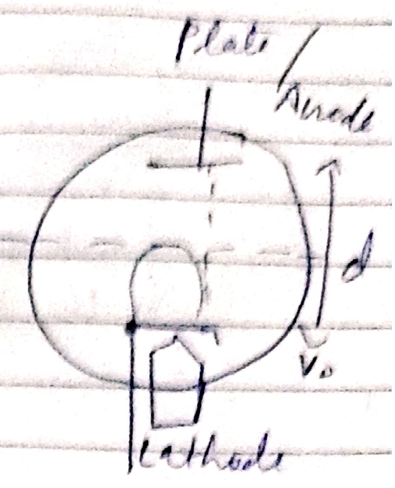
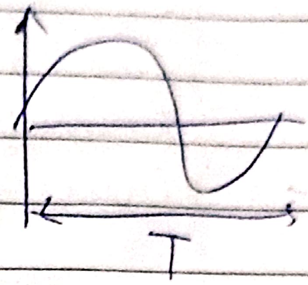
Transit angle $\theta_g = \omega\tau = \omega d / v_0$

Triode



At low frequencies, $\tau << T$, i.e. the e^- reach instantaneously the anode plate from cathode

At high freq. $\tau << T$. so potential betn cathode and grid changes 10 - 100 times.



The grid potential in time $\frac{1}{2}$ cycles takes back the energy given to the e^- in the half cycle.

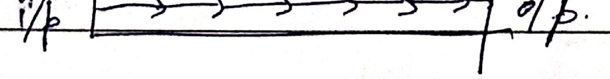
e^- may oscillate back and forth in the cathode grid space or return to the ~~ano~~ cathode

To minimize this effect, dist^n betn electrodes is to be reduced and high voltage must be applied but this will increase the inter-electrode capacitance.

***

Physical Structure, Working principle, applied diagram.

Skin Effect: Conductor losses.



At higher 'f', current won't flow through conductor interior but through surface

Hence we use hollow conductor - low cost, reduced weight.

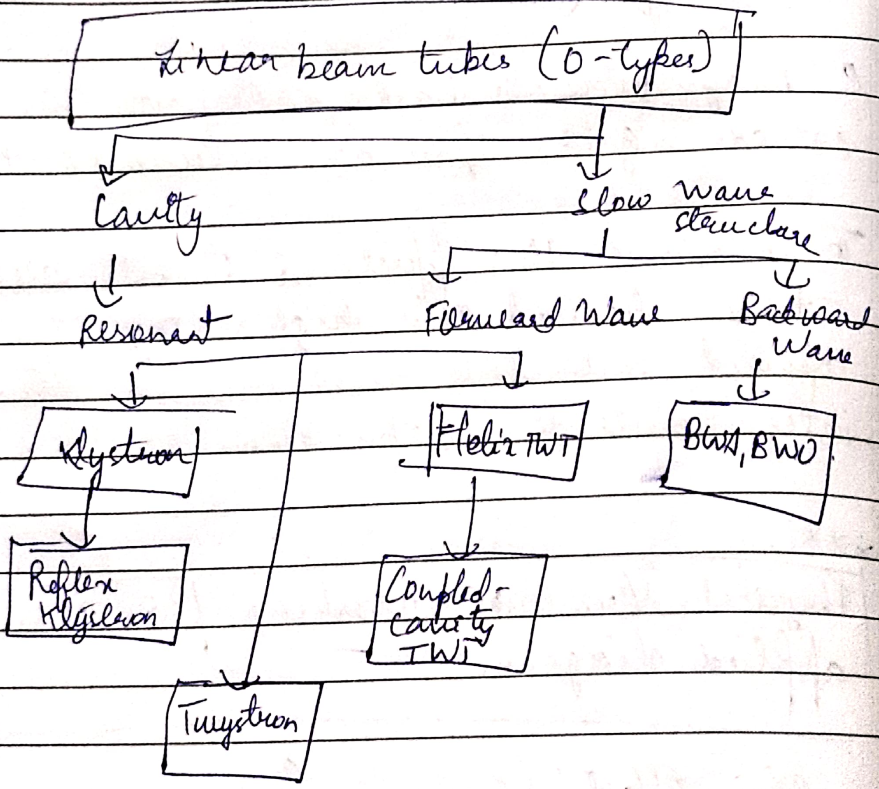
Radiatn Loss — When current flows through surface, there are radiatn losses

Dielectric Loss.

Dielectrics have different dielectric const. based on which the tangent loss varies (the loss ~~will~~ change when freq. changes).

Microwave Tubes

Linear Beam Tubes
Cross field tubes



Linear Beam Tubes.

These are a type of vacuum tube in which the electron beam travels in a straight line (linear path) from the cathode to anode, without significant deflection. It uses electrostatic or magnetic fields to focus and control the beam.

