MICROWAVE DEVICES

EEEN 566 – MICROWAVE ENGINEERING

Friday, 07 February 2025

RECAP-WHAT ARE MICROWAVES? /01

1. Microwaves have frequencies in the range 300 MHz to 300GHz
2. Stray reactances are more important as frequency increases
3. Device capacitance and transit time are important
4. Cable losses increase with frequency and as a result waveguides are preferred to transmission lines.

RECAP-WHAT ARE MICROWAVES? /02

5. Wave guides act as pipes through which waves propagate
6. Waveguides can have various cross sections
   a) Rectangular
   b) Circular
   c) Elliptical
7. Waveguides can be rigid or flexible
8. Waveguides have very low-losses compared with transmission lines.

ADVANTAGES OF WAVEGUIDES(1)

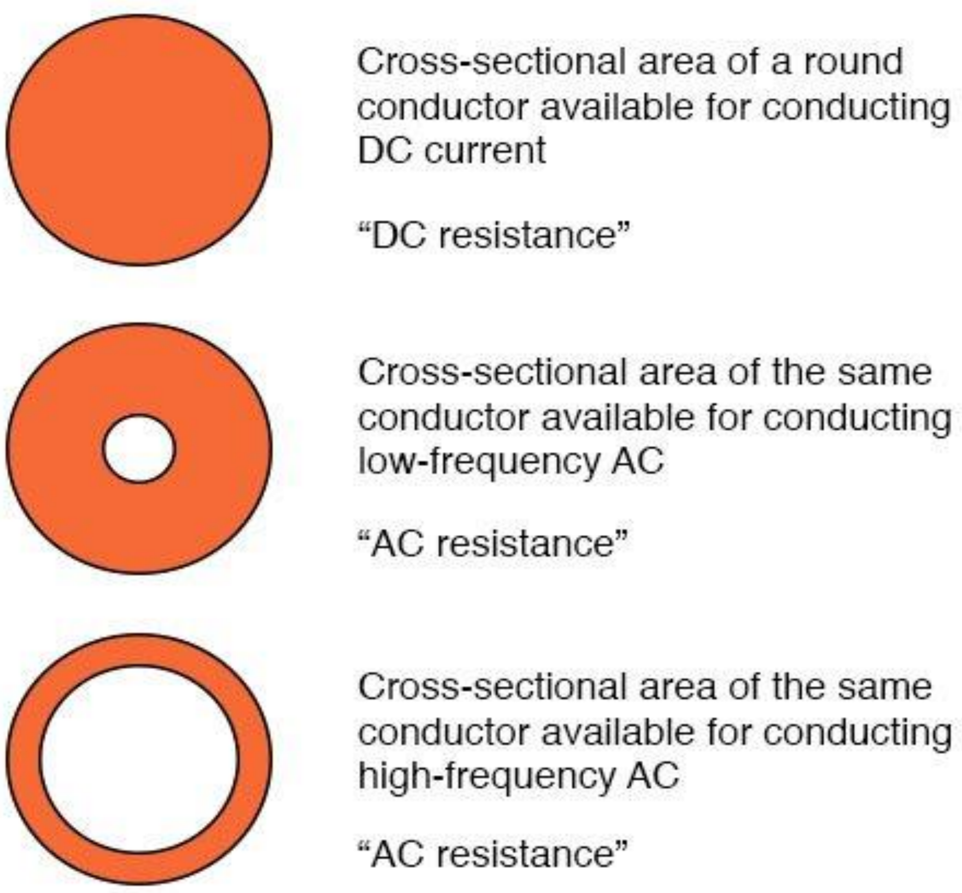
There are 3 advantages of using waveguides, i.e

1. **Copper Losses:** Two-wire transmission lines have high copper losses because they have a relatively small surface area.

   The surface area of the outer conductor of a coaxial cable is large, but the surface area of the inner conductor is relatively small.

RECAP: SKIN EFFECT

At high frequencies, the current-carrying area of the inner conductor is restricted to a very small layer at the surface of the conductor by an action called 'Skin Effect.'



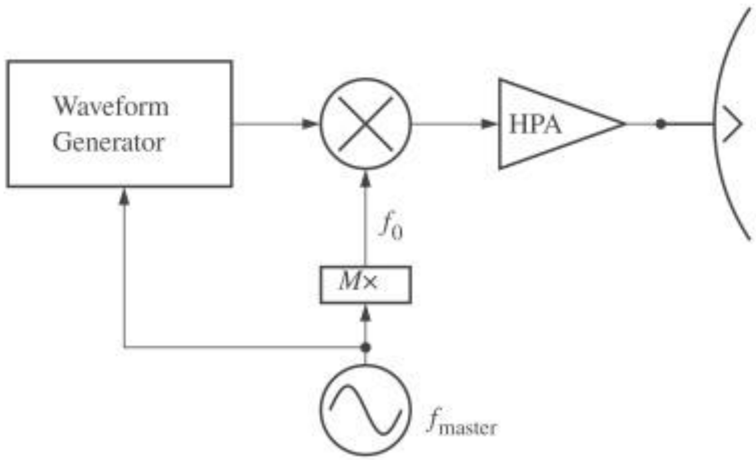
ADVANTAGES OF WAVEGUIDES(2)

2. **Dielectric Losses** are lower in waveguides than in two-wire and coaxial transmission lines because it is air filled.

Dielectric losses in two-wire and coaxial lines are caused by the heating of the insulation between the conductors.

ADVANTAGES OF WAVEGUIDES(3)

3. <u>Power-handling capability</u>: Waveguides can handle more power than coaxial lines of the same size.



(a) Radar transmitter

(b) Microwave oven

OTHER ADVANTAGES OF WAVEGUIDES

1. Waveguides have Low insertion loss.

$$Insertion\ Loss = 10\ log_{10}\left(\frac{Incidence\ Power}{Transmitted\ Power}\right)$$

1. Waveguides have wider bandwidth.
2. They are used in designing Waveguide filters.

DISADVANTAGES OF WAVEGUIDES(1)

Waveguides have the following disadvantages:

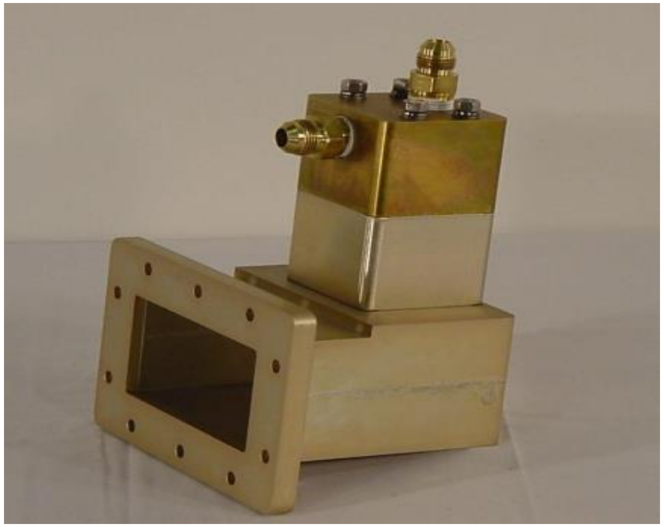
1. Physical size is the primary lower-frequency limitation of waveguides. The width of a waveguide must be approximately a half wavelength at the frequency of the wave to be transported. Generally, waveguides are not used below 1GHz.

DISADVANTAGES OF WAVEGUIDES(2)

2. Difficult to install: Waveguides are difficult to install because of their rigid, hollow-pipe shape.

They require special couplings at the joints to assure proper operation.

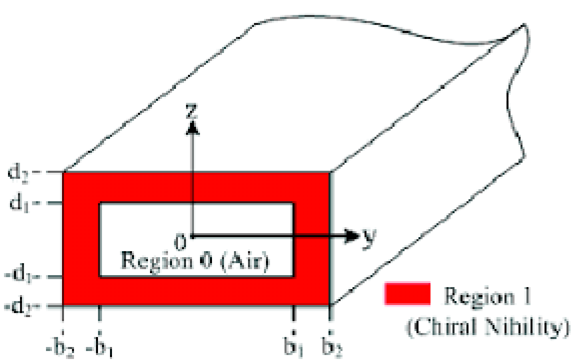
(a) Coaxial Cable-simple joints



(b) Waveguides-Complex joints

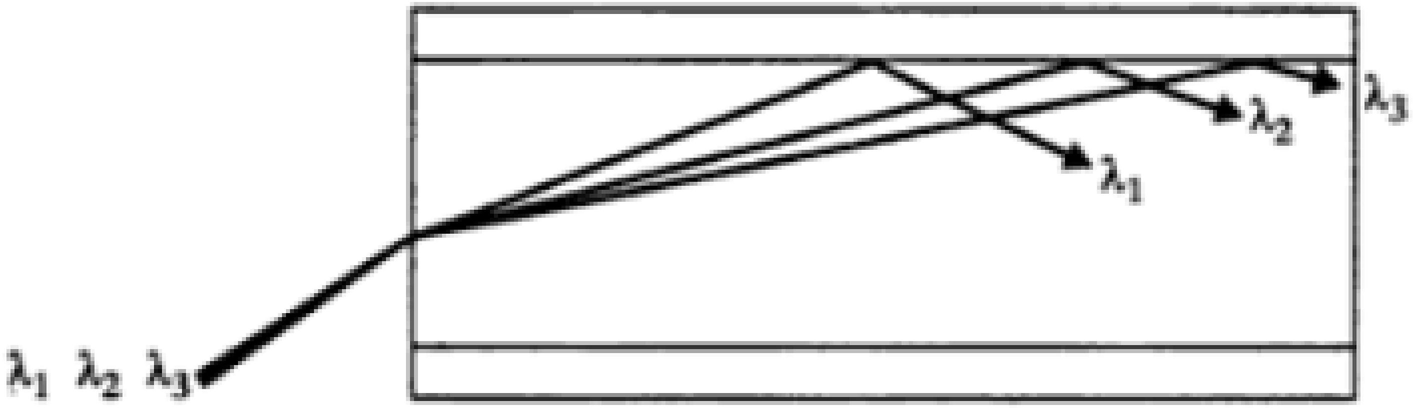
DISADVANTAGES OF WAVEGUIDES(3)

3. High Cost: The inside surfaces of waveguides are often plated with silver or gold to reduce skin effect losses. This makes them expensive.



