

MICROWAVE DEVICE

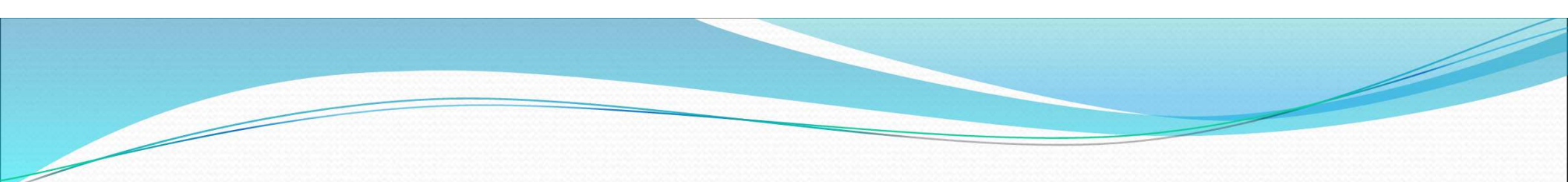
MICROWAVE SOURCE

4.1 GENERATION OF MICROWAVE SIGNAL

- Microwave Tubes – klystron, reflex klystron, magnetron and TWT.
- Diode semiconductor – Tunnel, Gunn, Impatt, Varactor diodes, PIN, LSA, Schottky barrier diode.

4.1.1 MICROWAVE TUBES

- Used for high power/high frequency combination.
- Tubes generate and amplify high levels of microwave power more cheaply than solid state devices.
- Conventional tubes can be modified for low capacitance but specialized microwave tubes are also used.

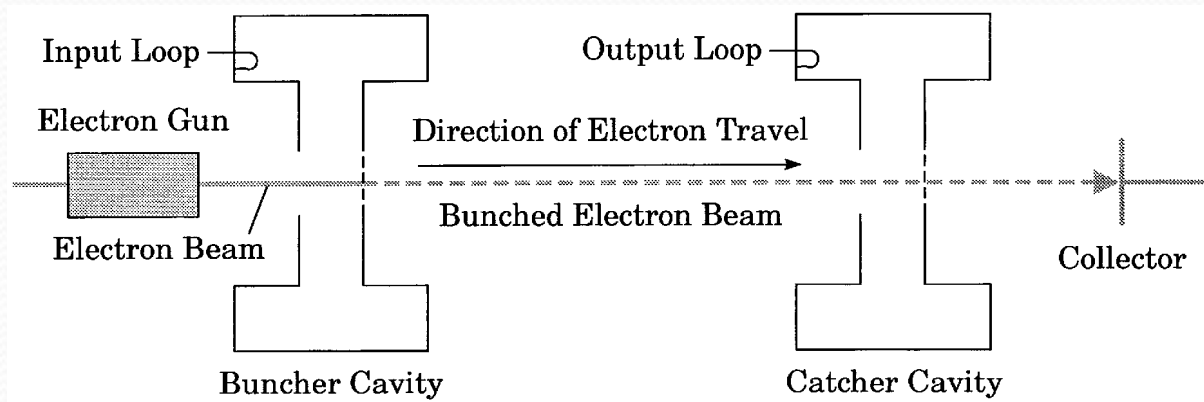
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- **CROSSED-FIELD AND LINEAR-BEAM TUBES**
 - Klystrons and Traveling-Wave tubes are examples of linear-beam tubes
 - These have a focused electron beam (as in a CRT)
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 - Magnetron is one of a number of crossed-field tubes
 - Magnetic and electric fields are at right angles



- **4.1.1.1 KLYSTRON**

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- Used in high-power amplifiers
- Electron beam moves down tube past several cavities.
- Input cavity is the *buncher*, output cavity is the *catcher*.
- *Buncher* modulates the velocity of the electron beam

