely resistive and equal to the characteristic impedance of the line.This is highly desirable since all of the generator power capability is getting to the load. This results agrees perfectly with what is to be expected with a lossless line in principle. Thus,a lossless line is the most ideal type of line for transmission .

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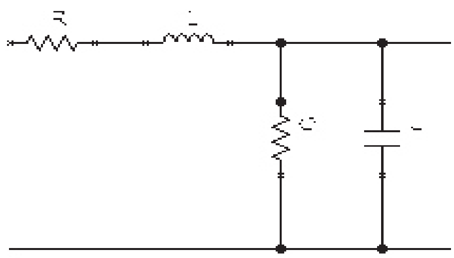

Figure 1: Equivalent Circuit of short Section of a general transmission line model

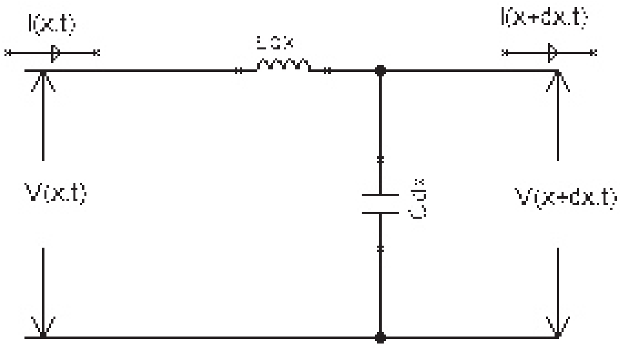

Figure 2: Distributed element model of a lossless transmission line

Table 1: Input parameters for a lossless cable

Length (l)	Source Voltage (V_g)	Characteristic Impedance (Z_o)	Source Impedance (Z_g)	Velocity ($V \approx \frac{1}{\sqrt{LC}}$)	Frequency (f)
100m	1V	300Ω	300Ω		1×10^5 Hz

