

PROPAGATION OF GUIDED WAVES

EEEN 566 – MICROWAVE ENGINEERING

Friday, 13 February 2025

RECAP: ADVANTAGES & DISADVANTAGES OF WAVEGUIDES

Waveguides have the following advantages:

1. High-power handling capability.
2. High-frequency application.
3. Signal attenuation is very low compared to other transmission lines.
4. Installation is easy in a microwave system.

Disadvantages of waveguides are:

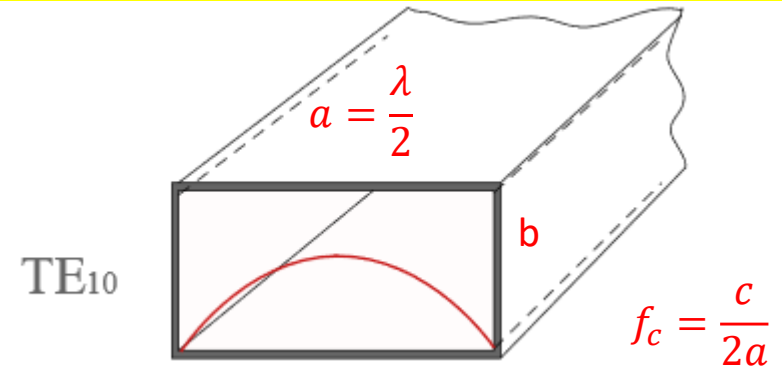
1. Attenuation of low-frequency signals
2. Large size and weight
3. TEM Mode not supported
4. Costly
5. Only suitable for special purpose design/application

DIFFERENCES BETWEEN WAVEGUIDES & TRANSMISSION LINES

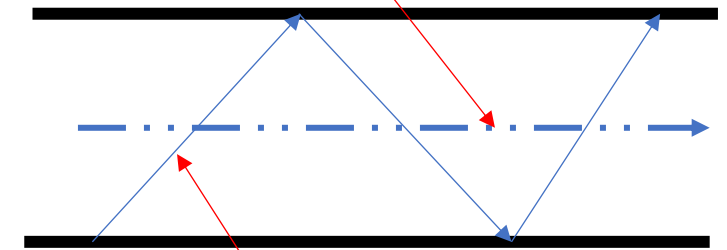
TRANSMISSION LINES	WAVEGUIDES
1. Supports TEM wave	Cannot support TEM wave
2. All frequencies can pass through	Only the frequencies that are greater than cut-off frequency can pass through
3. Two conductor transmission	One conductor transmission
4. Reflections are less	A wave travels through reflections from the walls of the waveguide
5. It has a characteristic impedance	It has <u>wave impedance</u>
6. Propagation of waves is according to "Circuit theory"	Propagation of waves is according to "Field theory"
7. It has a return conductor to earth	Return conductor is not required as the body of the waveguide acts as earth
8. Bandwidth is not limited	Bandwidth is limited

CHARACTERISTICS OF A WAVEGUIDE (1)

- 1. Critical (cut-off) frequency, f_c (Hz):** the lowest frequency for which a mode will propagate in a waveguide.
- 2. Critical (cut-off) wavelength, λ_c (m/cycle):** the largest wavelength that can propagate in the waveguide without any attenuation (or the smallest free space wavelength that is just unable to propagate in the waveguide).
- 3. Group velocity (v_g , m/s):**
 - a) The velocity at which a wave propagates in a waveguide.**
 - b) Refers to the velocity of a group of waves.
 - c) It is also the velocity at which information signals or energy is propagated.



Generally, signal moves in this direction at the group velocity, v_g .



Here, TE₁₀ wave moves at the speed of light, c .

CHARACTERISTICS OF A WAVEGUIDE (2)

4. Phase velocity (v_p , m/s) is the speed at which a point of constant phase of a propagating electromagnetic wave travels along the waveguide, essentially representing the speed at which the wave's phase progresses through the waveguide.

1. It is the apparent velocity of the wave.

2. v_p always equal to or greater than v_g ($v_p \geq v_g$).

