RF and Microwave Transmission Lines

ELEC 2230

Section 1

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Introduction to transmission lines

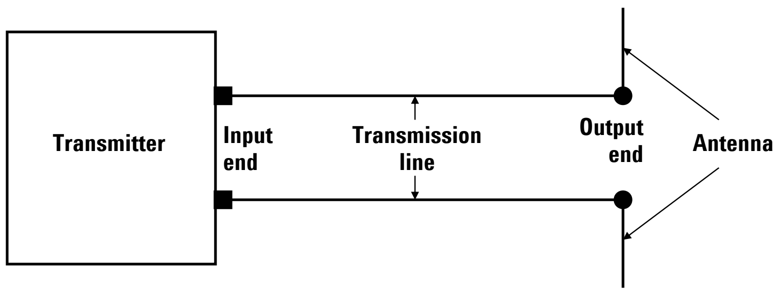
A TRANSMISSION LINE is used to guide electrical energy from one point to another.

e.g. to transfer the output RF energy of a transmitter to an antenna, usually located some distance away from the transmitter.

The transmission line has a single purpose for both the transmitter and the antenna - to transfer the energy output of the transmitter to the antenna with the least possible power loss.

Terminology

All transmission lines have two ends. The end of a 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.



Transmission line impedances

The ratio of voltage to current (E_{in}/I_{in}) at the input end is the INPUT IMPEDANCE (Z_{in}). (Impedance presented to the transmitter by the transmission line and its load, the antenna.)

The ratio of voltage to current (E_{out}/I_{out}) at the output end is known as the OUTPUT IMPEDANCE (Z_{out}). (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.

Types of transmission lines

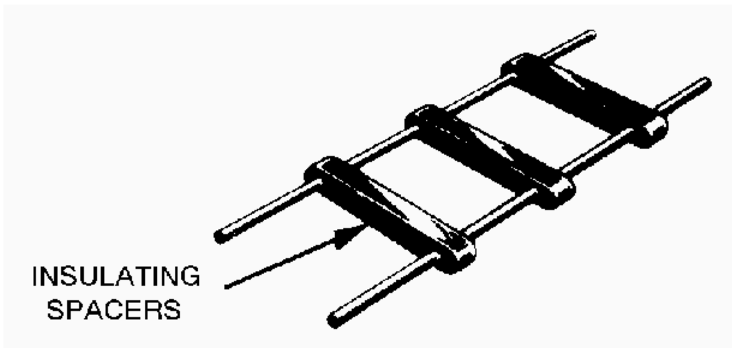
There are many different types of transmission line. Each type (may be called line or waveguide) has a certain characteristic impedance value, current-carrying capacity and physical shape and is designed to meet a particular requirement.

Examples of transmission line types are PARALLEL-LINE, TWISTED PAIR, SHIELDED PAIR, COAXIAL LINE, (HOLLOW TUBE) WAVEGUIDES, STRIPLINE and MICROSTRIP. The use of a particular line depends, among other things, on the applied frequency, the power-handling capabilities, the physical environment and the application.

Two-Wire Open Line

Consists of two wires spaced from 50 to 150 mm 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.

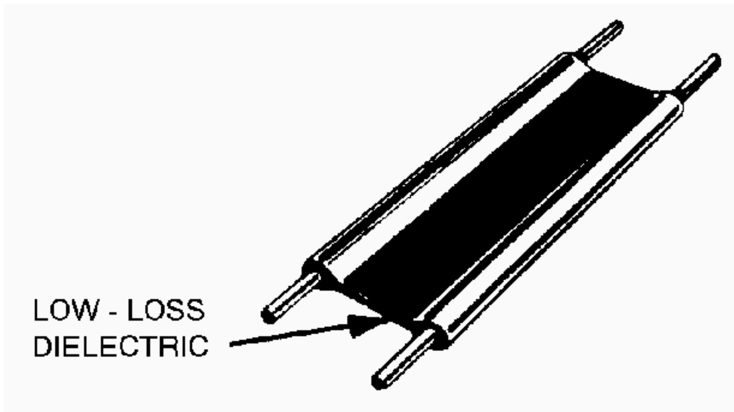
Two-Wire Open Line



Two-wire ribbon type line

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. Since the wires are embedded in the thin ribbon of polyethylene, the dielectric space is partly air and partly polyethylene.

