Microwaves

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Uses of Microwaves

- Cooking
- Communication
  - Radios
  - Satellites
  - RADAR
- Medicine

How A Microwave Oven Works

Electricity flows from the wall, through fuses and safety mechanism to the controller

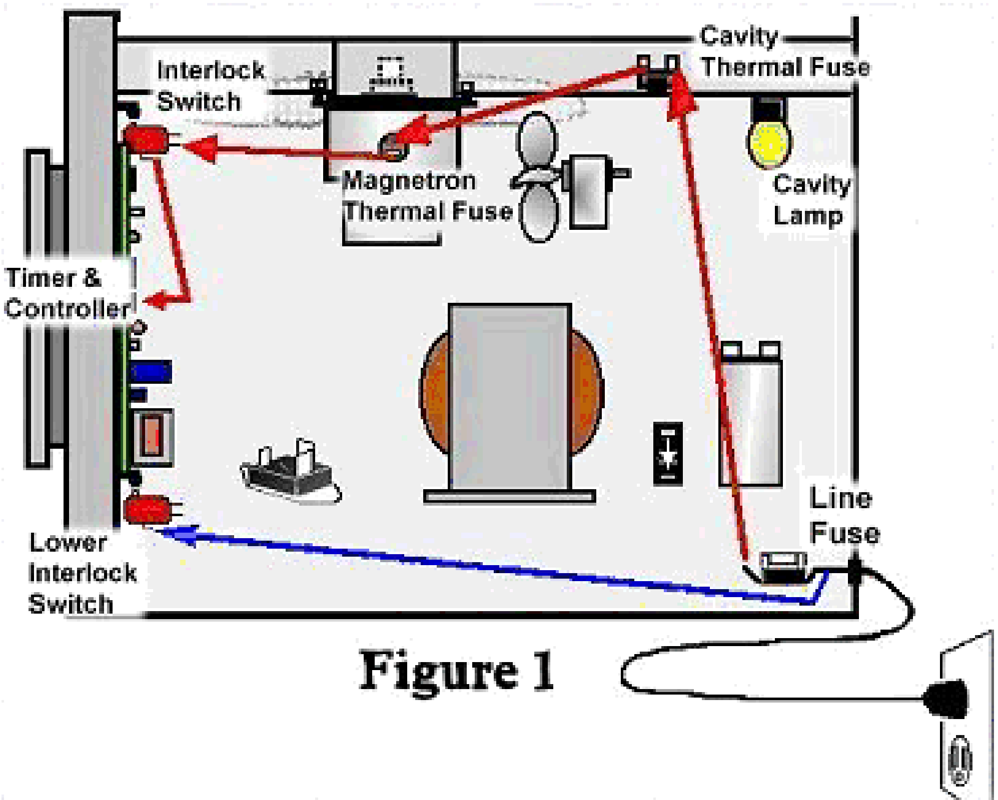


Figure 1

How A Microwave Oven Works

When the controller says to go, the triac activates, sending power to the high voltage transformer (About 3000-4000 V)

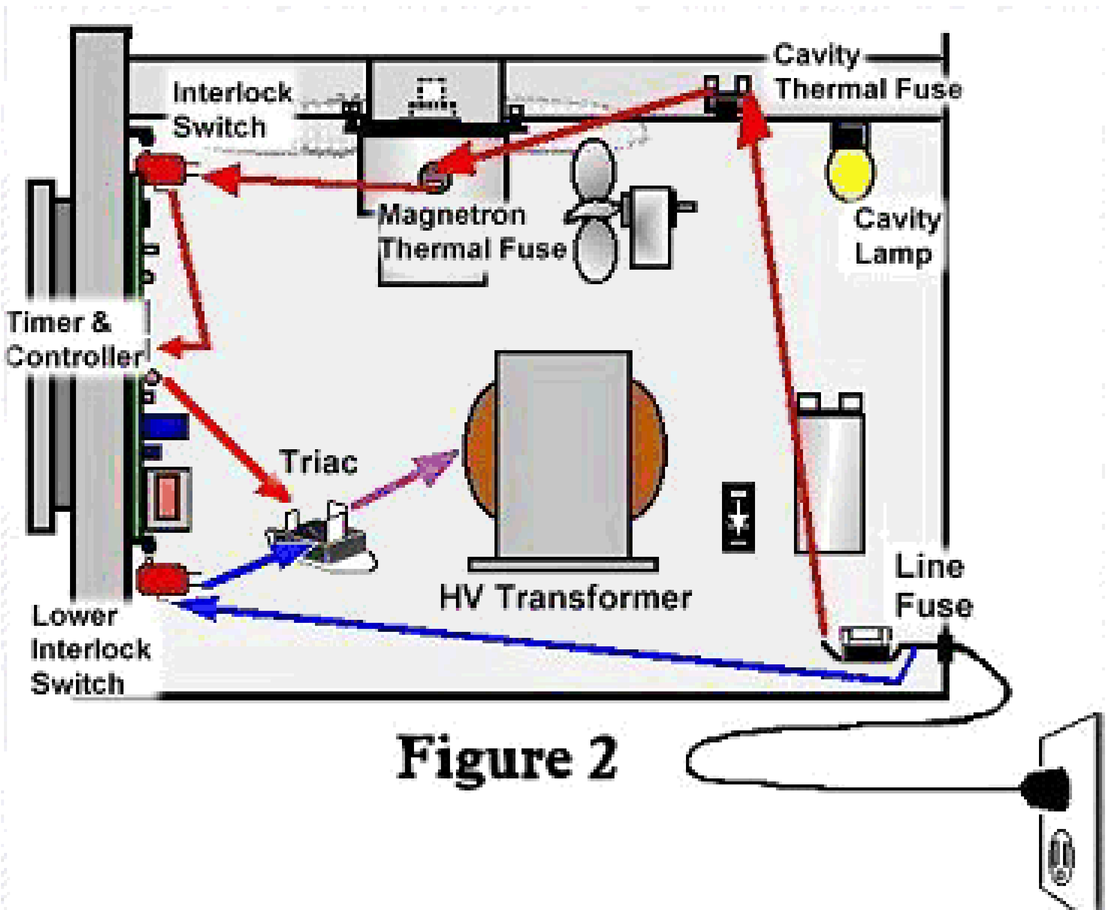


Figure 2

How A Microwave Oven Works

- The magnetron tube transforms the high voltage into electromagnetic energy
- A waveguide guides the microwaves into the cooking chamber
- A stirring blade spreads the microwaves evenly

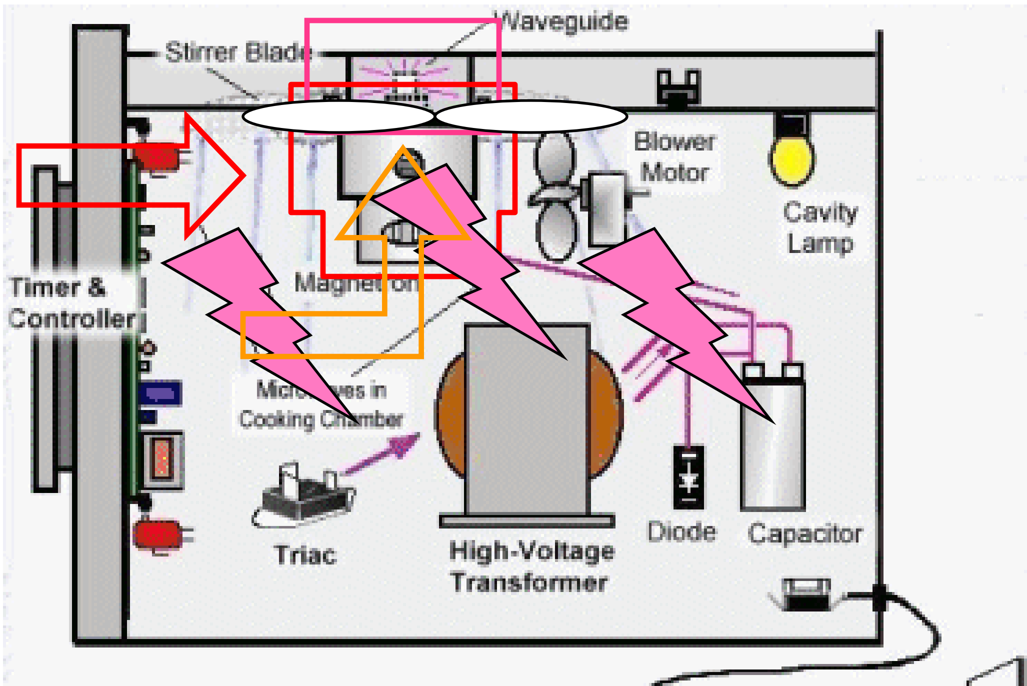
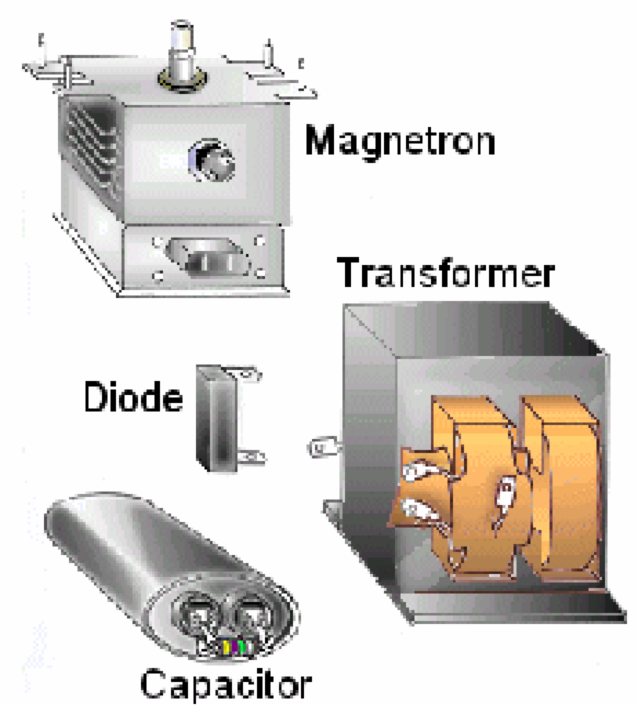
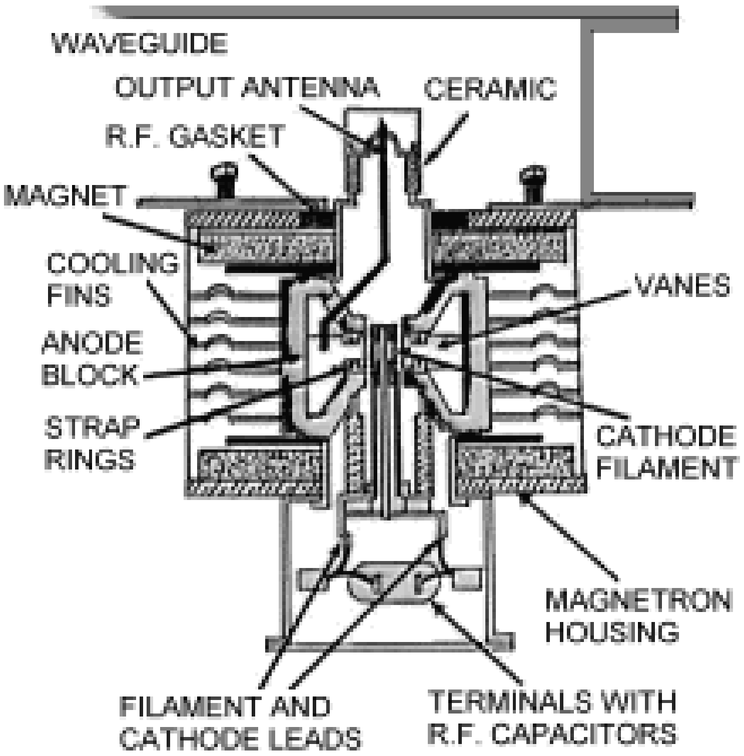