● KLYSTRON CROSS SECTION



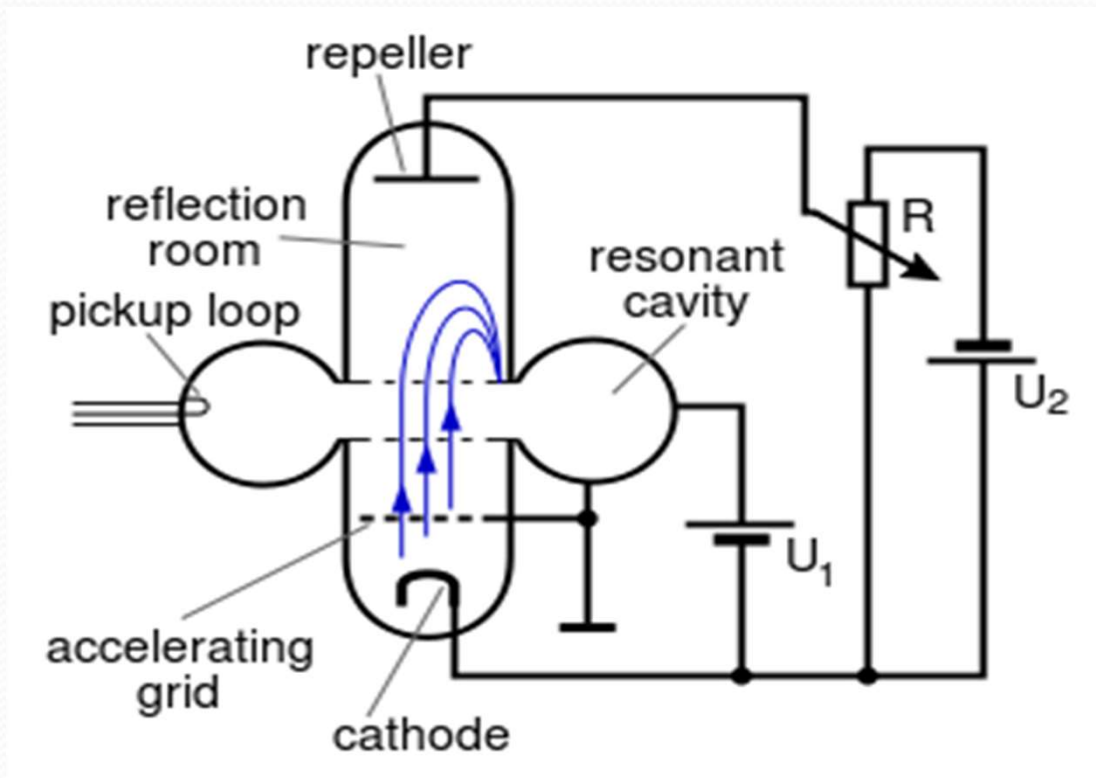
The major elements are;

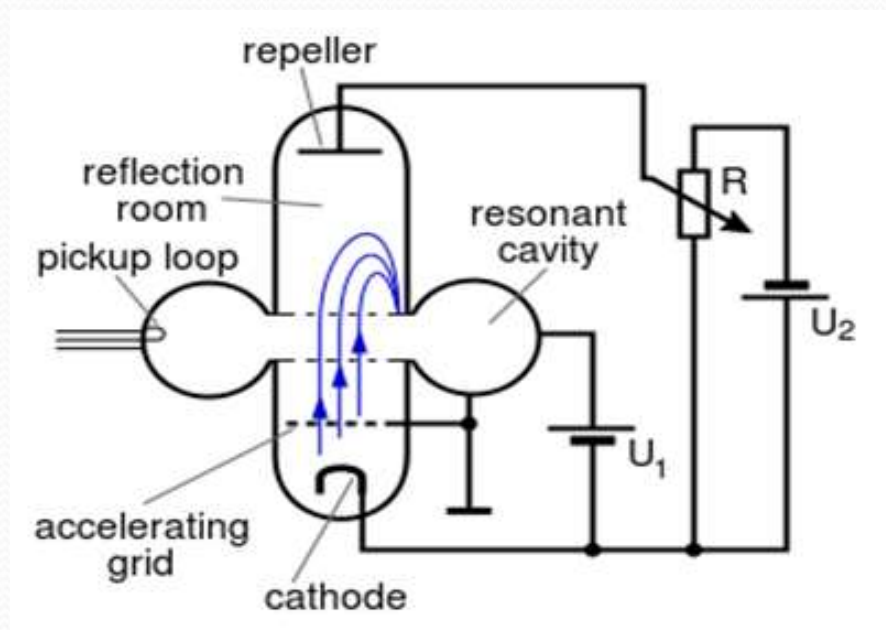
- An electron gun to form and accelerate a beam of electrons
- A focusing magnet to focus the beam of electrons through the cavities
- Microwave cavities where the electron beam power is converted to microwave power
- A collector to collect the electron beam after the microwave power has been generated
- A microwave input where the microwave signal to be amplified is introduced into the klystron
- A microwave output where the amplified microwave power is taken out

VELOCITY MODULATION

- Electric field from microwaves at buncher alternately speeds and slows electron beam
- This causes electrons to bunch up
- Electron bunches at catcher induce microwaves with more energy
- The cavities form a slow-wave structure

