RF and Microwave Transmission Lines

ELEC 2230

Section 3

Roger D. Pollard
School of Electronic & Electrical Engineering
The University of Leeds

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Losses in transmission lines

Types of line losses

- **Conductor**
- **Dielectric**
- **Radiation or induction losses.**

Conductor losses

- I^2R loss

In any transmission line the resistance of the conductors is never zero. Whenever current flows through one of these conductors, some energy is dissipated in the form of heat - POWER LOSS. With copper braid, which has a resistance higher than solid tubing, this power loss is higher.

Conductor losses

- Skin effect loss

When d.c. flows through a conductor, the movement of electrons through the conductor cross section is uniform.

When ac is applied the expanding and collapsing fields about each electron encircle other electrons. This 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 centre 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 above a few hundred MHz, the electron movement in the center is so small that the centre of the wire could be removed without any noticeable effect on current. The result is 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. Since power loss increases as resistance increases, power losses increase with an increase in frequency because of skin effect.

Skin effect

The d.c. (i.e. very low frequency) impedance of a wire which has a circular cross-section and is uniform may be said to consist of a resistance per unit length (in ohms/m) of

$$R_0 = \frac{1}{\pi r^2 \sigma}$$

where σ is the bulk conductivity value of the wire and r is the radius of the wire.

The wire will also exhibit an effective inductance per unit length (in H/m) at very low frequency due to its internal fields. At very low frequencies this has the value

$$L_0 = \frac{\mu}{8\pi}$$

Skin effect (ctd.)

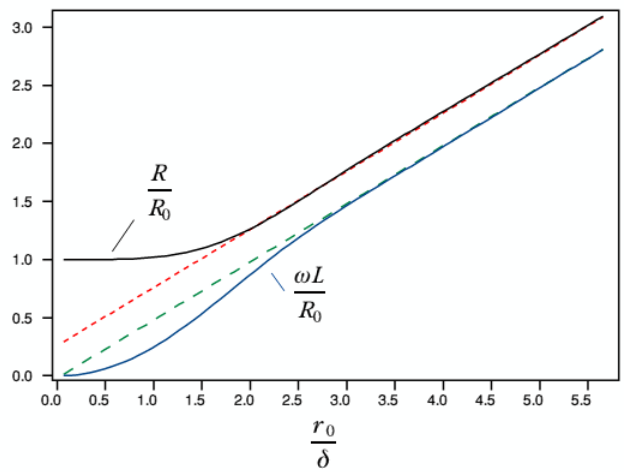
Detailed analysis (see Ramo, *et. al.*), results in

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Where δ is the skin depth, and f the frequency.
(The skin depth is the distance at which the current is $1/e$ of the surface value.)

The calculation of the total impedance of a conductor is difficult, but there are reliable approximations for high frequency operation.

Impedance as a function of skin depth



Conductor losses

At high frequencies, conductor losses due to skin effect can be minimized and conductivity increased by silver plating the line. Since silver is a better conductor than copper or aluminium, most of the current will flow through the silver layer. The remaining tubing then serves primarily as a mechanical support.

Dielectric losses

The non-ideal resistive property (heating effect) of the dielectric material between the conductors. Power from the source is used in heating the dielectric. The heat produced is dissipated into the surrounding medium.

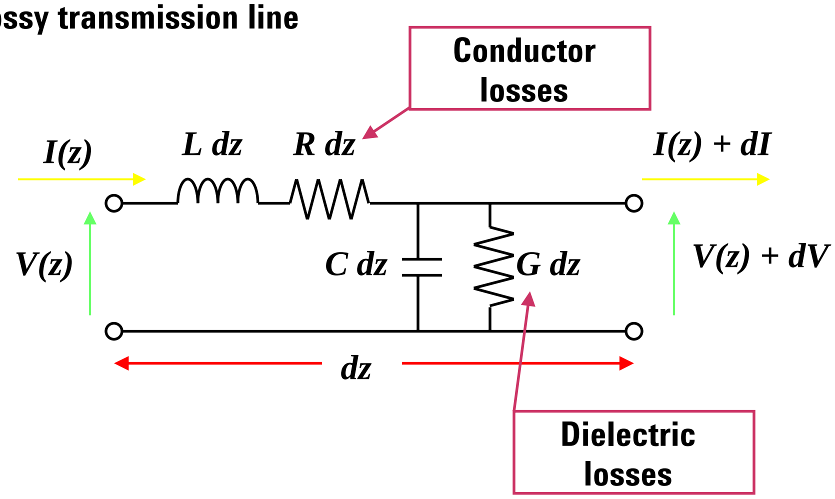
Radiation and Induction Losses

Caused by the fields surrounding the conductors.