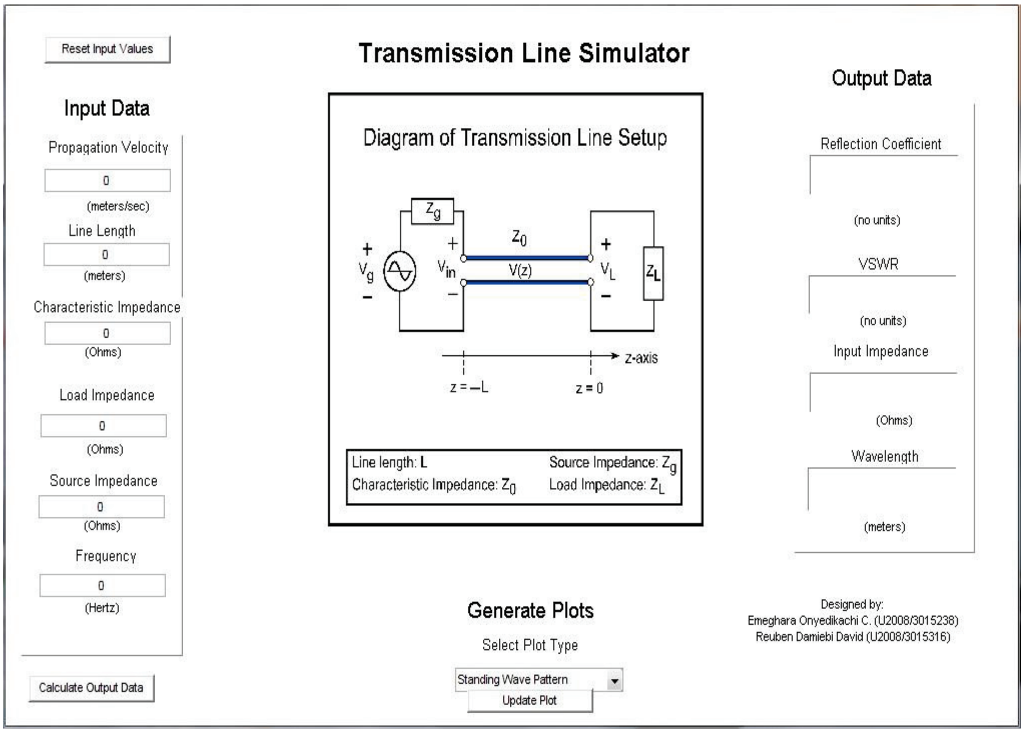

Figure 3: Graphical User Interface for transmission line simulator

Table 2: Input parameters for transmission line terminated in short circuit

Line Length **(l)**	Source Impedance ($\boldsymbol{Z_g}$)	Characteristic Impedance ($\boldsymbol{Z_o}$)	Load Impedance ($\boldsymbol{Z_g}$)	Propagation Velocity	Frequency **(f)**
500m	50Ω	75Ω	25Ω	2×10^8 m/s	3×10^5 Hz

Table 3: Input parameters for transmission line terminated in open circuit

Line Length **(l)**	Source Impedance ($\boldsymbol{Z_g}$)	Characteristic Impedance ($\boldsymbol{Z_o}$)	Load Impedance ($\boldsymbol{Z_g}$)	Propagation Velocity	Frequency **(f)**
500m	50Ω	75Ω	250Ω	2×10^8 m/s	3×10^5 Hz

Table 4: Input parameters for transmission line terminated in matched load

Line Length **(l)**	Source Impedance (Z_g)	Characteristic Impedance (Z_0)	Load Impedance (Z_g)	Propagation Velocity	Frequency **(f)**
500m	50Ω	75Ω	75Ω	2×10^8 m/s	3×10^5 Hz

Table 5: Output parameters for a lossless cable model

Load Impedance	Reflection Coefficient	Line Impedance	Voltage Standing wave ratio	Wavelength
50Ω	0.00049553+3.364e-008i	49.9432-0.0210192i Ω	1.4916	660.7205 m

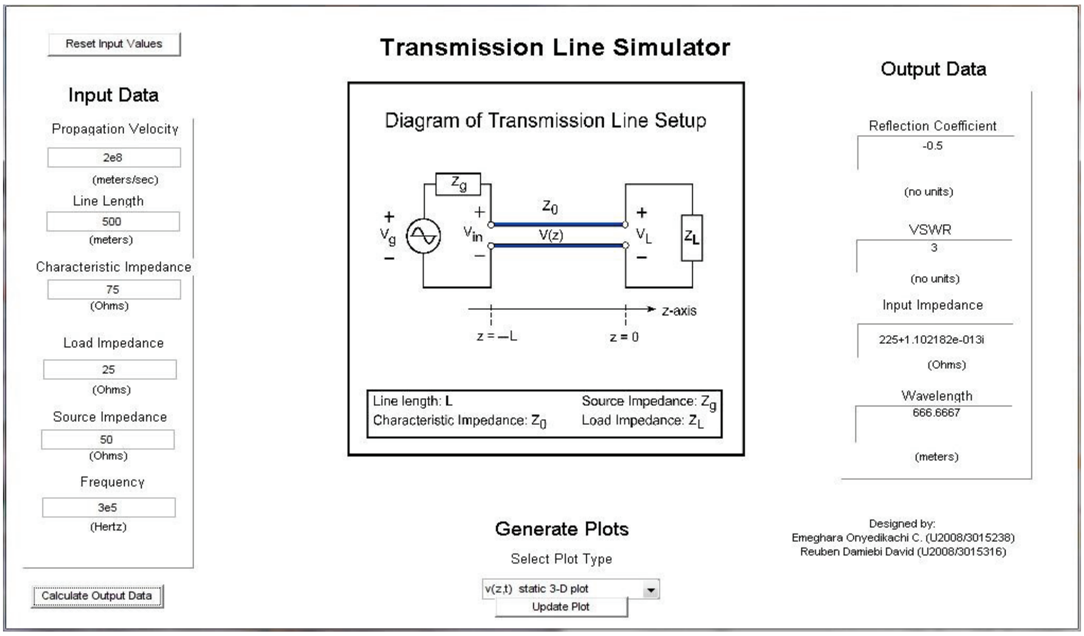

Figure 4.GUIresults showing output datain short circuit case

Table 6: Output parameters for a GUI model of a line terminated in short circuit

Reflection Coefficient	Input impedance	Voltage Standing wave ratio	Wavelength
-0.5	225+1.1012182e-013Iω	3.3333	666.6667 m