DISADVANTAGES OF WAVEGUIDES(4)

4. Dispersion: The wave velocity in a waveguide varies with wavelength (frequency), causing distortion when wideband signals, such as is in digital communications, are propagating.



COMMON APPLICATION OF WAVEGUIDES

Common applications of waveguides are:

1. Radar (commercial and military)
2. Satellite earth stations
3. Radiation therapy e,g. CLINAC systems
4. Industrial ovens and heating

ALTERNATIVES TO WAVEGUIDES

1. Striplines & Microstrips

- Are good at many different frequencies.
- Operate at low power levels ($\leq$100W)
- **Applications:**
  - Cell phones
  - Bluetooth devices
  - GPS
  - RFID tags
  - Other small electronics

ALTERNATIVES TO WAVEGUIDES

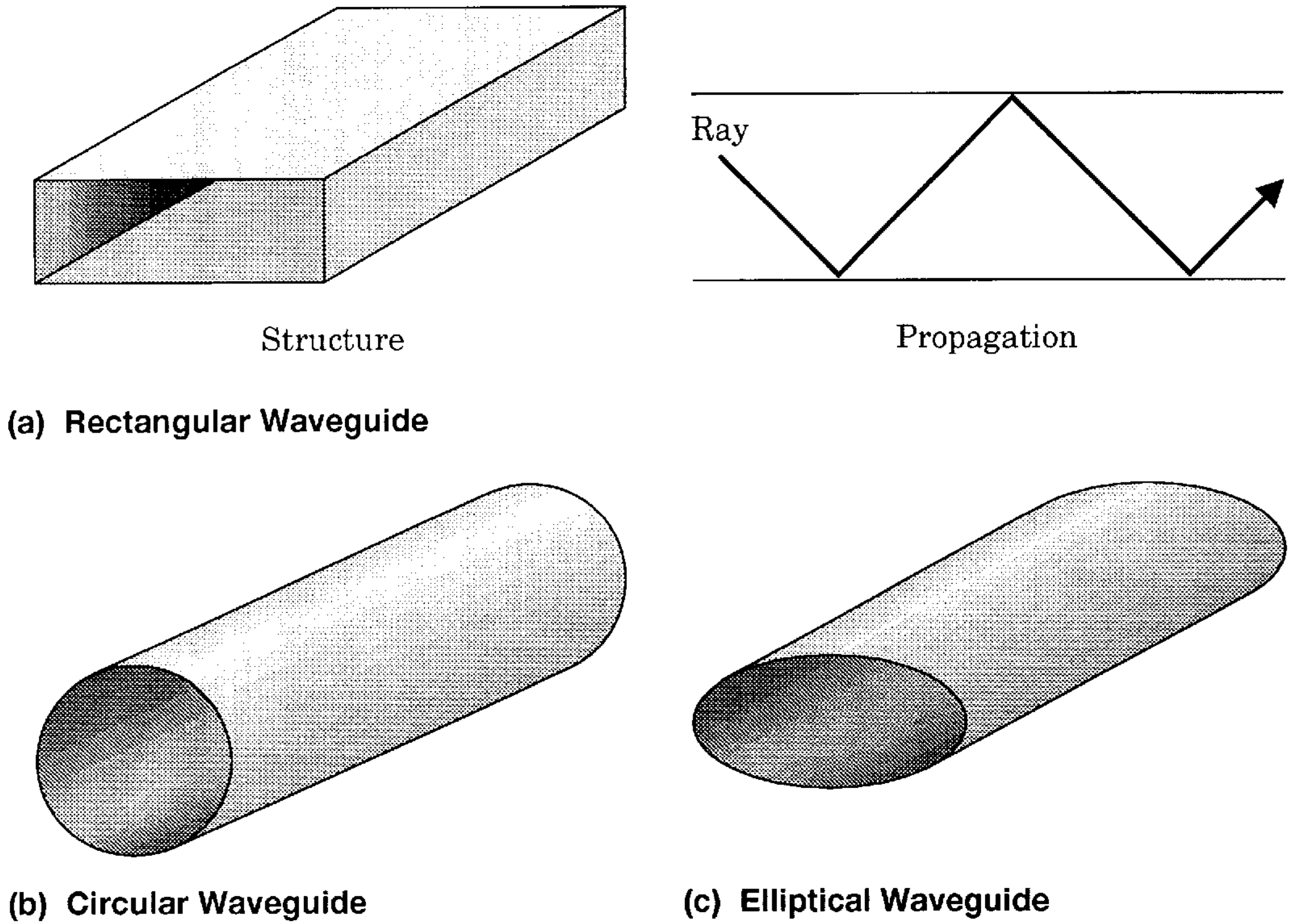
1. Co-axial Cables

- Good response over wide frequency range
- limited to medium-low power levels

Common Applications

- Cellular Base Stations
- TV and radio Transmitters
- And a host of low-frequency applications

TYPES OF WAVEGUIDES

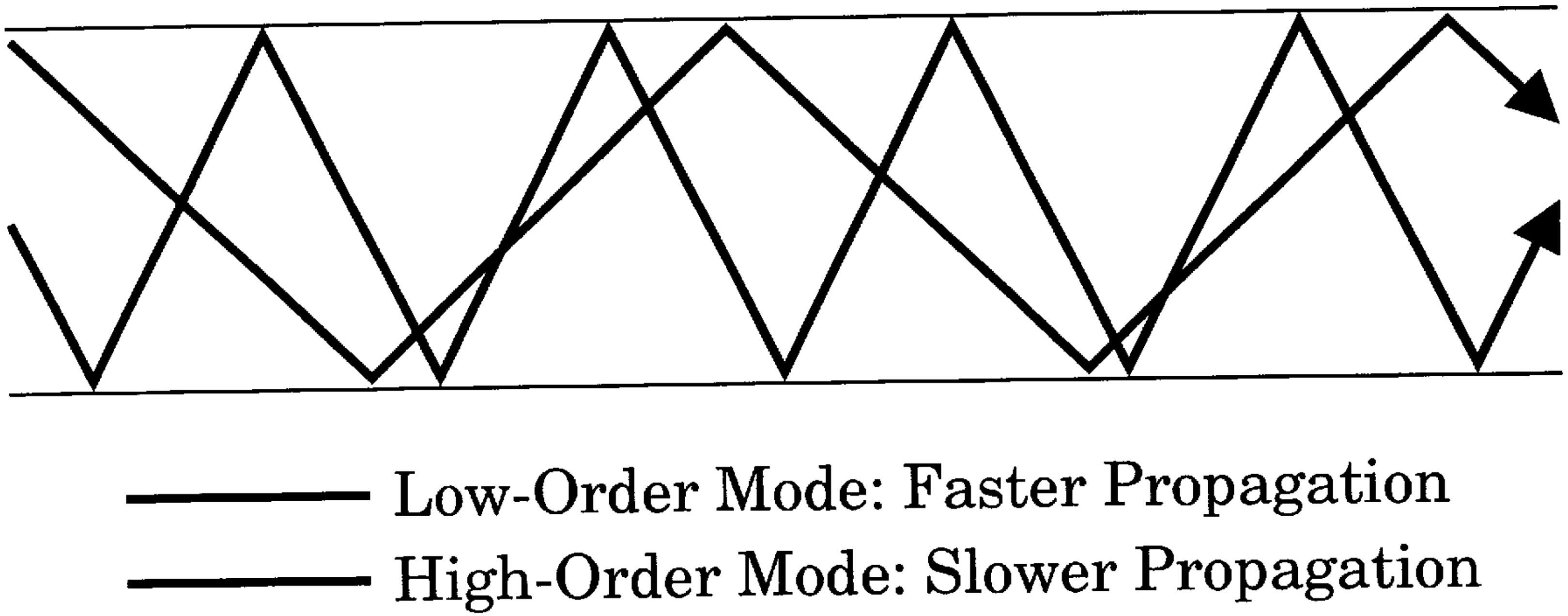


Transparency 250 (Figure 19.1)

WAVEGUIDE MODES

1. Waves can propagate in various ways
2. Time taken to move down the guide varies with the mode
3. Each mode has a cutoff frequency below which it won't propagate
4. The mode with lowest cutoff frequency is **dominant mode**

WAVEGUIDE MULTIMODE PROPAGATION



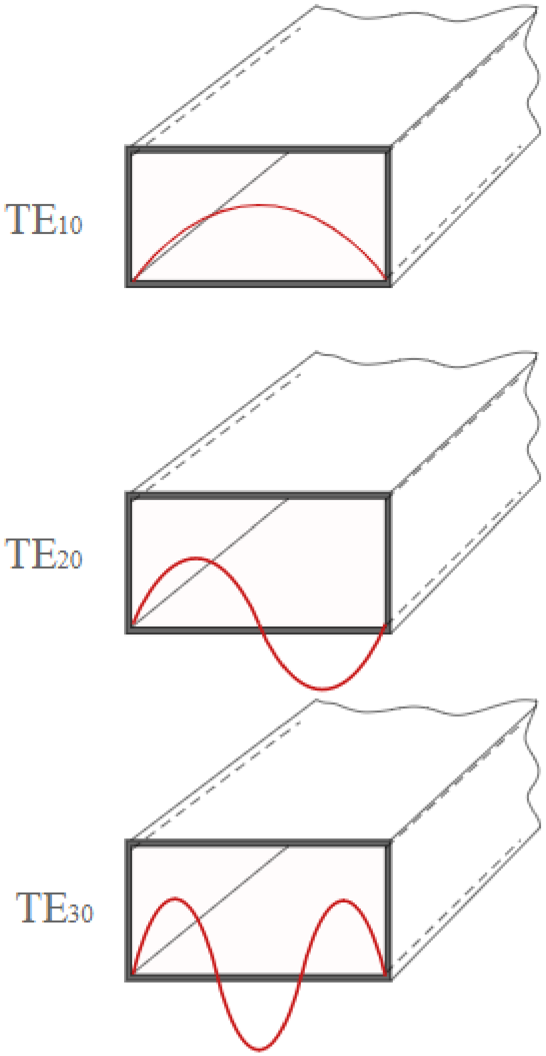
Transparency 251 (Figure 19.2)

