Transmission line

→ The inter-connections that convey electromagnetic energy from one point to another is called transmission line.

Transmission line parameters

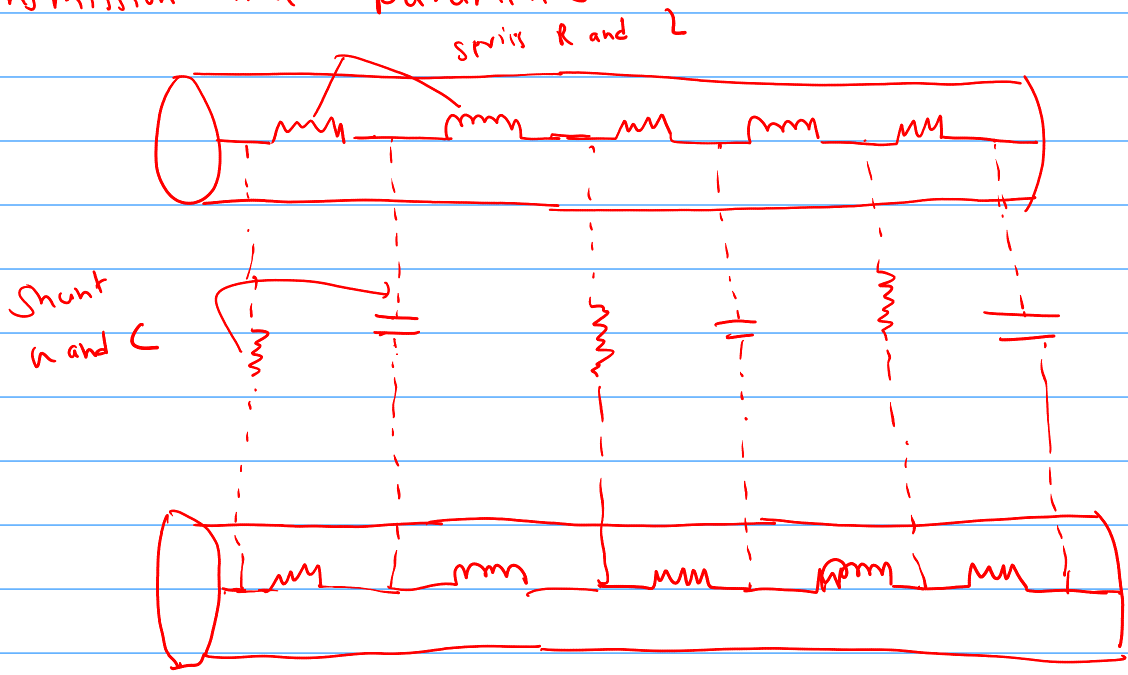


Fig: Distributed parameters of a two-conductor transmission line

/ Parameters

→ resistance per unit length (R),
→ Inductance per unit length (L)
→ Conductance per unit length (G)
→ Capacitance per unit length (C)

$$G \neq \frac{1}{R}$$

Propagation constant, characteristic Impedance of Transmission line.

The general expression for propagation constant is ÷

$$\gamma = \sqrt{(R+jwL)(G+jwC)}$$

where,

$\gamma = \alpha + j\beta$; α and β are attenuation constant (Np/m) and phase constant (rad/m)

The general expression for characteristic impedance is ÷

$$Z_0 = \sqrt{\frac{R+jwL}{G+jwC}}$$ = Characteristic impedance

(i) lossless line

$(R = 0 = G)$

(ii) Distortionless line $\left(\frac{R}{L} = \frac{G}{C}\right)$

Case	propagation constant $\gamma = \alpha + j\beta$	characteristic impedance ($Z_0 = R_0 + jX_0$)
① General	$\sqrt{(R+jwL)(G+jwC)}$	$\sqrt{\frac{R+jwL}{G+jwC}}$
② lossless	$0 + jw\sqrt{LC}$	$\sqrt{\frac{L}{C}} + j0$
③ Distortionless	$\sqrt{RG} + jw\sqrt{LC}$	$\sqrt{\frac{L}{C}} + j0$

Explain and prove that every lossless line is also distortion less but every distortion less line may not be lossless.

soln:-

lossless line ; $R = 0 = G$ — (i)

Distortionless line : $\frac{R}{L} = \frac{G}{C}$ — (ii)

