Chapter 11: Transmission Lines

Chapter 11 Objectives

At the conclusion of this chapter, the reader will be able to:

∉ Describe the physical construction of several common types of transmission line.
∉ Identify several connector styles used with coaxial line.
∉ Define important line parameters, such as characteristic impedance, velocity factor, and loss coefficient.
∉ Describe how waves travel on a transmission line.
∉ Calculate the effects of impedance mismatches.
∉ Describe the physical construction of several impedance-matching devices.
∉ Utilize a Smith chart to perform basic transmission line calculations.
∉ Set up test equipment to verify transmission line performance.

Transmission lines are the short-haul truckers of the communications field. Whenever RF energy needs to be transported between two nearby points, a transmission line is used. *The purpose of a transmission line is to get RF energy from one point to another, with a minimum of signal loss.*

Signal energy can be lost in two ways. First, it can be lost to the resistance of the wires that carry it, which converts it to heat. This is undesirable and can be minimized by choosing conductors of appropriate size. Second, signal can be lost by *radiation*. When power is lost in this manner, it moves out into space as a radio wave. When a transmission line radiates, it acts as an antenna, which is not very useful; the signal leaks out where it shouldn't!

Many people find the subject of transmission lines to be mysterious, and a lot of misinformation circulates. Actually, you'll see that transmission lines operate according to the principles of physics, many of which you already know intuitively.

11-1 Basic Construction of Transmission Lines

There are only a few basic ways of building a transmission line. Figure 11-1 shows several types of common line. Let's talk about each type.

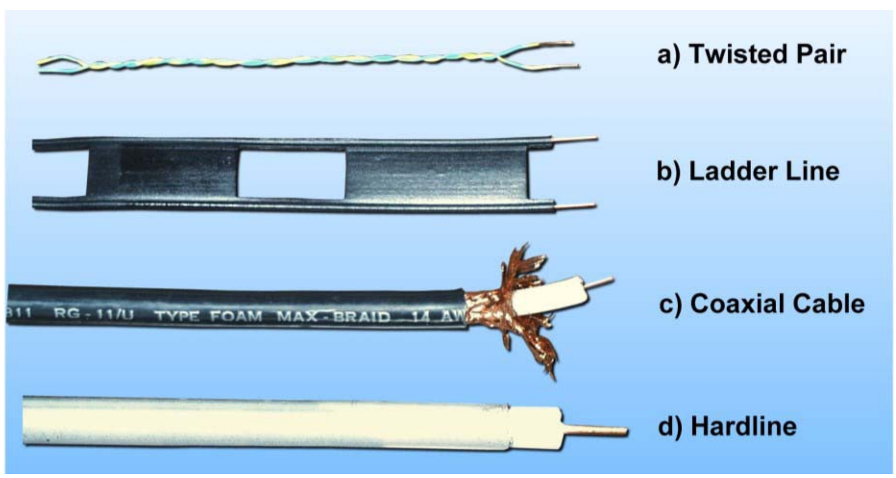

Figure 11-1: Basic Transmission Line Types

Twisted Pair

Twisted pair as shown in Figure 11-1(a) is an inexpensive transmission line. It is a *balanced* medium - both of the conductors are of equal size and shape. Twisting the wires closely together improves the shielding (the ability to reject unwanted signals), however, this also increases the high-frequency losses of the line, mainly because the capacitance between the wires increases. Above a few MHz, twisted pair isn't very useful as a transmission line; it is too lossy there. It's not a good RF transmission line.

This type of line is primarily used for low-frequency work. It is used extensively in the telephone system to connect homes and businesses with the telephone company central office. The telephone system uses twisted pair to carry audio frequencies; at such low frequencies, the loss in this type of line is relatively low. Twisted pair has a characteristic impedance between 25 and 200 T, depending on the type of insulation on the wires and how tightly they are twisted together (number of twists per unit length).

Ladder Line

One of the simplest and lowest cost transmission lines is the *ladder line* of Figure 11-1(b). This line consists of two parallel conductors, separated by an insulating material. You may have seen it on the back of your TV set in the form of *flat line*. This type of line has a *characteristic impedance* (which we will define in the next section) between 200 and 600#T, depending on how far apart we've spaced the conductors.

Ladder line is a *balanced* transmission line; just like twisted pair, both of the wires are of equal size, which means that the paths for outgoing and incoming current are equal. This type of line has a very low loss, but above 100 MHz, begins to experience an increasing loss by *radiation*. We would say that this line is not well shielded. In fact, if you install this type of line, make sure it is kept at least 6 inches from any metal objects. Because it is poorly shielded, a nearby metal object can interfere with the signal on the line. Ladder line is the simplest transmission line that works well for radio frequencies.