Figure 3

High Voltage Components

- Several components needed
- The Magnetron is the heart of the microwave
  - 2450 MHz





- 2450 MHz happened to be available
- RF Leakage

Normal Microwave Use

- RF energy excites water molecules
- Water molecules rotate on poles, friction with neighbor molecules
- Friction forces molecules to retain energy, otherwise it would just radiate energy away

16-1: Microwave Concepts

- **Microwaves** are the ultrahigh, superhigh, and extremely high frequencies directly above the lower frequency ranges where most radio communication now takes place and below the optical frequencies that cover infrared, visible, and ultraviolet light.

16-1: Microwave Concepts

Microwave Frequencies and Bands

- The practical microwave region is generally considered to extend from 1 to 30 GHz, although frequencies could include up to 300 GHz.
- Microwave signals in the 1- to 30-GHz have wavelengths of 30 cm to 1 cm.
- The microwave frequency spectrum is divided up into groups of frequencies, or **bands.**
- Frequencies above 40 GHz are referred to as **millimeter (mm) waves** and those above 300 GHz are in the **submillimeter** band.

16-1: Microwave Concepts

Figure 16-1: Microwave frequency bands.

Band designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
K_u band	12 to 18 GHz
K band	18 to 26.5 GHz
K_a band	26.5 to 40 GHz
Q band	30 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz
Submillimeter	>300 GHz

Millimeter waves (U band through Submillimeter)

16-1: Microwave Concepts

Benefits of Microwaves

- Moving into higher frequency ranges has helped to solve the problem of spectrum crowding.
- Today, most new communication services are assigned to the microwave region.
- At higher frequencies there is a greater bandwidth available for the transmission of information.
- Wide bandwidths make it possible to use various multiplexing techniques to transmit more information.
- Transmission of high-speed binary information requires wide bandwidths and these are easily transmitted on microwave frequencies.

16-1: Microwave Concepts

Disadvantages of Microwaves

- The higher the frequency, the more difficult it becomes to analyze electronic circuits.
- At microwave frequencies, conventional components become difficult to implement.
- Microwave signals, like light waves, travel in perfectly straight lines. Therefore, communication distance is limited to line-of-sight range.
- Microwave signals penetrate the ionosphere, so multiple-hop communication is not possible.

16-1: Microwave Concepts

Microwave Communication Systems

- Like any other communication system, a microwave communication system uses transmitters, receivers, and antennas.
- The same modulation and multiplexing techniques used at lower frequencies are also used in the microwave range.
- The RF part of the equipment, however, is physically different because of the special circuits and components that are used to implement the components.

16-1: Microwave Concepts

Microwave Communication Systems: Transmitters

- Like any other transmitter, a microwave transmitter starts with a carrier generator and a series of amplifiers.
- It also includes a modulator followed by more stages of power amplification.
- The final power amplifier applies the signal to the transmission line and antenna.
- A transmitter arrangement could have a mixer used to up-convert an initial carrier signal with or without modulation to the final microwave frequency.

16-1: Microwave Concepts

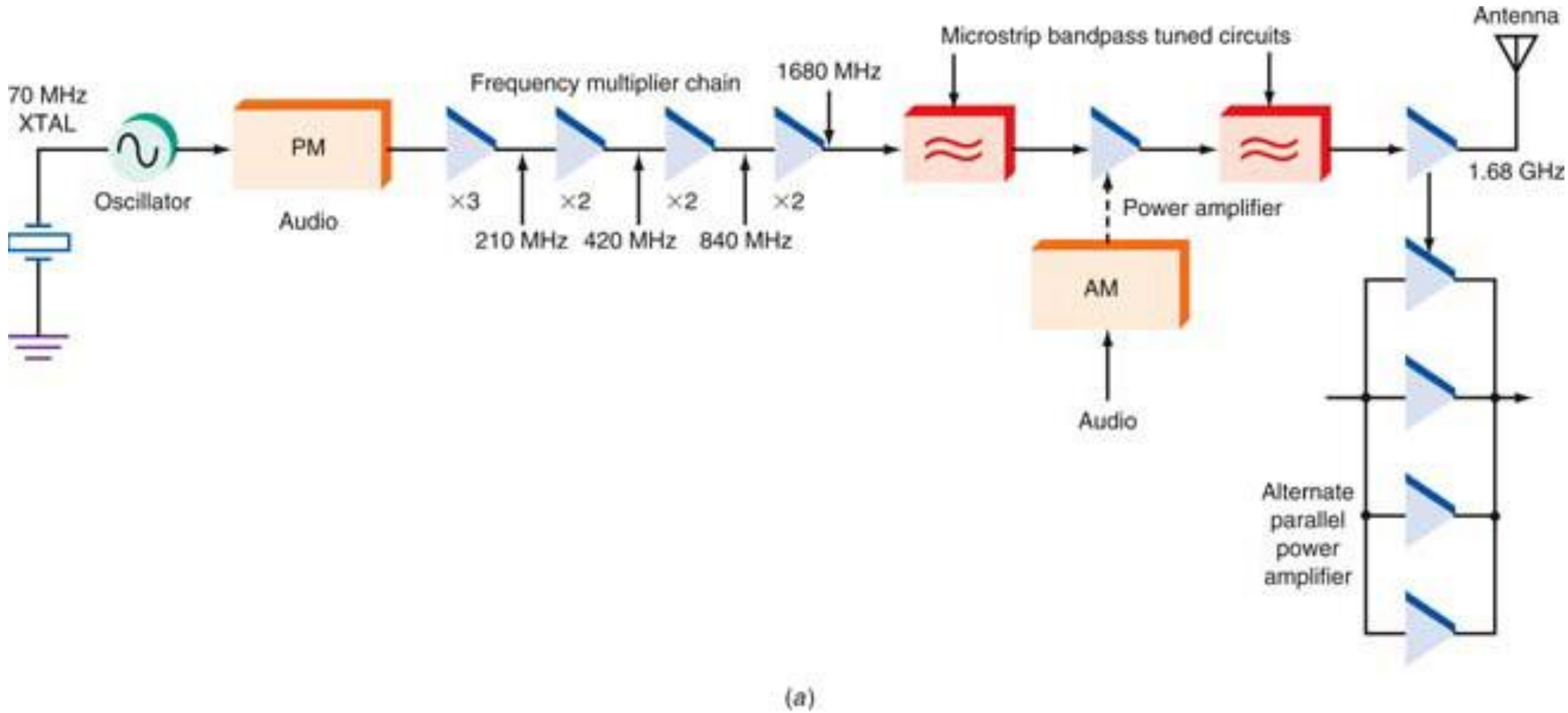


Figure 16-3: Microwave transmitters. (*a*) Microwave transmitter using frequency multipliers to reach the microwave frequency. The shaded stages operate in the microwave region.