ⓐ Every lossless line is distortionless

(sub (i) in (ii))

$$\frac{R}{L} = \frac{0}{L} = 0$$

$$\frac{G}{C} = \frac{0}{C} = 0$$

$$\therefore \frac{R}{L} = \frac{G}{C}$$ (every lossless line is distortionless)

ⓑ Every distortionless line may not be lossless

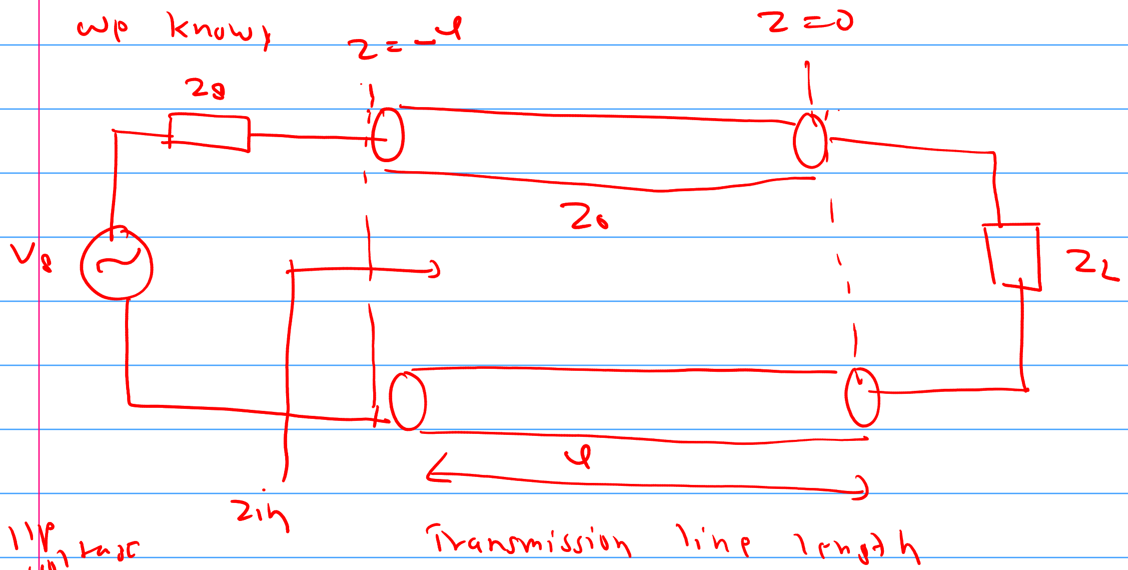
From (2)

$$\frac{R}{L} = \frac{G}{C}$$

here, R and G are not necessarily zero, so it may not be lossless.

Reflection coefficient, Standing wave ratio and Input Impedance.

we know,



$V_s \rightarrow V_0^+, V_0^-$

$I_s \rightarrow I_0^+, I_0^-$

Input current

$$V_s = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z} \quad \text{--- (i)}$$

$$I_s = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z} \quad \text{--- (ii)}$$

$$I_0^+ = \frac{V_0^+}{Z_0}, \quad I_0^- = \frac{-V_0^-}{Z_0}$$

$$I_s = \frac{V_0^+}{Z_0} e^{-\gamma z} - \frac{V_0^-}{Z_0} e^{\gamma z} \quad \text{--- (iii)}$$

Applying boundary conditions to eqn (i) and (ii) at $z=0$ (the load end)

$$V_s(z=0) = V_0^+ + V_0^-$$

$$I_s(z=0) = \frac{V_0^+}{Z_0} - \frac{V_0^-}{Z_0}$$

The ratio of $\left.\frac{V_s}{I_s}\right|_{z=0}$ is the load impedance Z_L

$$Z_L = \left.\frac{V_s}{I_s}\right|_{z=0} = Z_0\left[\frac{V_0^+ + V_0^-}{V_0^+ - V_0^-}\right]$$

or, $$Z_L = Z_0\left[\frac{1 + \frac{V_0^-}{V_0^+}}{1 - \frac{V_0^-}{V_0^+}}\right]$$

or $$Z_L = Z_0\left[\frac{1+\Gamma}{1-\Gamma}\right]$$

where Γ is reflection coefficient. The above expression can be simplified into :

$$\boxed{\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}}$$

→ The current reflection coefficient at any point is the negative of voltage reflection coefficient.

$$\boxed{VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}}$$

voltage standing wave ratio

Transmission coefficient

$$\boxed{\tau = \frac{2Z_L}{Z_L + Z_0}}$$

Input Impedance

① lossless line

$$Z_{in} = Z_0 \left[\frac{Z_L + jZ_0 \tan \beta l}{Z_0 + jZ_L \tan \beta l} \right]$$

(ii) lossy medium

$$Z_{in} = Z_0 \left[\frac{Z_L + jZ_0 \tanh \gamma l}{Z_0 + jZ_L \tanh \gamma l} \right]$$

Impedance Matching :

Advantages

(1) when Z_0 equals Z_L, all forward power is absorbed by the load - no energy bounces back.