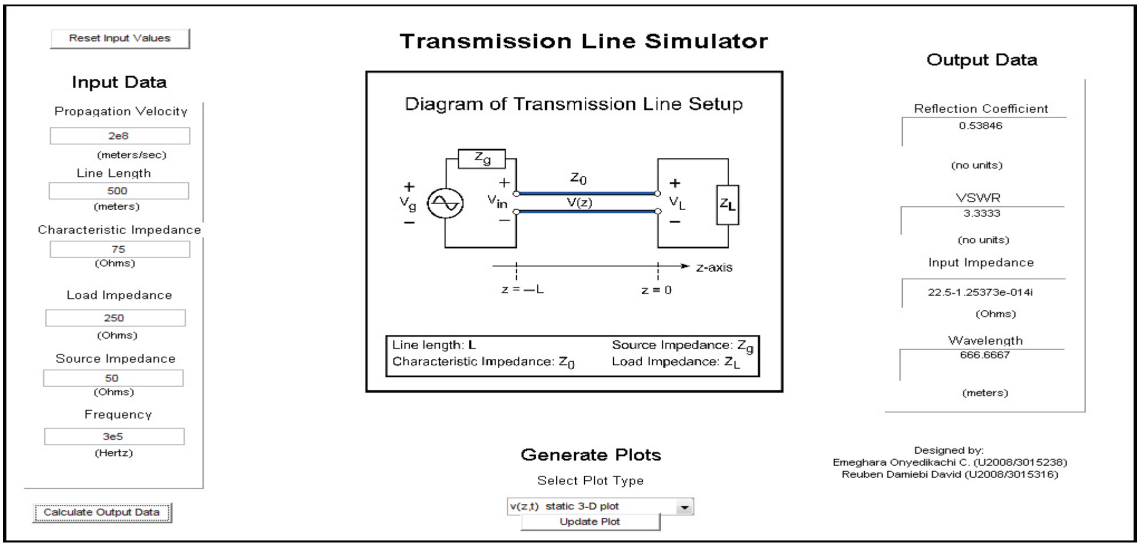

Figure 5: GUIresults showing output data in open circuit case

Table 7: Output parameters for a GUI model of a line terminated in an open circuit

Reflection Coefficient	Input impedance	Voltage Standing wave ratio	Wavelength
0.53846	22.5-1.2537e-014i Ω	3.3333	666.6667 m

