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Transmission Line Characteristics

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Abstract: *A Transmission line is a device designed to guide electrical energy from one point to another. It is used, for example, to transfer the output rf energy of a transmitter to an antenna. This report provides detailed discussion on the transmission line characteristics. Math lab coding is used to plot the characteristics with respect to frequency and simulation is done using HFSS.*

Keywords - *coupled line filters, micro strip transmission lines, personal area networks (pan), ultra wideband filter, uwb filters, ultra wide band communication systems.*

I. INTRODUCTION

Transmission line is a device designed to guide electrical energy from one point to another. It is used, for example, to transfer the output rf energy of a transmitter to an antenna. This energy will not travel through normal electrical wire without great losses. Although the antenna can be connected directly to the transmitter, the antenna is usually located some distance away from the transmitter. On board ship, the transmitter is located inside a radio room and its associated antenna is mounted on a mast. A transmission line is used to connect the transmitter and the antenna

The transmission line has a single purpose for both the transmitter and the antenna. This purpose is to transfer the energy output of the transmitter to the antenna with the least possible power loss. How well this is done depends on the special physical and electrical characteristics (impedance and resistance) of the transmission line.

1.1 Terminology

All transmission lines have two ends . The end of a two-wire transmission line connected to a source is ordinarily called the input end or the generator end. other names given to this end are transmitter end, sending end, and source. the other end of the line is called the output end or receiving end. other names given to the output end are load end and sink.

You can describe a transmission line in terms of its impedance. The ratio of voltage to current (E_{in}/I_{in}) at the input end is known as the input impedance (Z_{in}). This is the impedance presented to the transmitter by the transmission line and its load, the antenna[1,2]. The ratio of voltage to current at the output (E_{out}/I_{out}) end is known as the output impedance (Z_{out}). This is the impedance presented to the load by the transmission line and its source. If an infinitely long transmission line could be used, the ratio of voltage to current at any point on that transmission line would be some particular value of impedance. This impedance is known as the characteristic impedance.

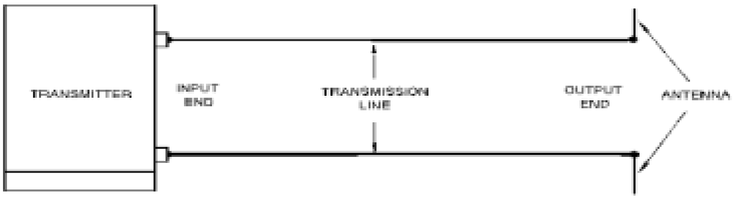

Figure 1-1. - Basic transmission line

1.2 Types of Transmission Mediums

The Navy uses many different types of transmission mediums in its electronic applications[3]. each medium (line or waveguide) has a certain characteristic impedance value, current-carrying capacity, and physical shape and is designed to meet a particular requirement.

The five types of transmission mediums that we will discuss in this chapter include parallel-line, twisted pair, shielded pair, coaxial line, and waveguides. The use of a particular line depends, among other things, on the applied frequency, the power-handling capabilities, and the type of installation.

1.2.1 Two-Wire Open Line

One type of parallel line is the TWO-WIRE OPEN LINE illustrated in figure. This line consists of two wires that are generally spaced from 2 to 6 inches apart by insulating spacers. This type of line is most often used for power lines, rural telephone lines, and telegraph lines. It is sometimes used as a transmission line between a transmitter and an antenna or between an antenna and a receiver. An advantage of this type of line is its simple construction. The principal disadvantages of this type of line are the high radiation losses and electrical noise pickup because of the lack of shielding.

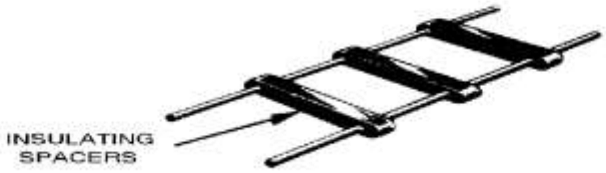

Figure 2. - Parallel two-wire line

Another type of parallel line is the two-wire ribbon (twin lead) illustrated in figure. This type of transmission line is commonly used to connect a television receiving antenna to a home television set. This line is essentially the same as the two-wire open line except that uniform spacing is assured by embedding the two wires in a low-loss dielectric, usually polyethylene[2]. Since the wires are embedded in the thin ribbon of polyethylene, the dielectric space is partly air and partly polyethylene.

1.2.2 Twisted Pair

The twisted pair transmission line is illustrated in figure. As the name implies, the line consists of two insulated wires twisted together to form a flexible line without the use of spacers. It is not used for transmitting high frequency because of the high dielectric losses that occur in the rubber insulation. When the line is wet, the losses increase greatly.

