Chapter 1: Review of principle and Analysis of Wave Guide

Sem. II, Year IV Microwave Devices and Systems By Waltengus A

Outline

- Introduction
- Wave Guide Principles and Analysis
- Types and Mode Classification

Principles and Analysis of Waveguides

- A Hollow metallic tube of uniform cross section for transmitting **electromagnetic waves** by successive reflections from the **inner walls** of the tube is called waveguide
- Waveguides may be used to **carry energy** between pieces of equipment or over longer distances to carry transmitter **power** to an **antenna or** microwave signals from an **antenna** to a **receiver**
- Waveguides are practical only for signals of extremely high frequency, where the wavelength approaches the cross-sectional dimensions of the waveguide.
- Below such frequencies, waveguides are useless as electrical transmission lines.

Continued

- Waveguides will only carry or propagate signals above a certain frequency, known as the cut-off frequency
- Below this the waveguide is not able to carry the signals
- This is obviously an important parameter, and one of the most basic specifications for its operation
- Often the insides of waveguides are plated with silver to **reduce resistance** and **transmission losses**

Continued

- The angles of **incidence** and **reflection** depend on the operating **frequency.**
- At **high** frequencies, the angle is **large** and the path between the opposite walls is relatively **long**.
- As the operating frequency decreases, the angle also decreases and the path between the sides shortens.
- When the operating frequency reaches the cutoff frequency of the waveguide, the signal bounces back and forth between the sidewalls of the waveguide.
- No energy is propagated.

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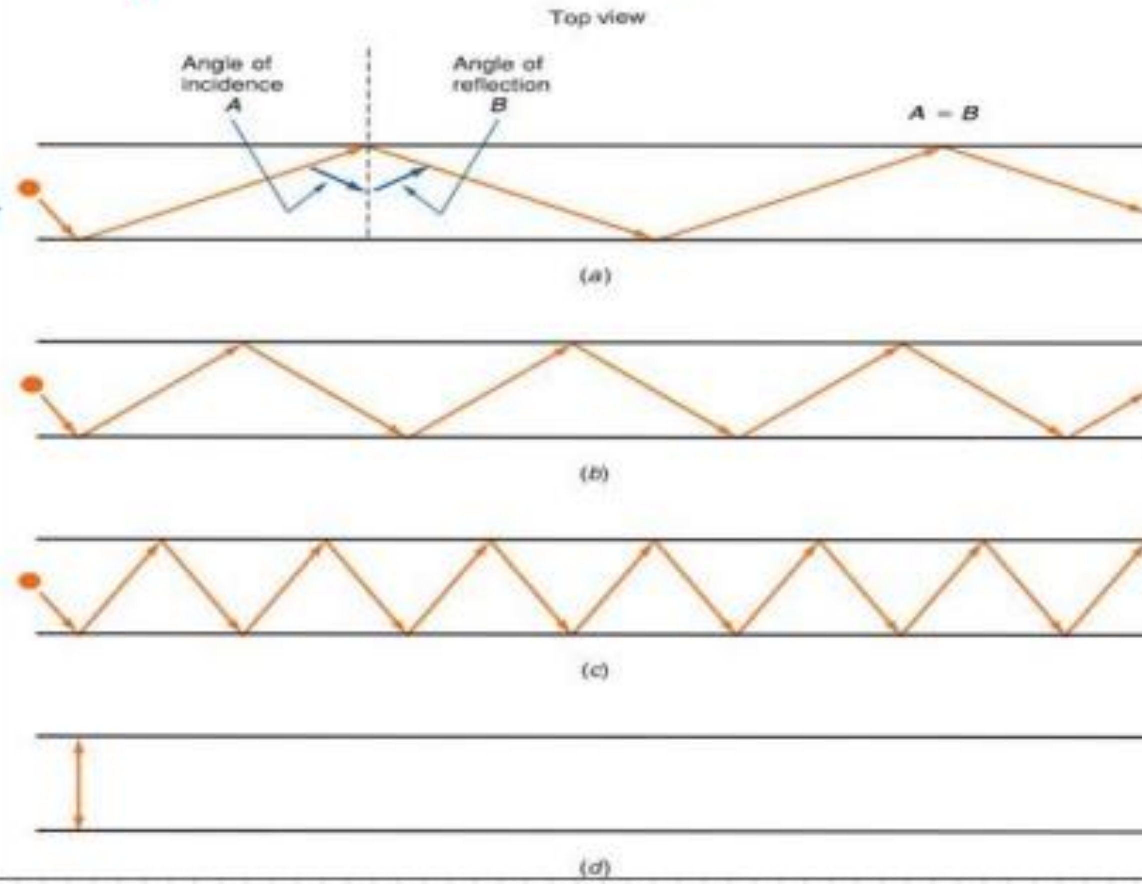
Figure 1: Wave paths in a waveguide at various frequencies