3. It may exceed the velocity of light (velocity in free space).

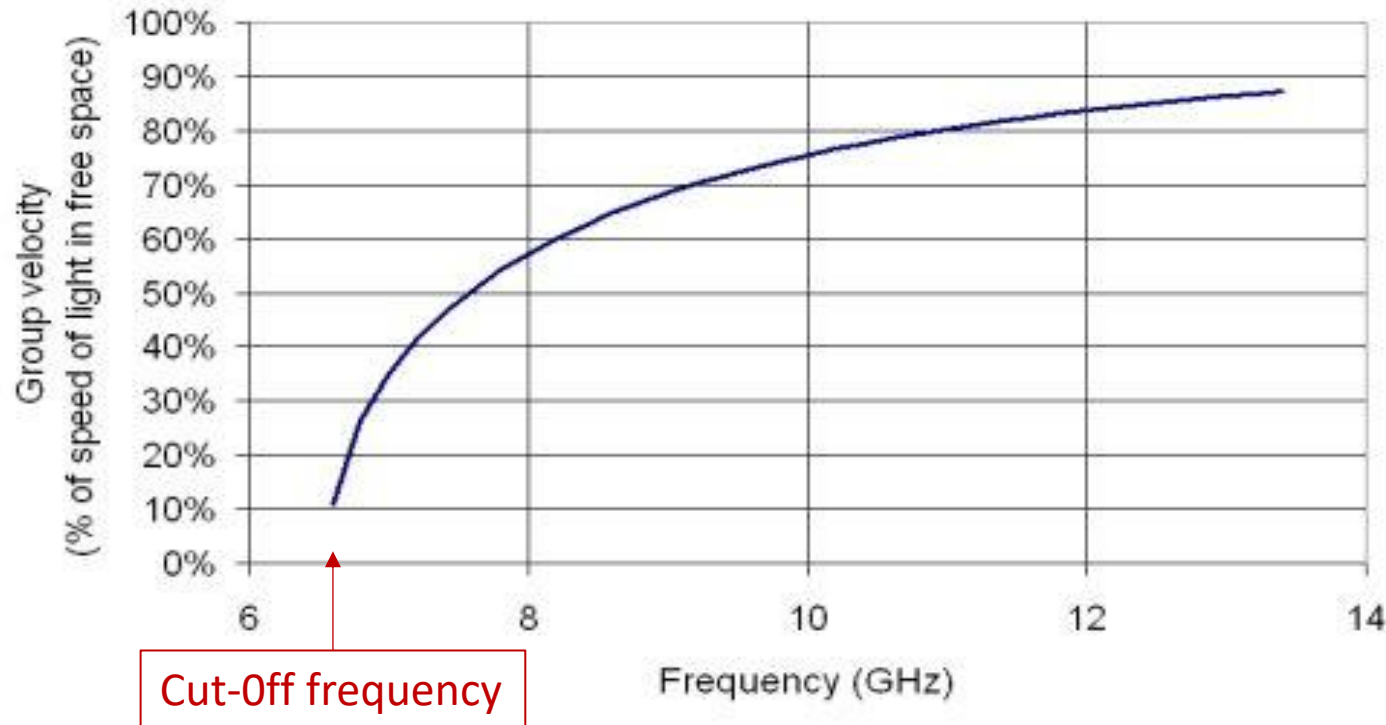
4. In theory: $v_g < c \leq v_p$.

5. The relationship between v_g , v_p and speed of light, C is given by:

$$C^2 = V_g V_p$$

GROUP VELOCITY VS SPEED OF LIGHT

Group velocity as a function of frequency
WR-90 rectangular waveguide



Note:

1. Characteristic is determined by the fundamental relationship

$$V_g = \frac{c^2}{v_p}$$

2. The cut-off frequency is given by

$$f_c = \frac{c}{2a} = \frac{3 \times 10^8}{2 \times 2.286 \times 10^{-2}} = 6.56 \text{ GHz}$$

- **Dimensions of WR Waveguide** are 0.8 x 0.4 inches (2.286 x 1.016 cm)
- **The recommended operating band** of WR-90 is from 8.2 to 12.4 GHz.
- **At 8.2 GHz** the signal is slowed to **60%** of the free-space speed of light.

CHARACTERISTICS OF A WAVEGUIDE (3)