1.3. Losses in Transmission Lines

The discussion of transmission lines so far has not directly addressed line losses; actually some line losses occur in all lines. line losses may be any of three types - copper, dielectric, and radiation or induction losses.

1.3.1 Copper Losses

One type of copper loss is I^2R LOSS. In rf lines the resistance of the conductors is never equal to zero. Whenever current flows through one of these conductors, some energy is dissipated in the form of heat. This heat loss is a POWER LOSS. With copper braid, which has a resistance higher than solid tubing, this power loss is higher[2].

Another type of copper loss is due to SKIN EFFECT. When dc flows through a conductor, the movement of electrons through the conductor's cross section is uniform. The situation is somewhat different when ac is applied. The expanding and collapsing fields about each electron encircle other electrons. This phenomenon, called self induction, retards the movement of the encircled electrons. The flux density at the center is so great that electron movement at this point is reduced. As frequency is increased, the opposition to the flow of current in the center of the wire increases. Current in the center of the wire becomes smaller and most of the electron flow is on the wire surface. When the frequency applied is 100 megahertz or higher, the electron movement in the center is so small that the center of the wire could be removed without any noticeable effect on current. You should be able to see that the effective cross-sectional area decreases as the frequency increases. Since resistance is inversely proportional to the cross-sectional area, the resistance will increase as the frequency is increased. Also, since power loss increases as resistance increases, power losses increase with an increase in frequency because of skin effect.

Copper losses can be minimized and conductivity increased in an rf line by plating the line with silver. Since silver is a better conductor than copper, most of the current will flow through the silver layer[2]. The tubing then serves primarily as a mechanical support.

1.4. Length of a Transmission Line

A transmission line is considered to be electrically short when its physical length is short compared to a quarter-wavelength of the energy it is to carry.

A transmission line is electrically long when its physical length is long compared to a quarter-wavelength of the energy it is to carry. You must understand that the terms "short" and "long" are relative ones.

When power is applied to a very short transmission line, practically all of it reaches the load at the output end of the line. This very short transmission line is usually considered to have practically no electrical properties of its own, except for a small amount of resistance.

However, the picture changes considerably when a long line is used. Since most transmission lines are electrically long (because of the distance from transmitter to antenna), the properties of such lines must be considered. Frequently, the voltage necessary to drive a current through a long line is considerably greater than the amount that can be accounted for by the impedance of the load in series with the resistance of the line.

1.5. Need for Transmission Lines

The need for construction of transmission line mainly falls into one of the four categories mentioned below.

a) A new generating station/unit is established and the power from the generating station is required to be evacuated. The transmission lines are built for injecting power from the generating station to the already existing high voltage network (also called Grid)[1]. These lines are most important types and get priority. The generating stations cannot generate without the commissioning of these lines.

b)Two already existing HV or EHV substations of the grid are interconnected by transmission lines for strengthening the network.

c) It is usually seen that two adjacent power transmission companies agree to interconnect their systems by tie lines. By interconnecting the two adjacent systems, power needed by one company as agreed by both sides(or emergency requirement) is supplied by other side. It is done to improve the reliability and stability of the systems

d) A transmission line may be required to be built to serve an upcoming large load. As an example if a new industry and/or its township is built (usually in new place) then transmission line is built to feed the distribution network of new industry/township from the existing grid. The power is received at the receiving station of load center and stepped down by transformer, which feeds the primary high voltage distribution network. See Fig-E. To enhance the availability of supply the receiving station at load center may be connected to two separate substations of the Grid forming.

For planning transmission line addition or alteration, computer simulated load flow study is carried out . The study is carried out for several alternative configurations under peak and off-peak loading and generation conditions. From several alternative configurations the most suitable one is finalized for construction.

II. Equivalent Circuit Model Of Transmission Line

2.1 Lossless Transmission Line Model

As a signal propagates down the pair of conductors, each new section acts electrically as a small lumped circuit element. In its simplest form, called the lossless model, the equivalent circuit of a transmission line has just inductance and capacitance. These elements are distributed uniformly down the length of the line, as shown in equivalent circuit model of a transmission line[1,5].