(a) High frequency

(b) Medium frequency

(c) Low frequency

(d) Cut off frequency



Uses

- To reduce attenuation loss
  - ✓ High frequencies
  - ✓ High power
- Can operate only above certain frequencies
  - ✓ Acts as a High-pass filter

Waveguide Disadvantages

- Physical size is the primary lower-frequency limitation of waveguides
  - The width of a waveguide must be approximately a **half wavelength** at the frequency of the wave to be transported
  - This makes the use of waveguides at frequencies below **300** Mega hertz increasingly impractical
  - The lower frequency range of any system using waveguides is limited by the **physical dimensions** of the waveguides
- Waveguides are difficult to install because of their rigid, hollow-pipe shape
  - Special couplings at the joints are required to assure proper operation
  - Also, the inside surfaces of waveguides are often plated with silver or gold to reduce skin effect losses
  - These requirements increase the costs and decrease the practicality of waveguide systems at any other than microwave frequencies

Mode Of Propagation

- An electromagnetic energy to be carried by a waveguide is injected into one end of the waveguide.
- The electric and magnetic fields associated with the signal bounce off the inside walls back and forth as it progresses down the waveguide
- In order to determine the EM field configuration within the waveguide,
  - ✓ Maxwell's equations should be solved subject to appropriate boundary conditions at the walls of the guide
- Such solutions give rise to a number of field configurations.
- Each configuration is known as a **mode**

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The following are the d/t modes possible in a waveguide system

1. Transverse Electro Magnetic (TEM) wave:

- The electric field, E and the magnetic field, H are oriented transverse to the direction of propagation of wave

$$E_z = 0 \text{ and } H_z = 0$$

- No cut-off frequency
- TEM wave cannot propagate within a hollow pipe
  - lacks an axial conductor to carry current

Continued

Transverse Electric (TE) wave:

- Here only the electric field is purely transverse to the direction of propagation and the magnetic field is not purely transverse. (i.e.)

  $E_z = 0, H_z \neq 0.$

Transverse Magnetic (TM) wave:

- Here only magnetic field is transverse to the direction of propagation and the electric field is not purely transverse. (i.e.)