Coaxial Line

In order to improve the shielding properties without incurring the heavy high-frequency losses caused by twisting the wires together, we can employ *coaxial* transmission lines, as in Figure 11-1(c). The word "coaxial" means "shared axis." Coaxial cable consists of a center conductor that is inside a hollow outer metal tube. In between the two conductors is the *dielectric*, which can be air, plastic, or some other insulating material. The dielectric is there to insulate the two conductors from each other. It also partially controls the electrical characteristics of the line. Coaxial line is an *unbalanced* line. The two conductors are unequal, and the paths for current going in and out are different.

The silver coaxial line in Figure 11-1(d) is called *hardline*. It's a special type of coaxial cable. The metal outer jacket is rigid and resists bending. Flexible cable is much more common; the black coaxial cable shown uses a braided outer conductor instead of a solid metal tube. The outer conductor of coaxial cable is approximately at ground potential (unless the cable is being used for certain special purposes). Therefore, coax cable is not only superior in shielding to the other types of transmission line, it is also relatively insensitive to placement. Normally, running a coax lead-in next to a metal object will not cause a problem with the line. However, coax should not be wrapped around metal objects like posts.

Coax is made with a wide range of characteristic impedances, from about 25 T to approximately 100 T. It is useful up to around 1000 MHz (1 GHz), where it begins to become fairly lossy. By "lossy" we mean that a significant portion of the transmitted energy is converted to heat within the line rather than being passed on to the load. Coaxial cable is used at even higher frequencies than 1 GHz, but only for short runs (such as for a RF signal patch cord or "jumper" between two pieces of gear).

Waveguide

Above 1000 MHz, coaxial cable is not a good solution when signals need to be sent more than a meter or so. At microwave frequencies, *waveguide* is commonly used. Waveguide is a hollow metal tube (or box) that carries UHF and SHF (microwave) radio energy. Energy is introduced into one end of the waveguide by a small *coupling stub* (a miniature antenna) or *loop*. The RF then travels down the waveguide to the other end. Because the walls of the waveguide are metal, the RF energy can't escape. There is no center conductor or dielectric. At the receiving end, another coupling stub extracts the microwave RF energy. Figure 11-2 shows how this works.

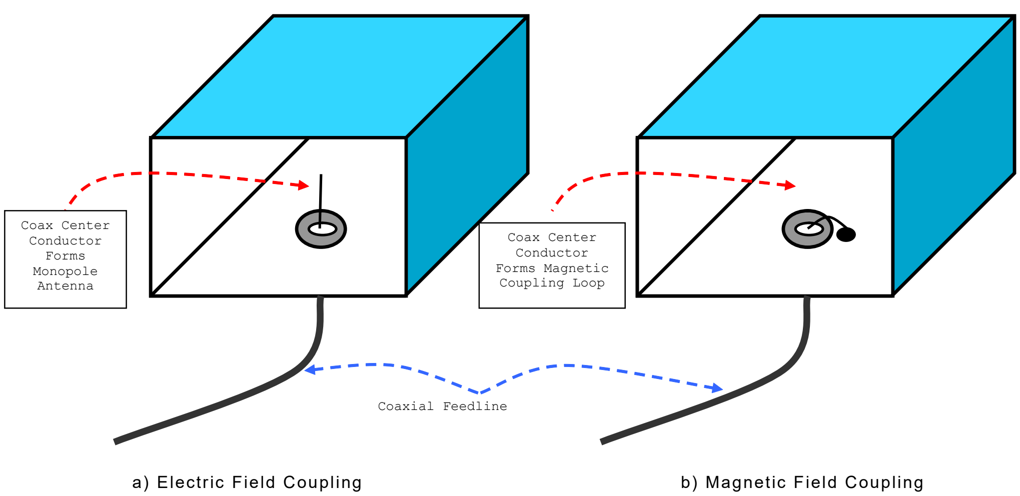

Figure 11-2: Getting Energy In and Out of a Waveguide

Waveguide can also be used to directly feed microwave antennas, which are usually *horns* or *dishes*. In this case, the receiving end of the waveguide just opens into the dish of the antenna.

Waveguide is a very low loss transmission line, and it is by far the most expensive of all the types discussed so far. However, it is not useful below about 1000 MHz (1 GHz), for its physical size is related to the *wavelength* of the signals that pass through it. At frequencies below 1 GHz, the required size for waveguide is very large. The formula for finding wavelength of a signal is

(11-1) $$\varsigma \mid \frac{v}{f}$$

Where v is the velocity or speed of the radio wave (3 x 10^8 m/s in free space), and f is the frequency of the wave.

Example 11-1

What is the wavelength for each of the following signal frequencies?

a) 1 MHz b) 30 MHz c) 3 GHz

Solution

Equation 11-1 solves all these problems. We get:

a) $$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^8 \, m/s}{1MHz} \mid \underline{\underline{300 \, meters}}$$

b) $$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^8 \, m/s}{30MHz} \mid \underline{\underline{10 \, meters}}$$

c) $$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^8 \, m/s}{3GHz} \mid \underline{\underline{10 \, cm}} \; /0.1 meter 0$$

Notice how the wavelength becomes smaller as frequency increases. At 3 GHz, the wavelength is only 10 cm (about 3.94”). At such a high frequency, a quarter-wavelength stub "antenna" need only be about 1"!