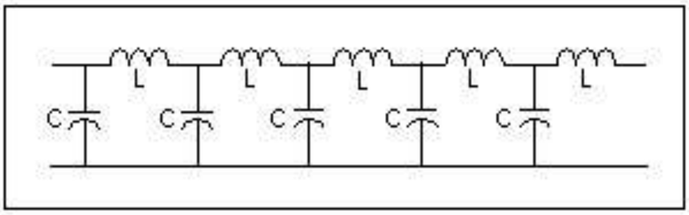

Figure 3. Equivalent Circuit Model of a Lossless Transmission Line

From this electrical circuit model, the two important terms that characterize a transmission line can be derived: the velocity of a signal (v) and the characteristic impedance (Z0).

$$v = \frac{1}{\sqrt{LlCl}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

And $Z0 = \sqrt{\frac{Ll}{Cl}}$…………………………..(2)

Ll = inductance per length
Cl = capacitance per length

This is the basis for the T Element used in Star-Hspice. It accounts for a characteristic impedance (Z0) and a time delay (TD). The time delay depends on the distance (d) between the two ends of the transmission line:

TD= d/v ………………………………..(3)

2.2 Lossy Transmission Line Model

When loss is significant, the effects of the series resistance (R) and the dielectric conductance (G) should be included. Equivalent model of lossy transmission line shows the equivalent circuit model of a lossy transmission line, with distributed "lumps" of R, L, and C Elements.

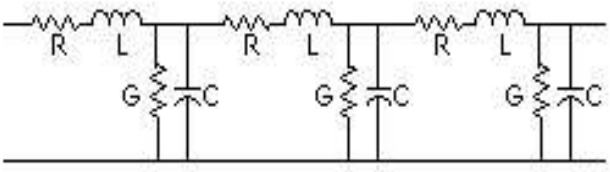

Figure 4. Equivalent Circuit Model of a Lossy Transmission Line

The U Element used in Star-Hspice is the equivalent circuit model for the lossy transmission line. In a transient simulation, the U Element automatically accounts for frequency-dependent characteristic impedance, dispersion (frequency dependence in the velocity), and attenuation.

The most common types of transmission line cross sections are micro strip, strip line, coax, wire over ground, and twisted pair. There is no direct relationship between cross section, velocity of propagation, and characteristic impedance.

In a balanced transmission line, the two conductors have similar properties and are electrically indistinguishable[1,2,6]. For example, each wire of a twisted pair has the same voltage drop per length down the line The circuit model for each wire has the same resistance capacitance and inductance per length.

This is not the case with a micro strip line or a coaxial cable. In those structures, the signal conductor has a larger voltage drop per length than the other conductor. The wide reference plane in a micro strip or the larger diameter shield in a coax have lower resistance per length and lower inductance per length than the signal line. The equivalent circuit model for unbalanced lines typically assumes the resistance and inductance per length of the ground path is zero and all the voltage drop per length is on the signal conductor. Even though the inductance of the reference plane is small, it can play a significant role when there are large transient currents

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2.3. Impedance

The impedance of a device (Z) is defined as the instantaneous ratio of the voltage across the device (V) to the current through it:

Z = V/I ……………………….(4)

2.4. Impedance of Simple Lumped Elements

The impedance of a device can be thought of as the quality of the device that causes it to transform a current through it into a voltage across it:

V = ZI …………………………….(5)

The admittance (Y) is less often used to characterize a device. It is the inverse of the impedance:

Y = 1/Z =I/V ………………………..(6)

There are three ideal circuit elements used to describe passive components: a resistor, a capacitor, and an inductor. They are defined by how they interact with voltage across them and current though them:
Resistor, with resistance (R):
$V = IR$ ………………………….(7)
Capacitor, with capacitance (C):
$I = CdV/dt$ ………………………(8)
Inductor with inductance (L):
$V = LdI/dt$ ………………………..(9)

When the voltage or current signals are time dependent, the impedance of a capacitive or inductive element is a very complicated function of time. You can simulate it with Star-Hspice, but it is difficult to build an intuitive model.

The impedance of a capacitor rotates the phase of the current 90° in the negative or direction to generate the voltage across the capacitor. The impedance of an inductor rotates the current 90° in the positive direction to generate the voltage across the inductor. For a resistor, the current and voltage have the same phase.

In the frequency domain, when all signals are sine waves in the time domain, the impedance of a capacitor and an inductor is frequency dependent, decreasing with frequency for a capacitor and increasing with frequency for an inductor. The impedance of a resistor is constant with frequency.

In the real world of finite dimensions and engineered materials, ideal circuit elements have parasitic associated with them, which cause them to behave in complex ways that are very apparent at high frequencies.

2.5. Inductance

2.5.1 Mutual Inductance and Self Inductance

The most confusing, subtle and important parameter in high-speed packaging and interconnect design is inductance. It plays a key role in the origin of simultaneous switching noise, also called common ground inductance, and a key role in crosstalk between transmission line structures.

2.5.2. Operational Definition of Inductance

Consider an inductor to be any section of circuit element which carries current: an interconnect trace, a ground plane, a TAB lead frame, a lead in a DIP package, the lead of a resistor or a pin in a connector. An inductor does not have to be a closed circuit path, but can be a small section of a circuit path.