(ii) A perfect match delivers max power to the load.

(iii) In RF front-ends (antennas, LNAs) a good match lowers noises.

(iv) In antennas matching prevents unwanted amplitude / phase distortions across elements.

3 matching techniques

(1) Quarter-Wave Transformer
(2) Single-stub matching
(3) Double-stub matching

Smith Chart

→ The smith chart is a graphical calculator that is useful in analyzing the characteristics of transmission lines.

→ It is the graphical indication of impedance of transmission line as one moves along the line.

Advantages

1. It represents the all the impedance from 0 to ∞
2. Impedance miss match is easily spotted in the chart
3. It gives direct reading of the SWR.

Wave guides :

→ A wave guide is a structure that guides waves, such as electromagnetic waves or sound with minimal loss of energy by restricting the transmission of energy to one direction.

→ without the physical constraint of a wave guide, wave intensities decrease according to the inverse square law as they expand into three dimensional space.

→ Transmission line support only transverse electromagnetic wave.

→ wave guide can support many possible field configuration.

Advantages of wave guide over transmission line

1. simple to manufacture
2. It can support many possible field configuration.
3. Power loss in wave guide is lower.

(4) Different signal can be transmitted on the same time.
(5) It can be opprated on the frequency up to 325 GHz
(6) Power handling capacity is high.

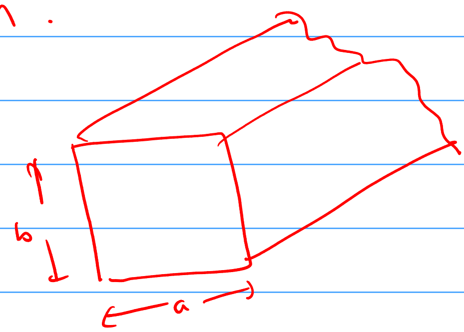
Disadvantages

(1) Physical size is the primary lower-frequency limitation of waveguide.
(2) difficult to install
(3) high cost and decreases practicality.

Types of wave guide

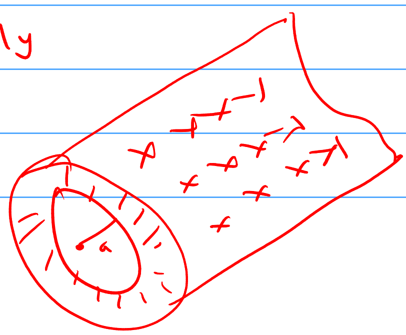
(1) Rectangular waveguide

→ hollow metallic tube with a rectangular cross section.
→ common modes are TE and TM.



(2) Circular waveguides

→ hollow metallic cylinder with a circular cross section like a long metal tube or pipes
→ supports TE and TM modes only



Waveguide Modes

-> When an electromagnetic wave travels inside a waveguide, the electric field (E) and magnetic field (H) can arrange themselves in different patterns. These different arrangements are called modes.

There are four main mode categories:

a. TEM Mode (Transverse Electromagnetic Mode)

-> Both the electric field (E) and magnetic field (H) are perpendicular (transverse) to the direction of wave travel.

-> No field components in the direction of propagation (say z-direction), meaning $E_z = 0$ and $H_z = 0$.

-> Example: Coaxial cables can support TEM mode easily.

b. TE Mode (Transverse Electric Mode)

-> The electric field is completely transverse (perpendicular) to the propagation direction.

-> Magnetic field may have a component in the propagation direction.

-> For waves moving in the z-direction: $E_z = 0$, $H_z \neq 0$

c. TM Mode (Transverse Magnetic Mode)

-> The magnetic field is completely transverse (perpendicular) to the propagation direction.

-> Electric field may have a component in the propagation direction.

