International Journal of Electronics Communication and Computer Engineering
Volume 6, Issue 1, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Investigating the Behaviour of Lossy Transmission Lines in Communication Systems

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Abstract: **This paper investigates the behavior of lossy transmission lines used in communication systems using a lossless transmission line as a case study. It has been the usual practice to skip the detailed study of the lossy transmission line theory by reducing it to the low-loss approximation. Although this is valid in the most common practical cases, however, the study of the general lossy case becomes very important due to the fact that it makes possible a better and deeper understanding of the physical effects associated to general losses. This paper deals with the analysis of some important parameters involved in the general lossy transmission line theory using MATLAB thus improving the understanding of the effects of losses on general transmission line performance. From the results obtained, it is observed that the phase shift really determines the difference between the Heaviside and the low-loss behaviors as there is an increasing mismatch in the line and load voltages as the losses increases.**

Keywords: **Behavior, Communication Systems, Investigation, Lossy, Transmission Lines.**

1. Introduction

In today's world, information is an important resource, and there is an ever increasing demand for information sharing, which may involve the moving of data over long distances. This transmission of information is carried out by means of transmission media, usually called a transmission line. Broadly speaking, a transmission line is defined as the conductive connections between system elements that carry signal power [1].

It is so desired that in the use of transmission lines for the above stated purposes, the line should have a minimum attenuation (distortion) to the signal, and must not radiate any of the signal as radio energy. Ideally, such transmission lines should be lossless; however, practical lines do have significant losses which cannot be ignored [2].

This losses includes copper losses which are caused when energy is dissipated from transmission lines in the form of I^2R losses, dielectric losses which increase with frequency, and are proportional to the voltage flow across the dielectric material; and radiation/induction losses which are caused by terminating the line with a resistive load other than the line's characteristic impedance and by improper shielding of the line. These losses can significantly affect the quality and performance of transmission lines.

However, there seems to be a lack of sufficient detailed study of the general behavior of lossy transmission line. This is probably due to the belief that the lossy transmission line theory is not important enough since the general assumption in the design of a real transmission line system is to minimize the signal loss during propagation to the barest minimum possible[3].Therefore, it is the objective of this paper to bridge this information gap by modeling and investigating the response and behavior of lossy transmission lines when used to transfer electrical signals from one point to another, and to understand the effect of certain line parameters on the overall line performance.

The method used for the design and analysis of this investigation is divided into three parts: The first step is the mathematical modeling of dynamic line equations of the lossy transmission line theory using a two-wire line model. The second step is designing the lossy transmission line models which is to be investigated using MATLAB/SIMULINK. The third step will be carrying out the analysis of these line models under different input and load conditions.

Gago-ribas et al analyzed the most important parameters involved in the general lossy transmission line theory by introducing a general complex analysis methodology which let us understand and predict the physical behavior of a lossy transmission line. Their work incorporated a software tool which makes it easier to visualize and understand the underlying analysis undertaken. The analysis they undertook provided important results that may be extended to the analysis of real waveguide systems, facilitating the understanding and description of their physical behavior[3]. Wentworth in his paper investigated the conditions under which a length of connecting wire must be treated as transmission line. He determined that if the operating frequency is high enough that the wire length is a significant portion of a wavelength, a transmission line model must be used. A MATLAB demonstration clarifies this, and demonstrates how the waves on each section of line behave[4],.

2. Theoretical Background

The two-wire line in Figure 1. is a type of parallel transmission line which generally consists of two wires spaced from 2 to 6 inches apart by insulating spacers. It is most often used for power lines, rural telephone lines, and telegraph lines and sometimes could also be used as a transmission line between a transmitter and an antenna or between an antenna and a receiver [5].

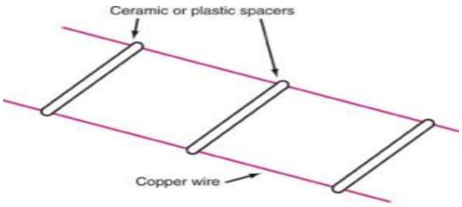

Figure 1: Parallel lines showing a two-wire open line (DOA, 2004) and a two-wire ribbon (Frenzel, 2008)

Generally, at transmission line has four basic parameters: Resistance, Inductance, Capacitance and Conductance.

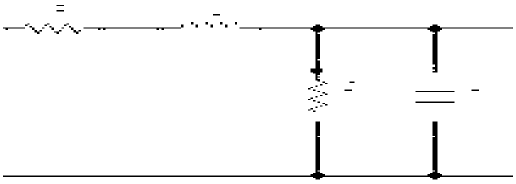

Figure 2: Equivalent circuit of a two-wire transmission line

The electrical characteristics of a two-wire transmission line are primarily dependent on the construction of the line, and a small section of the line as shown in Figure 2 can represent many feet of line. For this work, it is assumed that all the line parameters are uniform for all values, and equal at each unit length.