WAVEGUIDE MODE DESIGNATIONS

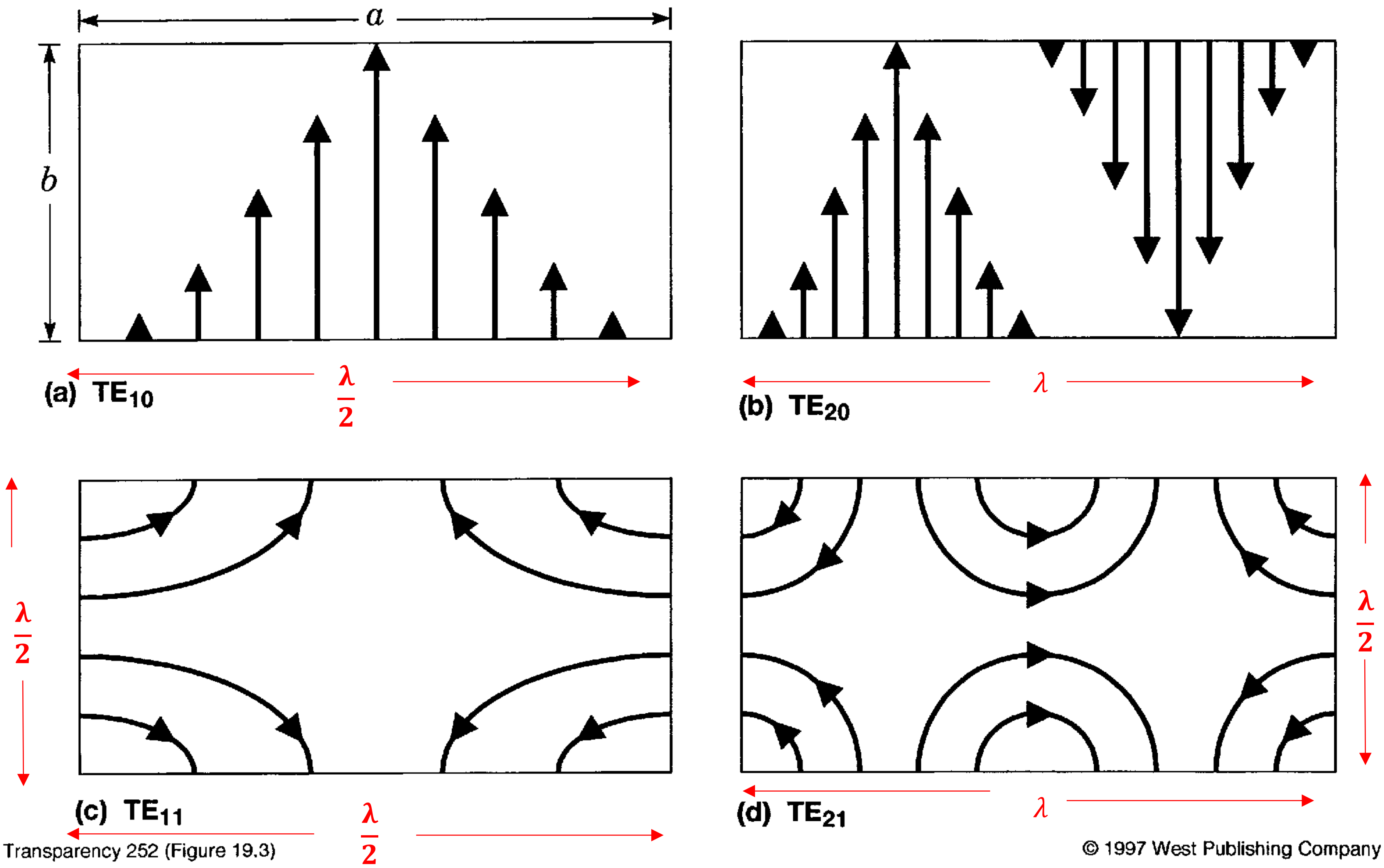
- **TE (T**ransverse **E**lectric)
  - Electric field is at right angles to direction of travel
- **TM** (**T**ransverse **M**agnetic)
  - Magnetic field is at right angles to direction of travel

RECTANGULAR WAVEGUIDES

1. Dominant mode is TE_{10}
   - 1 half cycle along long dimension, a
   - No half cycles along short dimension, b
   - Cutoff wavelength, $\lambda_c = \frac{c}{2a}$
2. Modes with next higher cutoff frequency are TE_{01} and TE_{20}
   - Both have cutoff frequency twice that for TE_{10}



TE MODES IN RECTANGULAR WAVEGUIDES



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TE MODES IN RECTANGULAR WAVEGUIDES

- For TE_{10} mode in rectangular waveguide with $a \approx 2\,b$

$$f_c = \frac{c}{2a}$$

- For TE_{20} mode in rectangular waveguide with $a = 2\,b$

$$f_c = \frac{c}{4a}$$

- For TE_{30} mode in rectangular waveguide with $a = 2b$

$$f_c = \frac{c}{6a}$$

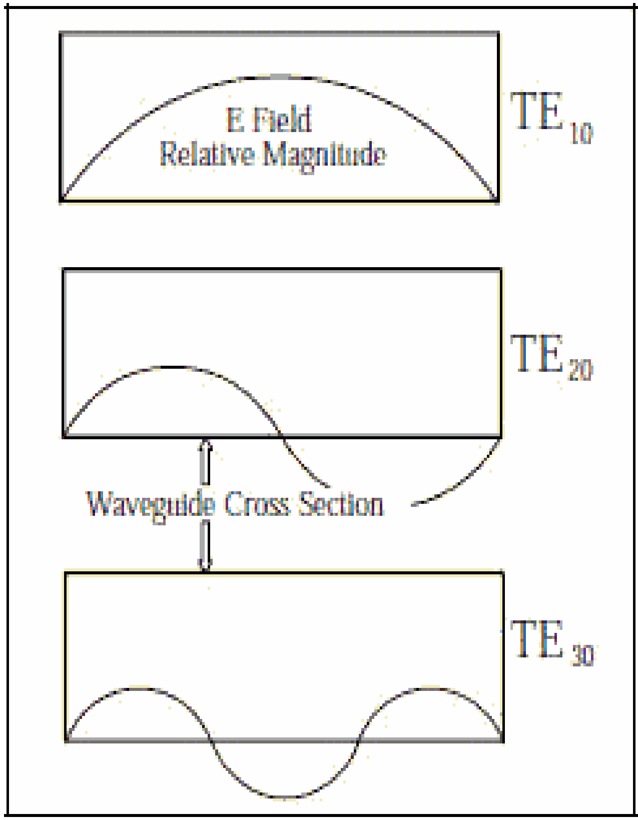


Figure 2. TE modes

USABLE FREQUENCY RANGE

- Single mode propagation is highly desirable to reduce dispersion and marks the usable frequency range.

- This occurs between cutoff frequency for TE_{10} mode and twice that frequency., i.e

$$\frac{c}{2a} \leq f \leq \frac{c}{a}$$

  for a rectangular waveguide.
- It is not good to use guide at the extremes of this range.

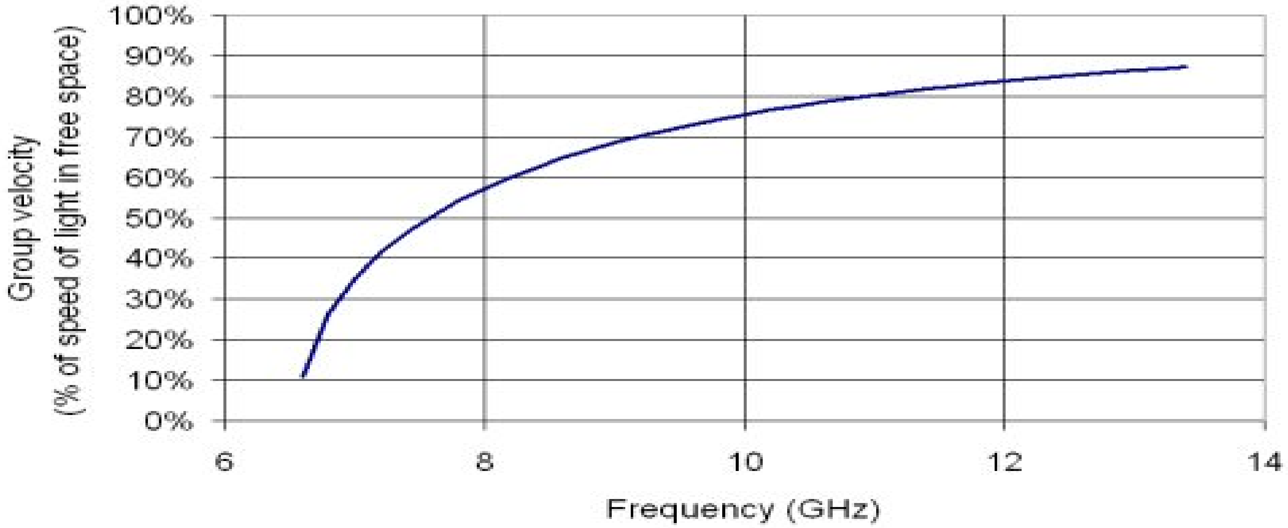
EXAMPLE WAVEGUIDE

1. Waveguide Type: RG-52/U
2. Internal dimensions 22.9 by 10.2 mm
3. Cutoff, $f_c = \frac{c}{2a} = \frac{3 \times 10^8}{2 \times 0.229} = 6.56$ GHz
4. Usable frequency range is 8.2-12.5 GHz

GROUP VELOCITY

1. Waves propagate at speed of light *c* in free space in a straight line.
2. Waves don't travel straight down a waveguide
3. Speed at which signal moves down waveguide is the group velocity, V_g and is given by:

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



PHASE VELOCITY

- **Phase velocity** is the apparent velocity of wave along wall.
- Phase velocity is used for calculating wavelength in guide and also during impedance matching.