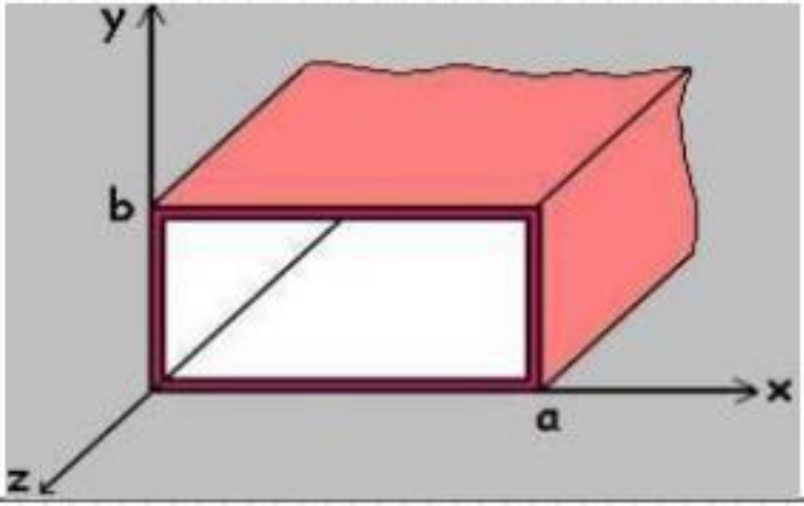
  $E_z \neq 0, H_z = 0$

Hybrid wave:

- Here neither electric nor magnetic fields are purely transverse to the direction of propagation. (i.e.) $E_z \neq 0, H_z \neq 0$

Rectangular Waveguides

- A waveguide having rectangular cross section is known as **Rectangular waveguide**
- Propagation **modes are** TM and TE but not TEM since only one conductor is present
- It is a standard convention to have the longest side of the waveguide along x-axis [a (width) > b (length)]



- The order of the mode refers to the field configuration in the guide, and is given by **m** and **n** integer subscripts, TE_{mn} and TM_{mn}.
  - ✓ The **m** subscript corresponds to the number of half-wave variations of the field in the **x direction**, and
  - ✓ The **n** subscript is the number of half-wave variations in the **y direction**

Applications

- High-power systems
- Millimeter wave applications
- Satellite systems
- Precision test applications

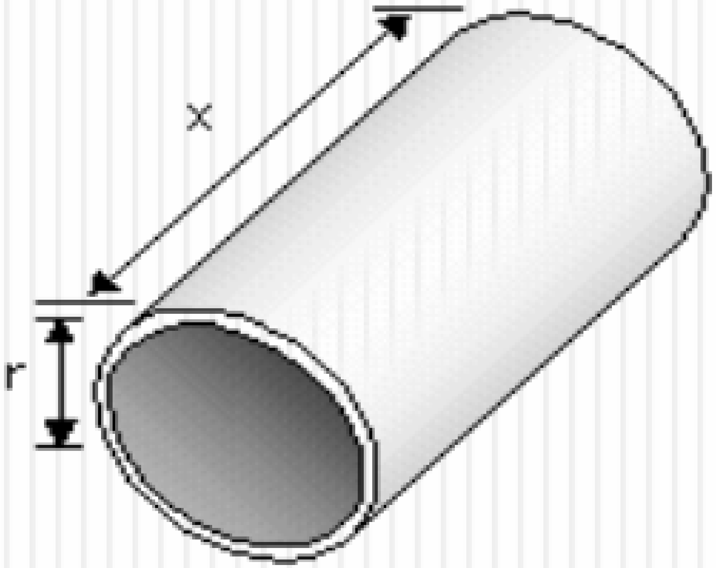
Circular Waveguide

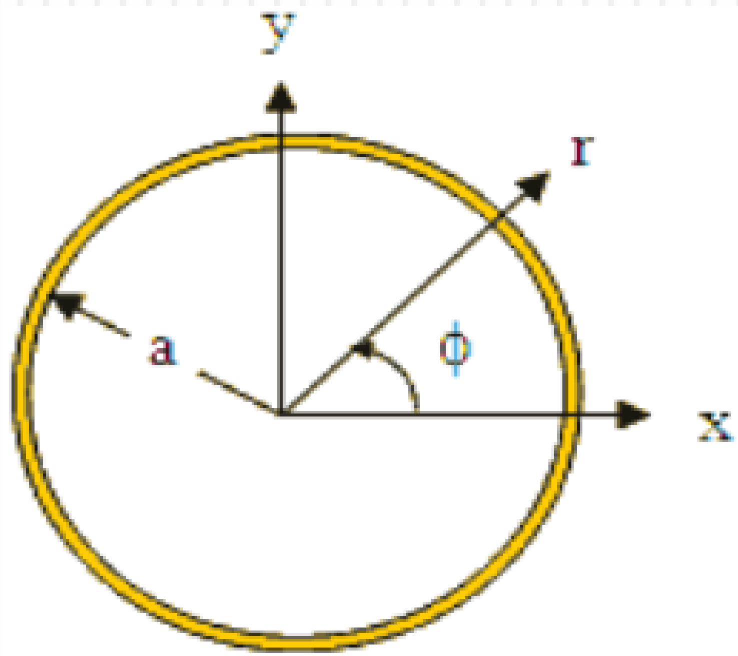
- It consists of a hollow, round (circular cross section) metal pipe that supports TE and TM waveguide modes.