A changing current passing through an inductor generates a voltage drop. The magnitude of the voltage drop (Δ V) for an inductance (L) and change in current (dI/dt) is:

$$\Delta V = L\frac{dI}{dt} \quad \text{…………………………..(10)}$$

This definition can always be used to evaluate the inductance of a section of a circuit. For example, with two long parallel wires, each of radius (r) and a center-to-center separation (s), you can measure the voltage drop per length for one of the wires when a changing current dI/dt flows through one wire and back through the other. The induced voltage per length on one of the wires is:

$$VL = \frac{\mu 0}{2\pi}\ln\left(\frac{s}{r}-\frac{r}{s}\right)\frac{dI}{dt} \quad \text{………………………..(11)}$$

[V in mV/inch, l in mA, t in ns]
From this expression, the effective inductance per length of one wire is found to be:

$$VL = \frac{\mu 0}{2\pi}\ln\left(\frac{s}{r}-\frac{r}{s}\right)\frac{dI}{dt} \sim 5\ln\left(\frac{s}{r}\right)(s \gg r) \quad \text{……………………..(12)}$$

[nH/inch]

2.5.3. Mutual Inductance

A second effect also is important: the induced voltage from currents that are adjacent to, but not in, the same circuit path. This is caused by the mutual inductance between two current elements.The voltage generated across the section of circuit 1, V1, is given in its general form by:

$$V1 = L11\frac{dI1}{dt} + L12\frac{dI12}{dt} + L13\frac{dI3}{dt} + L14\frac{dI4}{dt} \qquad \text{………………………..(13)}$$

The notation for mutual inductance is related to the induced voltage on circuit element a, from the current element, b. In some texts, the symbol used is M, rather than L[2]. The special case of the induced voltage on a circuit element from its own current is called self inductance.

Mutual inductance relates to the magnitude of induced voltage from an adjacent current. The magnitude of this voltage depends on the flux linkages between the two circuit elements.

2.5.4. Self Inductance

The self inductance of an isolated single trace is a well-defined, absolute mathematical quantity, but not a measurable physical quantity. There is always a return current path somewhere, and the mutual inductance from this return current path induces a voltage on the circuit element that subtracts from the self inductance. Self inductance can never be measured or isolated, independent of a mutual inductance of a return current path.

In the example above of two long parallel wires, the measured inductance per length (LL) of one wire is neither the self inductance nor the mutual inductance of the wire. It is a combination of these two terms. If the universe contained just the two wires, the measured voltage drop per length would be:

$$VL = L11\frac{dI1}{dt} - L12\frac{dI1}{dt} = (L11 - L12)\frac{dI1}{dt} = LL\frac{dI1}{dt} \qquad \text{………………………..(14)}$$

The minus sign reflects the opposite directions of the currents I1 and I2. Operationally, when the inductance per length of one wire is measured, what is really being measured is the difference between its self inductance and the mutual inductance of the return path. Because of this effect, it is clear that the nature of the return path greatly influences the measured inductance of a circuit element.

III. Transmission Line Equations

A typical engineering problem involves the transmission of a signal from a generator to a load. A transmission line is the part of the circuit that provides the direct link between generator and load. Transmission lines can be realized in a number of ways[1,2]. Common examples are the parallel-wire line and the coaxial cable. For simplicity, we use in most diagrams the parallel-wire line to represent circuit connections, but the theory applies to all types of transmission lines.

3.1. Characteristic Impedance or Surge Impedance

The characteristic impedance or surge impedance of a uniform transmission line, usually written Z_0, is the ratio of the amplitudes of a *single* pair of voltage and current waves propagating along the line in the absence of reflections. The SI unit of characteristic impedance is the ohm. The characteristic impedance of a lossless transmission line is purely real, that is, there is no imaginary component ($Z_0 = |Z_0| + j0$). Characteristic impedance appears like a resistance in this case, such that power generated by a source on one end of an infinitely long lossless transmission line is *transmitted through* the line but is not *dissipated in* the line itself. A transmission line of finite length (lossless or lossy) that is terminated at one end with a resistor equal to the characteristic impedance ($Z_L = Z_0$) appears to the source like an infinitely long transmission line.

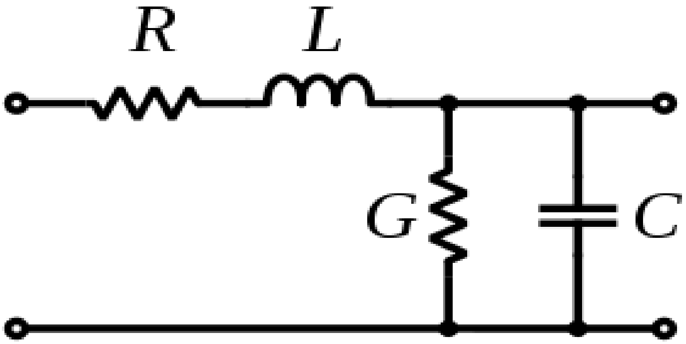


Figure 5. Schematic representation of the elementary components of a transmission line.