Two-wire ribbon type line



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Twisted Pair

The TWISTED PAIR transmission 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.

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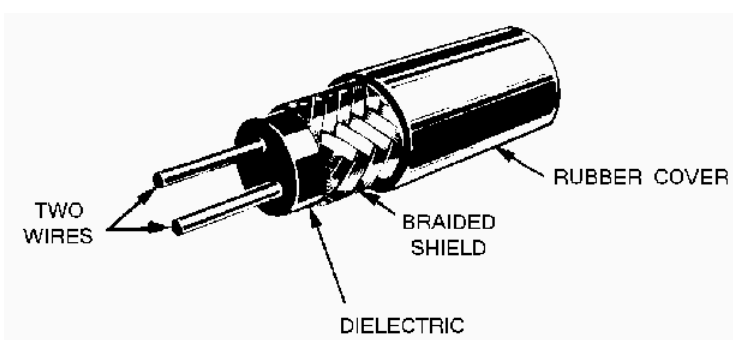
Shielded Pair

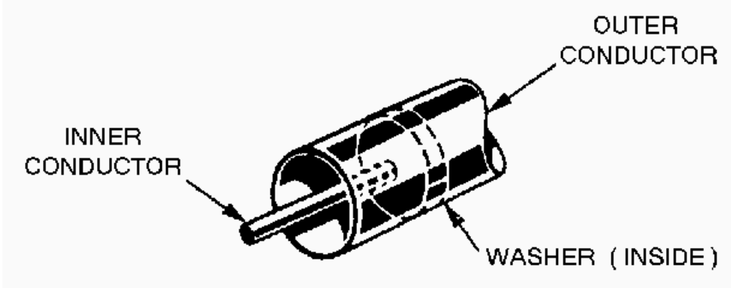
The SHIELDED PAIR consists of parallel conductors separated from each other and surrounded by a solid dielectric. The conductors are contained within a braided copper tubing that acts as an electrical shield. The assembly is covered with a rubber or flexible composition coating that protects the line from moisture and mechanical damage. The principal advantage of the shielded pair is that the conductors are balanced to ground; that is, the capacitance between the wires is uniform throughout the length of the line. This balance is due to the uniform spacing of the grounded shield that surrounds the wires along their entire length. The braided copper shield isolates the conductors from stray magnetic fields.

Shielded Pair



Coaxial Lines

There are two types of COAXIAL LINES, RIGID (AIR) COAXIAL LINE and FLEXIBLE (SOLID) COAXIAL LINE. The physical construction of both types is basically the same; that is, each contains two concentric conductors.



CABLE WITH WASHER INSULATOR

Rigid Coaxial Lines

The rigid coaxial line consists of a central, insulated wire (inner conductor) mounted inside a tubular outer conductor. The inner conductor is insulated from the outer conductor by insulating spacers or beads at regular intervals. The spacers are made of material that has good insulating characteristics and low dielectric losses at high frequencies.

Advantages

- **minimal radiation losses.**
- **interference from other lines is reduced.**

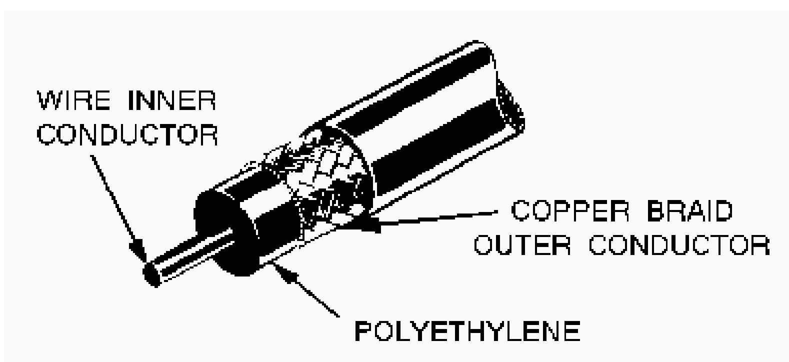
Disadvantages

- **expensive to construct**
- **must be kept dry to prevent excessive leakage between the two conductors**
- **high-frequency losses are large enough to limit the practical length.**