Applications

- Used in transmission of circularly polarized waves, to connect components having circular cross-section to rectangular waveguide

- The structure of such a circular waveguide with inner radius a, is shown below:





Ridged Waveguide

- It is formed with a rectangular ridged projecting inward from one or both of the wide walls in a rectangular waveguide.
- Ridged is used to concentrate the **electric field** across the ridge and to lower the cutoff frequency of TE mode.

Applications

- Attractive for UHF and low microwave ranges

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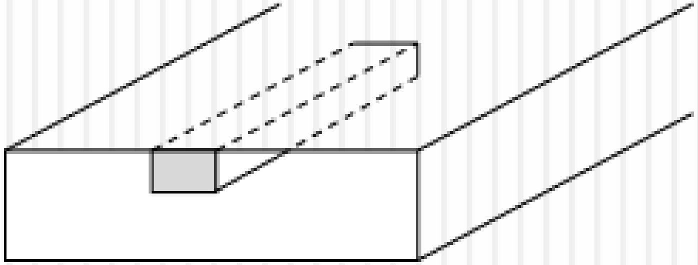
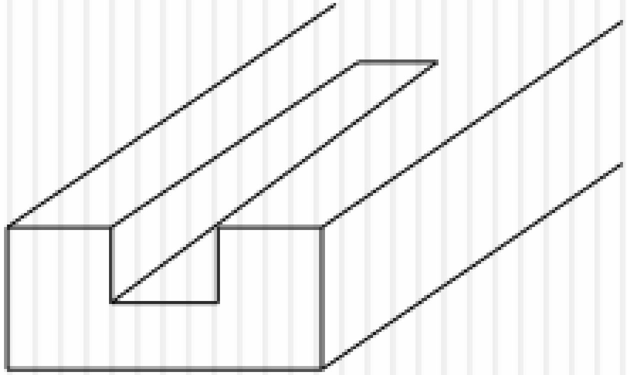
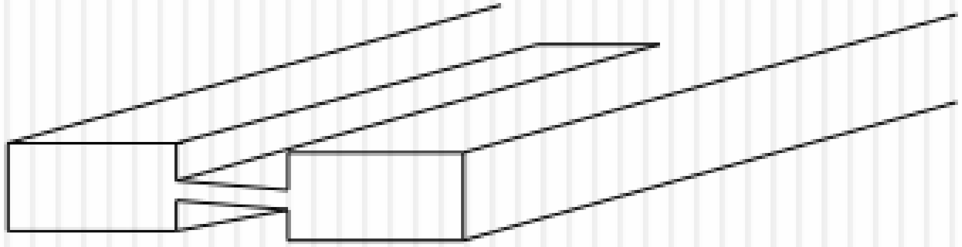