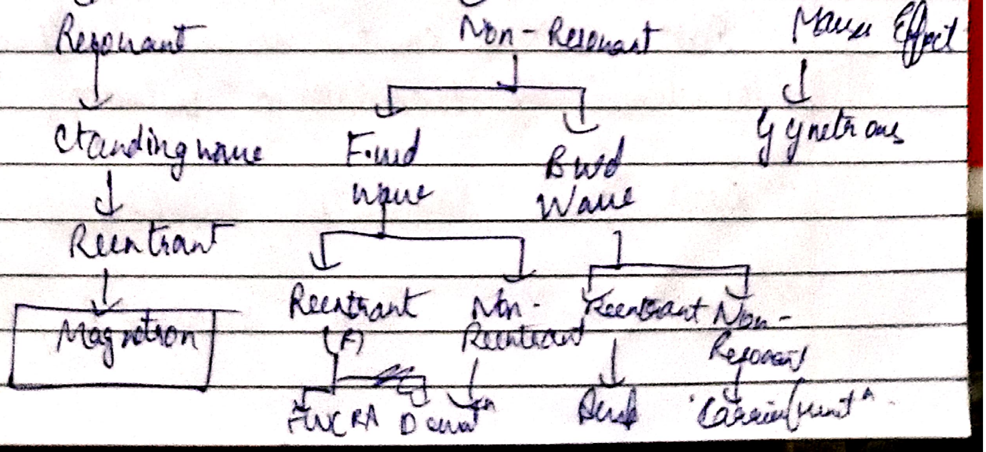
Key types :

1. **Klystron** – RF ampl^n in radars and communication systems
2. **Travelling wave Tube** – μ-wave & satellite comm^n
3. **Magnetron** – High-power μ-waves for radar and μ-wave ovens.

Features :

1. High power and efficiency
2. Used in RF and μ-wave appl^{n}s
3. Beam movement is controlled for ampl^n or oscill^n.

Crossed-Field tubes (M-type)



Electric field (E) ⊥ connected to Magnetic field (B).

Features

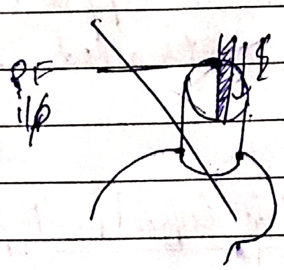
'E' accepts e^-
'B' forces e^- in curved paths
Operates in μ-wave frequencies (GHz)

Eg - Magnetron, Cross-Field Amp (CFA)

Klystron Amplifiers

Two-Cavity Klystron Amplifier

Principle : Velocity modulation and e^- bunching to amplify RF signals.



Components.

1. Electron Gun: Generates and accelerates the e^- beam.

Dist^n b/w^n 2 cavities is called drift-space

2. Buncher Cavity: Modulates e^- velocity

3. Drift Space: Allows e^- bunching.

4. Catcher Cavity: Extracts amplified RF power

5. Collector: Absorbs Remaining energy.

RF signal.
Anode repels (+)ve charge.
Cathode $\xrightarrow{e}$ Bunching (Mixing with RF signal).
Repels e^-

Either it goes to collector or gets reflected back (i.e. the cycle starts hence energy is absorbed)
High energy signal is taken as RF o/p.

Working:

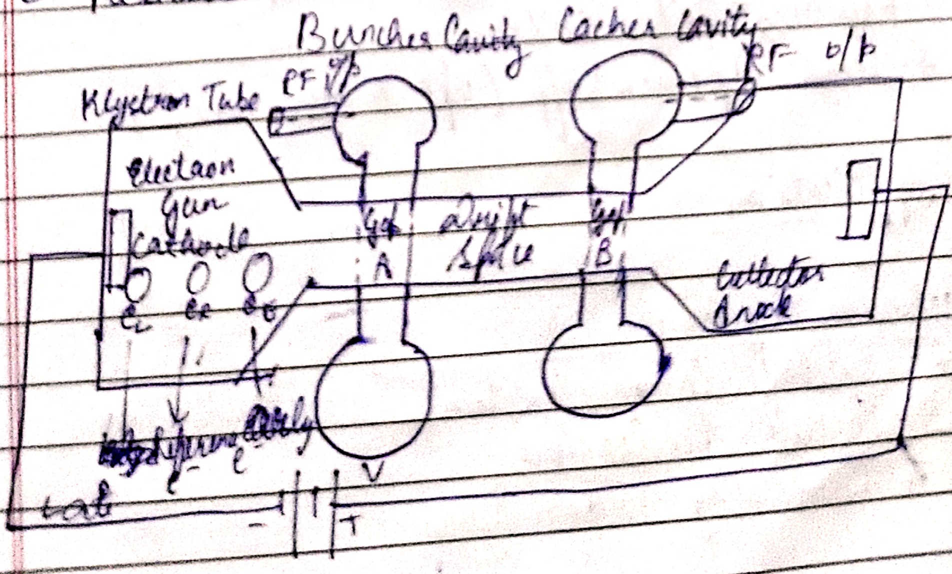
a. An e^- beam is produced and accelerated

b. The buncher cavity introduces velocity modulation using RF tube

c. Electron bunches form in the drift space.