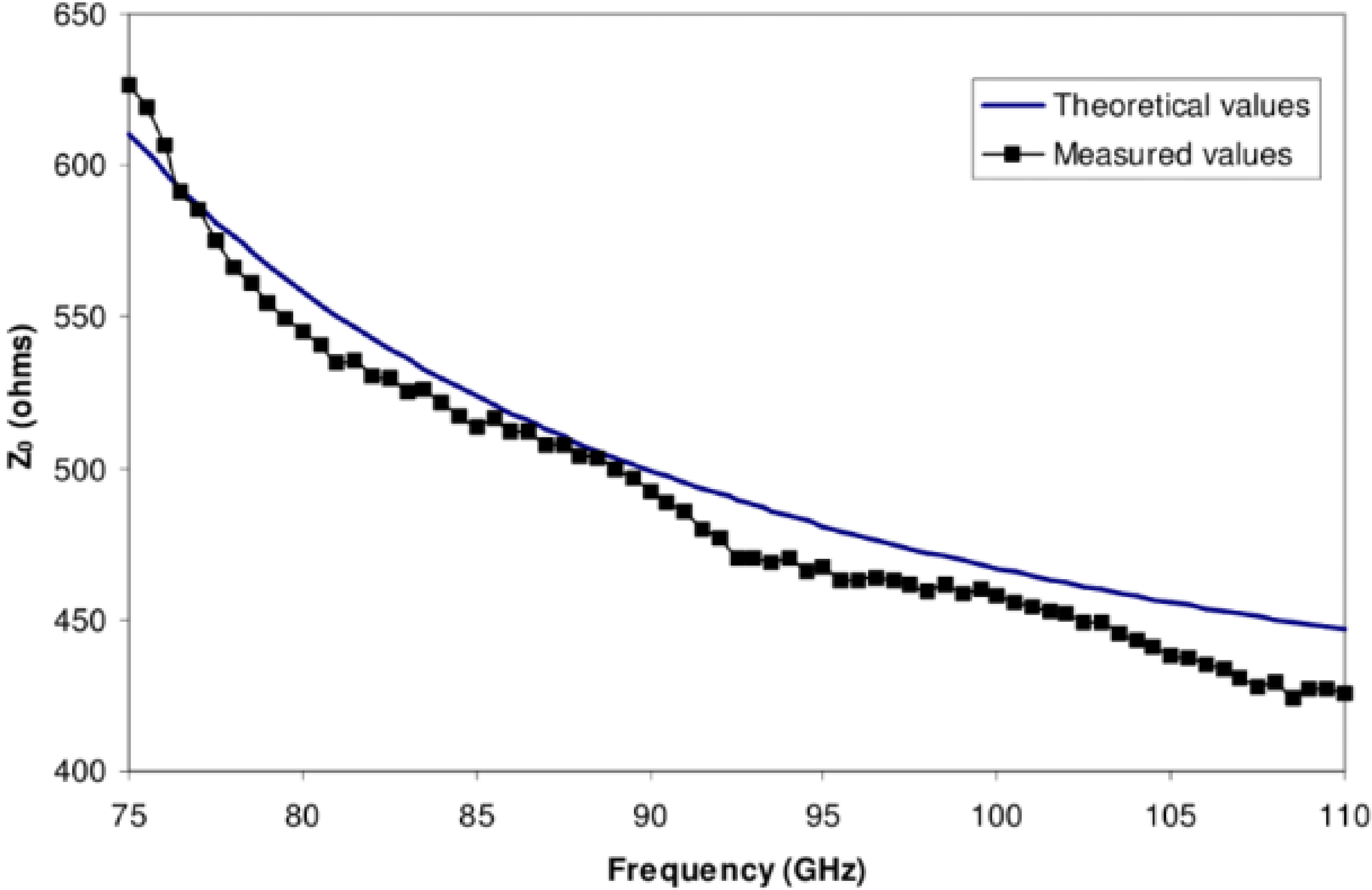
$$v_p = \frac{c}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

CHARACTERISTIC IMPEDANCE

Characteristic Impedance, Z_0 varies with frequency and is given by

$$Z_0 = \frac{377}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}\ \Omega$$

CHARACTERISTIC IMPEDANCE Zo OF RECTANGULAR WAVEGUIDE



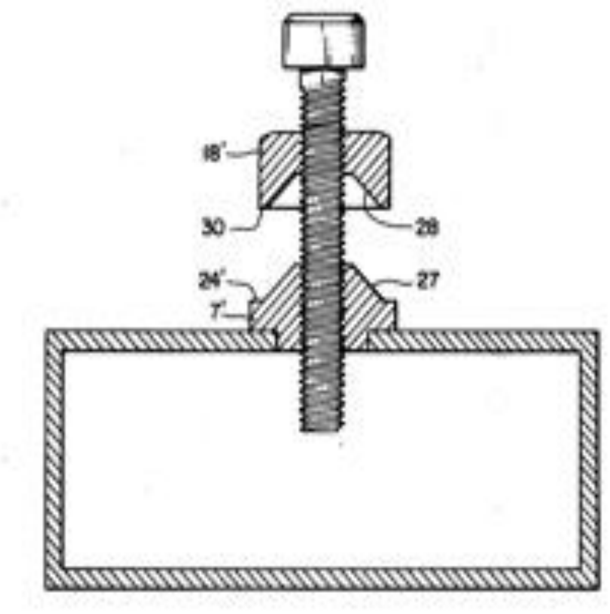
GUIDE WAVELENGTH

- Waveguide wavelength is longer than free-space wavelength at same frequency.

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

IMPEDANCE MATCHING

- Tuning screws can be used to add capacitance or inductance



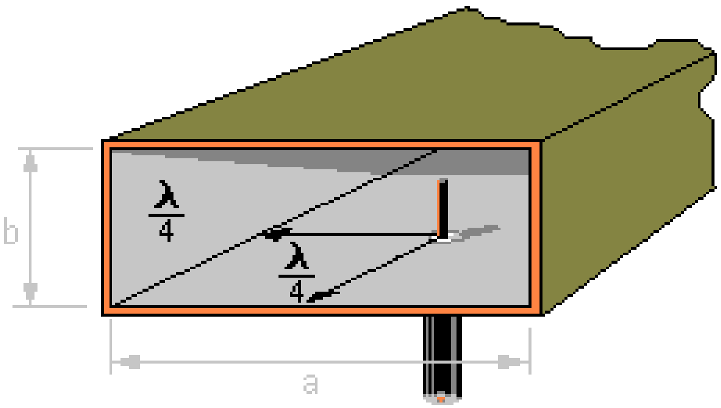
COUPLING POWER TO GUIDES

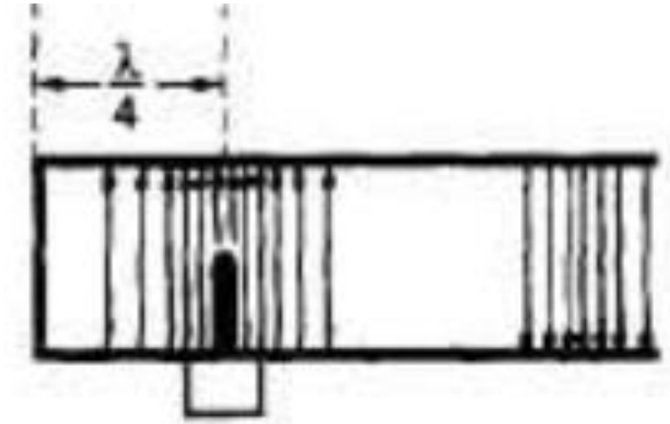
Three common methods of coupling power to waveguides are:

1. **Probe** inserted at a point where E-field is maximum

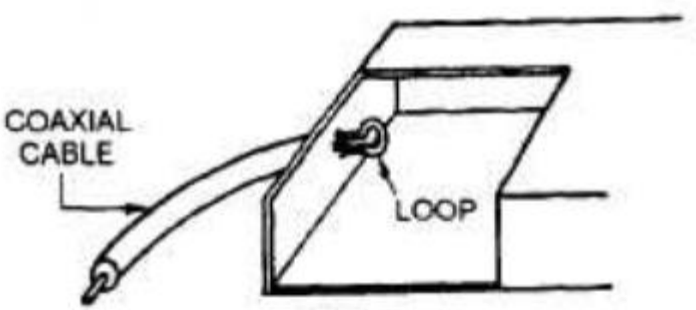
2. **Loop** inserted at a point where H-field maximum

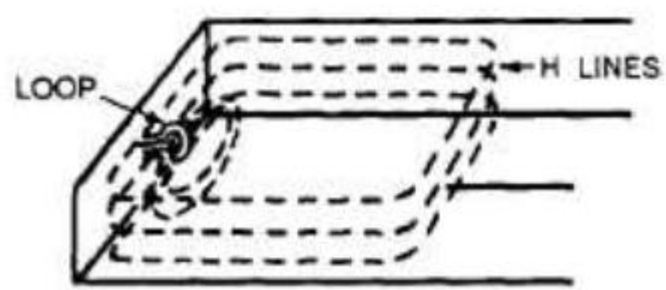
3. **Hole** inserted at a point where E-field maximum





(a) Waveguide probe acts as a quarter-wave antenna. Current flows in the probe and sets up an E field.