Connectors for Coaxial Cable

With ladder line and twisted pair, the end user can connect the cable to a device easily enough by using binding posts. Because of its concentric construction, connecting coaxial cable isn't quite so simple. In fact, simply stripping the end off a coax cable and connecting it to a circuit degrades the connection by causing an *impedance mismatch*. Special connectors are used for connecting coaxial cables, as shown in Figure 11-3.

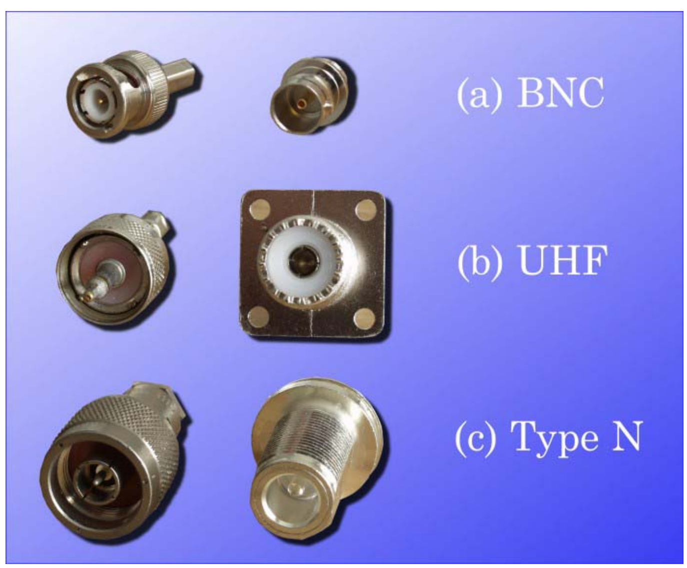

Figure 11-3: Coaxial Cable Connectors

You're likely to see all of the types of connectors shown in Figure 11-3 (plus others) at one time or another in your studies in electronics. You're probably most familiar with the *BNC* connector; it's used on almost all oscilloscopes. The *BNC* connector comes in both 75 and 50 T versions (they're nearly impossible to tell apart by sight), and is good to at least 200 MHz. The BNC connector is not weather-tight. It also can't be mated with the larger coaxial cable sizes.

The *PL-259*, or *UHF* connector, is another very common coaxial cable plug. These connectors are actually not very effective at UHF frequencies; they are a poor choice for anything operating over 100 MHz or so. Above 100 MHz, a UHF connector causes a slight impedance mismatch, which can degrade the performance of the equipment it is connected to. These connectors are also not weathertight, so if they're used outdoors, they must be sealed.

The *N* connector is the most expensive of all the connectors in Figure 11-3, but for UHF work, it's worth it. It is a true constant-impedance connector, which means that it does not introduce an impedance mismatch into the circuit it is connected to. N connectors are useful well into the microwave region (GHz frequencies); there's no real frequency limit except for that of the attached coaxial cable. In addition, the N connector has an internal rubber gasket to seal out moisture, so it's very suitable for outdoor work. Most technicians generally use a sealant over the finished connection, even though the connector has a gasket. It's very inconvenient and expensive to fix a "problem" connector on the top of a 500 foot tower that failed due to moisture entry!

Section Checkpoint

11-1 What is the purpose of a transmission line?
11- 2 When signal is lost on a transmission line, what two forms of energy might it be converted to?
11-3 Define *balanced line*.
11-4 Which transmission line type has the highest useful frequency?
11-5 Which type of line would be best for operation at 100 MHz near metal objects?
11-6 Why does twisted pair have poor high frequency response?
11-7 What connector type is usually found on oscilloscopes and other bench equipment?
11-8 What type of coax connector would be best for operation in a 450 MHz repeater system?
11-9 Why can't waveguide be used at low frequencies (30 MHz, for example)?
11-10 As the frequency of a signal is decreased, what happens to its wavelength?

11-2 Electrical Characteristics of Transmission Lines

A transmission line may look like plain wire and insulation, but there's a lot more hidden inside when we take a closer look. Even a single wire has three basic properties: *Resistance* to current flow (controlled by its cross-sectional area and length); *inductance*, controlled by its length (and any nearby magnetic objects); and *capacitance*, which the wire shares with ground.