Flexible coaxial Lines

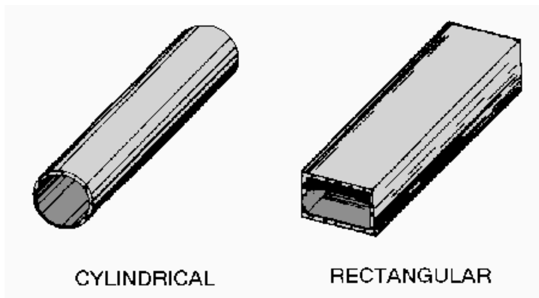
Flexible coaxial lines are made with an inner conductor that consists of flexible wire insulated from the outer conductor by a solid, continuous insulating material. The outer conductor is made of metal braid, which gives the line flexibility. The most commonly used insulator is polyethylene plastic, a solid material that remains flexible over a wide range of temperatures. It is unaffected by most liquids although its use as an insulator results in greater high-frequency losses than air although the losses are still lower than most other solid dielectric materials.

Flexible coaxial Lines



Waveguides

The WAVEGUIDE is an air dielectric transmission line. The principle by which it transmits energy down its length differs from the lines described previously. Waveguides may be cylindrical, elliptical, or rectangular. The rectangular waveguide is used more frequently than the cylindrical waveguide.



Waveguide

The term waveguide is applied to all types of transmission lines in the sense that they are all used to guide energy from one point to another. Note that the transmission of electromagnetic energy along any type of waveguide is at a velocity slower than electromagnetic energy traveling through free space.

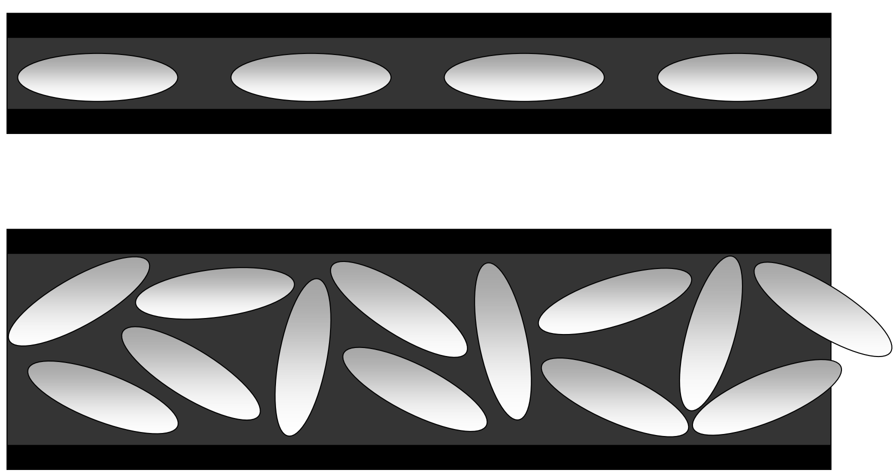
Common usage has generally limited the term to mean a hollow metal pipe or a dielectric transmission line. Henceforth, we will use the term waveguide only to mean "hollow metal pipe". Waveguides may be classified according to their cross section (rectangular, elliptical, or circular), or according to the material used in their construction (metallic or dielectric).

The details of waveguide operation will not be considered in this module, but it should be appreciated that the principles of transmissions lines apply equally to waveguides.

Transmission modes

- Electric and magnetic field, formed as voltage and current waves, travel down a transmission line with all waves varying in a periodic manner.
- As frequency increases, a significant proportion of the wavelength of the propagating signal becomes comparable to the cross-sectional geometry of the transmission line and more than one configuration of the electromagnetic field can fit the geometry. These are the “high-order modes” of propagation.
- The point at which a higher order mode can start to propagate in a given geometry is called the “cutoff frequency” for that mode.

Analogy for higher-order modes of propagation



Single mode propagation

Each mode propagates at its own velocity. In some modes, the propagation velocity depends on the frequency – this is called DISPERSION

In order for a signal to propagate undistorted down a transmission line, it must be confined to a single mode without dispersion.

The effect of multiple mode propagation or dispersion is to spread pulses and therefore “garble” data