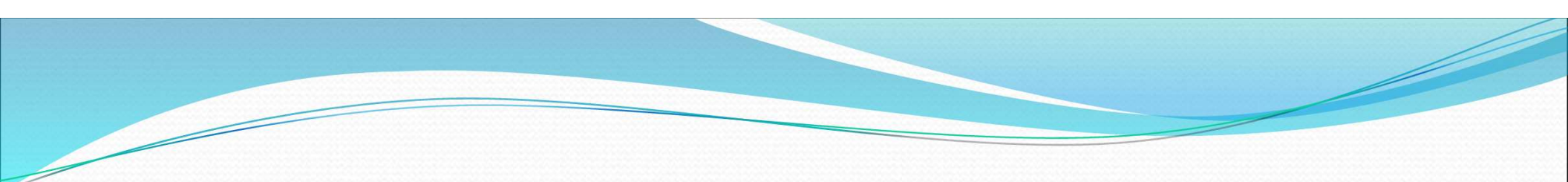
4.1.1.2 REFLEX KLYSTRON

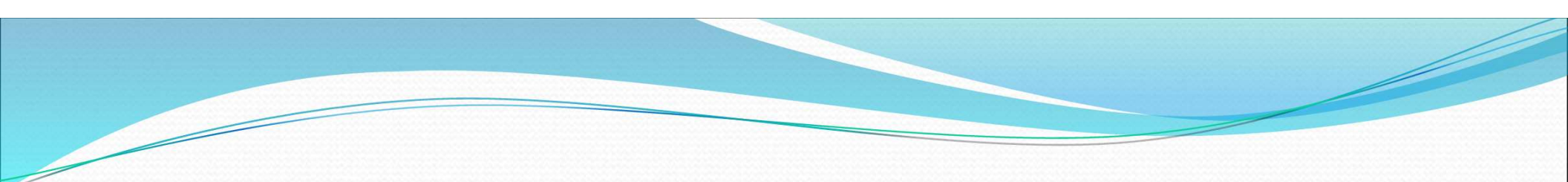




- The electron beam passes through a single resonant cavity.
- The electrons are fired into one end of the tube by an electron gun.
- After passing through the resonant cavity they are reflected by a negatively charged reflector electrode for another pass through the cavity, where they are then collected.
- The electron beam is velocity modulated when it first passes through the cavity.

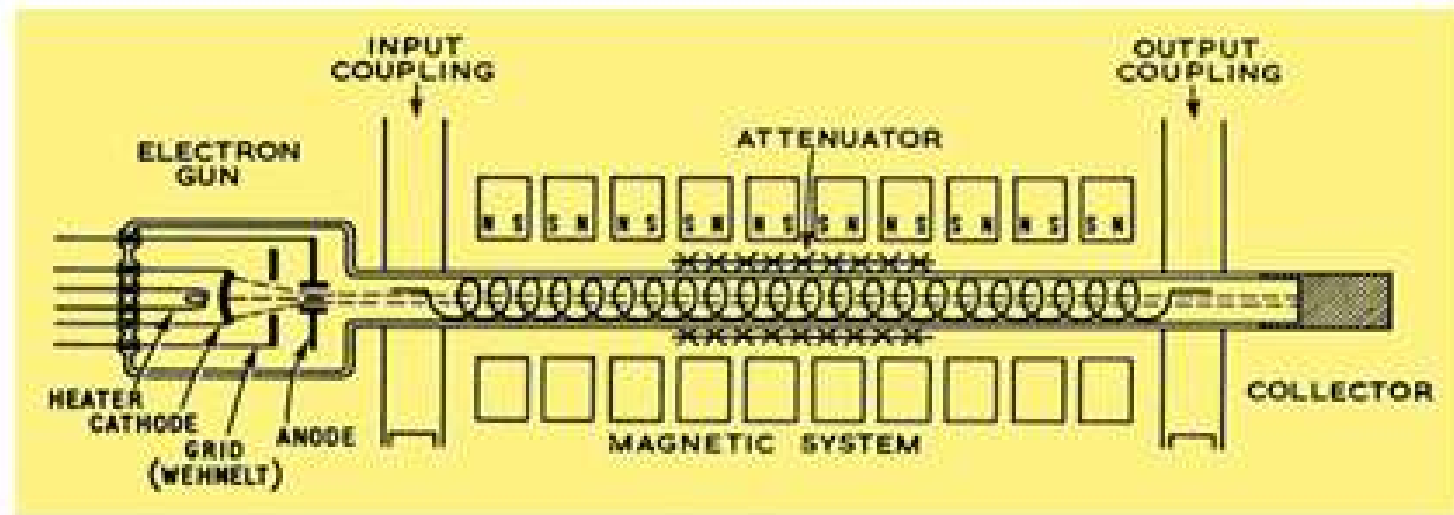
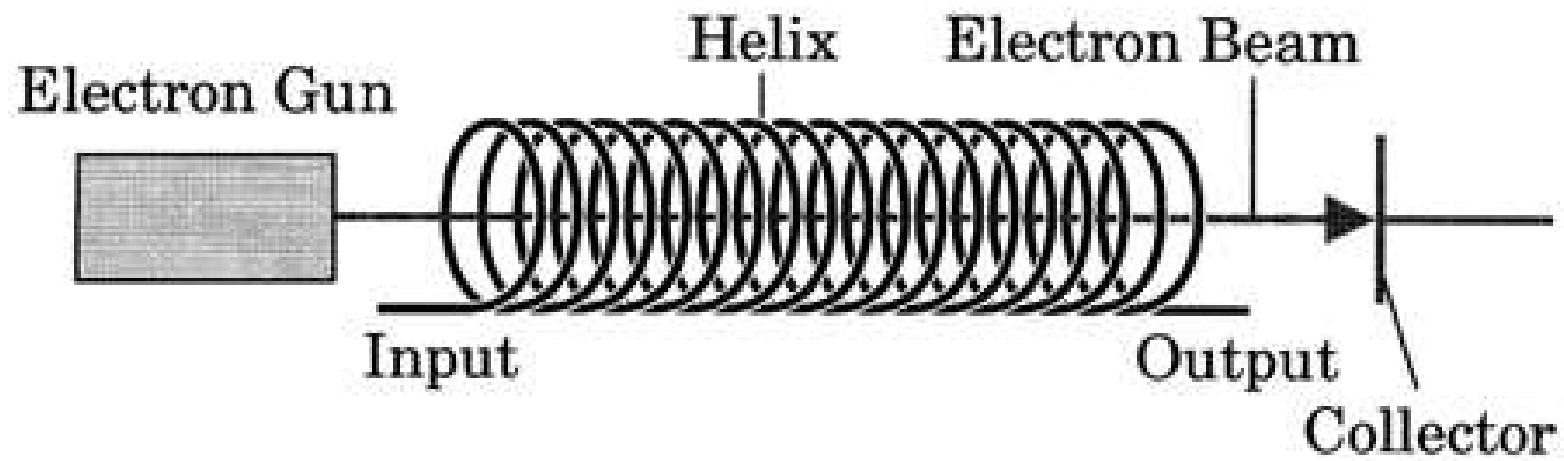
- The formation of electron bunches takes place in the drift space between the reflector and the cavity.
- The voltage on the reflector must be adjusted so that the bunching is at a maximum as the electron beam re-enters the resonant cavity, thus ensuring a maximum of energy is transferred from the electron beam to the RF oscillations in the cavity.
- The voltage should always be switched on before providing the input to the reflex klystron as the whole function of the reflex klystron would be destroyed if the supply is provided after the input.