5. Propagation wavelength in the waveguide (λ_g , m/s):

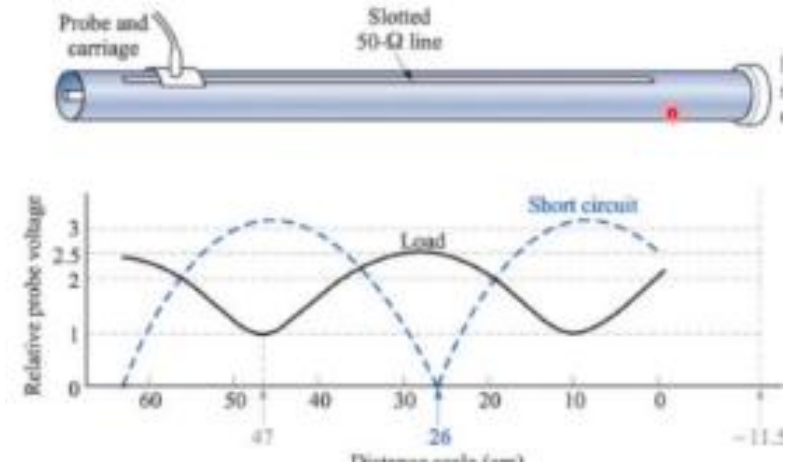
- Wavelength of travelling wave that propagates down the waveguide.
- **λ_g is greater in the waveguide than in free space (λ_o).**

WAVEGUIDE IMPEDANCE

- 6. Waveguide impedance** refers to the ratio of the electric field to the magnetic field within a waveguide, essentially representing the "resistance" a propagating wave encounters as it travels through the waveguide.
- a) It depends on the cut-off frequency, which in turn is determined by the guide dimension.
 - b) It is also closely related to the characteristic impedance of free space (377Ω).
 - c) Generally, $190 \Omega < \mathbf{Z}_o < 750 \Omega$

MEASURING WAVEGUIDE IMPEDANCE

1. A [vector network analyzer \(VNA\)](#) to measure the reflection coefficient at the waveguide port, then **calculate the impedance based on the known waveguide dimensions and the measured reflection coefficient.**
2. The VNA creates a standing wave pattern within the waveguide using a short circuit and observing the voltage standing wave ratio (VSWR) at different positions along the waveguide to determine the impedance mismatch.
3. **This method usually uses a slotted line to probe the electric field inside the waveguide.**



WAVEGUIDE IMPEDANCE MATCHING

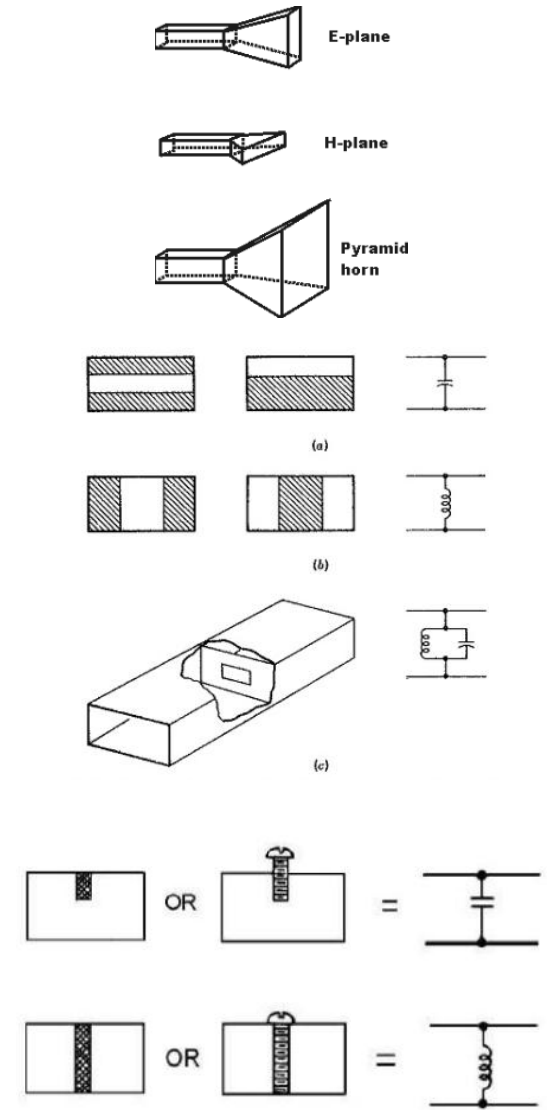
The main methods of impedance matching are

1. Use a gradual change in dimensions of waveguide.

Example is the horn antennas - these are funnel shaped antennas that provide the waveguide impedance match between the waveguide itself and free space.

2. Use of a waveguide iris which is an obstruction within the waveguide that provides a capacitive or inductive element. The element is able to provide the required matching of the characteristic impedance of the waveguide.

3. Use of a waveguide post or screw made from a conductive material. To make the post or screw inductive, it should extend through the waveguide completely making contact with both top and bottom walls. For a capacitive reactance the post or screw should only extend part of the way through.