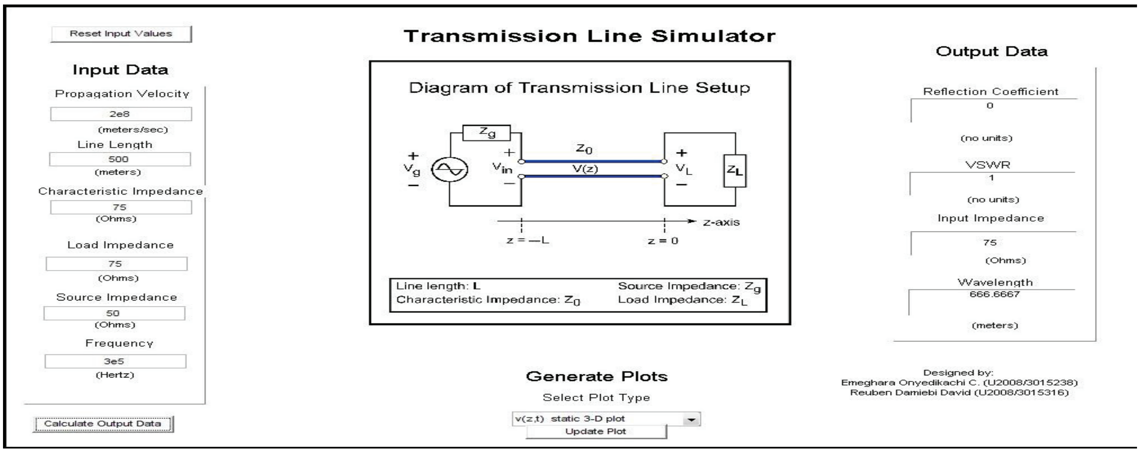

Figure 6; GUI results showing output data in matched load case

Table 8: Output parameters for a GUI model of a line terminated in matched load

Reflection Coefficient	Input impedance	Voltage Standing wave ratio	Wavelength
0	75Ω	1	660.6667 m