Telegraphers Equation for a Lossy Line

These are a pair of linear equations which0 characterize the voltage and current for an electrical transmission line with distance and time. [6][7].

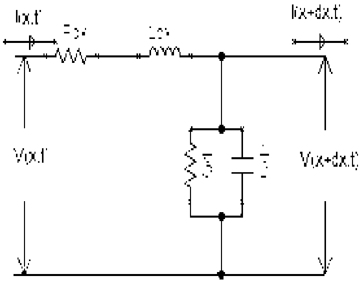

Figure 3: Distributed element model of a lossy transmission line showing voltage and current

Considering figure 3, the following equations are obtained.

$$V(x,t) - V(x+\delta x,t) = RdxI(x,t) + Ldx\frac{d}{dt}I(x,t) \quad (1)$$

$$I(x,t) - I(x+\delta x,t) = GdxV(x,t) + Cdx\frac{d}{dt}V(x,t) \quad (2)$$

Differentiating (1) and (2) above and dividing by dx, we get

$$\frac{d}{dx}V(x,t) = RI(x,t) + L\frac{d}{dt}V(x,t) \quad (3)$$

$$\frac{d}{dx}I(x,t) = GV(x,t) + C\frac{d}{dt}V(x,t) \quad (4)$$

Obtaining the second order telegraphers equations

$$\frac{d^2}{dx^2}V(x,t) = RGV(x,t) + (RC+LG)\frac{d}{dt}V(x,t) + LC\frac{d^2}{dt^2}V(x,t) \quad (5)$$

$$\frac{d^2}{dx^2}I(x,t) = RGI(x,t) + (RC+LG)\frac{d}{dt}I(x,t) + LC\frac{d^2}{dt^2}I(x,t) \quad (6)$$

Characteristic Impedance

Characteristic impedance (Z_O) is the ratio of input voltage (V) to current (I) at every point along the line. Mathematically

$$Z_O = \frac{V(x,t)}{I(x,t)} \quad (7)$$

Therefore,

$$I(x,t) = \frac{V\ (x,t)}{Z_o} = \frac{e^{j\omega t}e^{-(\alpha+j\beta)x}}{Z_o}$$

If we take the input voltage $\boldsymbol{V(x,t)}$to besinusoidal, of the form

$$V(x,t) = e^{j\omega t}e^{-\gamma x}$$

where $\gamma = \text{propagation constant} = (\alpha + j\beta)$, substituting equation in equation 1, we get

$$\frac{d}{dx}\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right] = R\frac{e^{j\omega t}e^{-(\alpha+j\beta)x}}{Z_O} + L\frac{d}{dt}\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right] \quad (8)$$

Simplifying equation, we get

$$Zo = \sqrt{\frac{(R+j\omega L)}{(G+j\omega C)}} \quad (9)$$

For a two wire line separated by dielectric, characteristic impedance may be obtained using the formula (Beasley and Miller, 2005)

$$Zo = \frac{276}{\sqrt{\epsilon}}\log 10\frac{2D}{d}$$

Where

D = spacing between the two wires

d = diameter of one of the conductors

ϵ = dielectric constant of the insulating material relative to air

Attenuation And Phase Shift Coefficient

Substituting equation 9 into equation 8; and differentiating it, we get

$$\frac{d^2}{dx^2}\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right] = RG\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right] + (RC+LG)\frac{d}{dt}\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right] + LC\frac{d^2}{dt^2}\left[e^{j\omega t}e^{-(\alpha+j\beta)x}\right]$$

Simplifying, we get

$$-(\alpha + j\beta) = \sqrt{[(R + j\omega L)(G + j\omega C)]} \quad ...(10)$$

This gives us a relationship for attenuation and phase shift coefficient for a lossy transmission line[8]. this can be further simplified as

$$\alpha = \left[\frac{1}{2}\left(\sqrt{[(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2) + (RG + \omega^2 LC)]}\right)\right]^{\frac{1}{2}} \quad ...(11)$$

$$\beta = \left[\frac{1}{2}\left(\sqrt{[(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2) - (RG + \omega^2 LC)]}\right)\right]^{\frac{1}{2}} \quad ...(12)$$

Figure 4 shows the graphical representation of the characteristics impedance in terms of R, L, C and G

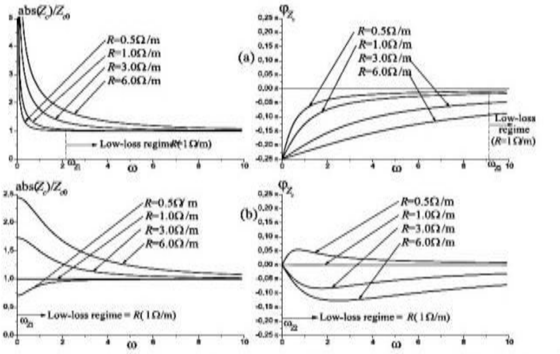

Figure 4: Representation of the characteristic impedance |Zc| and ϕZc , in terms of R, L, C and G (Gago-Ribas et al, 2006).