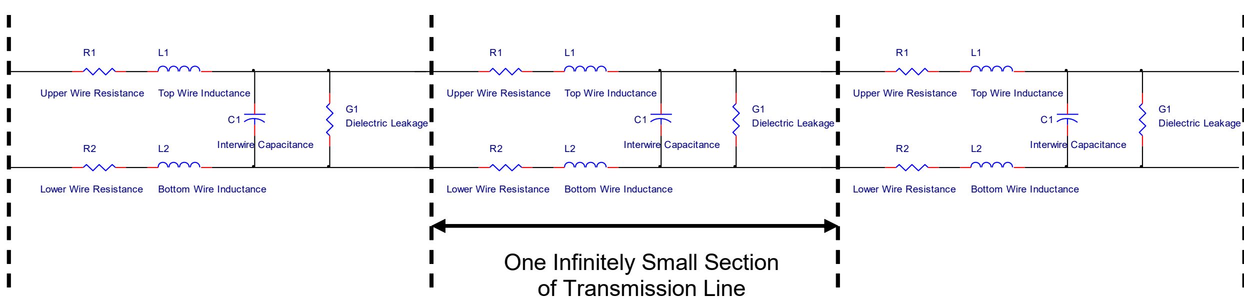

Figure 11-4: Model for a Real-World Transmission Line

The values of resistance, inductance, and capacitance are normally small enough to ignore for DC and low-frequency work. At radio frequencies, these effects can no longer be ignored. A transmission line can be considered to be made up of an *infinite* number of *infinitely small* sections like Figure 11-4.

The inductances L_1 and L_2 are the inductances per *unit length* of line; the capacitance C_1 is the capacitance per unit length; and the resistances R_1 and R_2 are the resistances per unit length for each wire. There is also a leakage conductance (recall that G=1/R) between the wires that represents the fact that the dielectric is not a perfect insulator. A small amount of energy is lost in the dielectric and is dissipated as heat.

The model of Figure 11-4 is too complex for most purposes, and most technicians prefer to simplify it by lumping the inductances of the two wires together as in Figure 11-5. Also notice that the resistors are gone from Figure 11-5; this means that the line is *lossless*, which never happens in real life. However, for short runs of transmission line, it is quite helpful to ignore loss when trying to understand how things work.

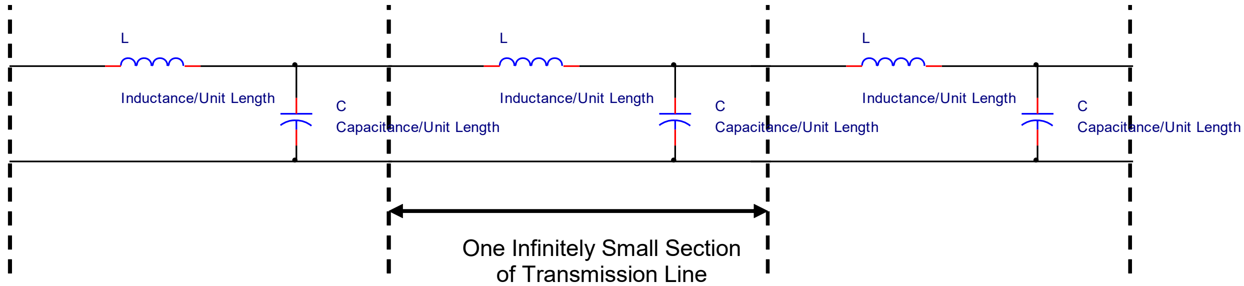

Figure 11-5: Model for a Lossless Transmission Line

A lossless section of transmission line contains an inductance L, and a capacitance C. If you're having trouble with the "infinitely small" concept, consider slicing a pie. You can divide a pie into six slices - or twelve - or twenty-four. You still have the same amount of pie. Each slice gets thinner and thinner as you divide the pie further. Eventually, you might end up with an *infinite* number of slices. Each will be "infinitely thin," which means *as thin as possible without ceasing to exist*. A transmission line is thought of in this way; each of the L-C sections above represents an infinitely small section of the line.

To the technician, the L and C are important because they control the characteristics of the transmission line. Also, the L and C components help to explain how energy travels down the line. Let's try an experiment. Let's hook the line of Figure 11-5 to a battery, switch, and some meters and see what happens. Figure 11-6 shows the setup.

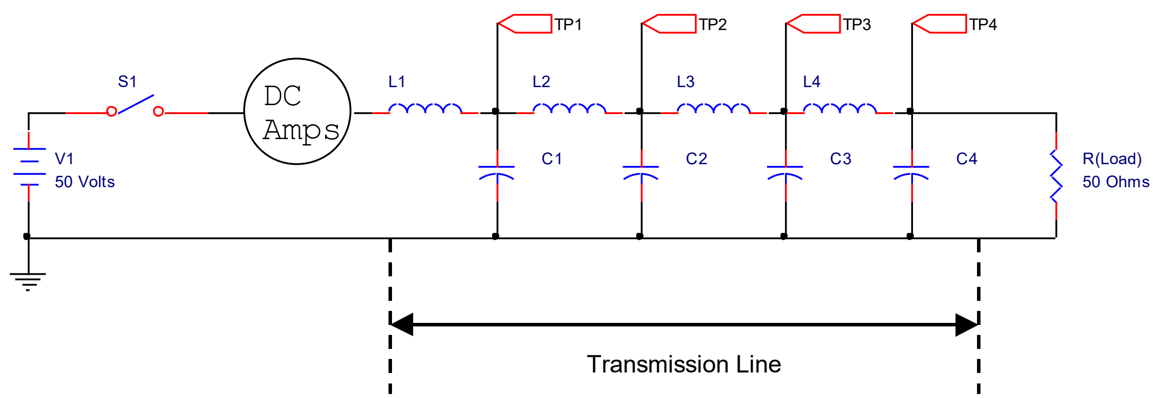

Figure 11-6: An Experimental Setup

In the figure we've connected a DC ammeter in series between the DC voltage source, and the transmission line and load. The test points TP_1 through TP_4 are located at consecutive points on the line. We will monitor the voltage in these places.