16-1: Microwave Concepts

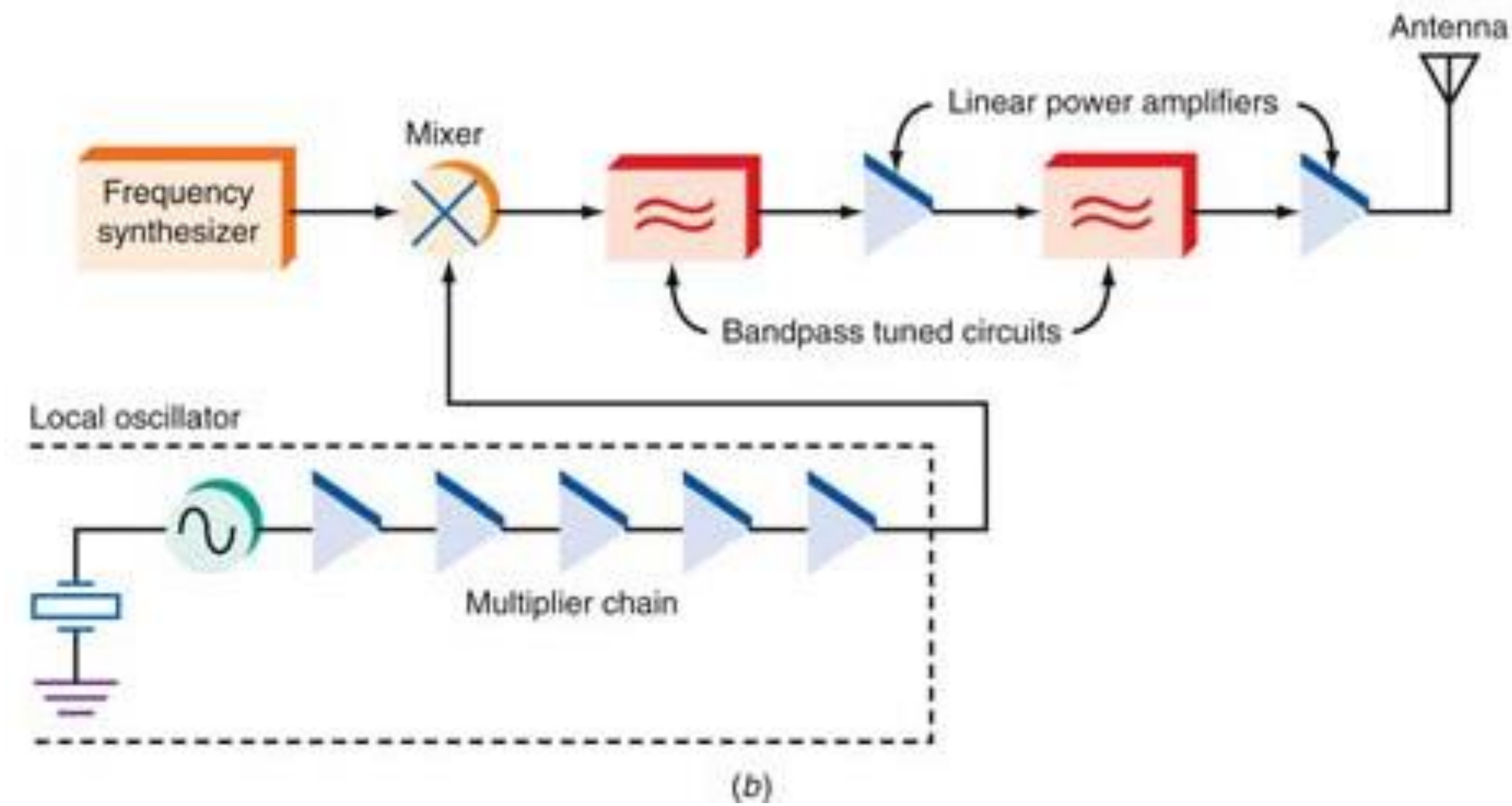


Figure 16-3: Microwave transmitters. (*b*) Microwave transmitter using up-conversion with a mixer to achieve an output in the microwave range.

16-1: Microwave Concepts

Microwave Communication Systems: Receivers

- Microwave receivers, like low-frequency receivers, are the superheterodyne type.
- Their front ends are made up of microwave components.
- Most receivers use double conversion.

16-1: Microwave Concepts

Microwave Communication Systems: Receivers

- The antenna is connected to a tuned circuit, which could be a cavity resonator or microstrip or stripline tuned circuit.
- The signal is then applied to a special RF amplifier known as a low-noise amplifier (LNA).
- Another tuned circuit connects the amplified input signal to the mixer.
- The local oscillator signal is applied to the mixer.
- The mixer output is usually in the UHF or VHF range.
- The remainder of the receiver is typical of other superheterodynes.

16-1: Microwave Concepts

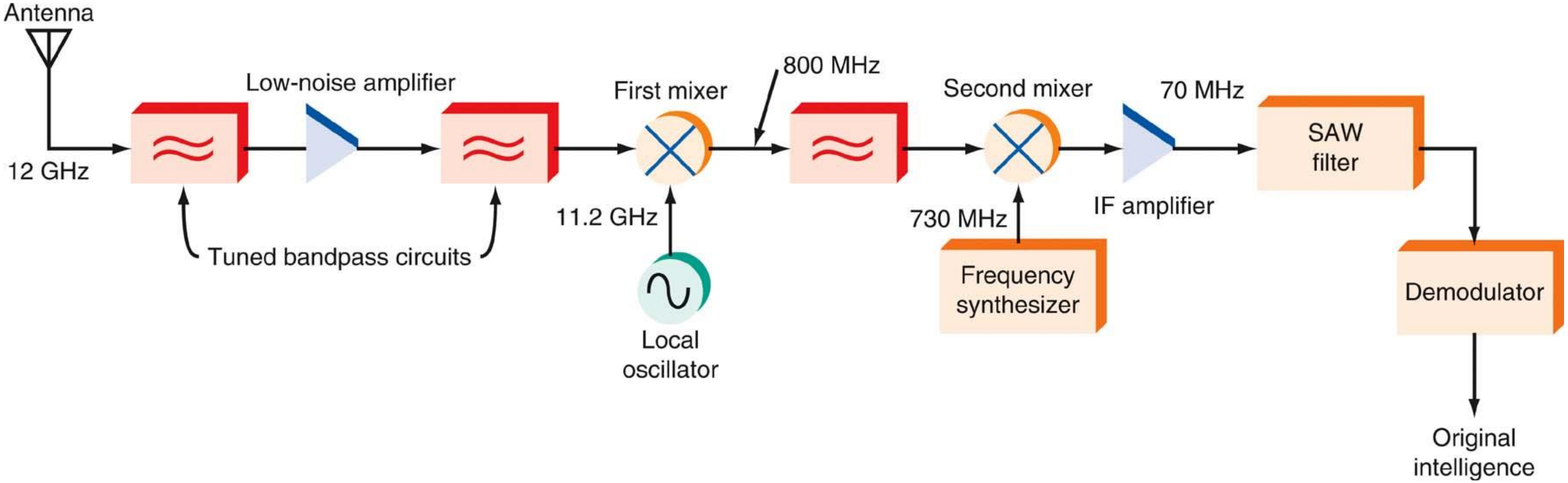


Figure 16-4: A microwave receiver. The shaded areas denote microwave circuits.

16-1: Microwave Concepts

Microwave Communication Systems: Transmission Lines

- Coaxial cable, most commonly used in lower-frequency communication has very high attenuation at microwave frequencies and conventional cable is unsuitable for carrying microwave signals.
- Special microwave coaxial cable that can be used on bands L, S, and C is made of hard tubing. This low-loss coaxial cable is known as **hard line cable.**
- At higher microwave frequencies, a special hollow rectangular or circular pipe called **waveguide** is used for the transmission line.

EP603

Microwave Devices

CHAPTER 1

WAVEGUIDE AND COMPONENTS

- Propagation mode of Electromagnetic Wave
- Microwave Waveguide & Transmission Line
- Characteristic of Waveguide
- Methods of Propagation Modes/ Excitation in Waveguides
- Discontinuities in Waveguide Components
- Attenuation in Waveguide Components