3. Modelling of the System Using MATLAB

The lossy transmission line theory constitutes a very important step when trying to analyze and understand the usual lossless case, which may be seen as a particular case of the general theory. We will attempt to analyze the behavior of lossy lines under two main conditions: Low loss approximation and Heaviside condition using a lossless line as a case study.

Case One: Lossless Transmission Lines

We modeled lossless transmission lines based on Phasor voltages (AC) Input. A MATLAB m-file is used to model a lossless transmission line under the below stated inputs in Table 1.

Input Data:

Considering a lossless cable which has the following parameters:

Table 1: Input parameters for a lossless cable

Length(I)	Source Voltage (V_g)	Characteristic Impedance(Z_0)	Source Impedance(Z_g)	Velocity ($V \approx \frac{1}{\sqrt{LC}}$)	Frequency (f)
100m	1V	300 Ω	300 Ω	2×10^8 m/s	2×10^5 Hz

Case Two: Low Loss Transmission Line

Here, a MATLAB m-file is used to model a lossy transmission line under low loss approximation. A lossy transmission line is considered to be a low loss line if it fulfills the condition $R \ll \omega L$ and $G \ll \omega C$. For this model, a load resistance of 50Ω was assumed. A source voltage of 10V in phasor form (rectangular form) was used.

Input Data: Considering a lossy cable which has the following parameters:

Table 2: Input parameters for a lossy cable which fulfill Low loss approximation

Length (I)	**Inductance (L)**	**Capacitance (C)**	**Characteristic Impedance (Z_0)**	**Resistance (R)**	**Conductance (G)**	**Velocity ($V \approx \frac{1}{\sqrt{LC}}$)**	**Frequency (f)**
100m	252×10^{-9} H/m	101×10^{-12}F/m	50 Ω	252×10^{-6} Ω	101×10^{-8}s/m	1.98216×10^8m/s	3×10^5 Hz

Case Three: Heaviside Condition

It is observed that if the different frequencies that comprise a signal travel at different velocities, that signal will arrive at the end of a transmission line distorted; this phenomenon is known as signal dispersion. Also, if the phase velocity is independent of frequency, then no dispersion will occur.

Heaviside found that a transmission line would be distortion less if the transmission line parameters exhibited the following ratio (Wikipedia, 2014).

$$\frac{R}{L} = \frac{G}{C}$$

Input Data:

For this model, a load resistance of 50Ω was also assumed. A source voltage of 10V in phasor form (rectangular form) was used.

A lossy cable which has the following parameters was considered.

Table 3: Input parameters for a lossy cable which fulfill Heaviside Condition

Length **(I)**	Inductance **(L)**	Capacitance **(C)**	Characteristic Impedance **(Z_0)**	Resistance **(R)**	Conductance $G = \frac{R}{L} \times C$	Velocity ($V \approx \frac{1}{\sqrt{LC}}$)	Frequency **(f)**
100m	25×10^{-9} H/m	100×10^{-12} F/m	50Ω	0.2Ω	8.0158×10^{-5}S/m	1.98216×10^8m/s	3×10^5Hz

4. Results

MATLAB m-files were used to model transmission under the above stated conditions. The figures below shows the output of the MATLAB program input data corresponding to the examples previously chosen in the analysis of a lossy transmission line.

For the lossy cables, some parameters which are derived based on RG58C/U Coaxial Instrumentation cable were assumed; and the line parameters were analyzed under two main cases: Low loss approximation and Heaviside condition.

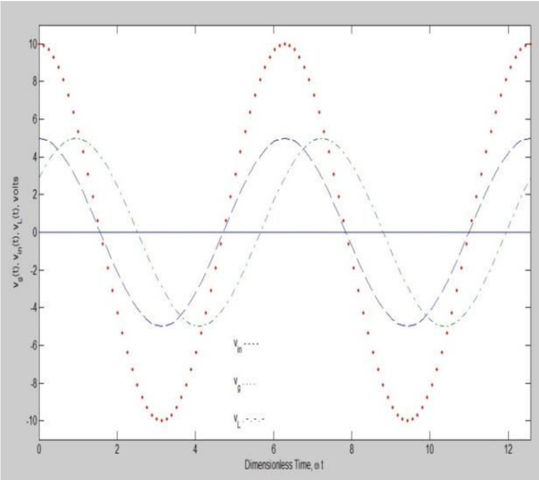

Figure 5:Modeling result from MATLAB in Low loss condition (x: Time, y: Voltage)

Using low loss approximation, a lossy transmission line was conditioned so that it functions with the least possible inherent losses. When the load resistance was matched to the characteristic impedance of the line, the losses are so slight that it could be safely ignore .