Imagine that the switch S_1 is open, and has been open for a very long time. There would be no voltage in any of the capacitors, and no voltage at the load (TP_4).

Now close S_1. What happens? Are you thinking of inductor and capacitor charging? Good, because that's what begins to take place. With the switch closed, capacitor C_1 can begin to charge through inductor L_1. As capacitor C_1 begins to develop some voltage (it's being charged), capacitor C_2 begins to charge through L_2. As C_2 begins to charge, capacitor C_3 now begins charging through L_3.

This looks complicated, but it isn't. Think of a line of dominoes. When the first one is tipped, it starts a chain reaction; the line of motion passes rapidly among all the dominoes in the row. This is very similar to what our little section of transmission line is doing. Each L-C section charges the next L-C section when it gets the voltage. The voltage *eventually* reaches the load and appears across it. Figure 11-7 shows the voltages at the test points along the way.

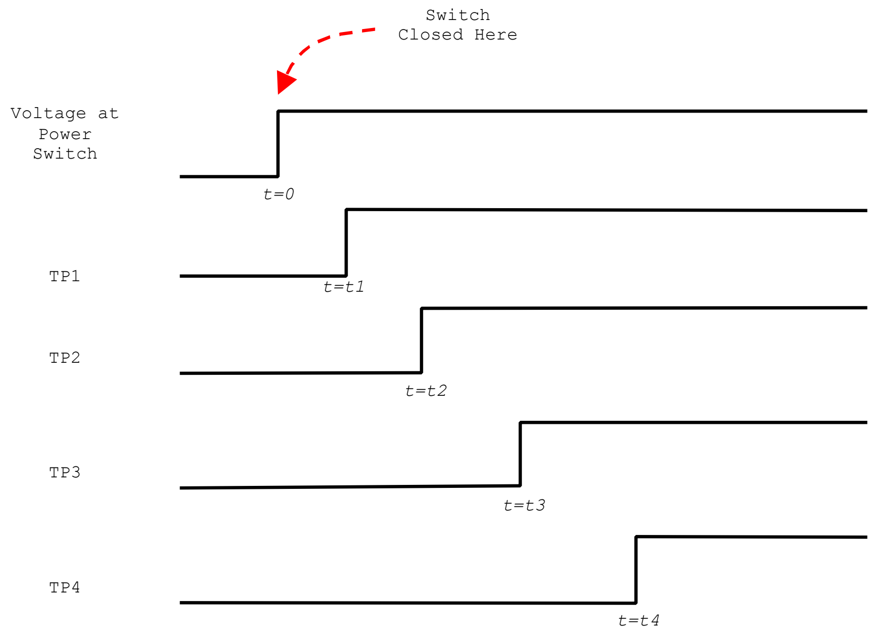

Figure 11-7: The Voltages at the Test Points

As you can see, the voltage simply takes time to reach each of the test points. It moves toward the load as a *traveling wave* with a square edge. Since they are infinitely small, the L and C components in the line do not change the shape of the edge; it remains perfectly sharp all the way down the line. Finally, the edge reaches the load, and voltage appears on the load. *The main idea here is that the voltage does not reach the load instantly*. It takes time for it to get there. *All* of the battery's 50 volts reaches the load. Because there is no resistance, there is no loss of voltage.

Curiously enough, the *ammeter* we placed in the circuit shows a *steady current* the entire time the experiment is running. As soon as the switch is closed, the ammeter needle deflects, and holds steady. Even before the load gets the voltage (t = t4), the ammeter is showing current draw. How can this be? The answer is that the ammeter shows that current is required for charging the L-C sections along the line. Once all the L-C sections have charged, then the ammeter shows the current in the load.

Velocity of Propagation and Velocity Factor

The *velocity of propagation* is defined as the speed at which waves move down a transmission line. It depends on the L and C per unit length, and is calculated as:

$$(11\text{-}2)\quad v_p = \frac{1}{\sqrt{LC}}$$

where L and C are the inductance and capacitance per unit length. The units of the answer are unit-lengths per second. If L is in henries/meter and C is in farads/meter, then the units will be meters/second. This is important to remember, because some manufacturers' data shows L and C in terms of feet, or some other units.