Ridged Waveguide Using Metal Bar



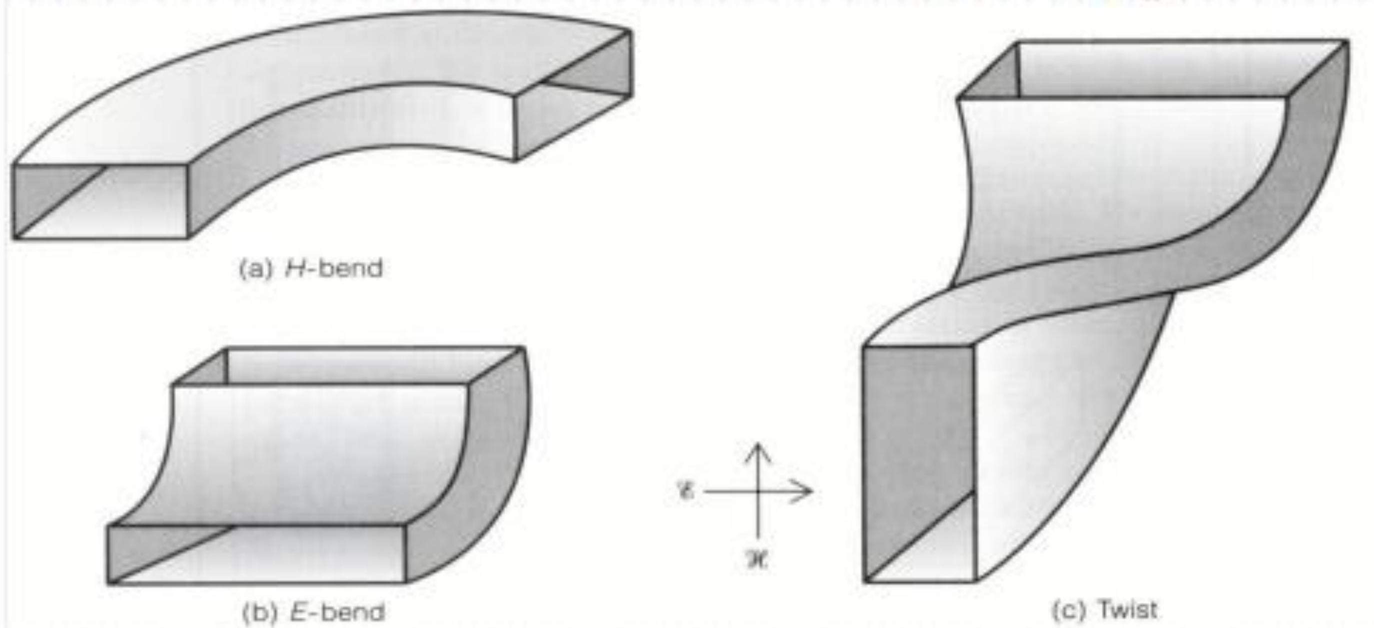
Singled Ridged Waveguide



Double Ridged Waveguide

Flexible Waveguide

- It is used for bends, twists or in applications where certain criteria may not be fulfilled by normal waveguides.
- Figure 1.2 below shows some of the flexible waveguides:



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- The *H bend* of Figure (a) is used to turn a 90° corner.
- The *E bend* Figure (b) also completes a 90° turn in either an upward or downward direction.
- The *twist* of Figure (c) is used to effect a shift in the polarization of the wave.

Characteristic of Waveguide

Critical (cut-off) frequency, f_c (Hz)

- the lowest frequency for which a mode will propagate in a waveguide.

Critical (cut-off) wavelength, λ_c (m/cycle)

- the largest wavelength that can propagate in the waveguide without any minimum attenuation

Group velocity (v_g, m/s)

- The velocity at which a wave propagates.
- Refers to the velocity of a group of waves.
- It is also the velocity at which information signals or energy is propagated

Continued

Phase velocity (v_p, m/s)

- The velocity at which the wave changes phase.
- It is the apparent velocity of the wave (i.e.: max electric intensity point).
- v_p always equal to or greater than v_g ($v_p \geq v_g$).
- It may exceed the velocity of light (velocity in free space)