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- The reflector voltage may be varied slightly from the optimum value, which results in some loss of output power, but also in a variation in frequency.
 - At regions far from the optimum voltage, no oscillations are obtained at all.
 - This tube is called a reflex klystron because it repels the input supply or performs the opposite function of a klystron.

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- There are often several regions of reflector voltage where the reflex klystron will oscillate; these are referred to as modes.
 - The frequency of oscillation is dependent on the reflector voltage, and varying this provides a crude method of frequency modulating the oscillation frequency, albeit with accompanying amplitude modulation as well.

4.1.1.3 TRAVELING-WAVE TUBE (TWT)

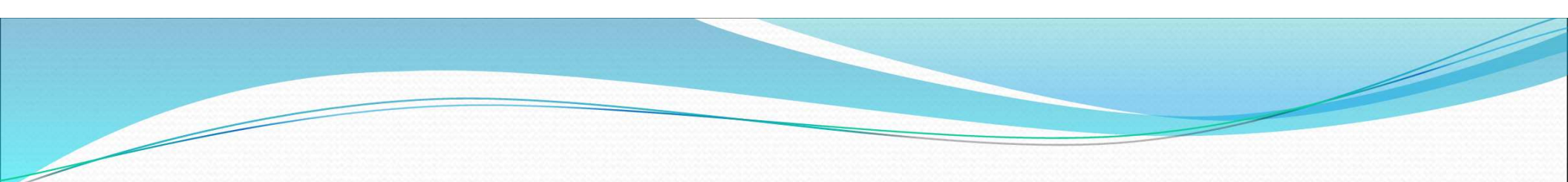
- Uses a helix as a slow-wave structure
- Microwaves input at cathode end of helix, output at anode end
- Energy is transferred from electron beam to microwaves





The major elements include;

- An electron beam to form and accelerate a beam of electrons
- A focusing magnet/magnetic system to focus the beam of electrons through the interaction structure
- A collector to collect the electron beam after the microwave power has been generate

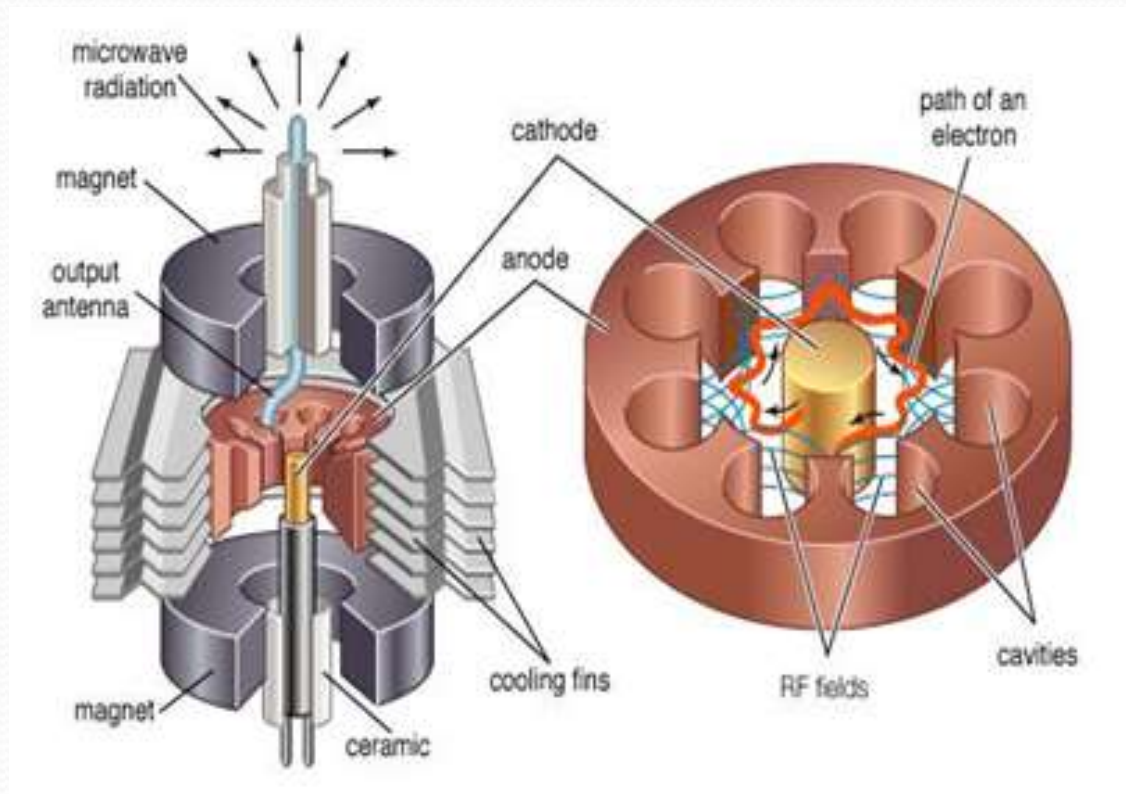
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- An input window where the small microwave signal to be amplified is introduced to the interaction structure
 - An helix as interaction structure, where the electron beam interacts with the microwave signal to be amplified
 - A microwave output window, where the microwave power is taken out of the tube
 - An internal attenuator, to absorb the power reflected back into the tube from mismatches in the output transmission line