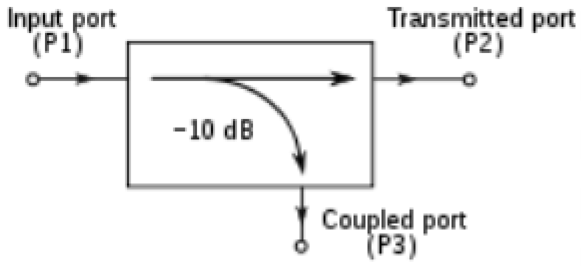




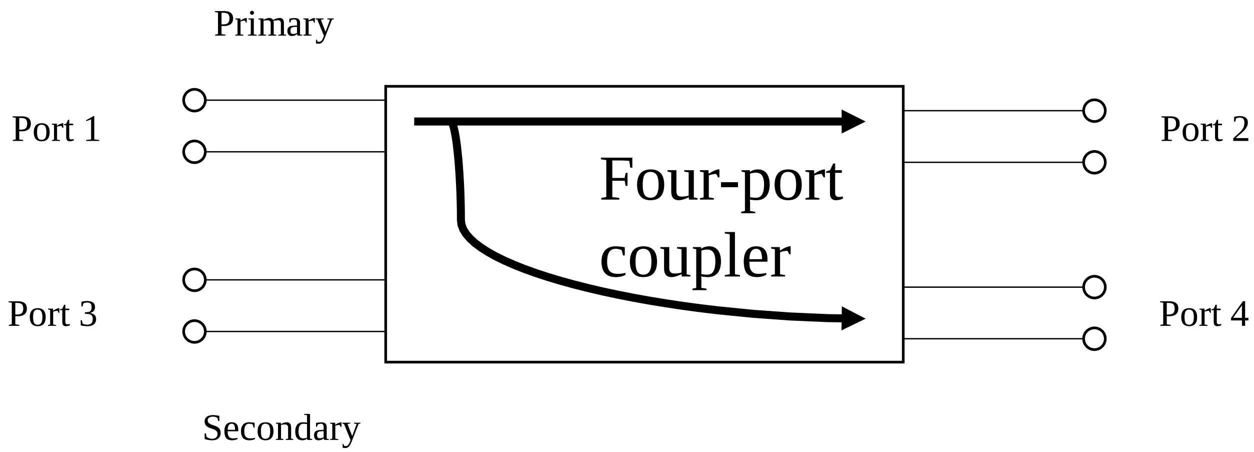
(b) Waveguide loop: the loop is inserted at one of several points where the magnetic field will be of greatest strength.

DIRECTIONAL COUPLER

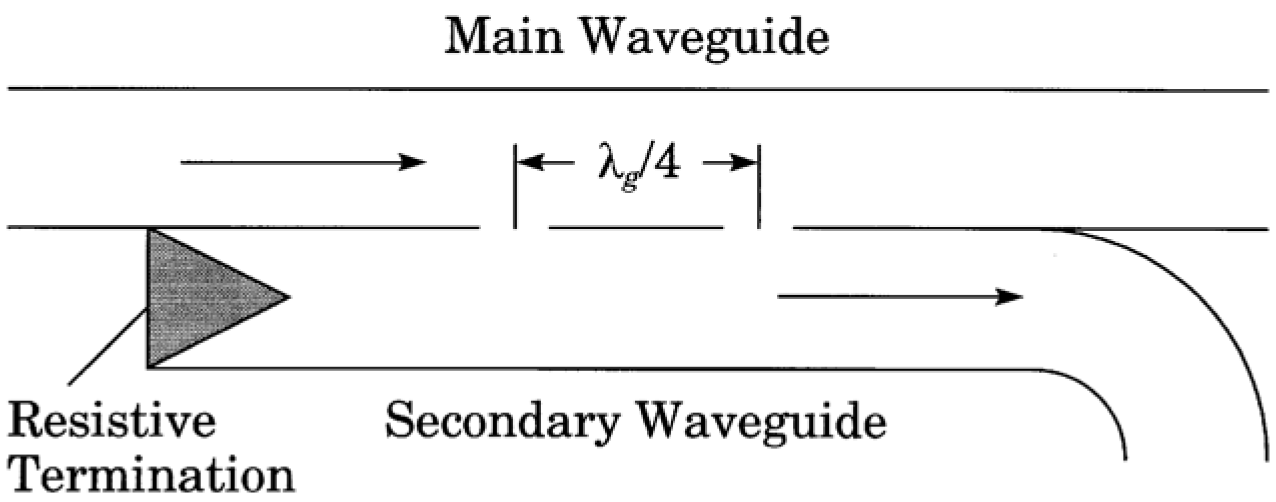
- Directional coupler launches or receives power in only 1 direction, i.e port 1 to port 2
- Used to split some of power into a second guide, i.e port 3
- Can use probes or holes to couple energy to the second guide.

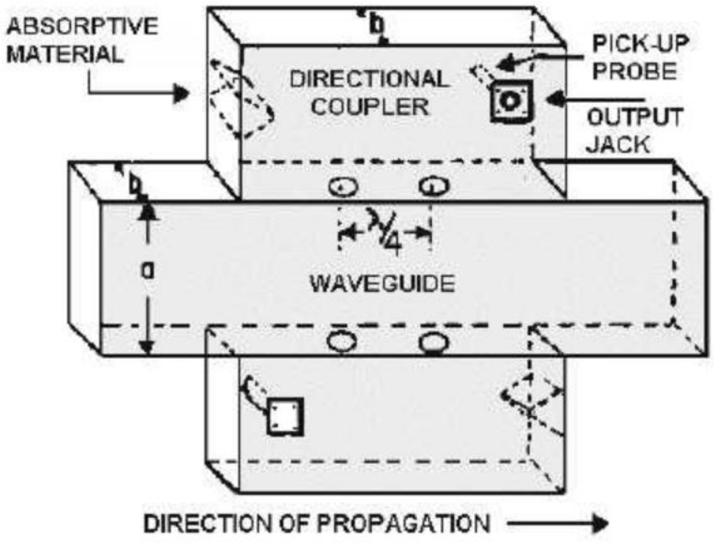


FOUR-PORT DIRECTIONAL COUPLER



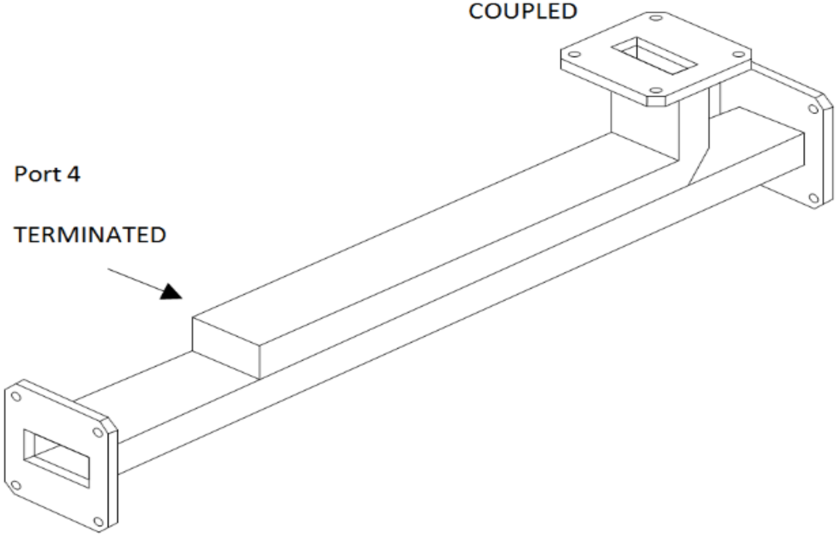
TWO-HOLE DIRECTIONAL COUPLER





MULTI-HOLE DIRECTIONAL COUPLERS(1)

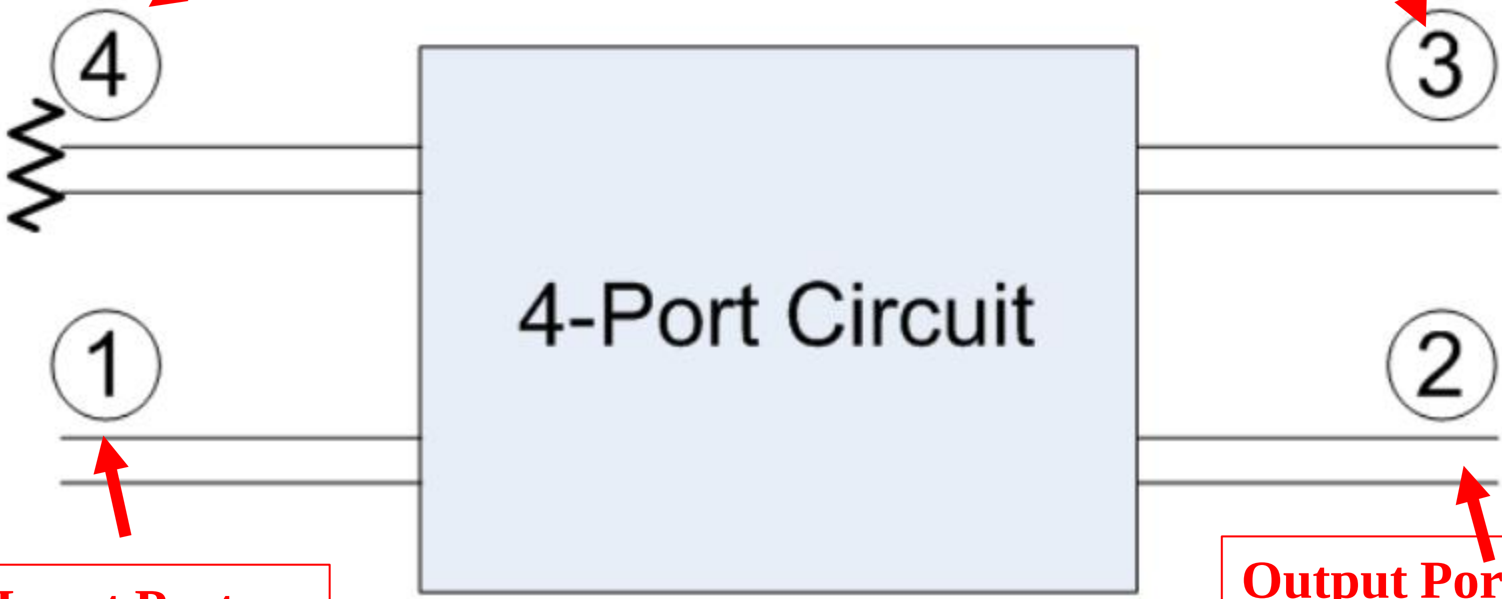
- **Multi-hole directional couplers** are assumed as four-port (Input, Output, Sampling/Coupled and Isolated/Terminated), devices which consisted of two transmission lines that are electromagnetically coupled to each other using more than two holes.