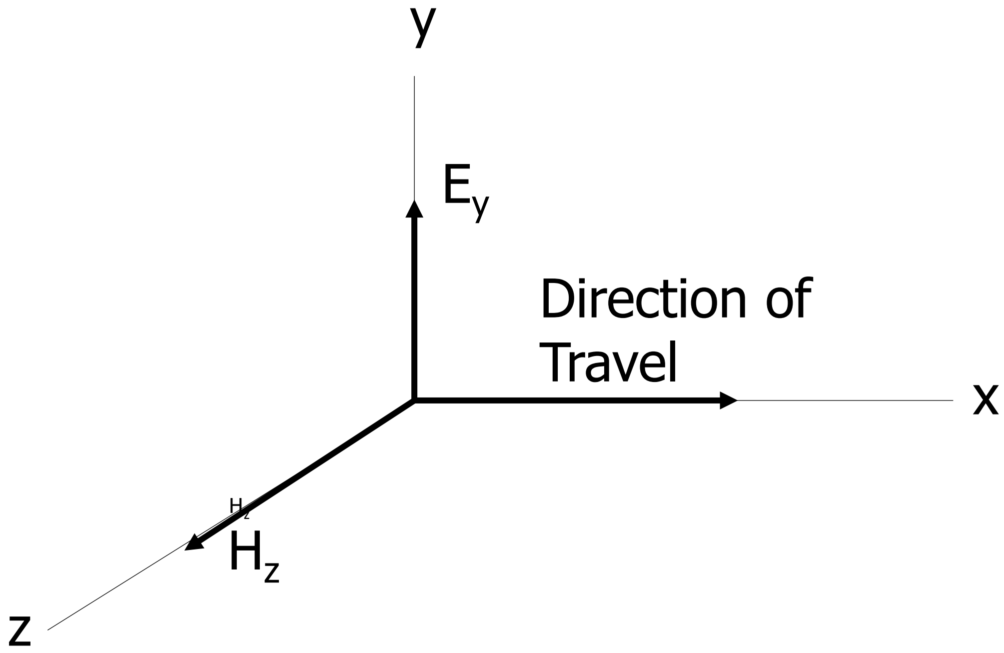
2.1 Propagation Mode of EM Wave

PROPAGATION MODE

- TEM
- TE
- TM

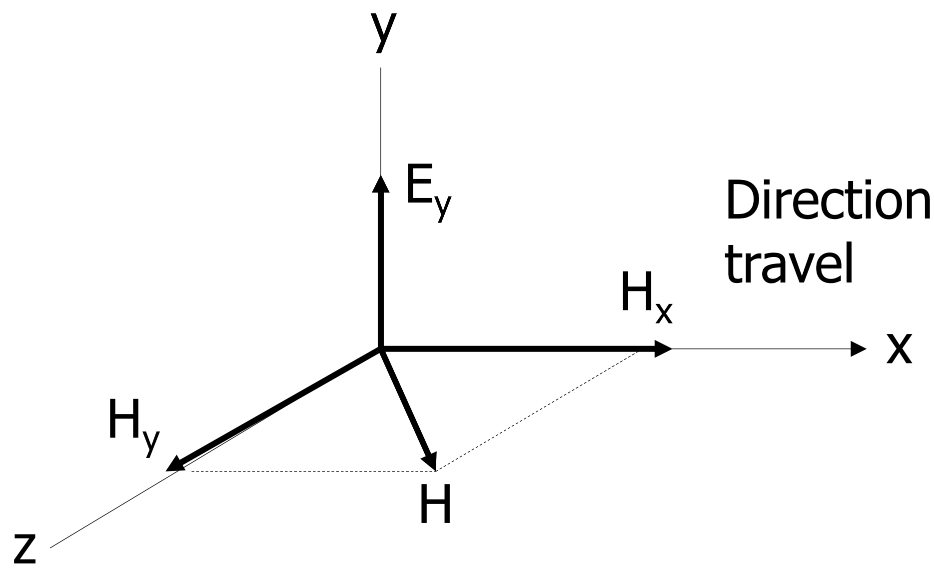
Transverse Electromagnetic (TEM)

- The electric field, E and the magnetic field, H are oriented transverse to the direction of propagation of wave.
- Exists in plane waves and transmission lines (2 conductors).
- No cut-off frequency.



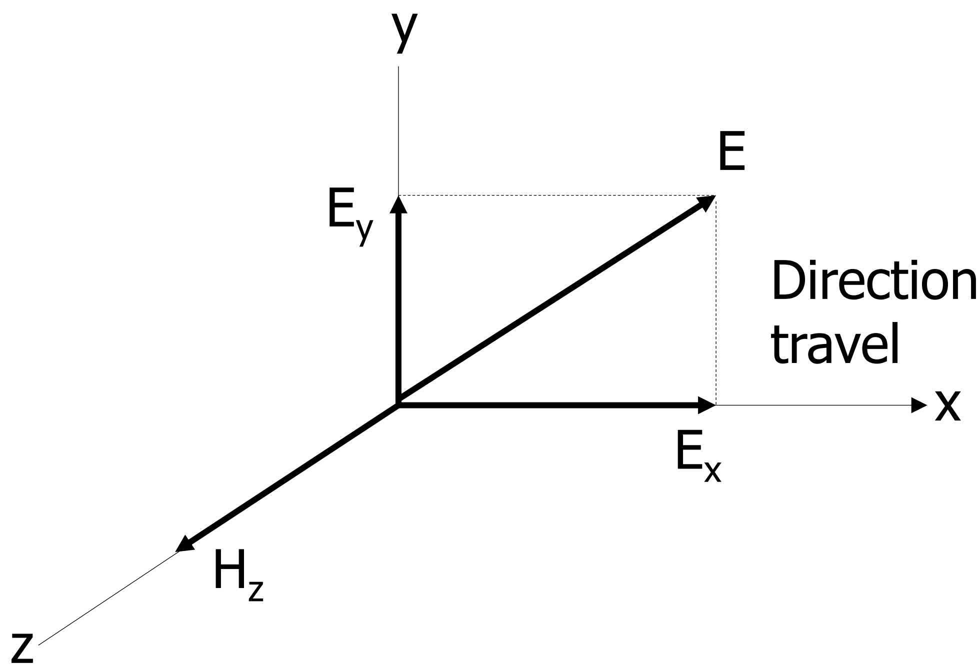
Transverse Electric (TE)

- The electric field, E is transverse to the direction of propagation of wave and the magnetic field, H has components transverse and in the direction of the wave.
- Exists in waveguide modes.



Transverse Magnetic (TM)

- The magnetic field, H is transverse to the direction of propagation of wave and the electric field, E has components transverse and in the direction of the wave.
- Exists in waveguide modes.



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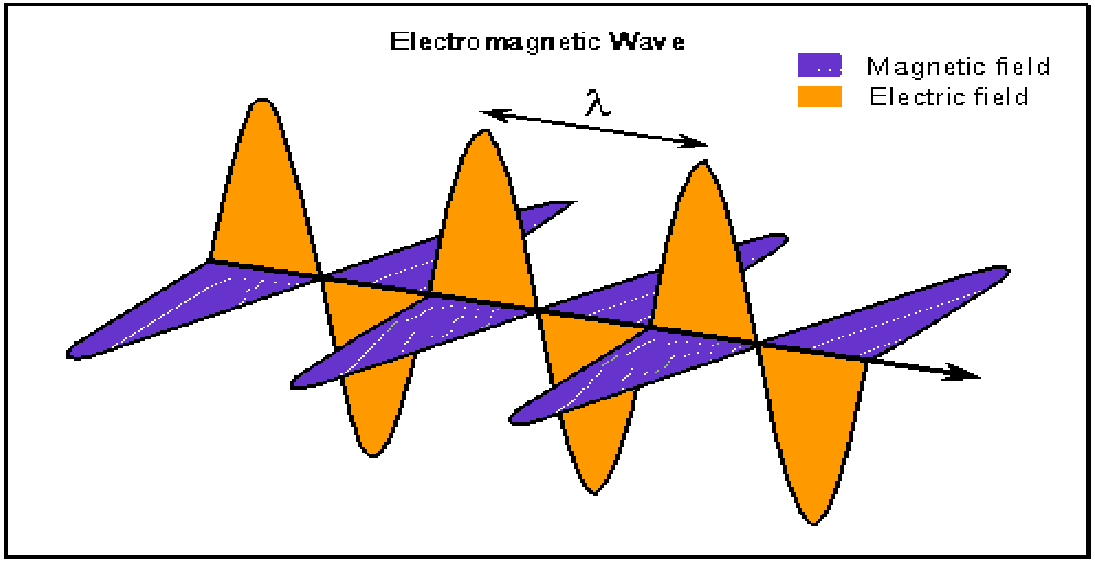
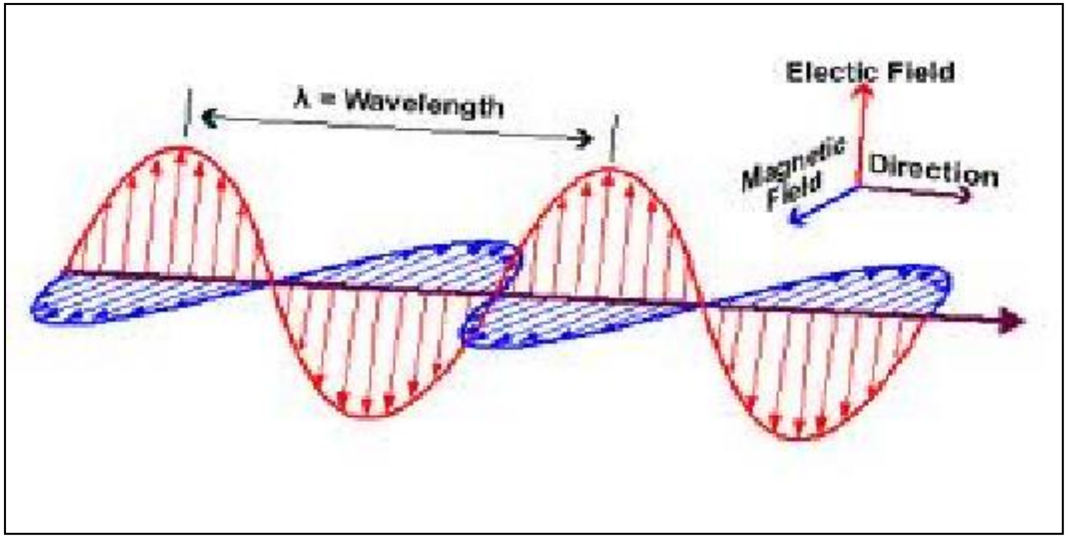