Applying the transmission line model based on the telegrapher's equations, the general expression for the characteristic impedance of a transmission line is:

$$Z0 = \sqrt{\frac{(R + jwL)}{(G + jwC)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

where
R is the resistance per unit length,
L is the inductance per unit length,
G is the conductance of the dielectric per unit length,
C is the capacitance per unit length,
j is the imaginary unit, and
ω is the angular frequency

3.2. *Propagation Equation*

The propagation constant is separated into two components that have very different effects on signals:

$$\gamma = \alpha + j\beta = \sqrt{(R + jwL)(G + jwC)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

The real part of the propagation constant is the attenuation constant and is denoted by Greek lowercase letter α (alpha)[8]. It causes a signal amplitude to decrease along a transmission line. The natural units of the attenuation constant are Nepers/meter, but we often convert to dB/meter in microwave engineering. To get loss in dB/length, multiply Nepers/length by 8.686. Note that attenuation constant is always a positive number, if it was negative you'd violate the First Law of Thermodymamics (you never get something for nothing!)

The phase constant is denoted by Greek lowercase letter β(beta) adds the imaginary component to the propagation constant. It determines the sinusoidal amplitude/phase of the signal along a transmission line, at a constant time. The phase constant's "natural" units are radians/meter, but we often convert to degrees/meter. A transmission line of length "l" will have an electrical phase of βl, in radians or degrees. To convert from radians to degrees, multiply by 180/π.

The two parts of the propagation constant have radically different effects on a wave. The amplitude of a wave (frozen in time) goes as cosine(β l). In a lossless transmission line, the wave would propagate as a perfect sine wave. In real life there is some loss to the transmission line, and that is where the attenuation constant comes in. The amplitude of the signal decays as Exp(-αl). The composite behavior of the propagation constant is observed when you multiply the effects of α and β.

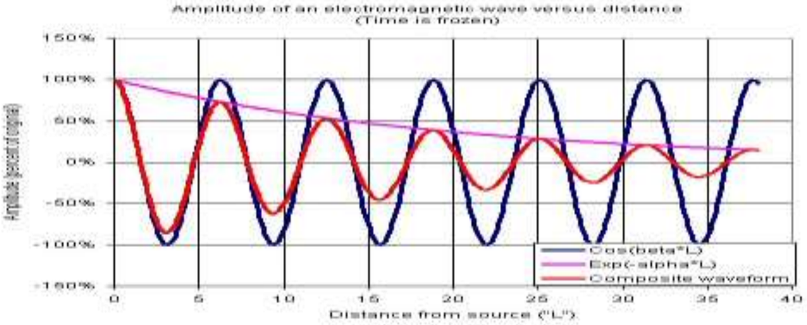


Figure 6. Amplitude of an electromagnetic wave versus distance

3.3. *Standing Wave Ratio*

Standing wave ratio may also be calculated by taking the line's terminating impedance and the line's characteristic impedance, and dividing the larger of the two values by the smaller.

$$SWR = \frac{Emaximum}{Eminimum} = \frac{Imaximum}{Iminimum} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

$$SWR = \frac{Zload}{Z0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(17)$$

IV.RESULTS AND DISCUSSIONS

In this chapter the simulation results of different parameters of transmission line have been presented. A mat lab code has been developed to plot the characteristics impedance and vswr. The length f the transmission line s selected as 100m.Here we use RG-58/U coaxial cable[6,7,8].

4.1. Theoretical Results(Math Lab)

The ratio of voltage applied to the current is called the input impedance; the input impedance of the infinite line is called the characteristic impedance.

$$Z0 = \sqrt{\frac{(R + jwL)}{(G + jwC)}} \quad \text{……………………..(19)}$$

4.2. Mat lab Simulation Results

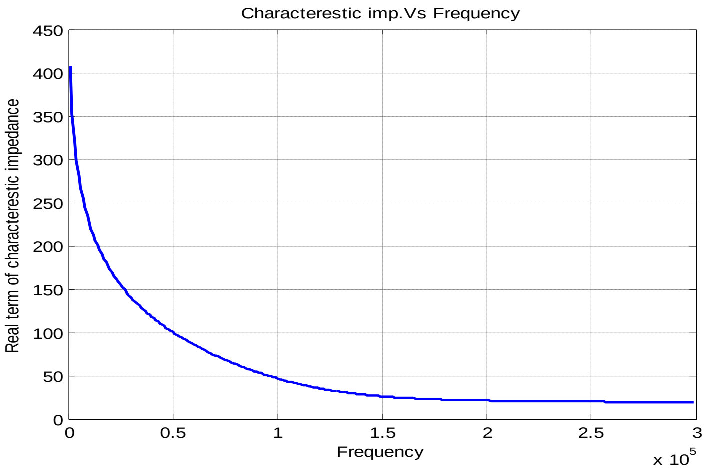


Figure 7. Characteristics impedance and Frequency (RG-58/U coaxial cable)