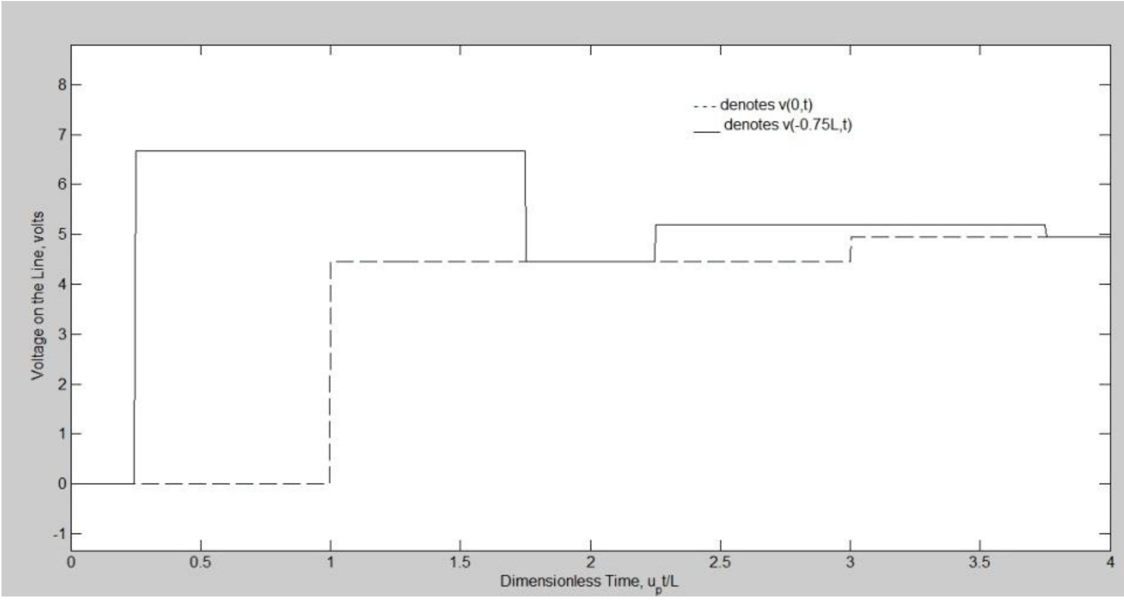

Figure 7: MATLAB results showing DC input voltage in a lossless line

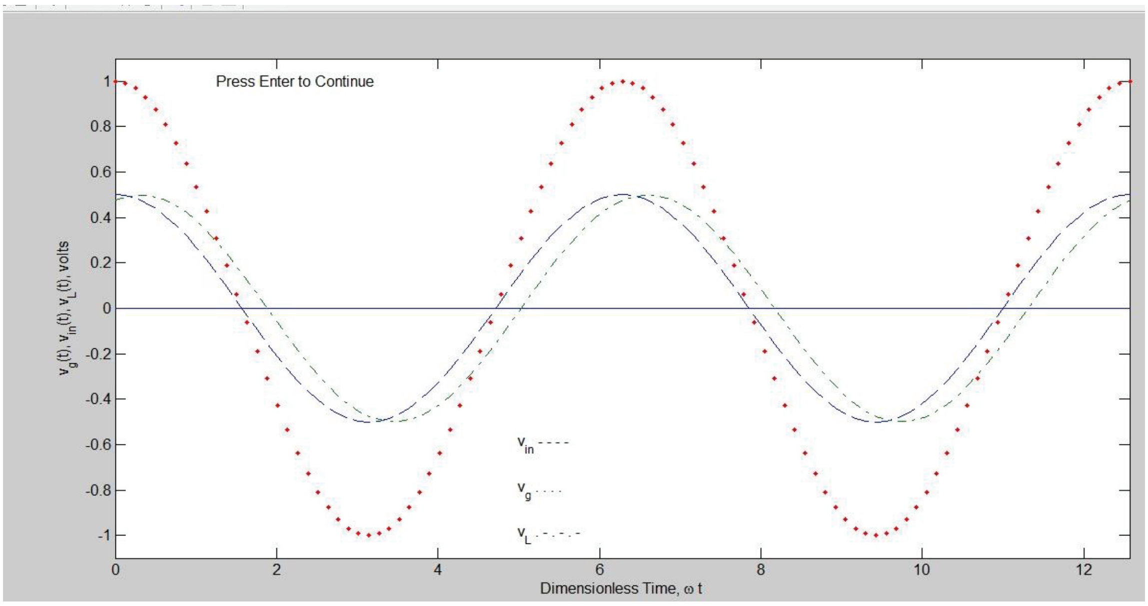

Figure 8: MATLABresults showing AC input voltage in a lossless line

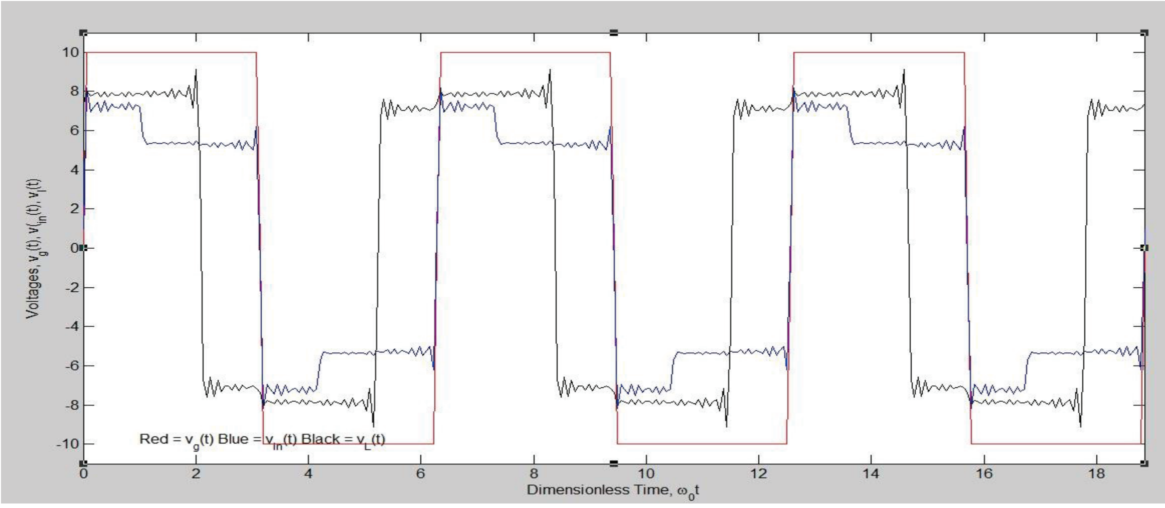

Figure 9: MATLAB results showing Square wave input voltage in a lossless line

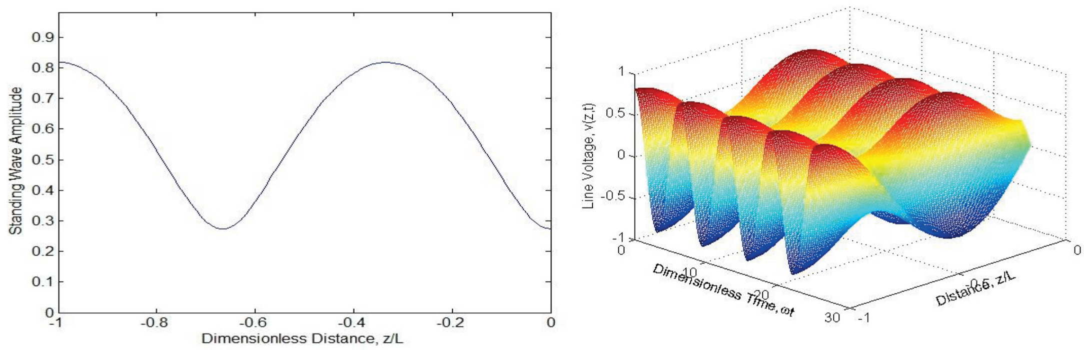

Figure 10 ; MATLABresults showing Standing wave amplitude and Voltage standing wave pattern in a short circuit line