Electromagnetic Wave
Magnetic field
Electric field
λ


λ = Wavelength
Electic Field
Magnetic Field
Direction

Boundary Condition

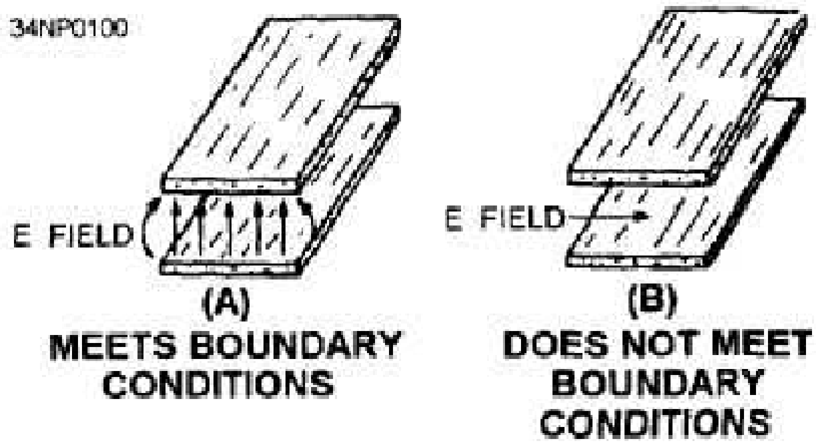
- It refers to the conditions that E-field and H-field within a waveguide must meet before energy travels down the waveguide.
- There are 2 conditions that must be met:

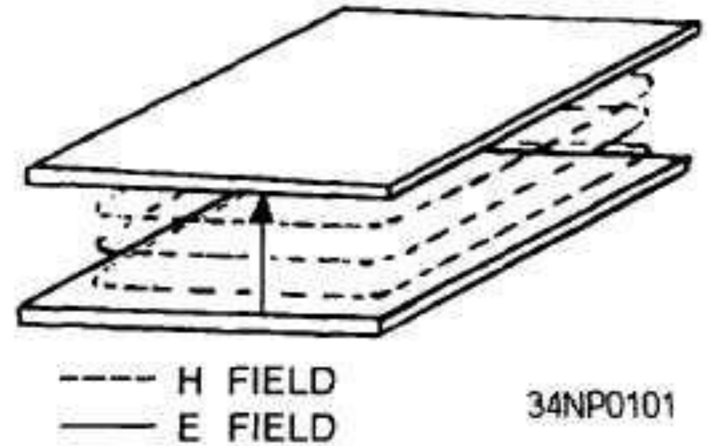
a) For an electric field to exist at the surface of a conductor, it must be perpendicular to the conductor. An electric field CANNOT exist parallel to a perfect conductor.

a) For a varying magnetic field to exist, it must form closed loops in parallel with the conductors and be perpendicular to the electric field.

- Energy travelling down a waveguide is similar to the electromagnetic waves travel in free space. The difference is that the energy in a waveguide is confined to the physical limits of the guide.

Cont.



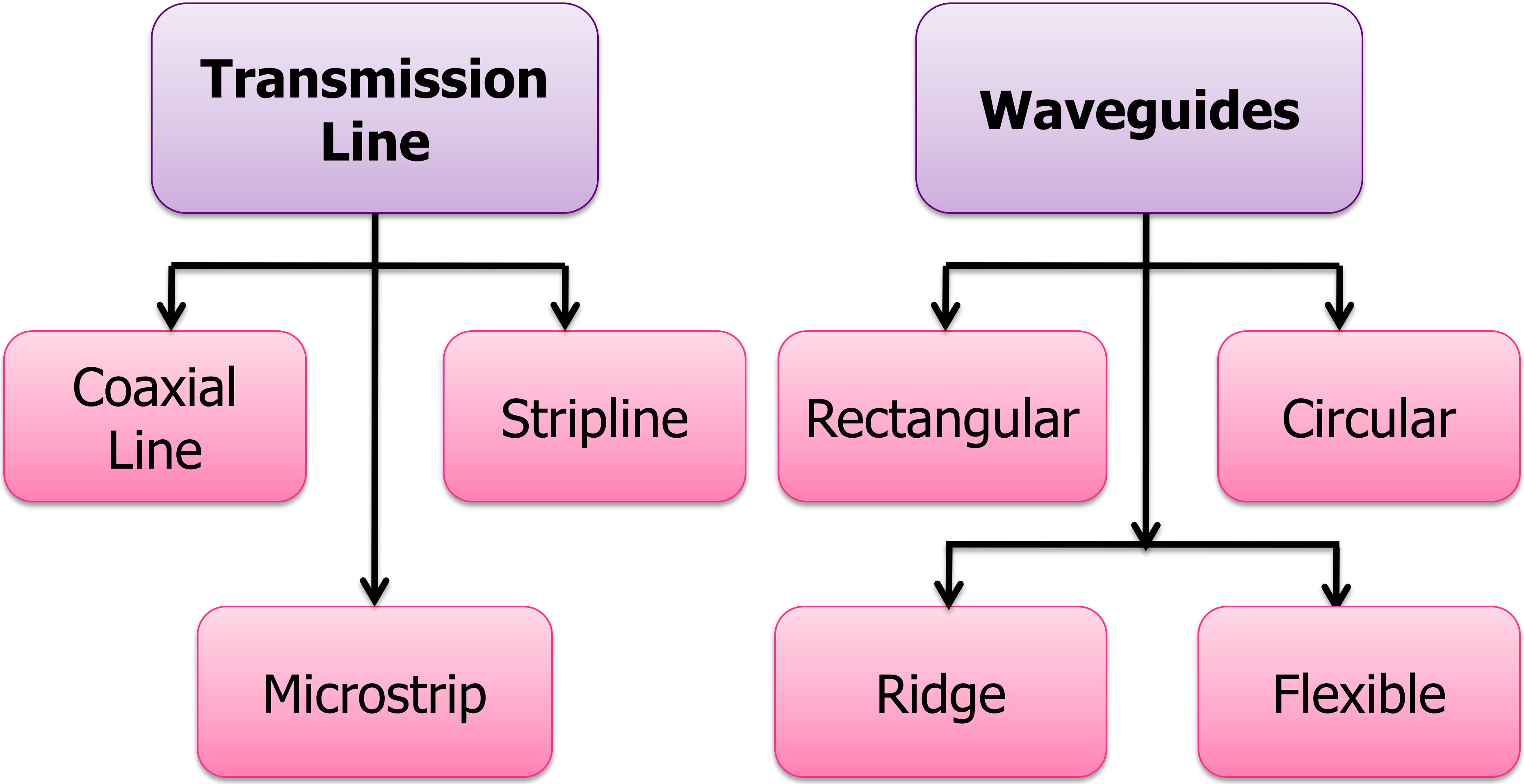


- Since E-field causes a current flow that in turn produces H-field, both fields always exist at the same time in a waveguide.
- If one field satisfies one of these boundary conditions, it must also satisfy the other since neither field can exist alone.

2.2 Waveguide & Transmission Line

- Waveguide: hollow metal tube used to guide e.m. energy from one point to another or through which e.m. waves propagate.
- Typically one enclosed conductor filled with an insulating medium.
- The transmission of e.m. energy along waveguide travels at velocity slower than e.m. energy traveling through free space.
- Transmission line: Two or more conductors separated by some insulating medium.

Cont.



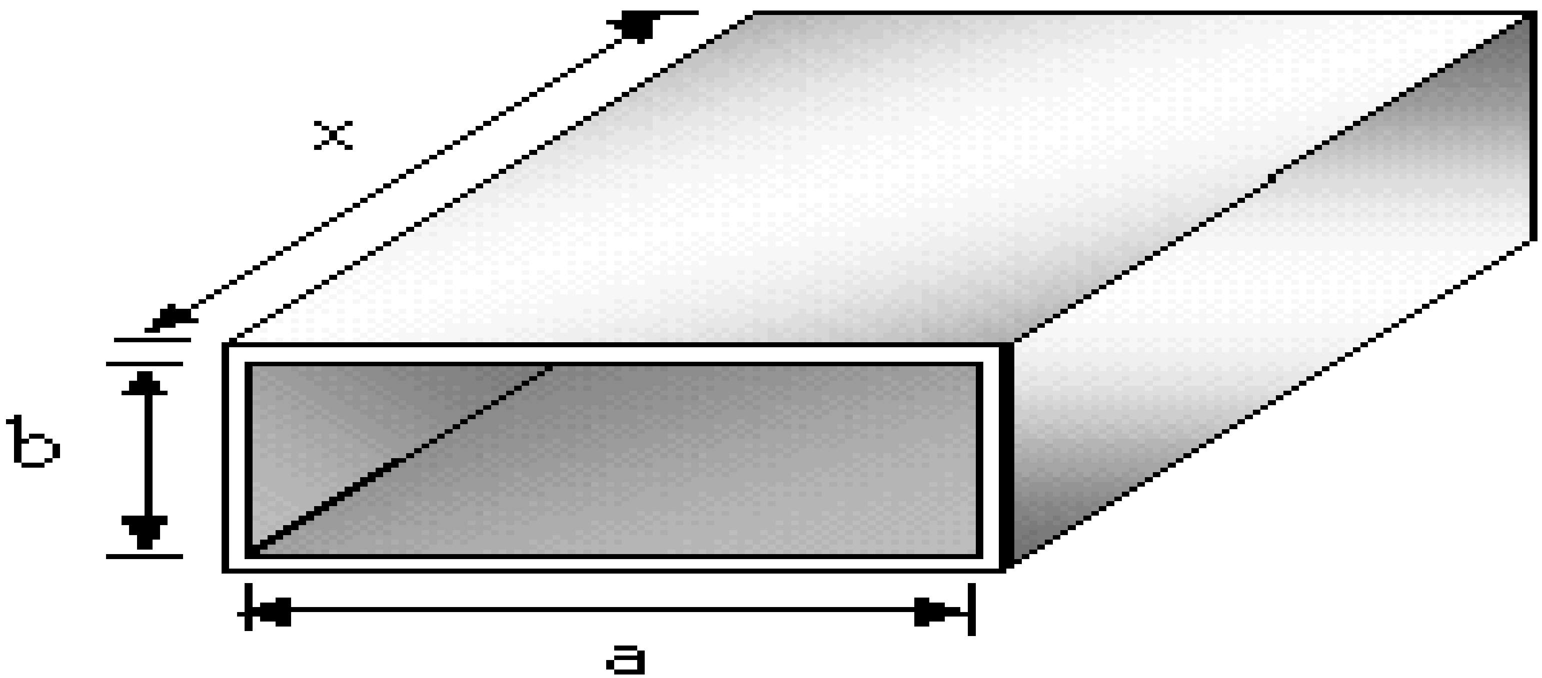
Transmission Line
Waveguides
Coaxial Line
Stripline
Microstrip
Rectangular
Circular
Ridge
Flexible