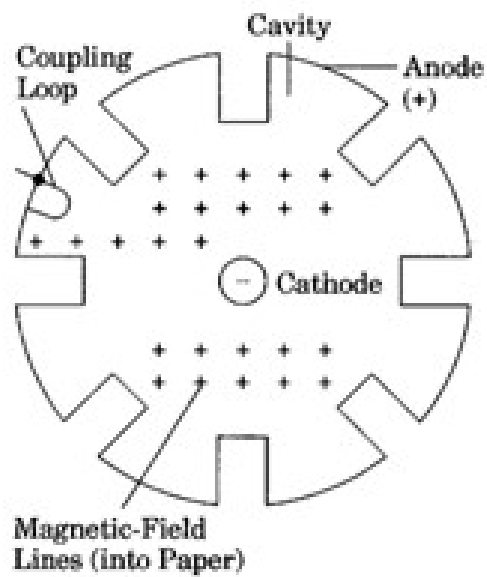
Operation

- The helix acts as a delay line, in which the RF signal travels at near the same speed along the tube as the electron beam.
- The electromagnetic field due to the RF signal in the helix interacts with the electron beam, causing bunching of the electrons (an effect called velocity modulation), and the electromagnetic field due to the beam current then induces more current back into the helix (i.e. the current builds up and thus is amplified as it passes down).
- A second directional coupler, positioned near the collector, receives an amplified version of the input signal from the far end of the helix.
- An attenuator placed on the helix, usually between the input and output helices, prevents reflected wave from traveling back to the cathode.

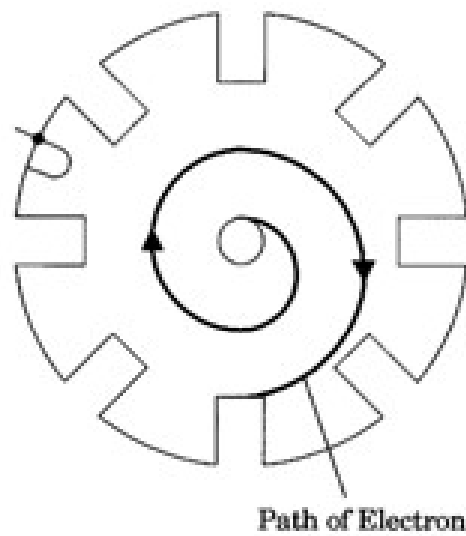
4.1.1.4 MAGNETRON

- The magnetron is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field.
- High-power oscillator
- Common in radar and microwave ovens
- Cathode in center, anode around outside
- Strong dc magnetic field around tube causes electrons from cathode to spiral as they move toward anode
- Current of electrons generates microwaves in cavities around outside