MULTI-HOLE DIRECTIONAL COUPLERS (2)

4. Isolated/Terminated
is internally is matched to damp the residual internally reflected waves from port 2 and port 3.

3. Coupled/Sampling
The rest of the input signal appears here.

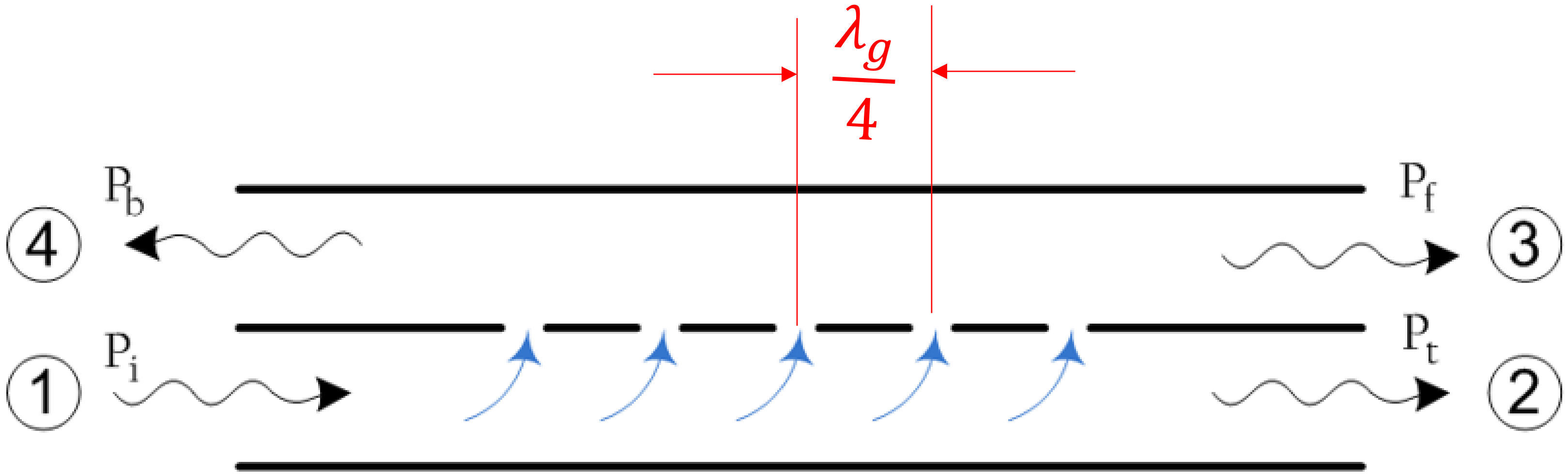


1. Input Port
Input Signal is applied here

Output Port
Part of input signal

MULTI-HOLE DIRECTIONAL COUPLERS (3)

The distances between holes should be about $\frac{\lambda_g}{4}$

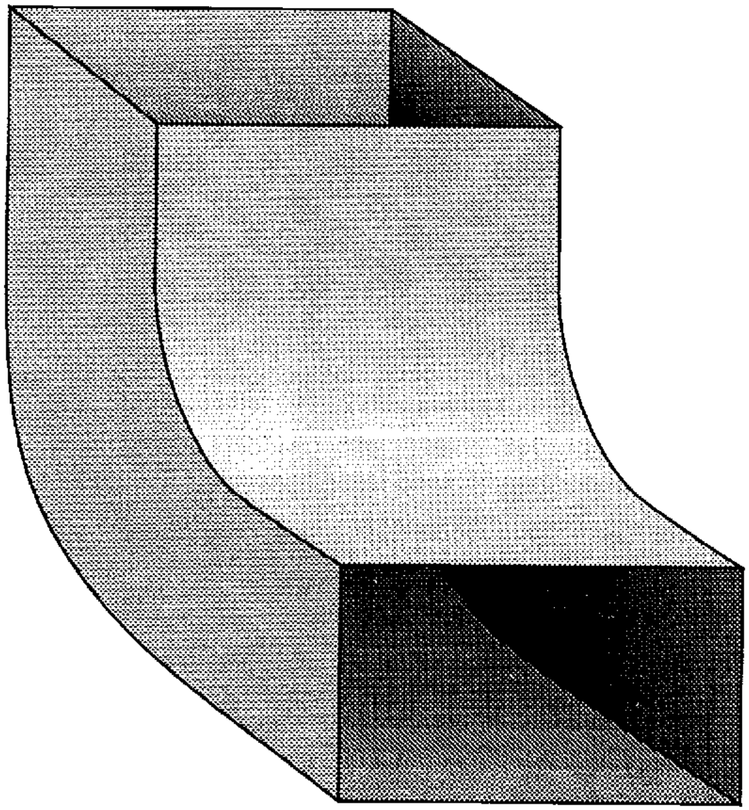


OTHER PASSIVE MICROWAVE COMPONENTS

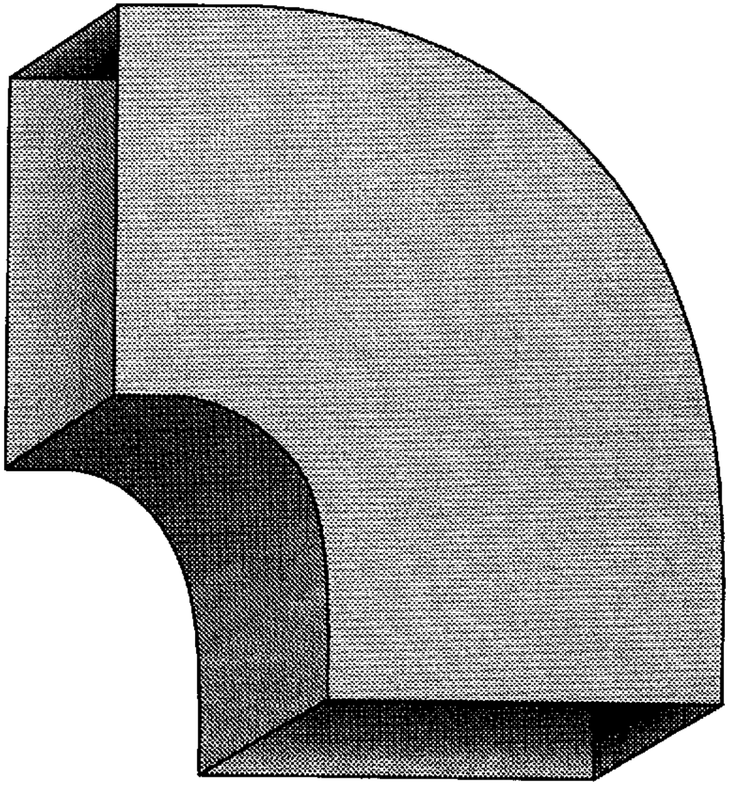
Other passive microwave components include:

- **Bends**
  - Called E-plane or H-Plane bends depending on the direction of bending
- **Tees**
  - Also have E and H-plane varieties
  - Hybrid or magic tee combines both and can be used for isolation

WAVEGUIDE BENDS



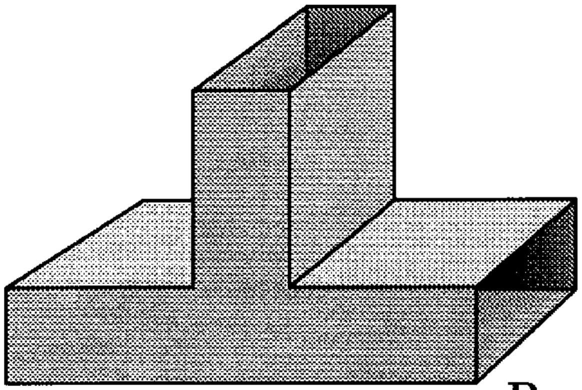
(a) E–Plane Bend



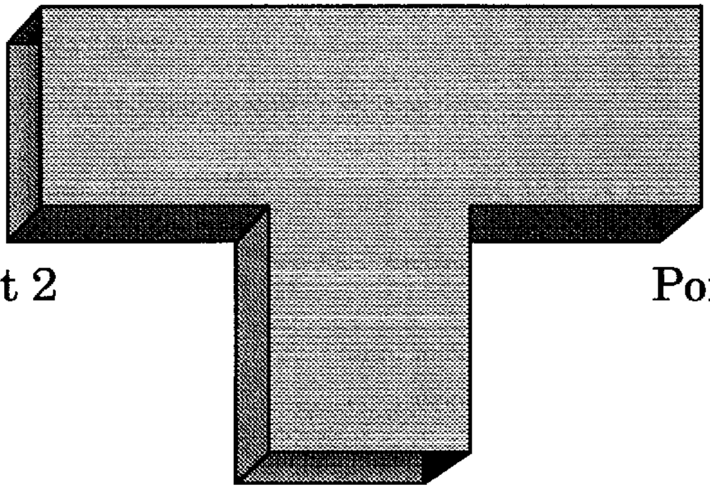
(b) H–Plane Bend

Transparency 258 (Figure 19.14)

WAVEGUIDE TEES



(a) E–Plane Tee

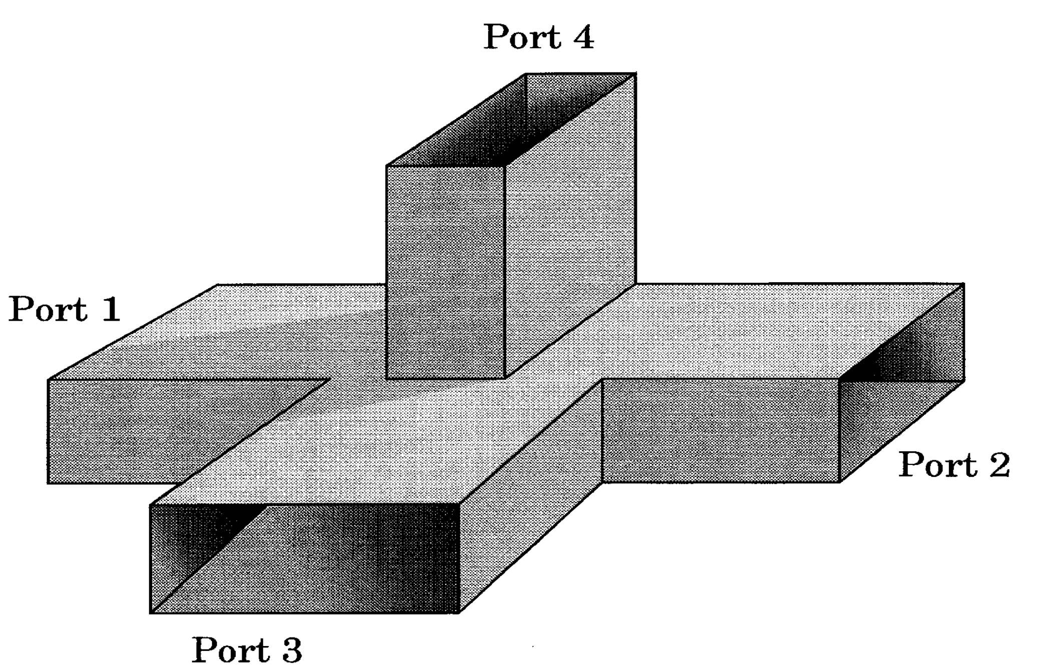


(b) H–Plane Tee

MICROWAVE HYBRID TEE

A Magic Tee junction is formed by attaching two simple waveguides one parallel and the other series, to a rectangular waveguide which already has two ports. This is also called an E-H Plane Tee junction or Hybrid or 3dB coupler.