-> For waves moving in the z-direction: $E_z \neq 0$, $H_z = 0$

d. HE Mode (Hybrid Mode)

-> Neither E nor H is purely transverse.

-> Both $E_z \neq 0$ and $H_z \neq 0$

-> These are called hybrid modes and often occur in optical fibers and circular waveguides.

Dominant Mode

-> In a waveguide, the mode with the lowest cutoff frequency is called the dominant mode.

-> For a rectangular waveguide:

- Dominant mode is TE_{10} or TM_{11}
- (TE_{10} is more common)

Cutoff Frequency

-> Cutoff frequency (f_c) is the minimum frequency below which the wave cannot propagate through the waveguide (it gets attenuated).

-> Only frequencies above f_c can properly travel.

For TE or TM modes:

$$f_c = \frac{v}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

where:

- v = speed of wave (in air, $v \approx c = 3 \times 10^8$ m/s)
- a = larger dimension of the rectangular waveguide
- b = smaller dimension
- m, n = integers representing mode numbers (like 1, 0, etc.)

Cutoff Wavelength λ_c is given by:

$$\lambda_c = \frac{1}{\sqrt{\left(\frac{m}{2a}\right)^2 + \left(\frac{n}{2b}\right)^2}}$$

Antennas

An antenna is a device, usually made of metal (like a wire or a set of wires), that converts high-frequency electrical currents into electromagnetic waves, and also receives electromagnetic waves and turns them back into electrical signals.

No matter what the shape or type, all antennas work on the basic principle that radiation happens when charges accelerate or decelerate.

Basic Antenna Parameters (Properties)

1. Radiation Pattern:
-> It shows how an antenna radiates energy into space.
-> Usually displayed as a graph in 2D or 3D.

2. Radiation Power Density: It tells how much power is radiated by the antenna at a certain point in space.

3. Radiation Intensity: It measures the power radiated per unit solid angle (steradian) from the antenna. Unlike power density, it removes the effect of distance.

4. Directivity: Higher directivity means the antenna concentrates more energy in one direction.

5. Gain: Tells how well the antenna converts input power into radio waves in a specific direction.

6. Antenna Efficiency: Efficiency = Radiated Power / Input Power. It is the ratio of power actually radiated by the antenna to the power supplied to it.

7. Beamwidth: It is the angular width of the main lobe of the radiation pattern.

8. Bandwidth : Range of frequencies over which the antenna operates effectively.

9. Polarization : The orientation of the electric field vector of the radiated wave.

10. Standing Wave Ratio (SWR) / Voltage Standing Wave Ratio (VSWR)

-> A measure of how well the antenna is matched to the transmission line.

-> VSWR = 1 (perfect match), higher VSWR = more mismatch.

Radiation from a Dipole Antenna

-> In a dipole antenna, alternating current (AC) flows back and forth through the metal rods.

-> As charges accelerate, they create changing electric and magnetic fields.

-> These fields combine and move away from the antenna as electromagnetic waves.

-> Most of the radiation is strongest perpendicular to the antenna and weakest along the axis of the antenna.

-> The dipole is the most basic and important antenna because it helps us understand how antennas radiate.

Types of Antennas

1. Wire Antennas

-> These are the most basic and commonly used antennas.
-> Made of thin wires (straight, looped, or coiled).
-> Applications: Radio broadcasting, TV, mobile communication.

2. Aperture Antennas

-> These antennas radiate or receive energy through an opening (aperture).
-> Often used at high frequencies like microwaves.
-> Applications: Satellite communications, radar systems.

3. Microstrip Antennas

-> These are also called "patch antennas."

-> Consist of a flat rectangular (or other shaped) metal patch on a flat surface (substrate).

-> Lightweight, low-profile, easy to fabricate.

-> Applications: Mobile phones, GPS devices, aircrafts.

4. Array Antennas

-> Combination of multiple antenna elements arranged in a specific pattern.

-> Used to increase signal strength or direct signals in desired directions (beamforming).

-> Applications: Military radars, 5G networks, satellites.

5. Reflector Antennas

-> Use a reflecting surface to direct radio waves.

-> The most common type is the parabolic reflector (like a satellite dish).

-> Applications: Satellite communication, deep-space communication, radio telescopes.

6. Lens Antennas

-> Use a dielectric lens to focus or direct radio waves (similar to how an optical lens focuses light).

-> Applications: Microwave communications, radar systems.