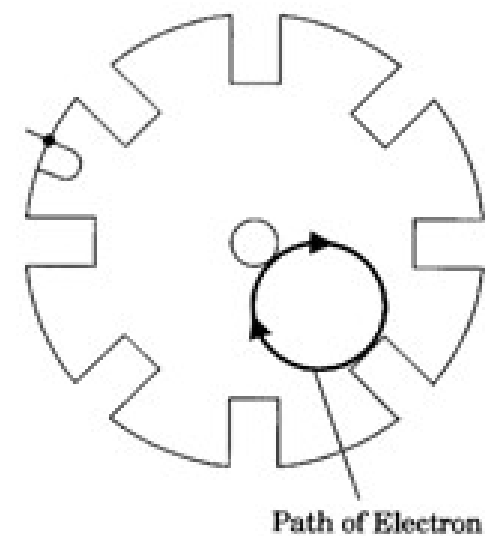




(a) Cross Section



(b) Electron Paths in Normal Operation

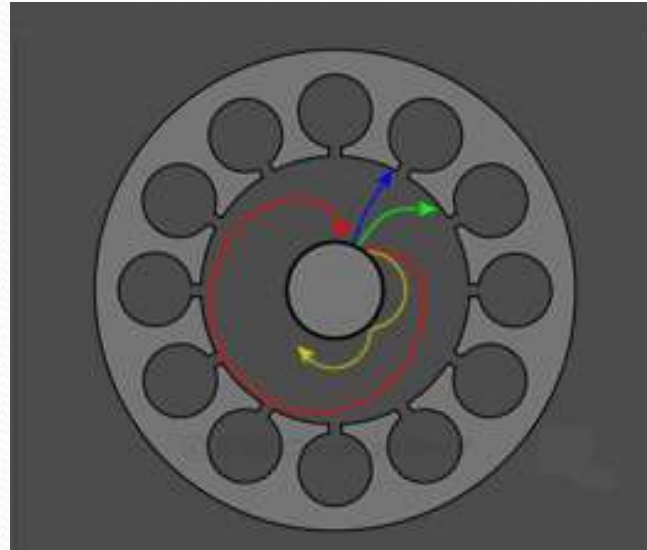


(c) Electron Paths at Cutoff

operation

- In a magnetron, the source of electrons is a heated cathode located on the axis of an anode structure containing a number of microwave resonators.
- Electrons leave the cathode and are accelerated toward the anode, due to the dc field established by the voltage source E .
- The presence of a strong magnetic field B in the region between cathode and anode produces a force on each electron which is mutually perpendicular to the dc field and the electron velocity vectors, thereby causing the electrons to spiral away from the cathode in paths of varying curvature, depending upon the initial electron velocity at the time it leaves the cathode.

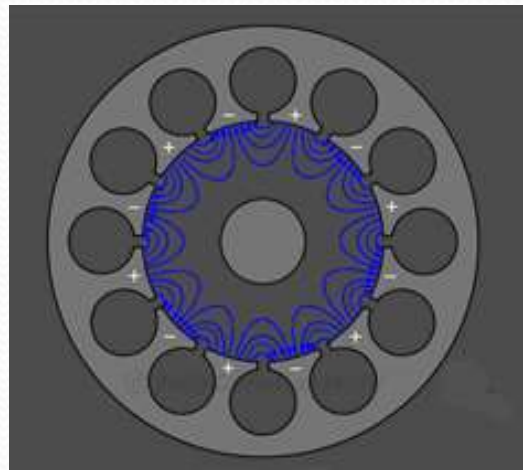
The electron path under the influence of different strength of the magnetic field



- As this cloud of electrons approaches the anode, it falls under the influence of the RF fields at the vane tips, and electrons will either be retarded in velocity, if they happen to face an opposing RF field, or accelerated if they are in the vicinity of an aiding RF field.

- Since the force on an electron due to the magnetic field B is proportional to the electron velocity through the field, the retarded velocity electrons will experience less "curling force" and will therefore drift toward the anode, while the accelerated velocity electrons will curl back away from the anode.
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- The result is an automatic collection of electron "spokes" as the cloud nears the anode with each spoke located at a resonator having an opposing RF field.

- On the next half cycle of RF oscillation, the RF field pattern will have reversed polarity and the spoke pattern will rotate to maintain its presence in an opposing field.

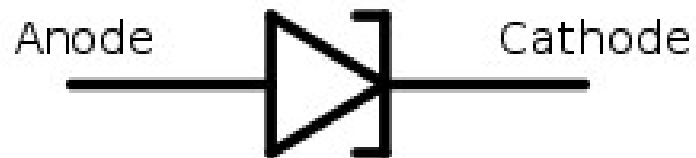


The high-frequency electrical field

4.1.2 MICROWAVE SOLID-STATE DEVICES (SEMICONDUCTOR DIODE)

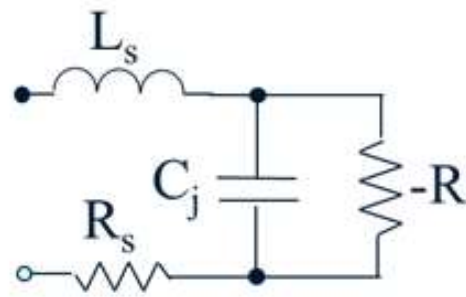
- Quantum Mechanic Tunneling – Tunnel diode
- Transferred Electron Devices – Gunn, LSA, *InP* and *CdTe*
- Avalanche Transit Time – IMPATT, *Read*, *Baritt* & *TRAPATT*
- Parametric Devices – Varactor diode
- Step Recovery Diode – PIN,
- Schottky Barrier Diode.
- Designed to minimize capacitances and transit time.
- NPN bipolar and N channel FETs preferred because free electrons move faster than holes
- Gallium Arsenide has greater electron mobility than silicon.