The *velocity factor* is the ratio of conduction speed to the speed of light in free-space. It is often abbreviated as *VF*, and is calculated by:

$$(11\text{-}3)\quad VF = \frac{v_p}{c}$$

where v_p is the velocity of propagation, and c is the speed of light. The velocity factor is always a number less than 1, since waves can't exceed the speed of light within a transmission line.

Example 11-2

What is the velocity of propagation and velocity factor of RG-58U coaxial cable having L= 250 nH/m and C= 100 pF/m?

Solution
The velocity of propagation can be calculated as:

$$v_p \mid \frac{1}{\sqrt{LC}} \mid \frac{1}{\sqrt{(250nH/m)(100pF/m)}} \mid \underline{\underline{2\Delta 10^8 m/s}}$$

The velocity factor can be computed:

$$VF \mid \frac{v_p}{c} \mid \frac{2\Delta 10^8 m/s}{3\Delta 10^8 m/s} \mid \underline{\underline{0.66666}} \mid 66.67\%$$

Therefore, waves travel in this cable at 66.67% of the speed of light.

Transmission lines are sometimes used to delay or slow a signal down on purpose. The time delay produced is dependent upon the length of the line, and the L-C product.

Example 11-3

How long will it take a pulse to travel through a 50' length of RG58U coaxial cable (VF = 0.66667, v_p = 2 x 10^8 m/s)?

Solution
To solve this problem, we use the old standby formula:

$D \mid RT$ (Where R is *rate*, which means the same thing as *velocity*).

Here, we must solve for *time*, so the formula is manipulated as:

$$T \mid \frac{D}{R}$$

There's one minor adjustment we have to make. The length is given in *feet*, rather than meters. Since we know the velocity in meters per second, it's probably easier to convert the 50' value into meters first, then substitute in the formula.

$$L_{meters} \mid L_{feet} \Delta \frac{1\,meter}{3.28\ ft} \mid 50\,ft \Delta \frac{1\,meter}{3.28\ ft} \mid 15.24\,m$$

We can now find the time:

$$T \mid \frac{D}{R} \mid \frac{15.24\,m}{2\Delta 10^8 m/s} \mid \underline{\underline{76.2\,ns}}$$

It will take 76.2 ns for the pulse to move down the line. (We hope you don't mind the wait.)

Characteristic Impedance

The *characteristic impedance* of a transmission line is the ratio of voltage to current at any point. Don't let this confuse you; this is *not* a resistance. The characteristic impedance of a transmission line is controlled mainly by the tiny L-C sections within it. Ohm's law is obeyed, so we get:

$$(11\text{-}4)\quad Z_0 \mid \frac{V(x)}{I(x)}$$

where *V(x)* is the voltage at some point *x*, and *I(x)* is the current at the same point. The symbol "Z_0" is used for the characteristic impedance, which is in ohms. This equation *defines* what characteristic impedance is, and it tells us somewhat about what characteristic impedance *means* (a ratio of voltage to current at any point); however, it doesn't tell us what *controls* characteristic impedance.

Since the lossless transmission line is just made up of L-C sections, you might guess that the equation for calculating Z_0 must have an L and a C in it; you're right! It looks like this:

$$(11\text{-}5)\quad Z_0 \mid \sqrt{\frac{L}{C}}$$

where *L* is the inductance per unit length, and *C* is the capacitance per unit length. Since we're dividing these two, it doesn't matter what the units of length are -- they will cancel, leaving us with units of *ohms*. Let's try a couple of examples.

Example 11-4

What is the characteristic impedance of RG58U coaxial line, if it has a capacitance of 30.5 pF/ft and an inductance of 76.25 nH/ft?

Solution
The units don't matter for the *L* and *C*, as long as they're the same. From equation 11-5, we get:

$$Z_0 \mid \sqrt{\frac{L}{C}} \mid \sqrt{\frac{76.25\ nH/ft}{30.5\ pF/ft}} \mid \underline{\underline{50\ \mathrm{T}}}$$

We would say that RG58U is "50 T coaxial cable." It is meant to be connected to generators and loads that have a resistance of 50 T.

The characteristic impedance also relates voltage and current at *any* point on the transmission line.

Example 11-5

Suppose that a certain transmission line has a characteristic impedance of 50 T. If there is an AC voltage on that line of 50 volts at a distance *x* of 72" from the generator, what is the current flowing at that same point?

Solution
Ohm's law can be applied, and we get:

$$Z_0 \mid \frac{V(x)}{I(x)}$$

so

$$I(x) \mid \frac{V(x)}{Z_0} \mid \frac{50\ V}{50\ \mathrm{T}} \mid \underline{\underline{1\ A}}$$

A current of 1 ampere must be flowing at that point on the line.

Surge Impedance

The characteristic impedance of a transmission line is sometimes called the *surge impedance*. Here's why. Suppose that the transmission line of Figure 11-6 is infinitely long. If the line is infinitely long, the process of *charging* the line also takes an infinite amount of time; the energy never gets to the load!