It is observed that the amplitude of the line voltage (Vin) is almost the same as the load voltage (Vl), this shows that there are no voltage drop along the line due to voltage drop. The load voltage lags the line voltage slightly, as there will always be a slight time delay as a signal propagates through a transmission line.

This shows that the amplitude of the line voltage is almost constant as signal propagates through the line. This is significant because since the value of resistance and conductance are very small, the effect of these two parameters is very slight on the wave propagation and signal attenuation

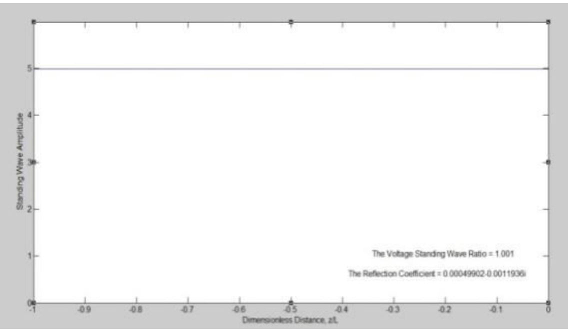

Figure 6: MATLAB results showing line voltage in Low loss condition (x: Distance, y: SWA)

Heaviside Condition

Heaviside condition states that there is no dispersion occurs when C, L, G, R has this relation: $\frac{R}{L} = \frac{G}{C}$

Using the input parameters as previously stated, Figure 7 shows the result of simulation.

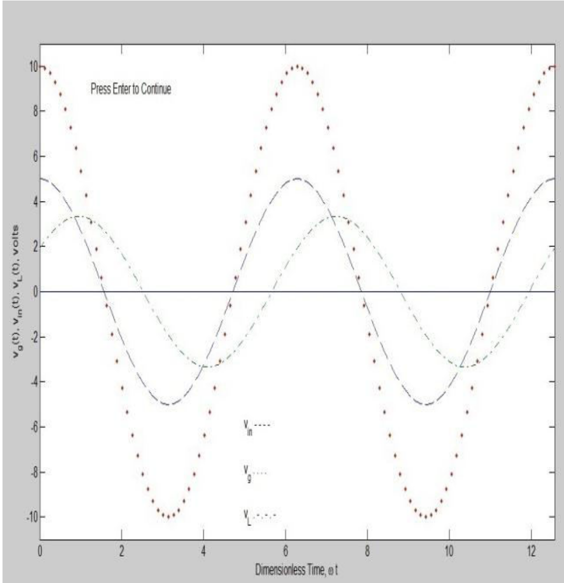

Figure 7: Modeling results from MATLAB showing input voltage in Heaviside condition (x: Time, y: Vg, Vin, Vl)

Unlike the low loss approximation, it is observed that the amplitude of the line voltage (Vin) varies from that of the load voltage (Vl), this shows the effects of line losses in this kind of cable leading to voltage drop.

A lossless transmission line was analyzed; and Figure 8 displays the result showing the effects of line losses on signal propagation.

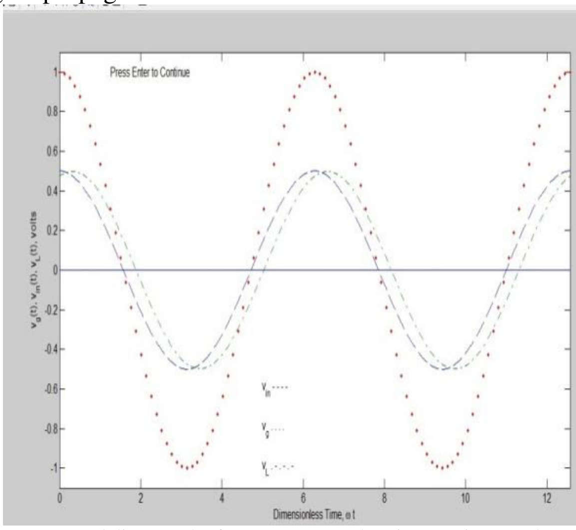

Figure 8: Modeling results from MATLABshowing AC input voltage in a lossless line (x: Time, y: Voltage)

The propagation constant of an electromagnetic wave is a measure of the change undergone by the amplitude of the wave as it flows in a given direction. 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.

5. Conclusion

This paper investigates the behavior of lossy transmission lines used in communication systems using a lossless transmission line as a case study. We observed the effect of certain conditions such as Low loss approximation and Heaviside condition on lossy lines; the generator, line and load voltage patterns. From the figures, it is observed that the phase shift really determines the difference between the Heaviside and the low-loss behaviors as there is an increasing mismatch in the line and load voltages as the losses increases.

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