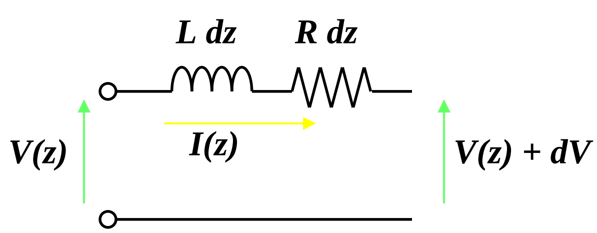
Induction losses occur when the electromagnetic field about a conductor cuts through any nearby metallic object and a current is induced in that object. As a result, power is dissipated in the object and is lost.

Radiation losses occur because some magnetic lines of force about a conductor do not return to the conductor when the cycle alternates. These lines of force are projected into space as radiation and this results in power losses. That is, power is supplied by the source, but is not available to the load. Antennas are designed to maximize this effect.

Lossy transmission line



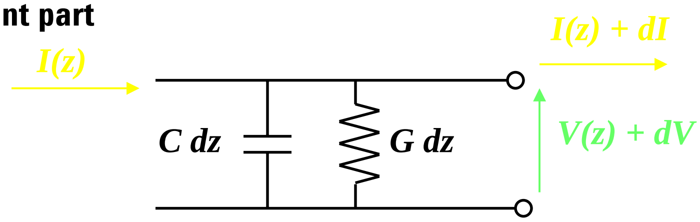
Series part



$$(V + dV) - V = -\left(j\omega L dz + R dz \right) I$$

$$\frac{dV}{dz} = -\left(j\omega L + R \right) I$$

Shunt part



$$dI = -\left(j\omega C dz + G dz\right)(V + dV)$$

$$= -\left(j\omega C + G\right)V dz + \underbrace{\cancel{\left(j\omega C + G\right) dV dz}}_{= 0}$$

$$\frac{dI}{dz} = -\left(j\omega C + G\right)V$$

As before - telegraphers' equations for a LOSSY line

$$\frac{dV}{dz} = -\left(j\omega L + R\right)I$$

$$\frac{dI}{dz} = -\left(j\omega C + G\right)V$$

Solve as before, to yield

$$V(z) = V^{+}e^{-\gamma z} + V^{-}e^{+\gamma z}$$

where $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$

write $\gamma = \alpha + j\beta$

so $V(z) = V^{+}e^{-(\alpha + j\beta)z} + V^{-}e^{+(\alpha + j\beta)z}$

$$V(z) = V^{+}e^{-(\alpha + j\beta)z} + V^{-}e^{+(\alpha + j\beta)z}$$

α **= attenuation**

β **= propagation**

$e^{-\alpha z}$ **purely real, affects only magnitude of wave**

$e^{-j\beta z}$ **magnitude = 1, affects only phase of wave**

Similarly, the current

$$I(z) = \frac{1}{Z_0}\left(V^+ e^{-\gamma z} - V^- e^{+\gamma z}\right)$$

where now $$Z_0 = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$$

The characteristic impedance is COMPLEX

Characteristic impedance - the infinite line

If you transmit a pulse into a uniform, infinite transmission line, there will be no reflections and no return signal. The impedance measured at the input port of a uniform infinite line, is (by definition) the characteristic impedance.

So, if you want a finite length of transmission line to be reflectionless, it must be terminated with an infinite line (impossible) or with the characteristic impedance.

The input impedance measured at the input of a reflectionless transmission line (defined as MATCHED) will therefore be the characteristic impedance.