Rectangular Waveguide TE/TM Calculations

- Dominant mode (mode with lowest cutoff frequency) for rectangular waveguide is TE
- A waveguide acts as a high-pass filter in that it passes only those frequencies above the cutoff frequency
- The cutoff frequency is given by

$$f_{c_{mn}} = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} = \frac{c}{2\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

$$u = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_o\mu_r\varepsilon_o\varepsilon_r}} = \frac{1}{\sqrt{\mu_o\varepsilon_o}}\frac{1}{\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$$

Continued

$$v_g v_p = c^2$$

$$\lambda_g = \frac{c}{\sqrt{f^2 - f_c^2}}$$

$$\lambda_g = \lambda_o \frac{v_p}{c}$$

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

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

$$\beta = \beta_u \sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

Continued

$$f_c = \frac{c}{2a} = \frac{c}{\lambda_c} (for TE)$$

$$Z_o = 377 \frac{\lambda_o}{\lambda_g} (TM \bmod e)$$

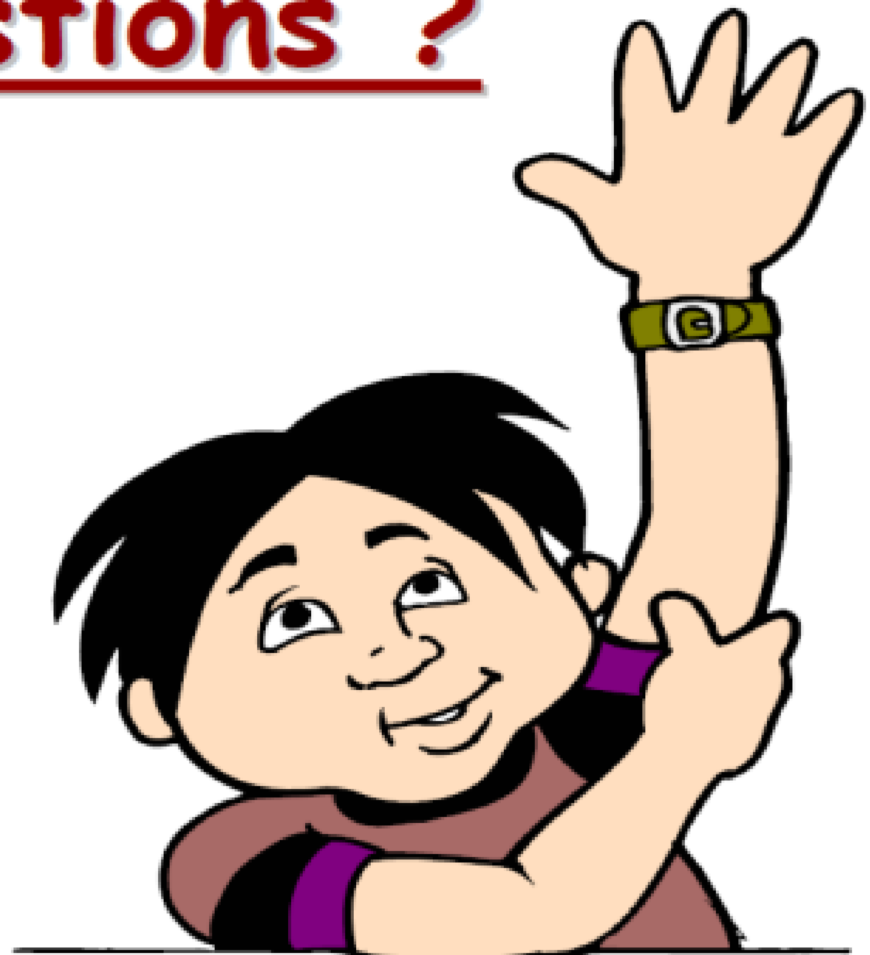
$$Z_o = \frac{377}{\sqrt{1-\left(f_c / f\right)^2}} = 377 \frac{\lambda_g}{\lambda_o} (TE \bmod e)$$

Continued

Exercise 1 For a rectangular waveguide with a width of 3cm and a desired frequency of operation of 6GHz (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

Questions ?



Thanks