How much current will flow to charge the line? Ohm's law and the characteristic impedance of the line give the answer to that. When the switch is closed in Figure 11-6, the transmission line is connected to the battery. It immediately draws a *constant* current from the battery. The current remains constant because there's always another L-C section to charge (remember, the line is infinitely long). Since the battery is 50 volts, and the line's characteristic impedance is 50 ohms, a current of 50 volts/50 ohms, or 1 ampere will flow from the battery.

When a line is infinitely long, it looks like a pure "resistance" that is equal to Z_0!

Further Defining Characteristic Impedance

Let's summarize: The *characteristic impedance*, or Z_0, of a transmission line can be defined in several ways. Don't let this bother you; these ways are just based on different methods of observing the line's action.

- Z_0 is the ratio of voltage to current at any point on the line.
- Z_0 is the input impedance (resistance) that appears at the end of an infinitely-long section of line.
- Z_0 is the input impedance of a line of *any* length that has a load resistance *equal* to Z_0 at the end. (We call the load a *termination* for the line.) A transmission line should always be terminated in a load equal to Z_0.
- Some data books will refer to Z_0 as the "surge impedance" of the line. That's just another way of saying characteristic impedance.

Physical Factors Controlling Velocity of Propagation and Characteristic Impedance

The physical construction of a transmission line determines both the speed of wave propagation and the characteristic impedance of the line. The following equations are rarely, if ever used directly by technicians. However, they do show how the physical details of a transmission line's construction define its electrical properties. In the equations, κ_r is the *relative permittivity* (dielectric constant) of the insulating material, or dielectric (see Table 11-1), and *s, D,* and *d* are the dimensions from Figure 11-8.

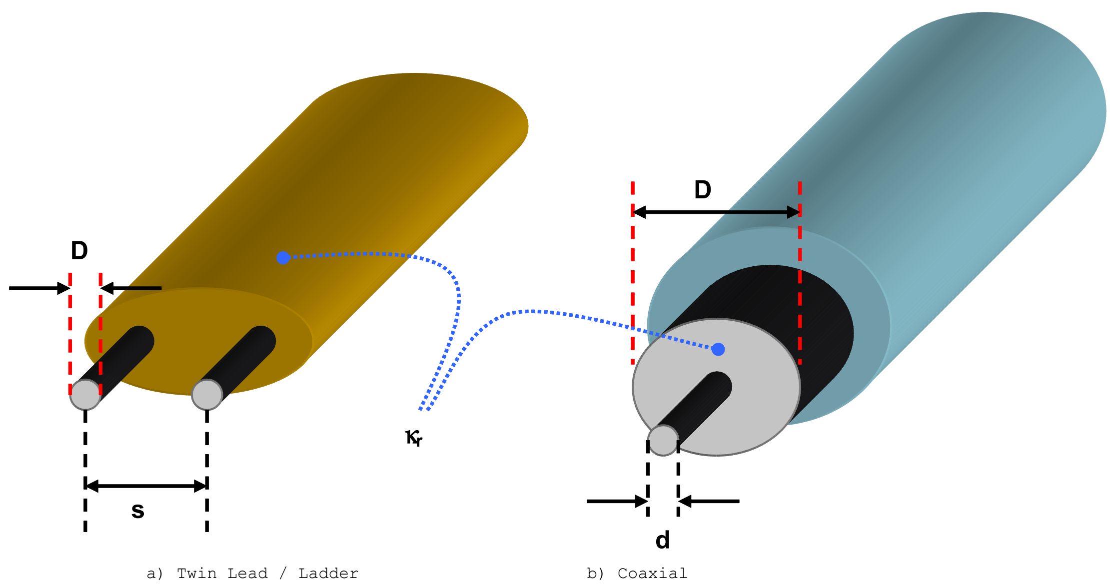

Figure 11-8: Physical Measurements of Transmission Line Dimensions

For either type of transmission line, the *velocity factor* (*VF*) can be closely approximated by:

$$(11\text{-}6)\quad VF - \frac{1}{\sqrt{\kappa_r}}$$

Notice that as κ_r gets larger, the velocity factor gets *smaller*. For transmission lines with an air dielectric, κ_r is 1 and velocity factor for that line will be close to 1. Placing a material with a high dielectric constant in between the conductors (such as polystyrene, a plastic) slows propagation even further.

In certain RF hybrid integrated circuits, the substrate (the flat insulating surface on which the components and conductors are placed) is formed from beryllium oxide, a white ceramic material with a very high dielectric constant. This makes the transmission lines formed on the material have a relatively low velocity of propagation, and allows them to be formed in a very small space.