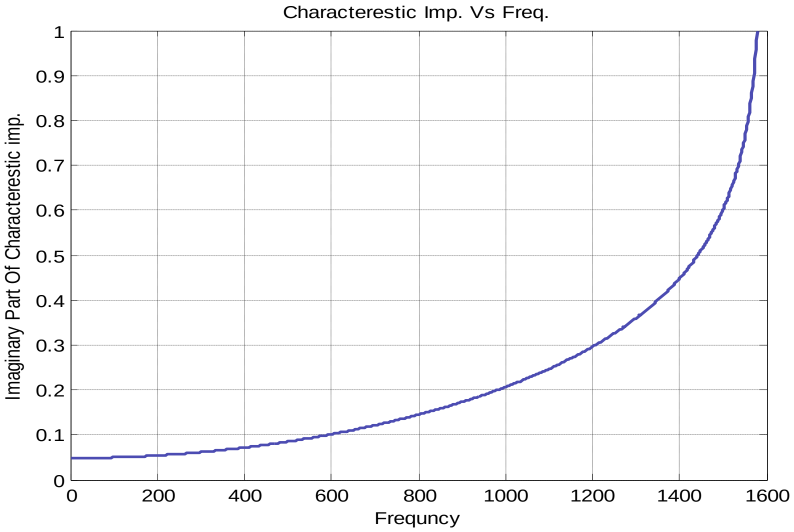


Figure 8. Characteristics impedance and Frequency (RG-59/U coaxial cable)

4.3. Standing Wave Ratio

Standing wave ratio may also be calculated by taking the line's terminating impedance and the line's characteristic impedance, and dividing the larger of the two values by the smaller[7,8].

$$WR = \frac{Emaximum}{Eminimum} = \frac{Imaximum}{Iminimum} \quad \text{…………………………….(19)}$$

$$SWR = \frac{Zload}{Z0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(20)$$

$$SWR=(Zin-Z0)/\ (Zin+Z0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

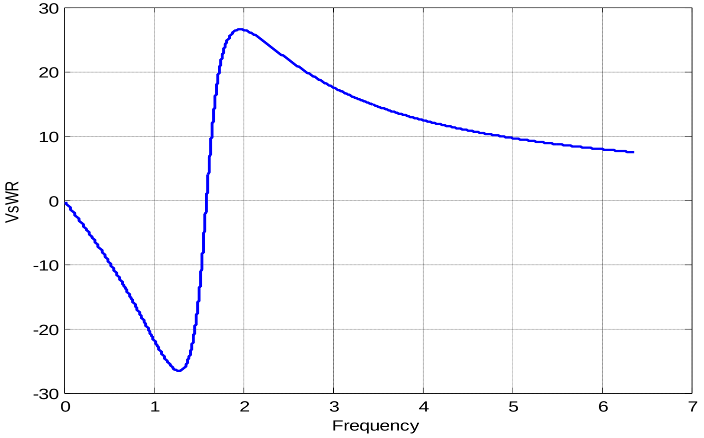


Figure 9. Frequency versus VSVWR

4.4. Simulation Results

The characteristics are also implemented in HFSS.

Procedure for Implementation

1) Make sure that the solution type is driven terminal and the units are in mm.
2) Model the inner conductor- Select a cylinder and assign the radius and length of it, material of the inner conductor.
3) Model the Teflon- Select a cylinder and assign the radius and length of it, material of the Teflon.
4) Model the metal braid- Select a cylinder and assign the radius and length of it, material of the braid.
5) Model the outer jacket- Select a cylinder and assign the radius and length of it, material of the outer jacket.
6) Assigning ports, select a circle and place it from the centre of the inner conductor till the metal braid and assign wave port to it, do it for both sides of the cable.
7) Go to solution setup and set up a frequency setup, and further set a frequency sweep for the same.
8) Validate your project and once that is over save your project and simulate it by analyzing your solution.
9) Once your simulation is over, go to results, right click it and select the 1st option and click new report for viewing the return loss/VSWR.
10) The same way after right clicking on your results, select Smith Chart for viewing your input impedance (Zi).