d. The catcher cavity extracts RF energy, amplifying the signal

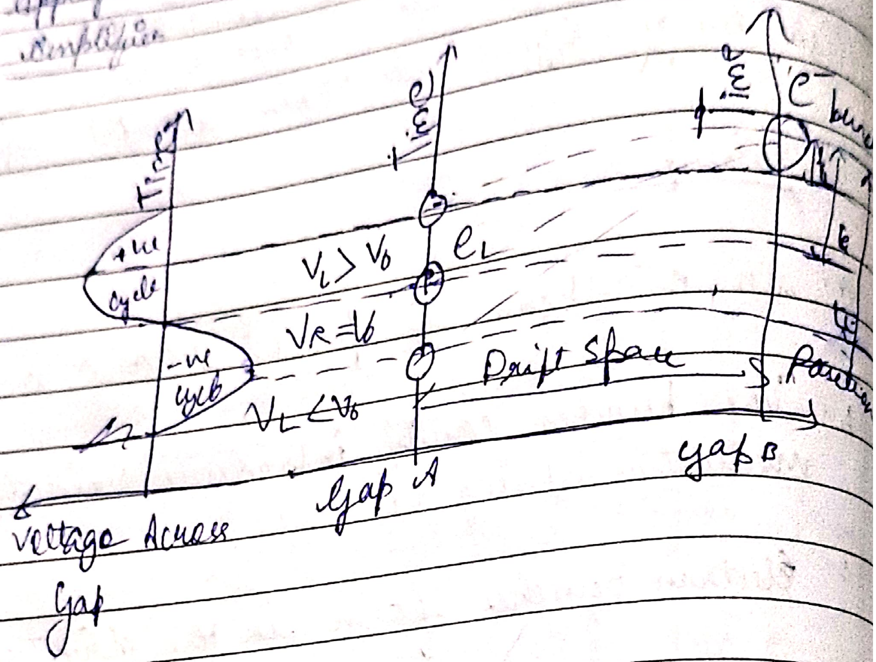
e. Residual electrons are collected.



Without RF signal, All the electrons travel with same velocity towards the anode;

$$\Rightarrow \frac{1}{2}mv_0^2 = eV \Rightarrow v_0 = \sqrt{\frac{2eV}{m}}$$

Applegate Diagram of 2- cavity Klystron Amplifier



Characteristics.

1. Frequency Range: 1 GHz – 100 GHz.
2. Gain: 30-60 dB
3. Efficiency: 20% - 50%.
4. High power o/p (up to MW range)

Application:

1. Radar Systems
2. Satellite Communication
3. Particle Accelerators
4. Brodcasting Transmitters

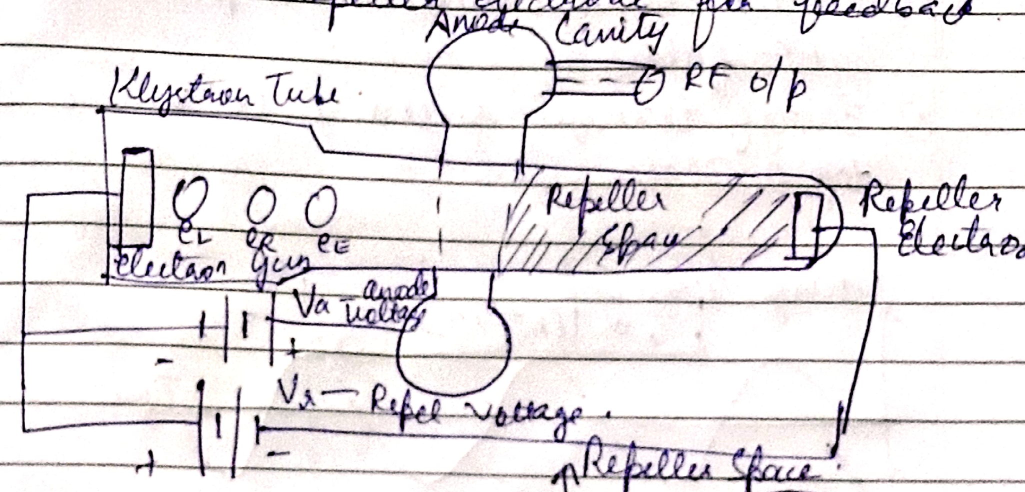
Advantages:
High power & gain, efficient at μ-wave frequencies

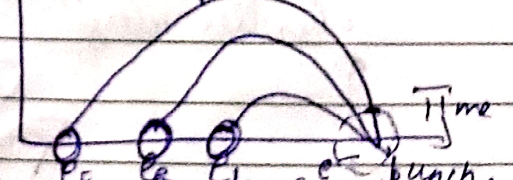
Disadvantages:
Bulky Requires high voltage, limited bandwidth.