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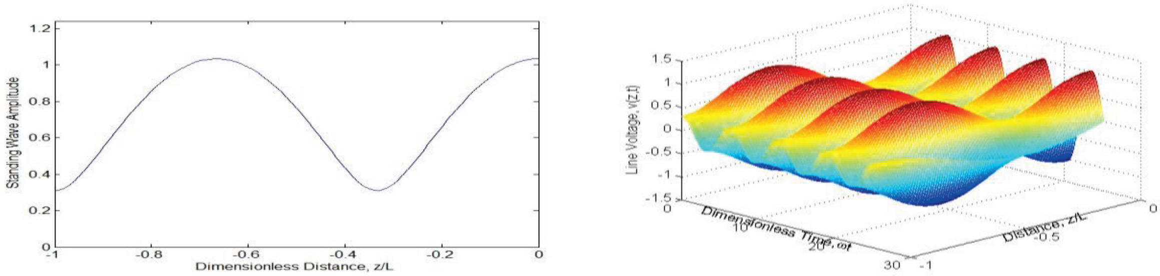

Figure 11: MATLAB results showing Standing wave amplitude and Voltage standing wave pattern in an open circuit line

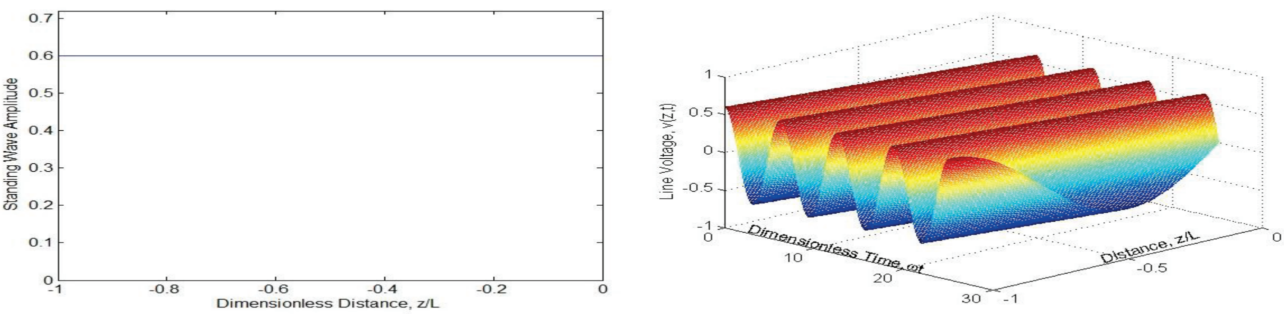

Figure 11 : MATLAB results showing Standing wave amplitude and Voltage standing wave pattern in a matched load line

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