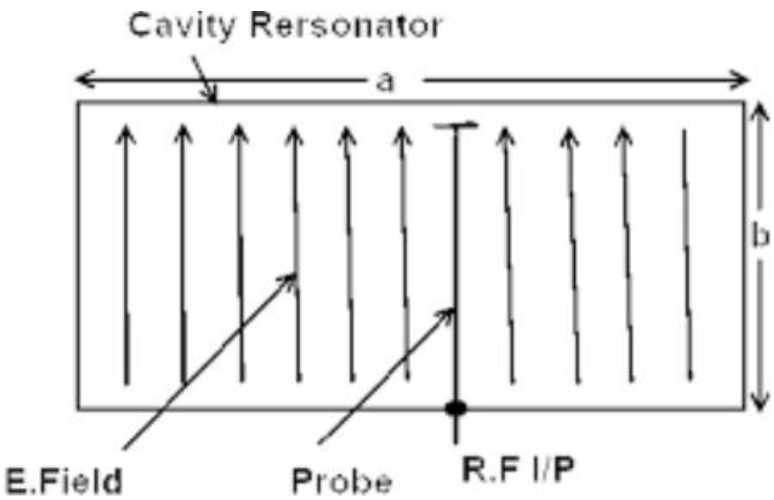
Hybrid Tee



Transparency 260 (Figure 19.18)

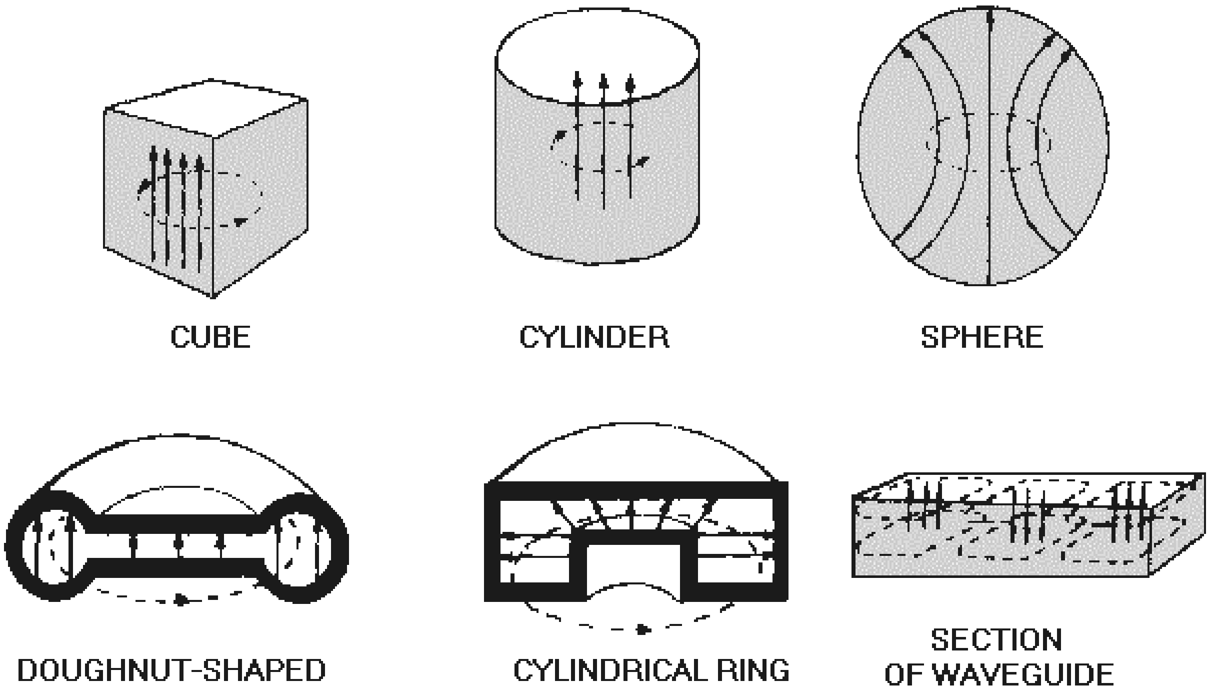
RESONANT CAVITY

1. A microwave cavity consists of a closed (or largely closed) metal structure that confines electromagnetic fields.
2. The structure is either hollow or filled with dielectric material.
3. At the cavity's resonant frequencies the waves reinforce to form standing waves in the cavity.
4. The cavity functions like an organ pipe or sound box in a musical instrument.



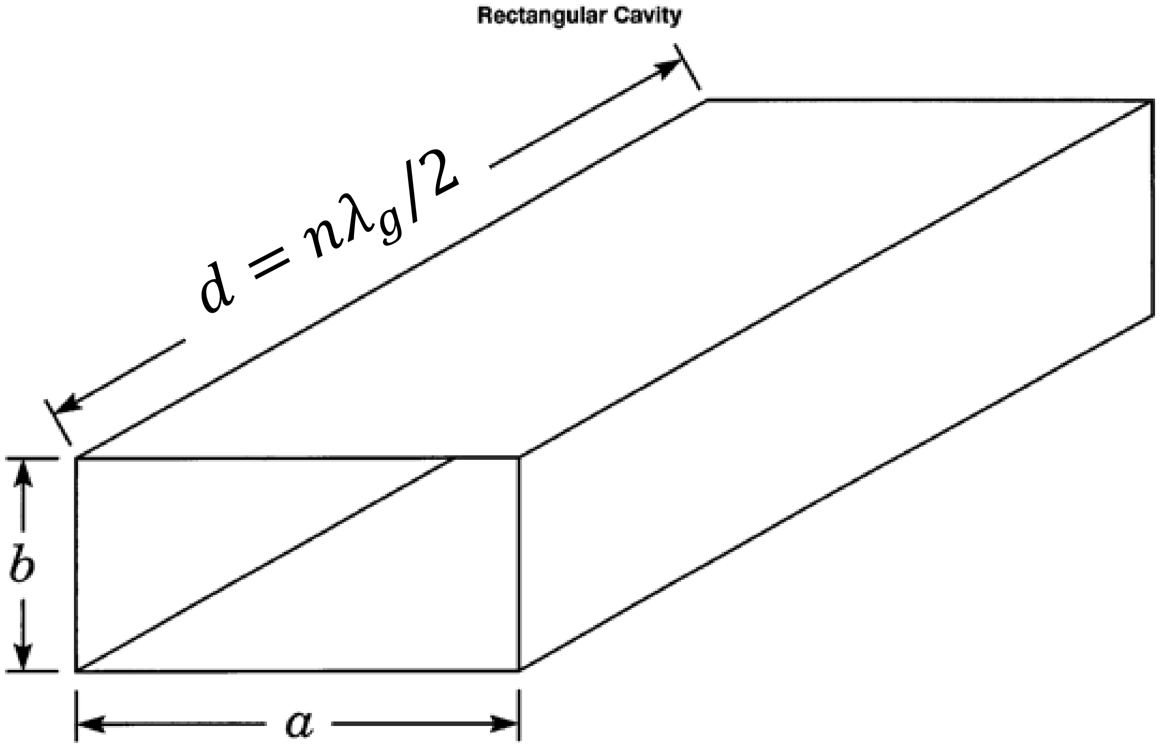
TYPES OF MICROWAVE CAVITIES

Microwave cavities can be cubes, cylinders, spheres or a combination.



RECTANGULAR RESONANT CAVITY

A rectangular cavity is formed by closing off one end of a rectangular waveguide width a, height b, and length d, where
$d \geq a \geq b$



ATTENUATORS AND LOADS

1. **Attenuator** is created by putting carbon vane or flap into the waveguide
2. Currents induced in the carbon cause loss
3. **Load** is similar but at end of guide.

(a) Fixed waveguide attenuator

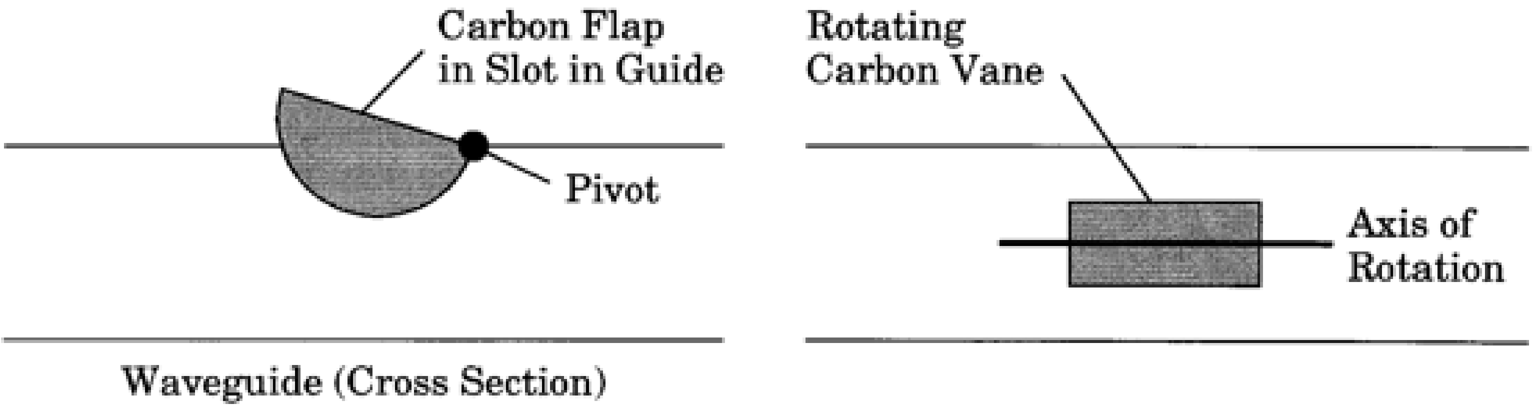
(b) Variable waveguide attenuator

MICROWAVE ATTENUATORS

Microwave attenuators are passive devices which control power levels in microwave system by absorption of the signal. They may be fixed or variable.