Klystron Oscillators

Reflex Klystron Oscillators

Principle: Works on velocity modulation and electron bunching, but uses a single cavity with a repeller electrode for feedback.





Components:

1. Electron Gun: Produces and accelerates Electrons

2. Resonator Cavity: Modulates electron velocity and extracts RF power.

3. Repeller Electrode: Reflects e^-s back to the cavity to reinforce oscillations.

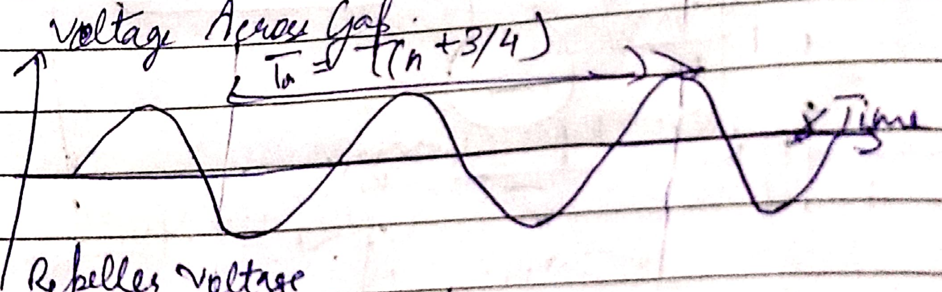
4. Collector: Absorbs residual e^-s

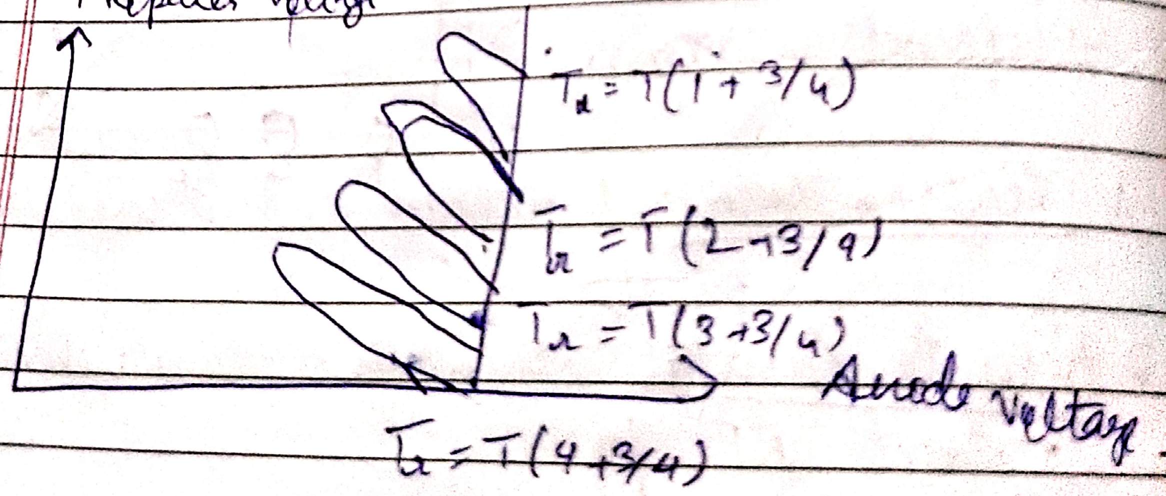
Early Electrons: a. Accelerated by RF Field, move faster.
b. Travel deeper into the repeller region.
c. Take longer to return to the cavity.

Late Electrons:
a. Decelerated by the RF field, move slower
b. Turn back sooner in the repeller region.
c. Take shorter time to return

Bunching Effect:

a. Velocity differences cause e^- to group into bunches.
b. These bunches return in phase with RF field.
c. Energy transfer sustains μ-wave ~~of~~ Oscillations.





Magnetron Oscillator

Principle: The operation of a magnetron is based on the crossed-field interaction between an electric field and a perpendicular magnetic field.

