TRANSMISSION LINES, PARAMETERS, AND APPLICATION IN COMMUNICATIONS SYSTEMS

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Abstract

Transmission of information is carried out by means of transmission media, usually is called a Transmission Line. Transmission line is rather a general term since it covers wide varieties of media such as air, twisted pair, and of course, fiber optic cable. Selection of transmission media for communication requires consideration of several factors such as characteristics impedance of the line, frequency dependent losses, radiation, interference , and so forth. This article describes some of the important parameters of transmission media with tabulated results to assist the designer of any communication system to select a proper media for his applications.

1. Ionosphere

Nature offers the cheapest media for signal transmission as shown in figure 1.
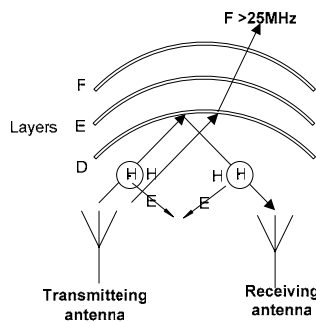

Fig.1 Reflection of sky-waves
by ionosphere layers

As seen from this figure, electromagnetic waves are reflected toward the receiving antenna by ionosphere layers. These layers move up and down at day and night during the seasons. This movement clearly will affect the reflected waves and the reception unless the position of the antenna is changed (this is unlikely) or the frequency can be adjusted. Sky waves can be used for coast to coast transmission very effectively. But there are two limitations for its applications: first is the change in the ionosphere layers' location and resulting ionization characteristics; and second is the maximum frequency of operation. The maximum useable frequency (MUF) for a sky wave is calculated theoretically to be 25 MHz. Any wave above this frequency is refracted toward the sky with no reflection. This is why short wave radios and H.F. transceivers are designed for 30 MHz [1].

Electromagnetic waves have one important parameter which is the wave impedance. If air is used as a transmission media, this impedance can be calculated as follows;

$$Z_c = \frac{V}{I} = \frac{E \, x \, L}{H \, x \, L} = \frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}} \quad (1)$$

Where Z_c shown in the chart is the characteristic impedance of the electromagnetic wave, E and H are electric and magnetic field intensities, and L is an imaginary length, μ and ε are permeability and permittivity respectively, their values for free space are, $\mu = 4\pi x10^{-7}$, $\varepsilon = 8.85x10^{-12}$. Using these values in equation (1), we obtain 377Ω [2]. It is important that the impedance of the receiving antenna be matched to this value to obtain a maximum transfer of power.

2. Twisted Pair

Twisted pair has been the first media of choice for short distance and low frequency communications. It is used mainly for voice transmission such as in telephone lines. Its

copper and radiation losses combined with skin-effect limits its applications to the lower frequency range of 300 Hz – 20 kHz. At higher frequencies, electrons tend to reside at the outer surface of the conductor. This has the effect of decreasing the effective internal area, and thus increases the AC resistance of the wire which in turn increases the copper losses.

Calculation of inductance and capacitance of twisted pair is rather complicated, but formulas given in the chart can be used with reasonable results to calculate the characteristic impedance of the cable. S and d are defined in figure 2, [3].
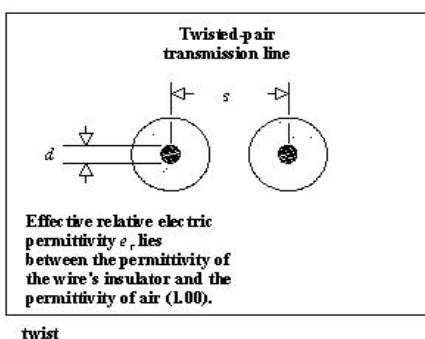

Fig. 2 parameters for twisted pair

3. Twin-Flat

Originally this cable's application was for TV reception because its characteristic impedance, Z_c, is 240 Ω. That matched the input impedance of a TV set for VHF channels 2-12. Radiation and copper losses combined with skin effect and dielectric losses limit its application to 200 MHz. Its inductance and capacitance can be calculated using the formulas given in the chart. Assuming a lossless cable, the characteristic impedance is given by equation (2) and the parameters are shown in figure 3.

$$Z_c = \sqrt{\frac{L}{C}} \qquad (2)$$

This impedance can easily be tailored to match the internal impedance of a TV set to VHF range, which is about 240 Ω as mentioned earlier. It is also interesting to compare this equation to equation (1) for the characteristic impedance of free space if we replace μ with L and ε with C. This similarity holds true between all electromagnetic parameters in free space and in transmission lines.
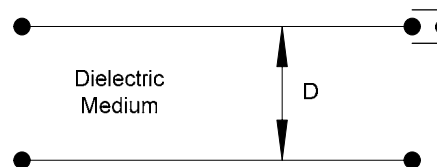