Implementation of Transmission Line Using HFSS

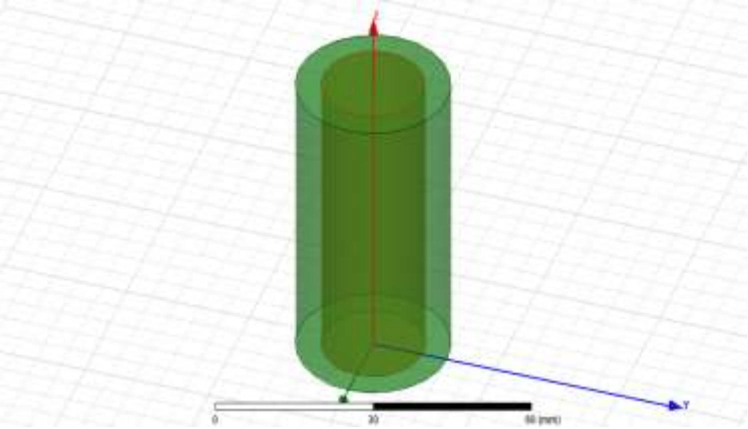


Figure 10. Implimentation of coacial Cable using HFSS

4.5. Plots using HFSS

These are the HFSS plots.

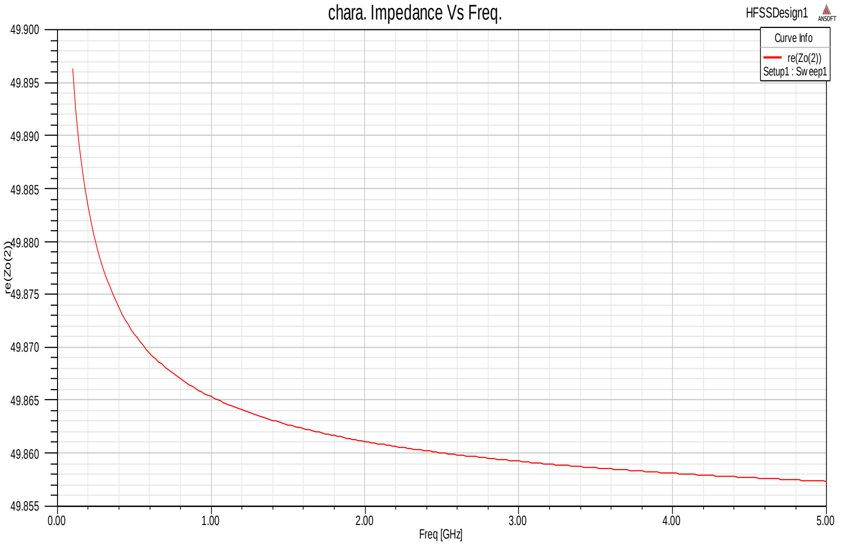
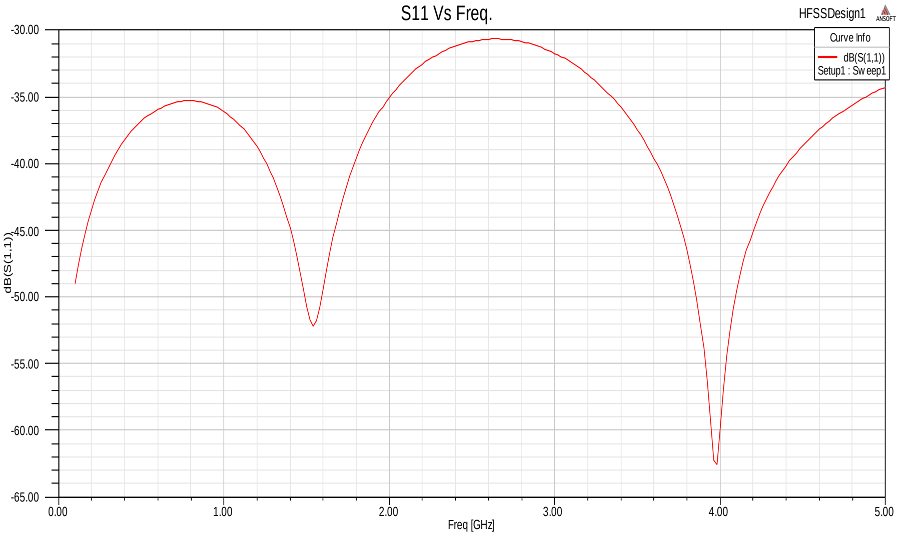
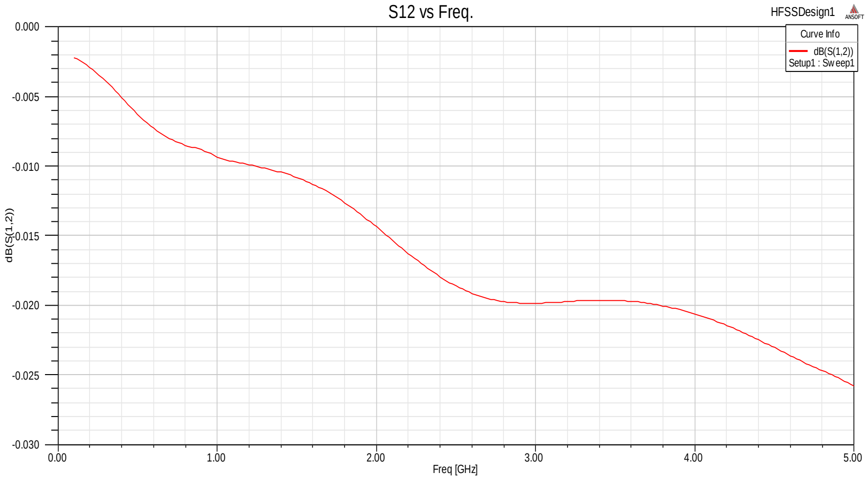


