ELECTRICAL CHARACTERISTICS OF TRANSMISSION LINES

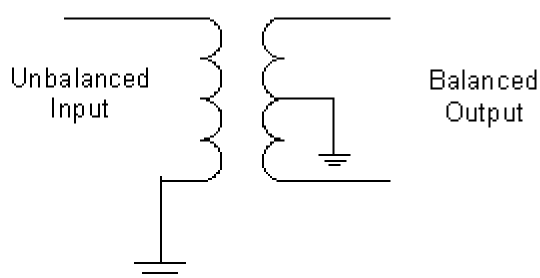
Transmission lines are generally characterized by the following properties:

- balance-to-ground
- characteristic impedance
- attenuation per unit length
- velocity factor
- electrical length

BALANCE TO GROUND

Balance-to-ground is a measure of the electrical symmetry of a transmission line with respect to ground potential. A transmission line may be unbalanced or balanced. An unbalanced line has one of its two conductors at ground potential. A balanced transmission line has neither conductor at ground potential. An example of an unbalanced transmission line is coax. The outer shield of coax is grounded. An example of a balanced transmission line is two-wire line. Neither conductor is grounded and if the instantaneous RF voltage on one conductor is +V, it will be –V on the other conductor.

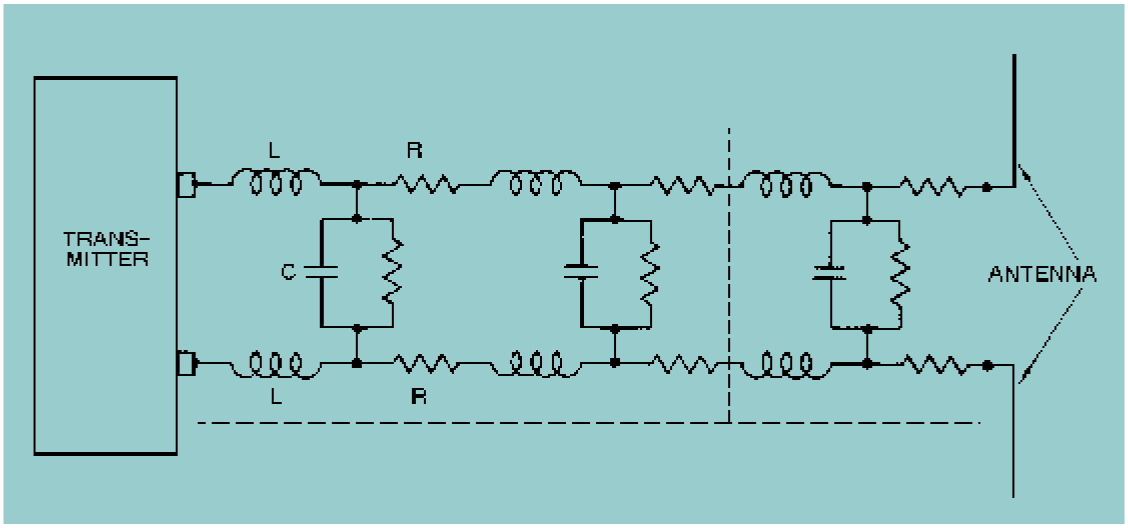
Problems can result if an unbalanced transmission line is connected directly to a balanced line. A special transformer, known as a balun (balanced-to-unbalanced transformer) must be used. The schematic diagram of one type of balun is shown below.



CHARACTERISTIC IMPEDANCE

The two conductors comprising a transmission line have capacitance between them as well as inductance due to their length. This combination of series inductance and shunt capacitance gives a transmission line a property known as characteristic impedance.