Fig.3 parameters for Twin-flat cable

4. Coax Cable

In these cables, the center conductor is surrounded by a dielectric medium and copper or aluminum as the second conductor. This shields the center conductor and is used as a ground connection as shown in figure 4(a). Radiation loss is reduced due to shielding, but copper losses and the skin effect limit their applications to 400 MHz. At this frequency, the inductive and capacitive impedances become much larger than the resistance and conductance, consequently a line can be presented as a two-element lossless transmission line as shown in figure 4(b).
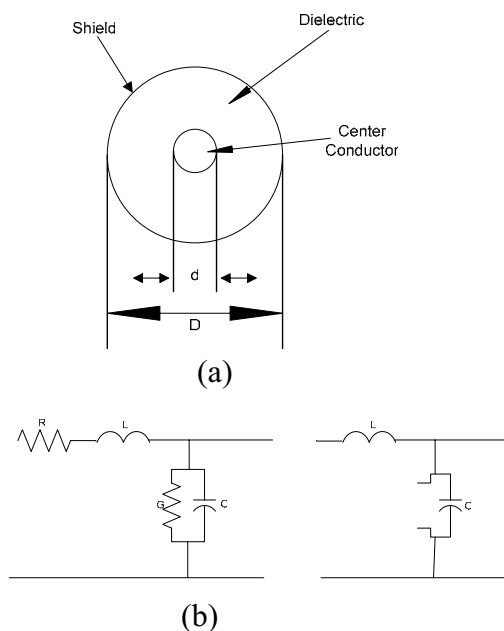

(a)

(b)

Fig. 4 Electrical presentation of a section of coaxial transmission line

Calculations of L and C are straight forward as indicated in the chart. The characteristic impedance of the lossless line is given by:

$$Z_c = \sqrt{\frac{L}{C}} \qquad (4)$$

Thus the characteristic impedance depends on the dimension of the cable and the dielectric material since L and C depend on these parameters. Poplar cables, RG 58 and RG59 have characteristic impedance of 50 and 75 Ohms respectively which is never close to the characteristic impedance of the electromagnetic wave in free space which is 377 Ω. RG 59 is used for TV sets since their input impedance is 75 Ω. For other applications an impedance matching transformer must be used.

5. Waveguides

These are hollow metallic rectangular or cylindrical transmission lines. Propagation of electromagnetic energy is confined within the hollow conductor, thus eliminating the dielectric and radiation losses. But moderate skin effect may exist. To reduce this effect the inside of the conductor is coated with silver or a high-conducting material to provide a very low resistance path so that current flow remains on the inside surface of the hollow conductor rather than penetrating in to the metal.

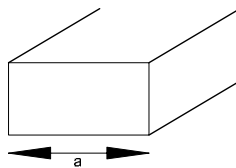The characteristic impedance of a rectangular waveguide shown in figure 5 is given by equation (5)

Fig. 5 A rectangular waveguide

$$Z_g = \frac{Z_o}{\sqrt{1-(f_c/f)^2}} \qquad (5)$$

Where:
$$Z_o = 377\,\Omega$$
$$f_c = cutoff\ frequency$$
$$= c/\lambda_c$$
$$a = \lambda_c/2$$

It is seen from this equation that the characteristic or the intrinsic impedance of a confined electromagnetic wave inside the waveguide is larger than the free space impedance. This is due to the impeding of multiple reflections of the wave inside the waveguide [2].

Waveguides are used for microwave propagation (1-40 GHz) mainly for satellite communication. The main disadvantages of waveguides are their heavy weights and bulky material.

6. Microstrip

Strip and micro-strip transmission lines are used most commonly at microwave frequency and above 40 GHz. Their light weight and small dimension are perfect for higher frequency applications. Their analysis and characterization, however, is complex, interested readers are requested to consult the references given at the end of this article [4, 5]. Their most important parameters are characteristic impedance and effective dielectric constant. With reference to Figure 6, the characteristic impedance can be approximated by equation 6;
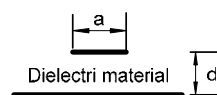

Fig.6 Cross section of a microstrip line

$$Z_c = 377\frac{d}{a\sqrt{\varepsilon}} \qquad (6)$$

where ε is the effective dielectric constant of the dielectric material. As far as losses are concerned, there is only one important loss associated with radiation. This is due to the fact that a microstrip is open to air thus, a radiation

loss can exist. Power handling capacity of these lines are relatively low.