4.1.2.1 TUNNEL DIODE (ESAKI DIODE)

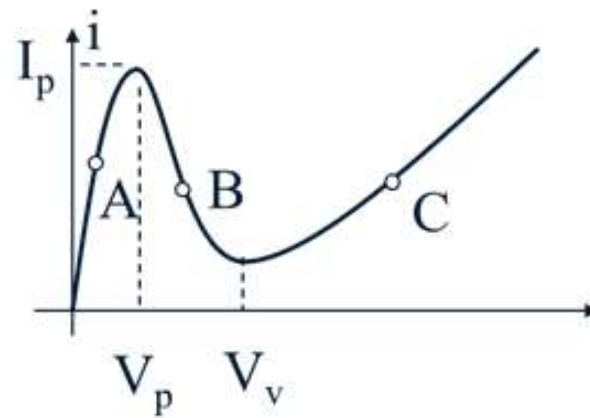




Symbol



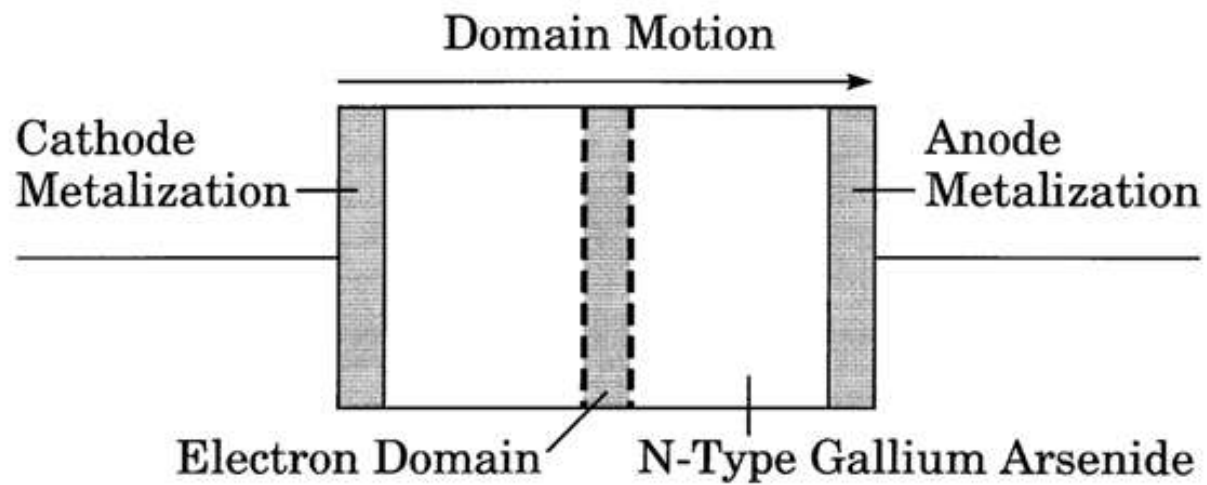
Equivalent Circuit



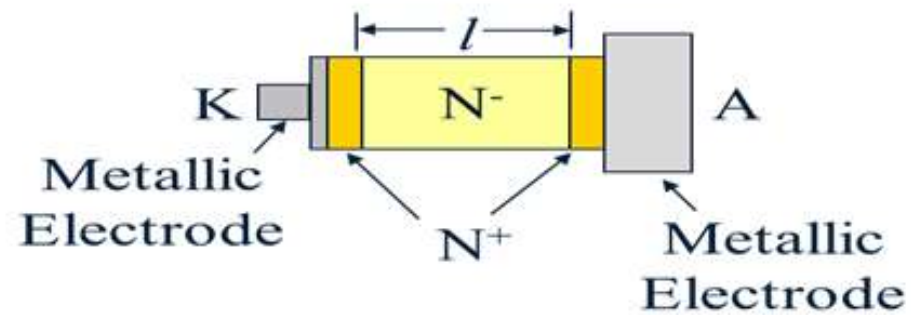
Characteristic Curve

4.1.2.2 GUNN DIODE

- Slab of N-type GaAs (gallium arsenide)
- Sometimes called Gunn diode but has no junctions
- Has a negative-resistance region where drift velocity decreases with increased voltage
- This causes a concentration of free electrons called a domain

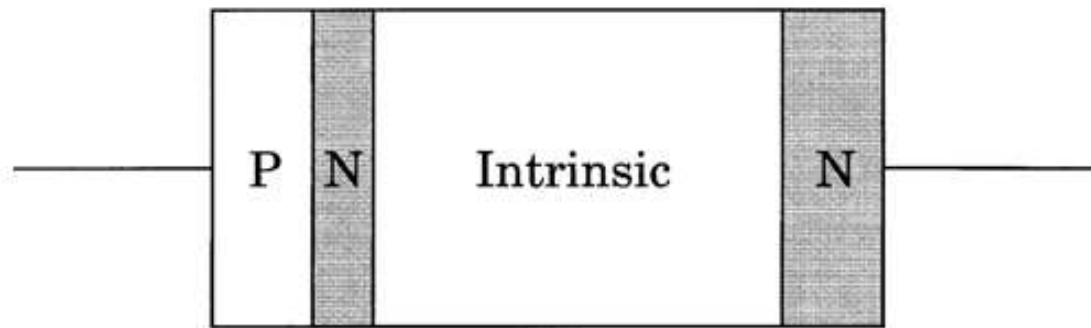


GUNN DIODE (CROSS SECTION)