Figure 11. Characterestic Impedance Vs Frequency





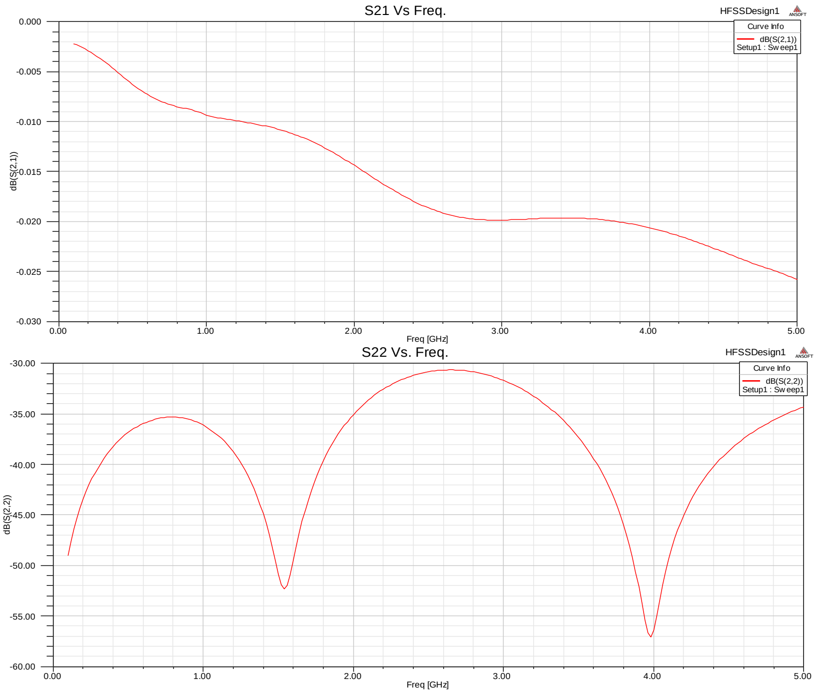


Figure 12. S-parametersVs.Frequency

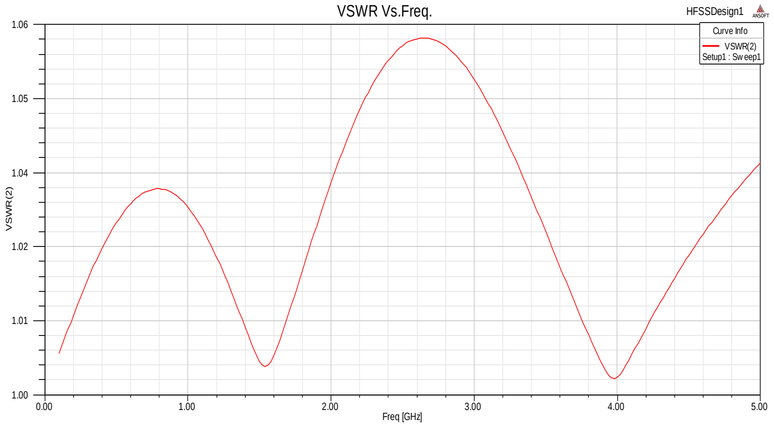


Figure 13. VSWR Vs Frequency

V. Conclusion

In this paper, transmission line was presented. The project started with a detailed literature survey in the fields of transmission line theory, study of coaxial cables etc. Initially the characteristics had been plotted with the help of mat lab coding. Then HFSS implementation is also done.

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