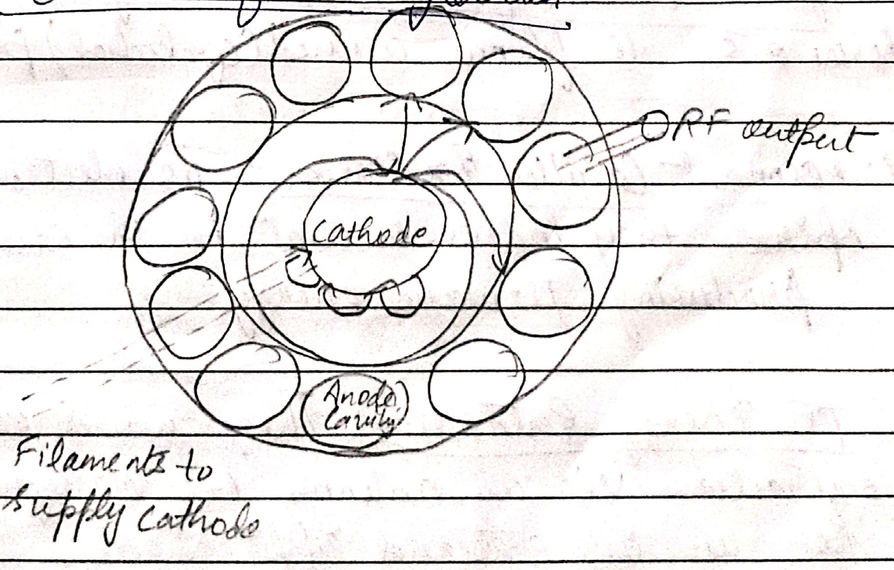
Magnetrons: 3 types:

1. Split-Anode Magnetron: Uses a static negative resistance between two anode segments.

2. Cyclotron-frequency magnetrons: Operates under influence of synchronism between an alternating component of electric field and a periodic oscillation of electrons in a dirⁿ parallel to the field.

3. Travelling-wave magnetrons: depends on interactⁿ of e⁻s with a travelling EM field of linear velocity; customarily referred to as magnetrons.

Structure of a Magnetron:



Components:

1. Cathode: Heated filament that emits electrons.

2. Anode: Cylindrical structure surrounding the cathode, containing multiple resonant cavities.

3. Resonant Cavities: Metal cavities determining the oscillat^n freq.

4. Permanent Magnet: Provides Static magnetic field ⊥ electric field.

5. O/P Coupling: Extracts μ-wave energy (eg - via a waveguide or antenna).

Working Principle:

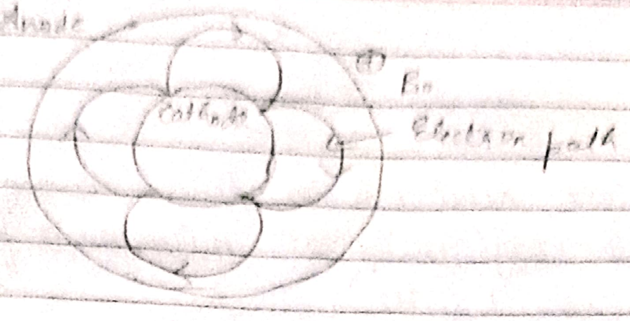
1. Electron Emission: The cathode emits electrons due to thermionic emission.

2. Radial Electric Field: A DC voltage bet^n cathode and anode accelerates e⁻ radially outward.

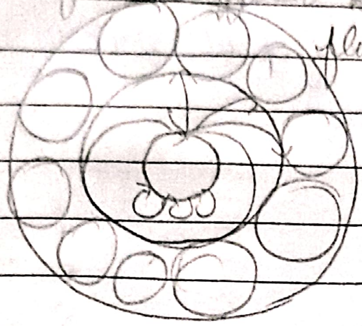
3. Magnetic Field Influence: A ⊥^r magnetic field forces e⁻s to follow curved (cycloidal) paths.

4. Resonant Cavities Excitation: As electrons spiral, they induce oscillat^n in the cavities, producing μ-wave energy.

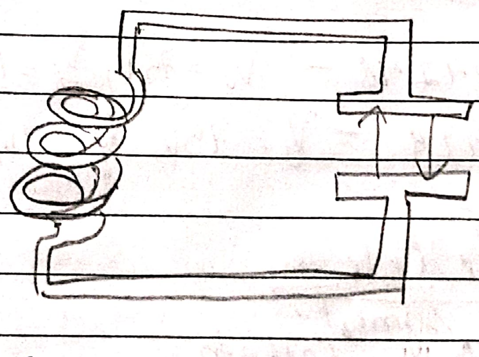
5. RF Energy Extraction: The μ-waves are extracted via an antenna or waveguide for use in external applications.



Trajectory of an electron for different magnetic flux densities



Equivalent Model.



Resonance occurs at $F = \frac{1}{2\pi\sqrt{LC}}$

Characteristics and Applications

Characteristics :

1. Operating Frequency : ~~100~~ Hundreds c
2. Power output
3. Efficiency : 40% – 80%

Microwave Diode.

Specialized semiconductor devices designed to operate efficiently at microwave frequencies (typically 1 GHz).

Semiconductor Materials

Semiconductor material band gap at 27°C:

- Si → 1.12 eV
- Ge → 0.66 eV
- GaAs → 1.43 eV
- InP → 1.27 eV.