DISTRIBUTED CAPACITANCE, INDUCTANCE AND RESISTANCE IN A TWO WIRE TRANSMISSION LINE



If the series inductance per unit length of line L_S and the parallel capacitance per unit length C_P are known, and the loss resistances can be neglected, one can calculate the characteristic impedance of a transmission line from the following equation:

$$Z_0 = \sqrt{\frac{L_S}{C_P}}$$

Examples:

RG-62 coaxial cable has a series inductance of 117 nH per foot and a parallel capacitance of 13.5 pF per foot. What is the characteristic impedance of this cable?

$$Z_0 = \sqrt{\frac{L_S}{C_P}} = \sqrt{\frac{117*10^{-9}}{13.5*10^{-12}}} = \sqrt{8667} = 93\Omega$$

A two-wire line has a series inductance of 315 nH per foot and a parallel capacitance of 3.5 pF per foot. What is the characteristic impedance of this cable?

$$Z_0 = \sqrt{\frac{L_S}{C_P}} = \sqrt{\frac{315*10^{-9}}{3.5*10^{-12}}} = \sqrt{90000} = 300\Omega$$

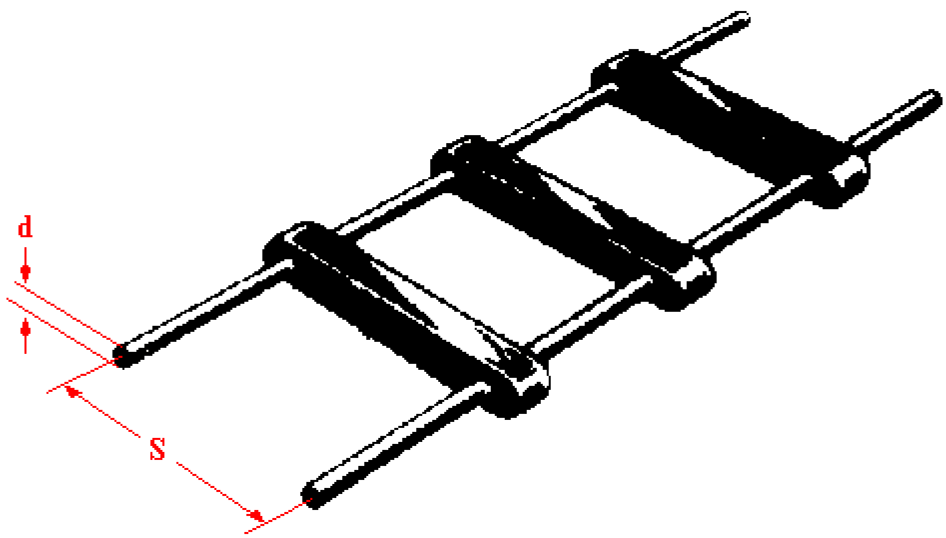
Quite often, the values of L_S and C_P are not known, but the physical dimensions (conductor diameter, spacing, dielectric properties, etc.) of the line are known. The following formulas can be used to determine the characteristic impedance of transmission line.

For parallel conductor line:

$$Z_0 = \frac{120}{\sqrt{K}} \ln\left(\frac{2S}{d}\right)$$

where:
K is the relative dielectric constant of the material between the two conductors
S is the center-to-center separation of the two conductors
d is the diameter of the wires.

S and d must be measured in the same units.

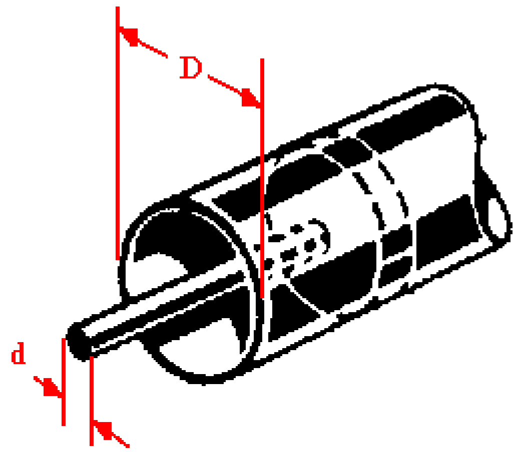


For a coaxial cable:

$$Z_0 = \frac{60}{\sqrt{K}} \ln\left(\frac{D}{d}\right)$$

where:
K is the relative dielectric constant of the material between the two conductors
D is the inside diameter of the outer conductor
d is the outside diameter of the inner conductor

D and d must be measured in the same units.