RECTANGULAR WAVEGUIDE TE/TM CALCULATIONS (1)

- 1. Dominant mode (mode with lowest cutoff frequency) for rectangular waveguide is TE_{10}**
- 2. A waveguide acts as a high-pass filter.** It passes only those frequencies above the cutoff frequency.

$$v_g v_p = c^2 \qquad \lambda_g = \lambda_o \frac{v_p}{c}$$

Where λ_o is the wavelength in free space.

RECTANGULAR WAVEGUIDE TE/TM CALCULATIONS (2)

$$f_c = \frac{c}{2a} = \frac{c}{\lambda_c} \quad v_p = \frac{c(\lambda_g)}{\lambda_o} = \frac{c}{\sqrt{1 - (f_c/f)^2}}$$

$$Z_o = \frac{377}{\sqrt{1 - (f_c/f)^2}} = 377 \frac{\lambda_g}{\lambda_o} \text{ (TE mode)}$$

$$Z_o = 377 \frac{\lambda_o}{\lambda_g} \text{ (TM mode)}$$

TYPICAL QUESTIONS

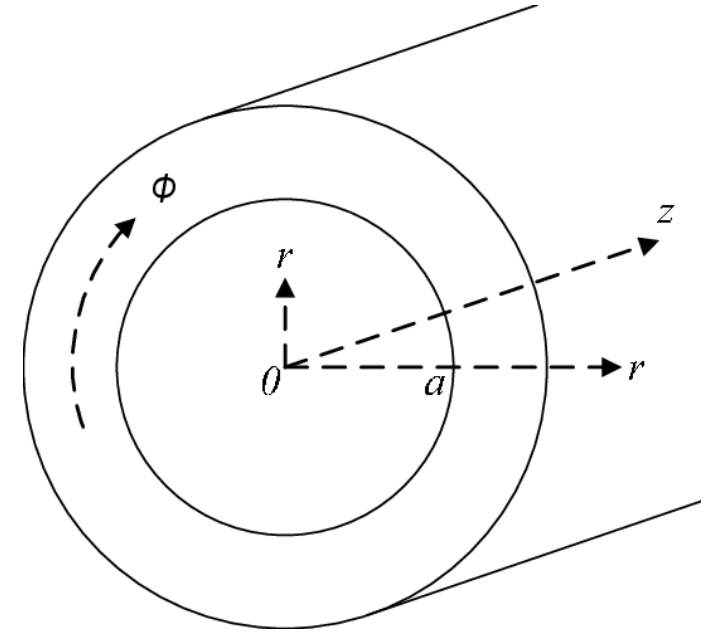
1. For a rectangular waveguide with a width of 3 cm and a desired frequency of operation of 6 GHz (for dominant mode), determine:
 - a) Cut-off frequency
 - b) Cut-off wavelength
 - c) Group velocity
 - d) Phase velocity
 - e) Propagation wavelength in the waveguide
 - f) Characteristic impedance
2. **Repeat Example 1 for a rectangular waveguide with a width of 2.5 cm and a desired frequency of operation of 7 GHz.**

CIRCULAR WAVEGUIDE TE/TM CALCULATIONS(1)

Dominant mode for circular waveguide is TE₁₁.

$$\text{Cut-off frequency, } f_c = \frac{c x_{np}}{2\pi a} = \frac{1.8412c}{2\pi a}$$

Where a is the radius of the waveguide
 x_{np} is a cut-off phase constant



$$\lambda_c = \frac{2\pi a}{x_{np}}$$

$$v_p = \frac{c}{\sqrt{1 - (f_c/f)^2}}$$

$$v_g v_p = c^2$$

CIRCULAR WAVEGUIDE TE/TM CALCULATIONS(2)

$$\lambda_g = \frac{\lambda_o}{\sqrt{1 - (f_c/f)^2}}$$

$$Z_o = 377 \frac{\lambda_g}{\lambda_o} (TE \text{ mode})$$

$$Z_o = 377 \frac{\lambda_o}{\lambda_g} (TM \text{ mode})$$

TYPICAL QUESTIONS

1. For a circular waveguide with a radius of 1 cm and a desired frequency of operation of 10 GHz (for dominant mode), determine:
 - a) Cut-off frequency
 - b) Cut-off wavelength
 - c) Group velocity
 - d) Phase velocity
 - e) Propagation wavelength in the waveguide
 - f) Characteristic impedance
2. **Repeat Example 1 for a circular waveguide with a radius of 2.5 cm and a desired frequency of operation of 7 GHz.**