Microstrip lines have several applications. They can be used as a directional coupler, hybrid ring, and as filters. For completeness of this section a simple T-type low pass filter is shown in Figure 7 with its equivalent lumped element presentation.
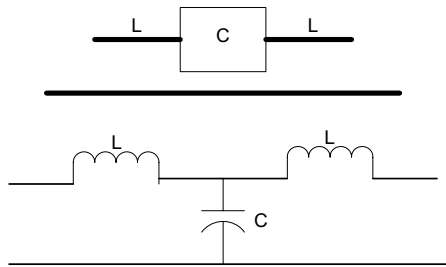

Fig. 7 Microstrip T-line with its equivalent lumped element presentation

7. Fiber Cable

Fibers were used for medical diagnostics long before the invention of the laser. Introduction of a laser as a carrier source opened a new era in the field of communication technology. It is expected that within the next ten years all activities in information transmission including audio, video, and data will be carried out with fiber cables. Presently there are several underwater fiber cables connecting the east and western hemispheres [6].

Fibers possess remarkable properties that make them attractive for high frequency applications. Fiber has no inductance or capacitance, thus a characteristic impedance becomes meaningless for their characterizations. There are no copper losses; however, they suffer from dielectric losses associated with the core material, depending on the type of fiber. Currently three types of fiber are in common use;

1. Plastic core plastic cladding
2. Silicon core plastic cladding
3. Silicon core silicon cladding

Type 3 yields the minimum dielectric losses, but is not economical and hard for bending applications. The losses associated with the dielectric material are due to water vapor or other impurities present in the core silicon. Technology has reduced these losses to about 0.1 db/km whereas coax would be 20 db/km operating at the same frequency.

As far as radiation losses, it must be emphasized that this loss is completely minimized if the incident ray follows a certain angle, called Snell's angle. Under this condition, no radiation can leak outside. An outside electromagnetic wave may penetrate the fiber, but since it does not follow Snell's angle, it cannot propagate very far in the fiber. This remarkable feature of fiber makes it attractive for higher frequency applications. However, power handling capacity of fibers is small. The question remains to be seen; what happens to the core material over a long period of time? Will the fiber performance degrade or after water vaporization will it perform better?

References

[1].http://en.wikipedia.org/wiki/Ionosphere.
[2]. Stephen C. Harsany, Principles of Microwave Technology, Prentice Hall, 1997.
[3].http://www.sigcon.com/lib/htm/TWIST.htm.
[4]. Dennis Roddy, Microwave Technology, Prentice Hall, 1986.
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[6]. Jeffrey S. Beasley, Gary M.Miller, Modern Electronic Communication, Prentice Hall, 2005.

Lossless Transmission Lines Characteristics

T-Line	$L(\mu H/m)$	$C(pF/m)$	Zc	$\dfrac{Losses}{I^2R\text{-}Dielectric}$	Skin Effect	Radiation	Power	B.W./M.U.F.	Applications
Ionosphere			$\sqrt{\mu/\varepsilon}$ 377	None High	None		Moderate	25 MHz	HF
Twisted-pair	$10.16\,x10^{-3}$ $\ln\left(\dfrac{2s}{d}\right)$	$\dfrac{0.7\varepsilon_r}{\ln\left(\dfrac{2s}{d}\right)}$	$\sqrt{\dfrac{L}{C}}$	High High	High	High	Low	100 MHz	Audio
Twin-flat	$\dfrac{\mu Ln(b/a)}{\pi}$	$\dfrac{\pi\varepsilon}{Ln\left(\dfrac{D}{d}\right)}$	$\sqrt{\dfrac{L}{C}}$ 240	High High	High	High	Low	200 MHz	Video, VHF
Coax	$0.2Ln\left(\dfrac{R}{r}\right)$	$\dfrac{2\pi\varepsilon}{Ln\left(\dfrac{D}{d}\right)}$ 20-30pF	$\sqrt{\dfrac{L}{C}}$ 50-75	High High	High	None	Moderate	400 MHz	Video, UHF
Waveguide			$\dfrac{377\Omega}{\sqrt{1-(\lambda/\lambda_c)^2}}$ 450	Low None	None	None	High	40 GHz	Radar, Satellite
Microstrip	$\mu\left(\dfrac{d}{a}\right)$	$\varepsilon\left(\dfrac{a}{d}\right)$	$\sqrt{\dfrac{L}{C}}$ 25-100	Low Low	None	High	Low	100 GHz	Cell Phone
Fiber Cable				None Low	None	None	Low	10^{14}	Video, Data
Nanotechnology									

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