For parallel-wire line (such as ladder line), the characteristic impedance is found by:

$$(11\text{-}7)\quad Z_0 = \frac{120}{\sqrt{\kappa_r}} \ln\left(\frac{2s}{d}\right)$$

For coaxial line, the characteristic impedance is calculated using:

$$(11\text{-}8)\quad Z_0 = \frac{60}{\sqrt{\kappa_r}} \ln\left(\frac{D}{d}\right)$$

Equations 11-7 and 11-8 tell us that the *closer* the wires are spaced in a transmission line, the *lower* the characteristic impedance becomes. This explains why coaxial cable tends to have low values of characteristic impedance (120 T or less), while flat (twin lead) cable has higher impedance; the flat cable has a larger space between the conductors. The dielectric also affects characteristic impedance; the higher the dielectric constant, the *lower* Z_0 becomes. The dielectric constant κ_r of various materials is given below in table 11-1:

Material	Relative Permittivity, κ_r
Air	1.0
Styrofoam	1.03
Teflon	2.25
Vinyl	2.3
Polyethylene	2.3
Wood	2 - 4
Polystyrene	2.7
Water	80-81
Beryllium Oxide, BeO	6.7

Table 11-1: Dielectric Constants for Common Materials

Example 11-6

What is the velocity factor (VF) and characteristic impedance (Z0) of a coaxial transmission line with a vinyl dielectric, and electrode dimensions D = 0.27 " and d = 0.075"?

Solution
The dielectric constant κ_r for vinyl is 2.3, and can be substituted into equation 11-6:

$$VF = \frac{1}{\sqrt{\kappa_r}} = \frac{1}{\sqrt{2.3}} = \underline{\underline{0.659}}$$

RF energy travels through this cable at about 66% the speed of light.

The characteristic impedance is found using Equation 11-8:

$$Z_0 = \frac{60}{\sqrt{\kappa_r}} \ln\left(\frac{D}{d}\right) = \frac{60}{\sqrt{2.3}} \ln\left(\frac{0.27"}{0.075"}\right) = \underline{\underline{50.6\text{T}}}$$

This is pretty close to 50 T, a standard value.

Physical Factors Controlling Transmission Line Losses

In any transmission line, there are two main sources of energy loss, *ohmic resistance* and *dielectric heating*. Ohmic resistance (sometimes called I^2R loss) refers to the resistance of the wires that make up the line. In general, the larger the conductors, the lower I^2R will be. At radio frequencies, most of the current tends to flow on the outside surface of conductors (rather than being uniformly distributed throughout the cross-sectional area). This is known as the *skin effect*, and it becomes more severe as frequency is increased. At very high frequencies, the *circumference* of the conducting wire becomes much more important than its cross sectional area due to the skin effect. This means that the effective resistance of a wire increases as frequency increases.

When energy is lost in the dielectric, it is converted to heat. The best dielectric, as far as loss is concerned, is air. Other materials, such as plastics, heat more readily in the presence of the RF energy field inside a transmission line, and lose more energy. Dielectric losses increase with frequency, and are also somewhat dependent on the *voltage* being applied.

Both of these effects (ohmic loss and dielectric loss) *increase* with frequency, therefore, we can say that transmission line losses, in general, increase with frequency. Manufacturers rate each type of transmission line in *dB loss per unit length* at specific frequencies. The loss per unit length is called *specific loss*. Technicians and engineers use this data when choosing transmission lines for different applications. Table 11-2 shows the *specific loss* for several types of coaxial line at three frequencies.

Cable Type	dB Loss @ 50 MHz	dB Loss @ 100 MHz	dB Loss @ 400 MHz
RG58U	3	4.5	9.5
RG59U	2.4	3.4	7.1
RG62A	1.9	2.7	5.4
Belden 9913	1.0	1.4	2.8
300 T twin lead	0.8	1.1	2.4
3/4" 50 T hardline	0.4	0.64	1.45
RG174 (mini 50 T)	8.0	10.9	20.4

Table 11-2: Specific Loss in dB/100 Feet for Various Transmission Lines

Example 11-7

What power will be delivered to an antenna from a 100 MHz, 100 watt transmitter if it supplies the antenna through a 200 foot length of Belden type 9913 transmission line?

Solution

From table 11-2, the *specific loss* of '9913 is 1.4 dB for every 100 feet at 100 MHz. Therefore, the total power loss is

$$dB_{loss} = 200\,ft \times \frac{1.4\,dB}{100\,ft} = \underline{2.8\,dB}$$

This doesn't give us the power at the load; it just says that the load power is *2.8 dB less* than the transmitter power. A 2.8 dB *loss* is the same as a -2.8 dB *gain*, and therefore the dB power gain formula can be used:

$$dB = 10\log\left(\frac{Po}{Pi}\right) = 10\log G_p$$

Where *Po* is the power at the antenna, *Pi* is the power at the transmitter, and *Gp* is the power gain. By rearranging this equation, and substituting a *gain* of -2.8 dB (remember that a negative dB gain number is the same thing as a positive dB loss), we get:

$$Po = Pi \times 10^{(dB/10)} = 100\,W \times 10^{(-2.8/10)} = \underline{\underline{52.5\,watts}}$$