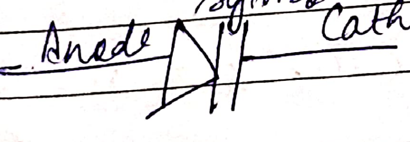
PN Junction Diode

~~1N41~~ 1N4148 – $V_r = 75V$, $V_f = 1V$, $I_f = 200mA$

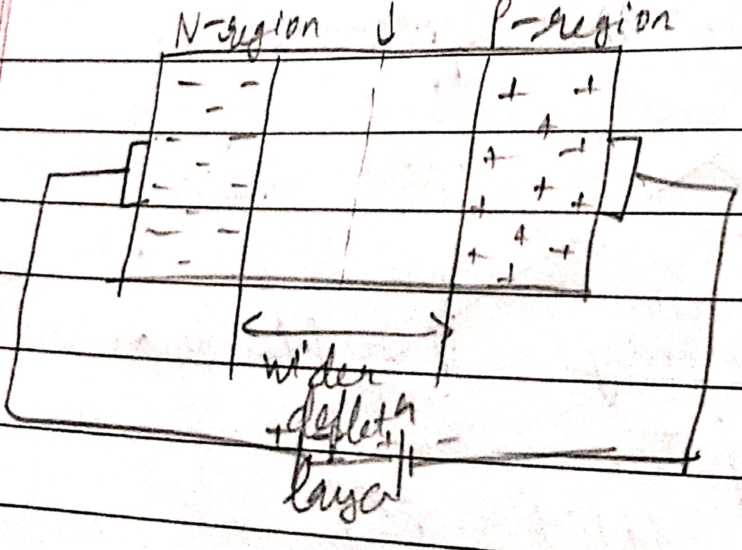
1N914 – $V_r = 75V$, $V_f = 1V$, $I_f =$ ~~20~~mA.

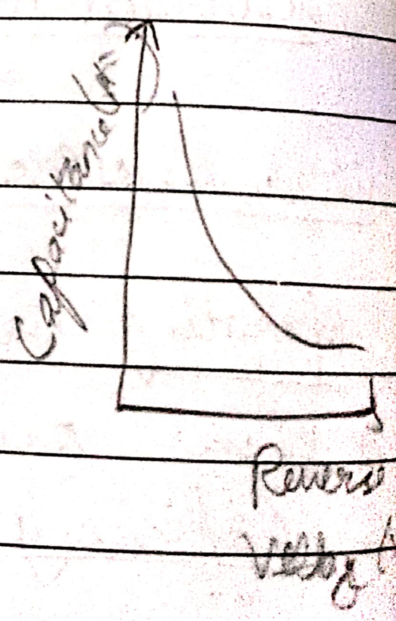
Varactor Diode.

Symbol:



Structure





Increase in R.B. voltage increase the depletion region and hence reduce the capacitance, given by.

$$C_j(V) = \frac{C_j(0)}{\left(1 - \frac{V}{\phi_0}\right)^{\gamma}}$$

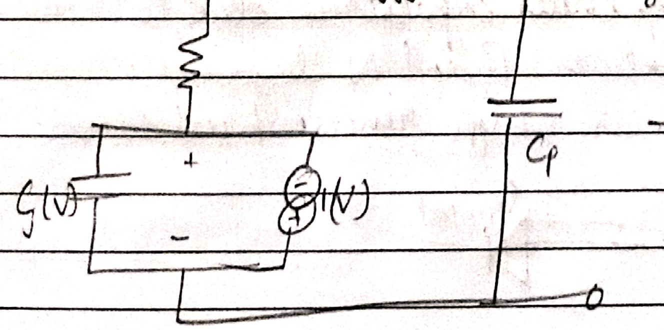
$\gamma = 1/2$, and $1/3$ for abrupt and linearly graded junction, respectively.

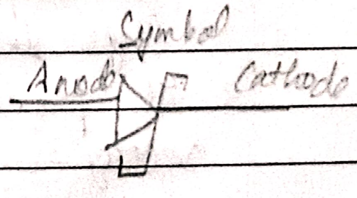
Applicatn.