Rectangular Waveguide

- It consists of a hollow rectangular waveguide (rectangular cross section) that can propagate TM and TE modes but not TEM since only one conductor is present.
- The wall of the guides are conductors and therefore reflection from them may take place.
- Applications: high-power systems, millimeter wave applications, satellite systems, precision test applications.

Cont.

- It is a standard convention to have the longest side of the waveguide along x-axis [a (width) > b (length)]

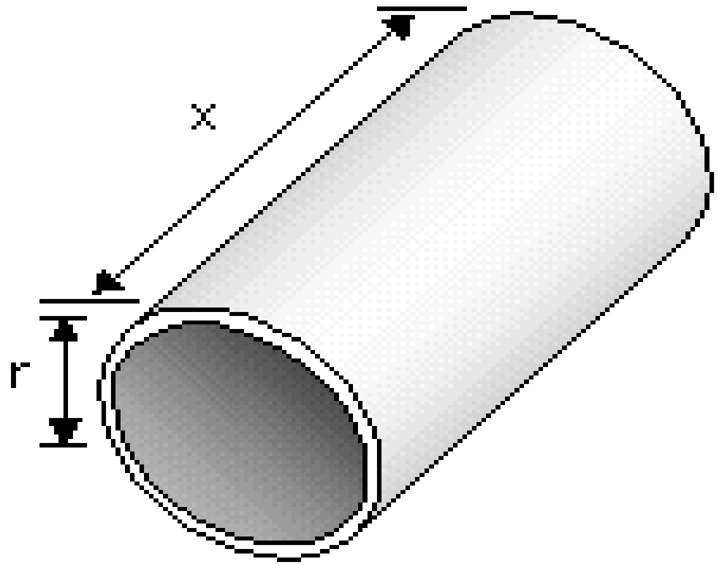


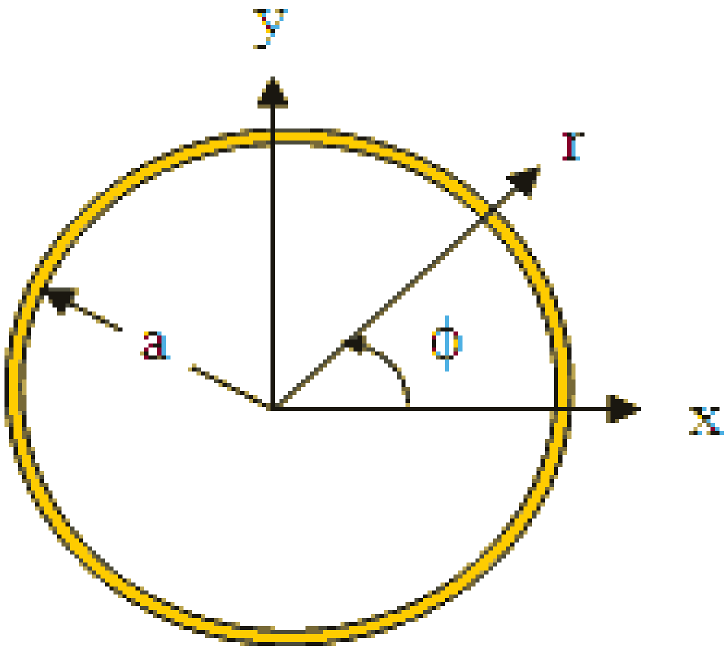
Circular Waveguide

- 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 (e.g.: isolators or attenuators) to rectangular waveguide.

Cont.

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

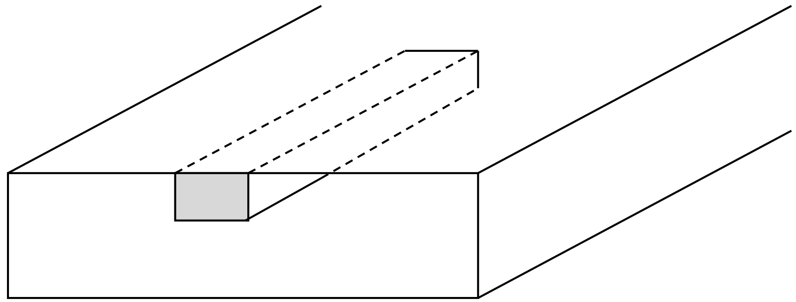




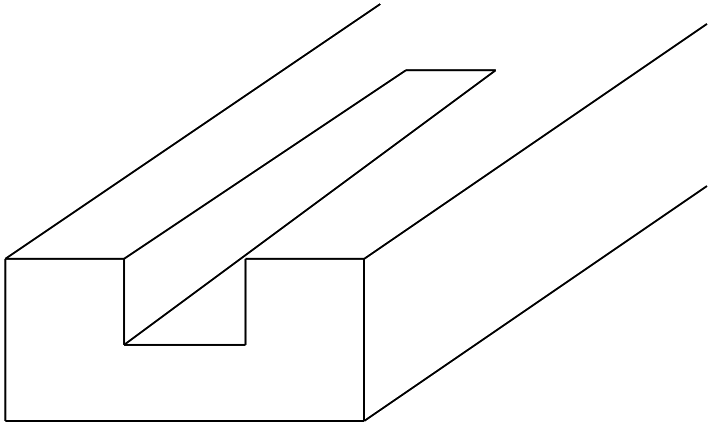
Ridge Waveguide

- It is formed with a rectangular ridge projecting inward from one or both of the wide walls in a rectangular waveguide.
- Ridge is used to concentrate the electric field across the ridge and to lower the cutoff frequency of TE_{10} mode.
- Applications: attractive for UHF and low microwave ranges.

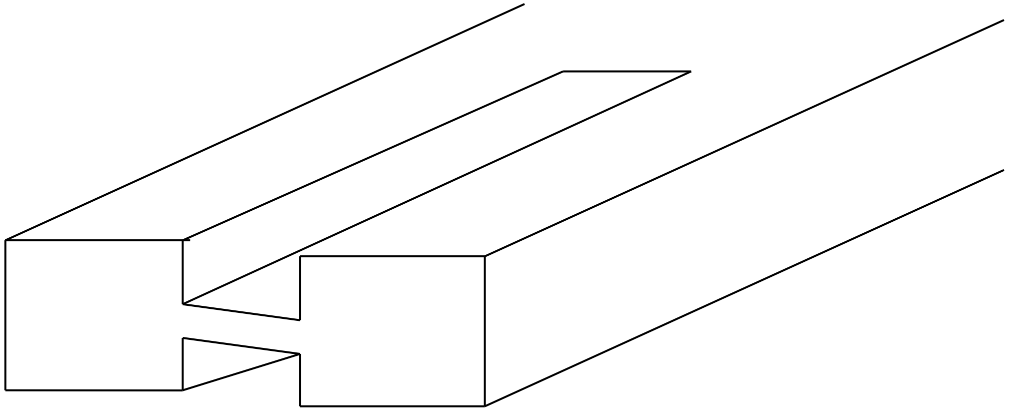
Cont.