ATTENUATION PER UNIT LENGTH

Attenuation per unit length measures how much of the RF signal is lost per unit length of transmission line. Typically, the attenuation per unit length has units of dB/100ft. Losses in transmission lines arise from 3 sources:

radiation (leakage)
dielectric losses
skin effect losses

Radiation loss occurs in two-wire lines because the fields from one line do not completely cancel out those from the other line. A small amount of RF is radiated, which is dependent on the separation of the wires and the frequency of the RF. Radiation occurs in braided coaxial lines because the braid does not provide 100% shielding. Special types of coax with multiple braids, or a solid outer conductor have no measurable radiation losses.

The conductors of a transmission line are separated from one another by an insulating material known as a dielectric. This dielectric could be air or a plastic or any insulating material. All dielectrics exhibit losses that increase as the voltage on the conductors increases. Dielectric losses also increase with increasing frequency.

Skin effect is a phenomenon that occurs in conductors carrying an AC current. As the frequency increases, the current tends to be concentrated near the surface of the conductor. At RF, almost no current flows down the center of wire. It is all on the surface. A copper rod and a copper tube of equal diameter will have the same resistance above a few MHz, even though the DC resistance of the solid rod is much lower. As frequency increases, the skin effect becomes more pronounced and the loss in conductors increases dramatically.

The total losses in a transmission line are roughly proportional to the square root of the frequency. If the attenuation per unit length is known for a particular frequency f1, the loss at any other frequency f2 can be estimated from the following equation:

$$\alpha_{f2} = \alpha_{f1}\sqrt{\frac{f_2}{f1}}$$

α_{f2} = attenuation at frequency f2
α_{f1} = attenuation at frequency f1

VELOCITY FACTOR

The radio frequency (RF) current flowing along a transmission line creates a radio wave that is guided by the transmission line. This guided wave propagates along a transmission line with a velocity given by the following equation:

$$v = \frac{1}{\sqrt{L_S C_P}}$$

where:
v = the wave velocity
L_S is the series inductance per unit length
C_P is the parallel capacitance per unit length

The wave propagation velocity of the guided wave will always be less than the speed of light in a vacuum, which is approximately 300,000,000 m/sec.

Because the wave velocity is a very large number, manufacturers of transmission lines generally specify the velocity factor of a transmission line. The velocity factor is simply the wave velocity on the transmission line divided by the speed of light in a vacuum:

$$vf = \frac{1}{c\sqrt{L_S C_P}}$$

where:
vf = the velocity factor
L_S is the series inductance per unit length
C_P is the parallel capacitance per unit length
c is the speed of light in a vacuum ($3.0 * 10^8$ m/sec)

Velocity factors for commercially available transmission lines range from approximately 0.6 to 0.9, depending on the construction of the line.

ELECTRICAL LENGTH

The electrical length of a cable is its length measured in wavelengths (λ) and is related to the frequency of the wave and the velocity with which it propagates along the transmission line. The electrical length of a transmission line can be computed from the following formula:

$$l_{ELECTRICAL} = \frac{lf}{984V_F}$$

l = length of the line in feet
f = frequency in MHz
V_F = the velocity factor of the line

The velocity factor is the ratio of the wave velocity to the speed of light. Typical values range from 0.66 to 0.97.

Let’s look at an example:

What is the electrical length of 117 feet of RG-8/U coaxial cable at 57 MHz? The velocity factor for this cable is 0.66.

Solution:

$$l_{ELECTRICAL} = \frac{lf}{984V_F} = \frac{117*57}{984*0.66} = \frac{6669}{649.4} = 10.3$$

Here is a second example:

A two-wire line has a velocity factor of 0.95 and a length of 3406 ft. What is its electrical length at 2.82 MHz?

Solution:

$$l_{ELECTRICAL} = \frac{lf}{984V_F} = \frac{3406*2.82}{984*0.95} = \frac{9605}{934.8} = 10.3$$

Notice that these two transmission lines of very different design and physical length have the same electrical length.

The concept of electrical length is important because the properties of a resonant transmission line are periodic with respect to electrical length.

Previous Page	Index	Next Page