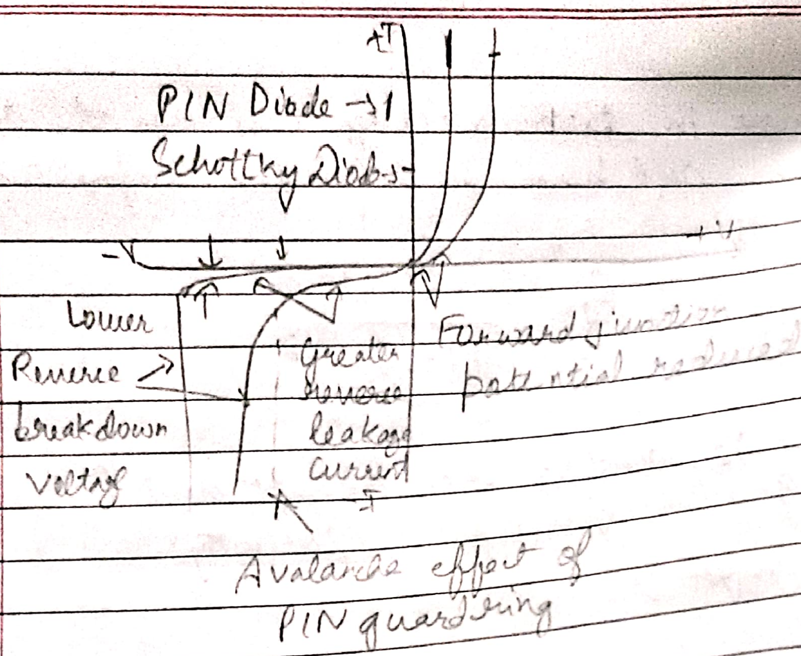
1. Voltage controlled oscillators (VCO)
2. Tunable filters.
3. Phase Shifters
4. Amplitude Modulator.
5. Frequency Multipliers, etc.

Schottky Diode.

1. Semiconductor - metal junction with low built in potential.
2. Fast switching and reverse recovery time,
3. It suffers with high reverse leakage current and low break down voltage.







Applications:

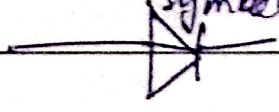
1. RF mixers and detectors.
2. Power rectifiers.
3 Switched mode power supplies
4. Clamping.

PIN Diode:

Characteristics

1. PIN diode offers high resistance.
2. Provides lower capacitance due to intrinsic layer between P and N layer.
3. It provides high reverse breakdown voltage.

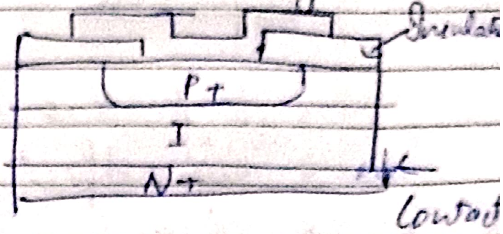
Symbol.

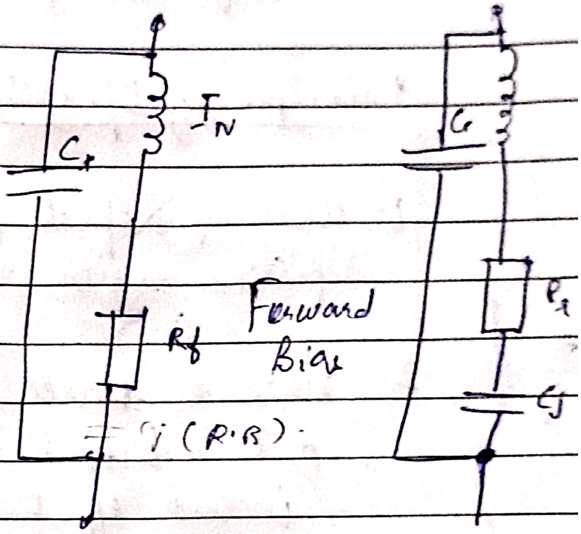


Applications :

1. Variable Attenuators
2. RF switches
3. Phase Shifters
4. High Voltage Rectifiers
5. RF modulator

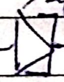
Structure





Tunnel Diode

Symbol:



High-speed semiconductor device. ~~that exhibits~~ negative resistance due to the quantum mechanical phenomenon of tunneling. Invented by Leo Esaki in 1957 making it also called Esaki Diode.

Key Features

Negative Resistance Region: Enables oscillation and amplification

Fast Response: operates in μ-wave range (up to THz frequencies).

Low Noise: Useful in low-noise applications.

Applications

1. μ-wave oscillators
2. High-speed switching ckts
3. Frequency Mixers
4. Amplifiers (RF and Microwave)
5. Memory Storage Devices (due to bistable state)