Ridged Waveguide Using Metal Bar



Singled Ridged Waveguide

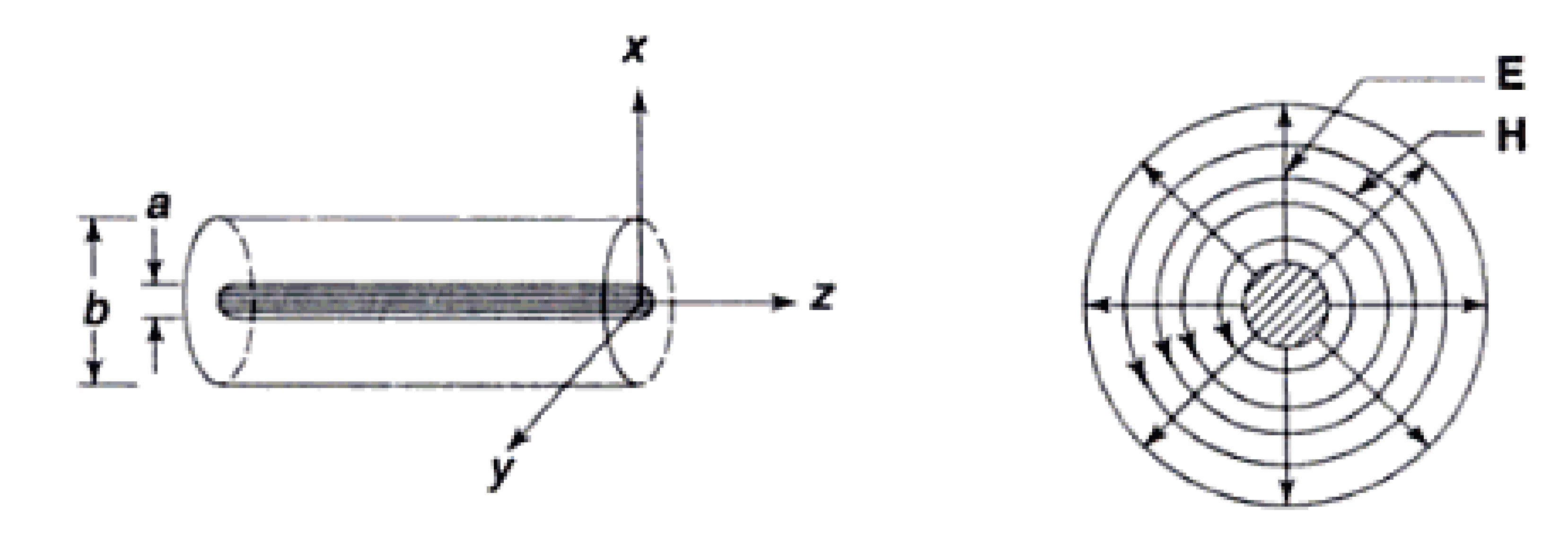


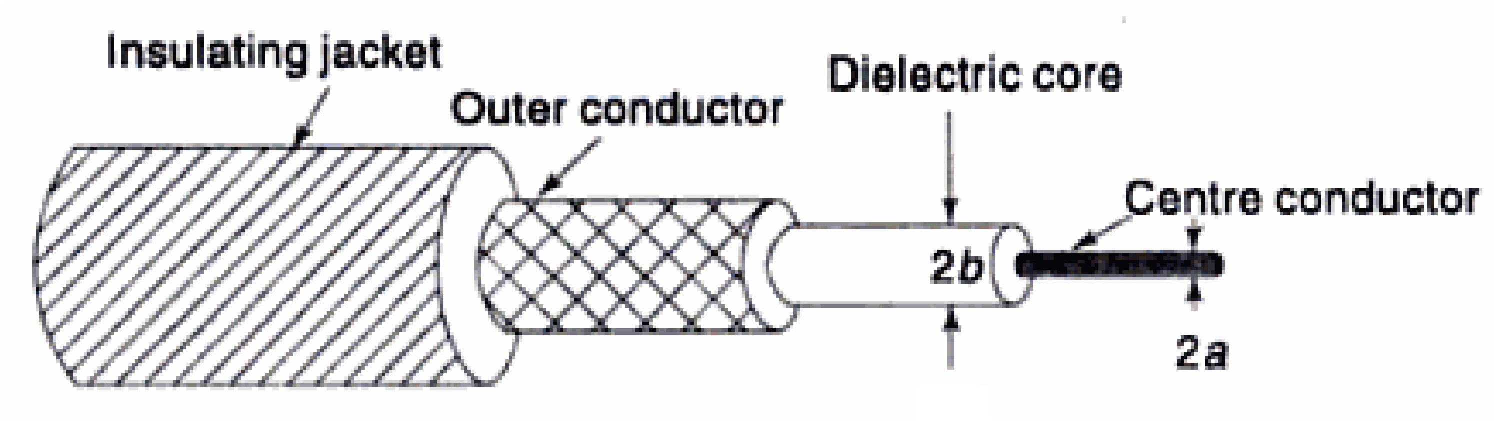
Double Ridged Waveguide

Coaxial Line

- Coaxial line: an electrical cable with an inner conductor surrounded by a flexible insulating layer, surrounded by a conducting shield (outer conductor).
- Microwaves travel through the flexible insulation layer.
- Applications: feed lines connecting radio transmitter and receivers with their antennas, computer network (internet) connections and distributing cable television(signal).

Cont.


x
a
b
z
y
E
H

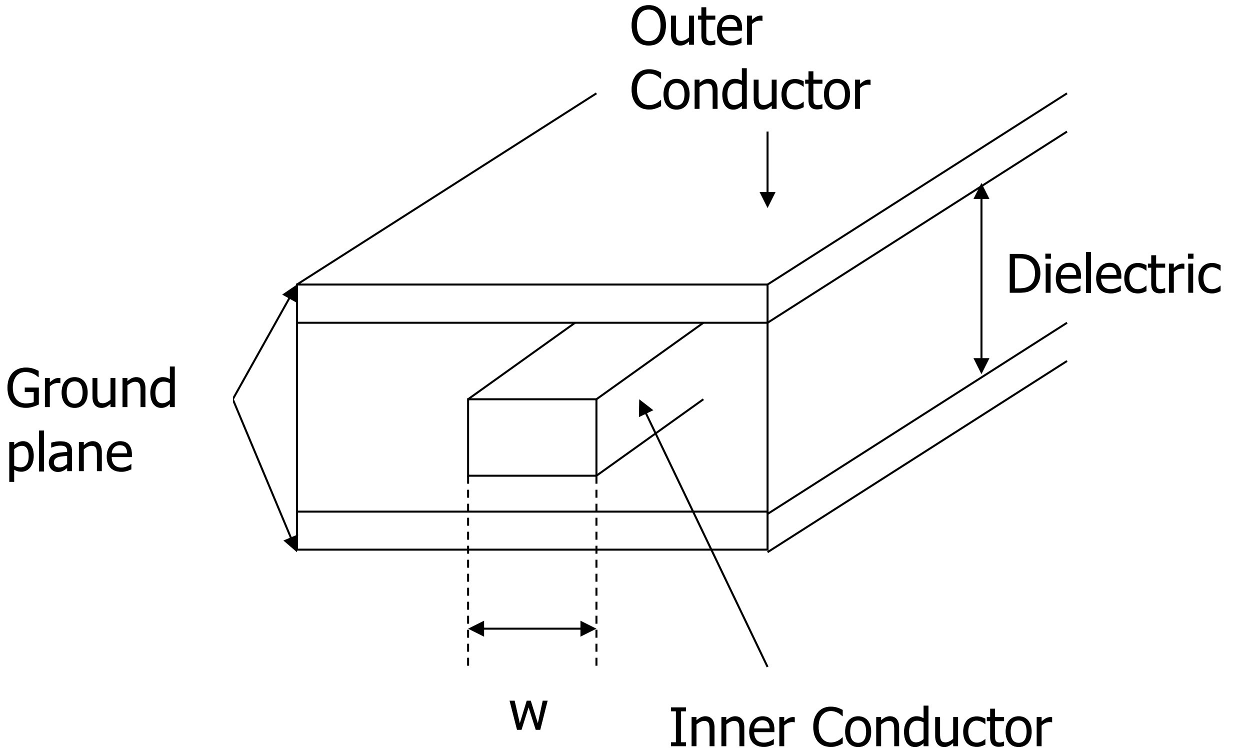

Insulating jacket
Outer conductor
Dielectric core
Centre conductor
2b
2a

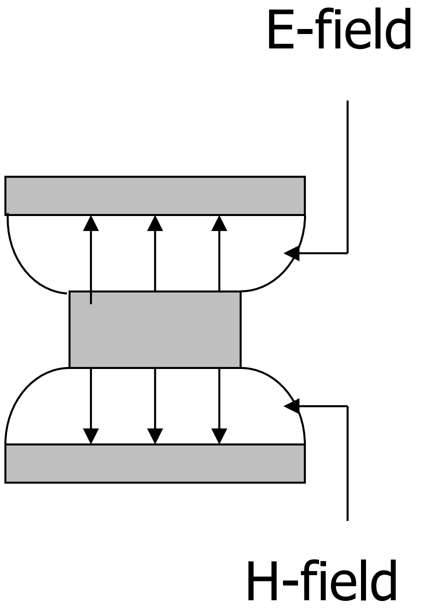
Strip Line

- It consists of a thin conducting strip of width W that is centered between two wide conducting ground planes.
- Dielectric material is placed on both sides of the strip conductor.

- Applications: used inside of the microwave devices themselves (e.g.: microwave integrated circuitry).

Cont.