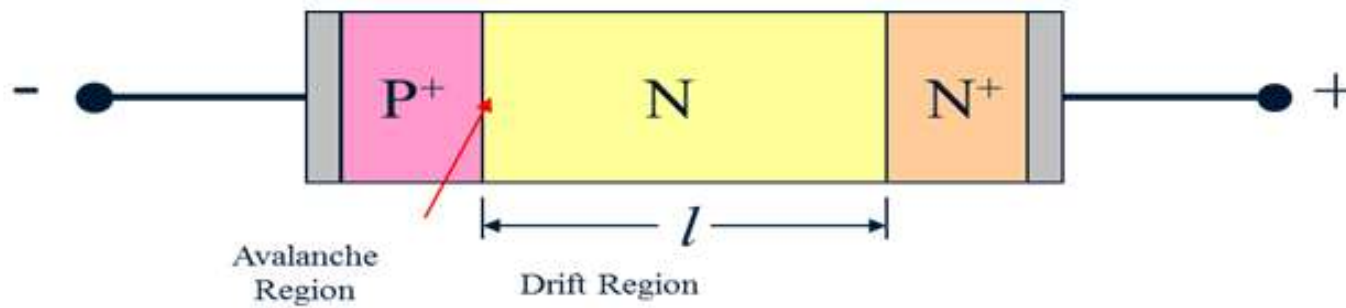


4.1.2.3 IMPATT DIODE



Gallium Arsenide

IMPATT DIODE



4.1.2.4 VARACTOR DIODES

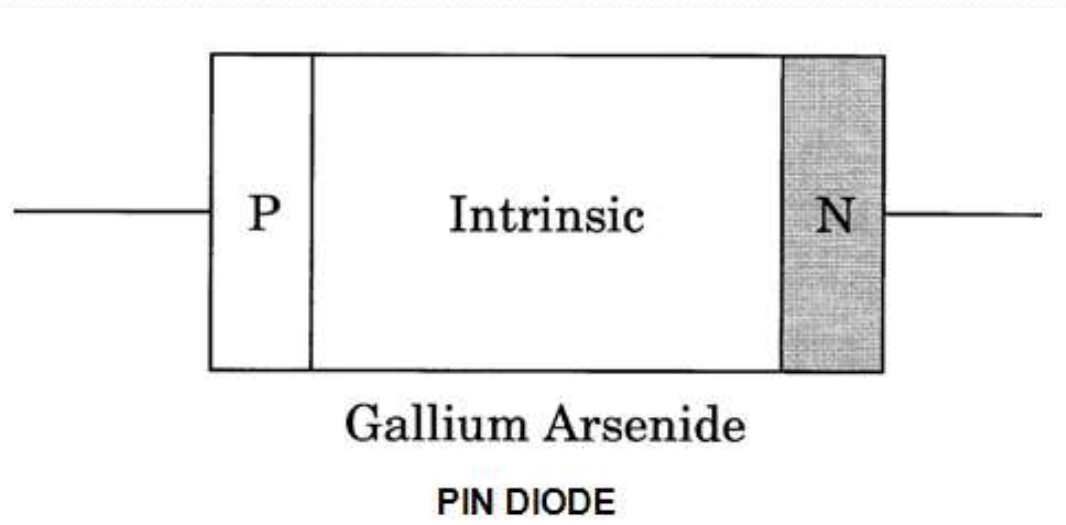
- The variable-reactance (varactor) diode makes use of the change in capacitance of a *pn* junction is designed to be highly dependent on the applied reverse bias.
- The capacitance change results from a widening of the depletion layer as the reverse-bias voltage is increased.
- As variable capacitors, varactor diodes are used in tuned circuits and in voltage-controlled oscillators.
- Typical applications of varactor diodes are harmonic generation, frequency multiplication, parametric amplification, and electronic tuning.
- Multipliers are used as local oscillators, low-power transmitters, or transmitter drivers in radar, telemetry, telecommunication, and instrumentation.
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- Lower frequencies: used as voltage-variable capacitor
- Microwaves: used as frequency multiplier
 - this takes advantage of the nonlinear V-I curve of diodes



- Varactors are used as voltage

4.1.2.5 PIN DIODE

- P-type --- Intrinsic --- N-type
- Used as switch and attenuator
- Reverse biased - off
- Forward biased - partly on to on depending on the bias





LSA

4.1.2.7 SCHOTTKY BARRIER DIODE



- A Schottky barrier diode (SBD) consists of a rectifying metal-semiconductor barrier typically formed by deposition of a metal layer on a semiconductor.
- The SBD functions in a similar manner to the antiquated point contact diode and the slower-response *pn*-junction diode, and is used for signal mixing and detection.
- The point contact diode consists of a metal whisker in contact with a semiconductor, forming a rectifying junction.
- The SBD is more rugged and reliable than the point contact diode.
- The SBD's main advantage over *pn* diodes is the absence of minority carriers, which limit the response speed in switching applications and the high-frequency performance in mixing and detection applications.
- SBDs are zero-bias detectors.
- Frequencies to 40 GHz are available with silicon SBDs, and GaAs SBDs are used for higher-frequency applications.