Fixed attenuators are used to lower the amplitude balance to enable measurements, or to protect the measuring device from signal levels that could be damaging.

Variable attenuations may be operated with a multi-turn screwdriver-slotted shaft, turns counting dial, knob control dial option.



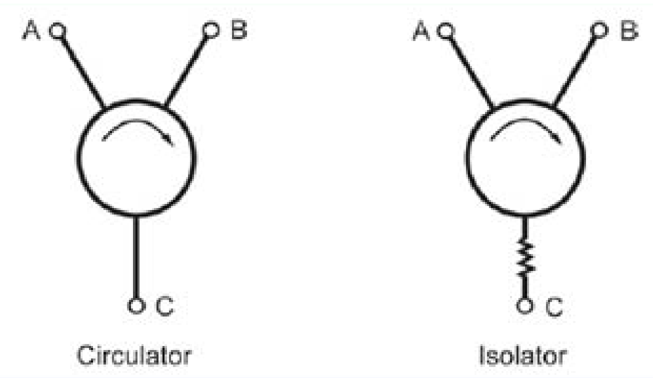
(a) Flap (b) Rotating Vane

CIRCULATOR AND ISOLATOR

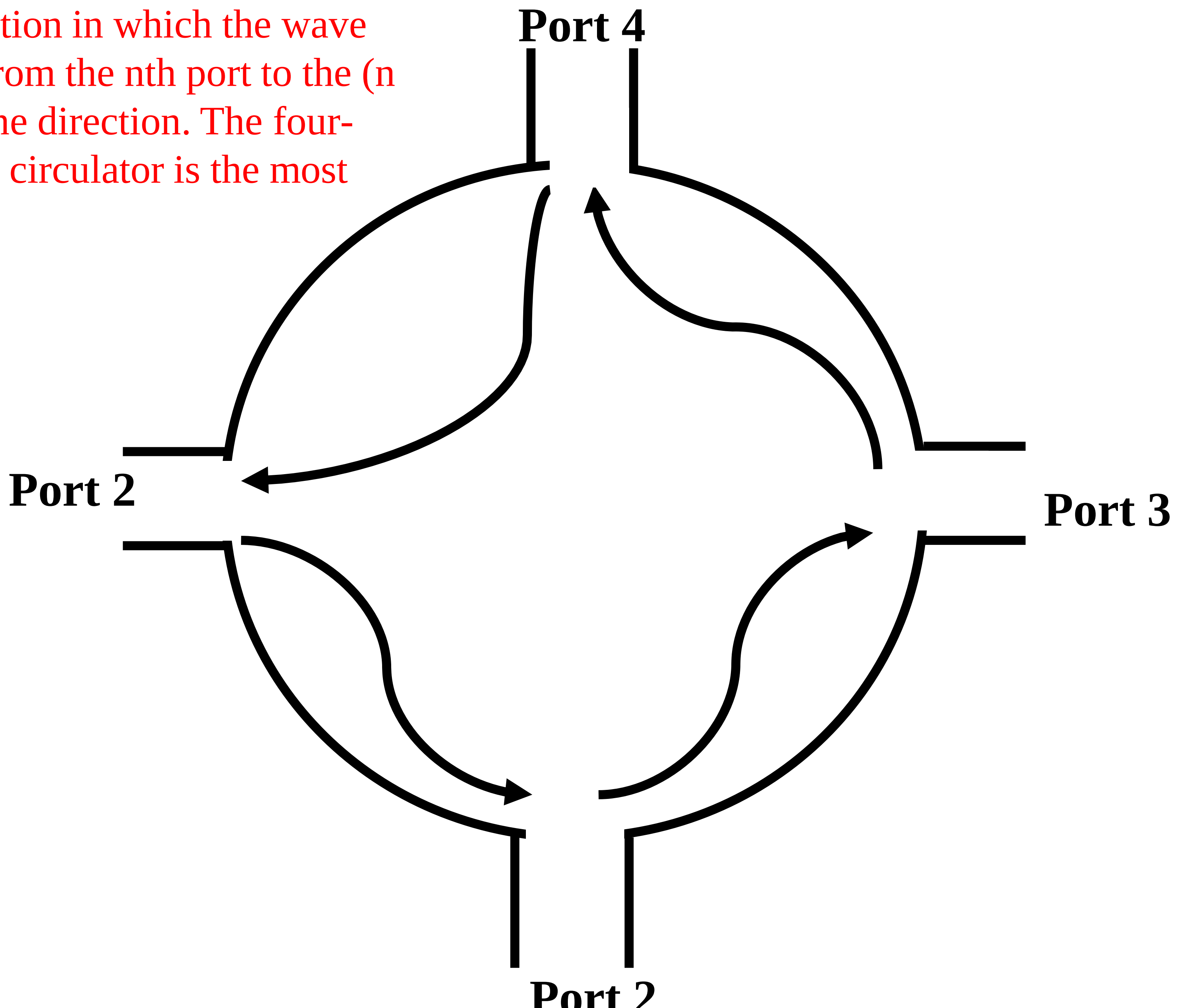
- **Circulators and isolators** use the unique properties of ferrites in a magnetic field.

- **Isolator** passes signals in one direction, attenuates in the other.

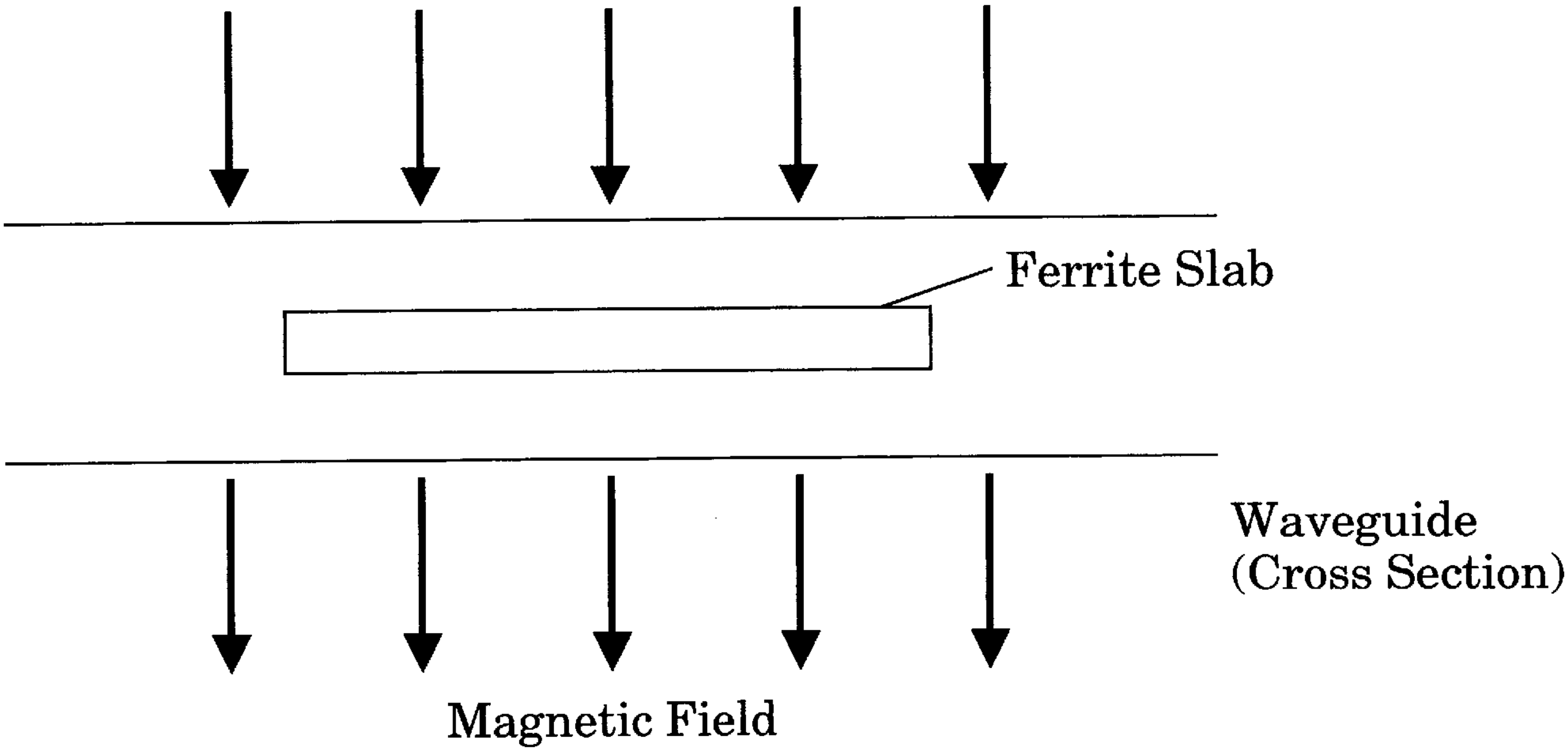
- **Circulator** passes input from each port to the next around the circle, not to any other port.



A microwave circulator is a multiport waveguide junction in which the wave can flow only from the nth port to the (n + 1)th port in one direction. The four-port microwave circulator is the most common.



FERRITE ISOLATOR



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