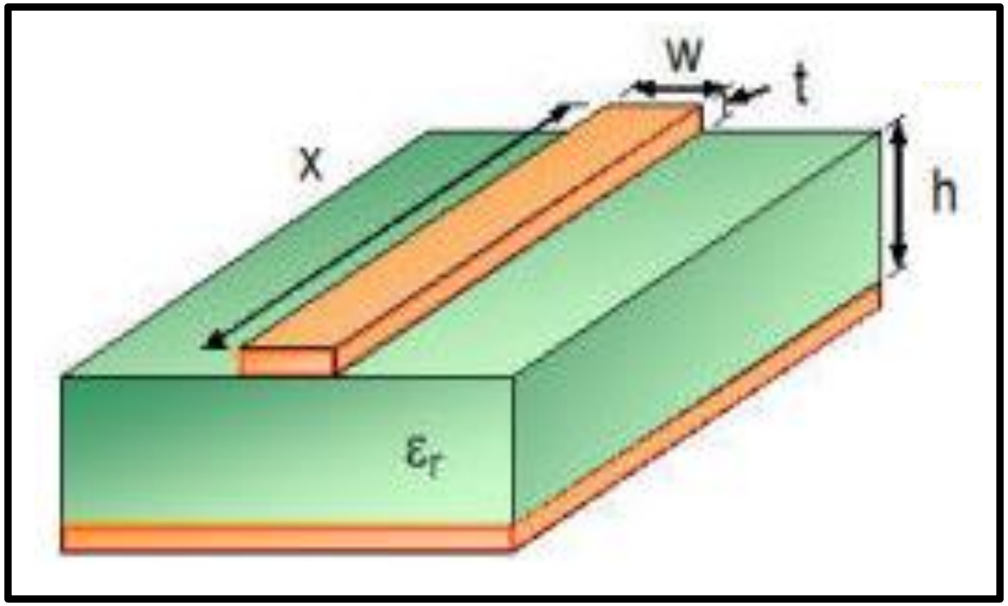

Outer
Conductor
Dielectric
Ground
plane
w
Inner Conductor

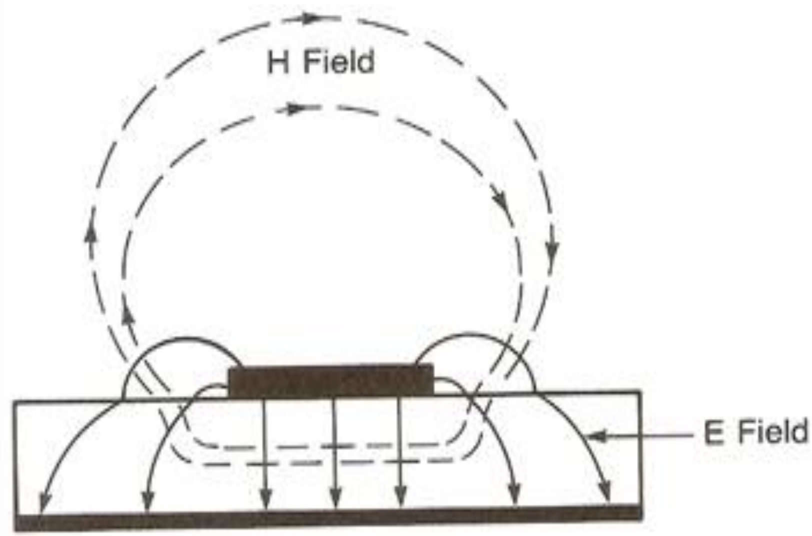

E-field
H-field

Microstrip

- It consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate.
- A conductor of width W is printed on a thin, grounded dielectric substrate of thickness h and relative permittivity ε_r.
- <u>Applications</u>: used inside of the microwave devices themselves (e.g.: microwave integrated circuitry).

Cont.

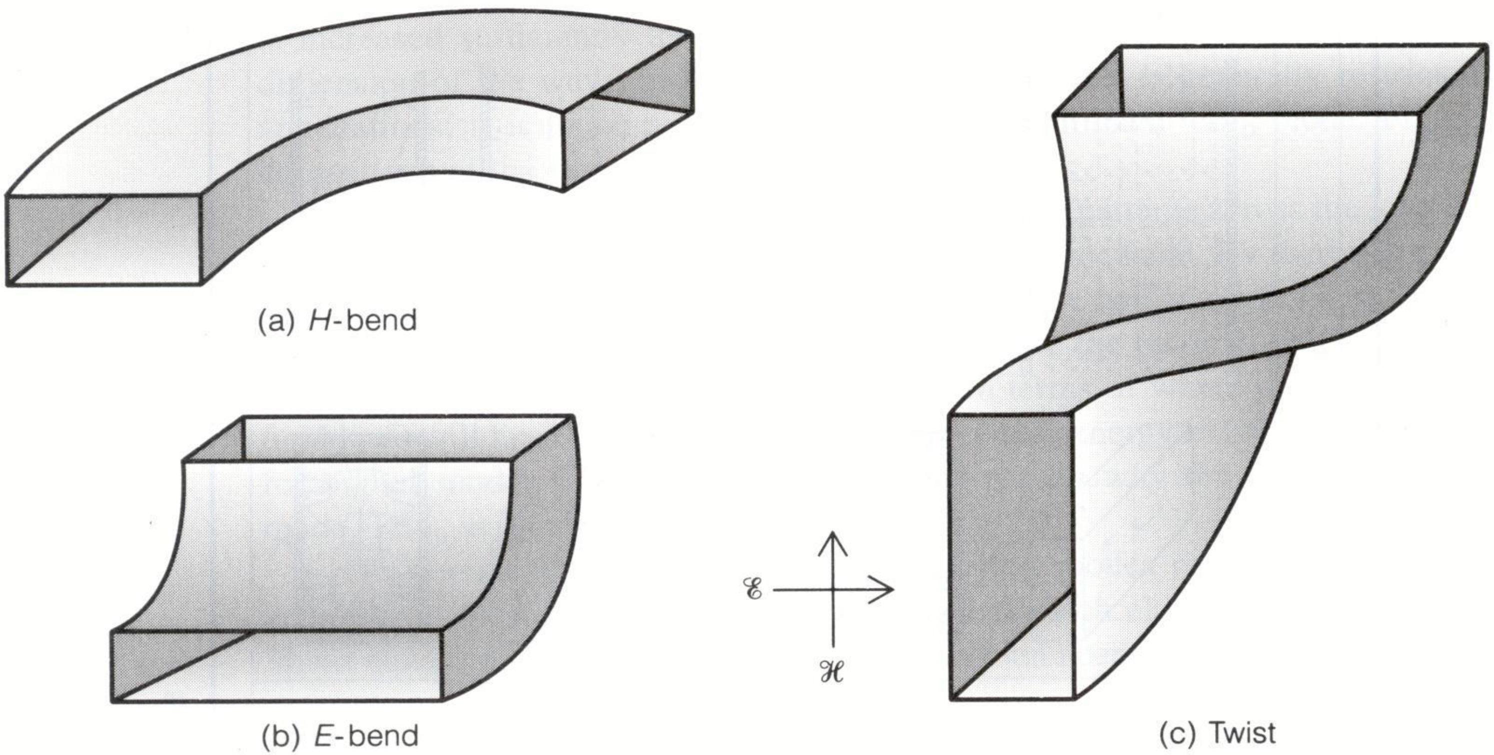




(b)

Flexible Waveguide

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



(a) *H*-bend

(b) *E*-bend

(c) Twist

2.3 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 (or the smallest free space wavelength that is just unable to propagate in the waveguide).
- Group velocity (v_g, m/s):

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

Cont.

- Phase velocity (v_p, m/s):

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

- In theory: $c < v_g \leq v_p$.
- The relationship between v_g, v_p and speed of light, c is given by:

$$c^2 = v_g + v_p$$

Cont.

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

a)Wavelength of travelling wave that propagates down the waveguide.
b)λ_g will be greater in the waveguide than in free space (λ_o).

- Waveguide characteristic impedance (Z_o, Ω):

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 (377 Ω).
c)Generally, $Z_o > 377$ Ω.

Rectangular Waveguide TE/TM Calculations

- Dominant mode (mode with lowest cutoff frequency) for rectangular waveguide is $TE_{1,0}$.
- A waveguide acts as a high-pass filter in that it passes only those frequencies above the cutoff frequency.

$$v_g v_p = c^2$$

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

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

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

Cont.

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

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

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

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

Example

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

- Dominant mode for circular waveguide is $TE_{1,1}$.
- For $TE_{1,1}$ mode, x'11 = 1.841 (solution of Bessel function equation).

$$f_c = \frac{c x_{np}}{2\pi a}$$

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

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

$$v_g v_p = c^2$$

Cont.

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

$$Z_o = 377\frac{\lambda_g}{\lambda_o}(TE\ \mathrm{mod}e)$$

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

Cont.

TE modes

χ'_{mn}	m=0	m=1	m=2	m=3	m=4	m=5	m=6	⋯
n=1	3.8318	1.8412	3.0542	4.2012	5.3175	6.4155	7.5013	⋯
n=2	7.0156	5.3315	6.7062	8.0153	9.2824	10.5199	11.7349	⋯
n=3	10.1735	8.5363	9.9695	11.3459	12.6819	13.9872	15.2682	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱

TM modes

χ_{mn}	m=0	m=1	m=2	m=3	m=4	m=5	m=6	⋯
n=1	2.4049	3.8318	5.1357	6.3802	7.5884	8.7715	9.9361	⋯
n=2	5.5201	7.1056	8.4173	9.7610	11.0647	12.3386	13.5893	⋯
n=3	8.6537	10.1735	11.6199	13.0152	14.3726	15.7002	17.0038	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱

Example

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.