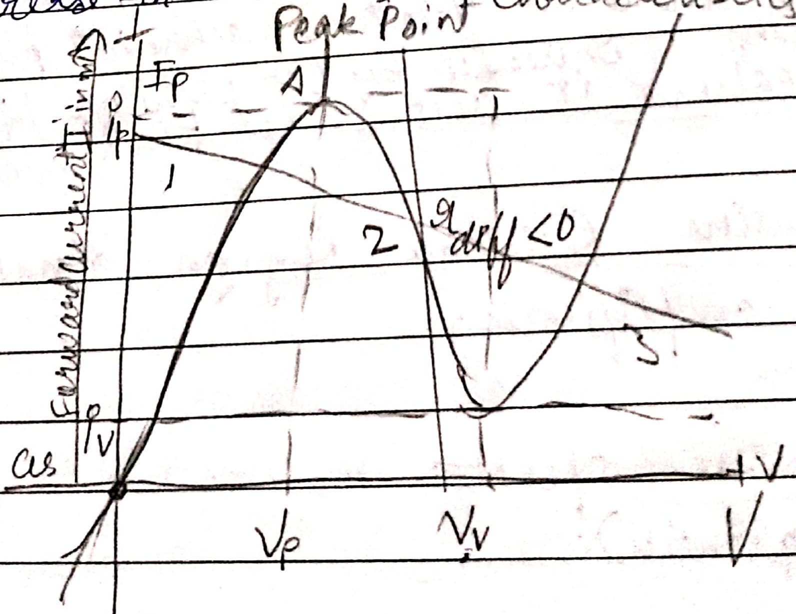
Principle of Operation

1. Heavily doped P-N junction, reducing the depletion region to a few nm.

2. When a small fixed voltage is applied e^-'s "tunnel" through the energy barrier instead of overcoming it.

3. This results in unusual negative resistance region, where increasing voltage causes a decrease in current.

I-V characteristics



Gunn Diode.

2 different valleys, each having different mobility.

Functions in four different modes based on operating freq. F and length of material L.

A. Transit time mode ($V_0 = F \times L = 10^7$ cm/sec, $\tau_0 = \tau_t$)
b. Delay Domain Mode ($V_0 = F \times L < 10^7$ cm/sec, $\tau_0 > \tau_t$)
C. Quenched Domain Mode ($V_0 = F \times L = 2V_d = 2 \times 10^7$ cm/sec, $\tau_0 < \tau_t$)
d. LSA mode. ($V_0 = F \times L > 2 V_d = 2 \times 10^7$ cm/sec, $3\tau_0 = \tau_t$)

$\tau_0 \to$ Oscillat^n time
$\tau_t \to$ Transient Time.

IMPATT Diode

IMPATT (Impact Ionization Avalanche Transit-Time) diode.

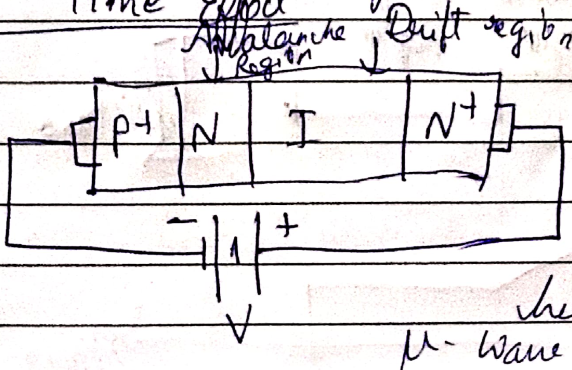
Used for generating μ-wave freq. from (3 - 300) GHz.

Principle of Operation

ionizat^n - gain in charge, energy and inc. in electric field

1. Avalanche Multiplication: A high R.B. voltage causes impact ionization in the depletion region, generating a large no. of charge carriers. + →

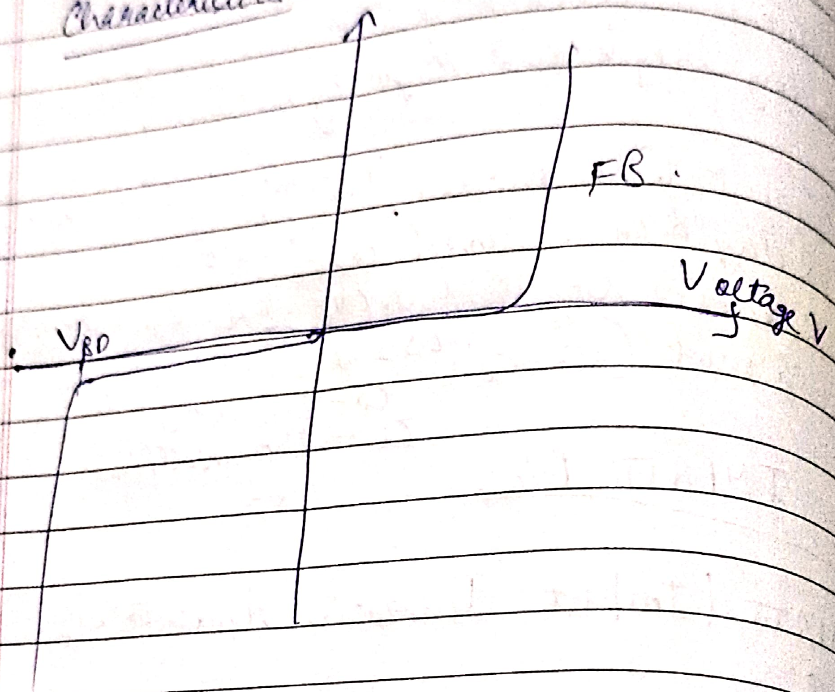
2. Transit - Time Effect: generated carriers drift through the intrinsic region, leading to a phase delay that helps sustain μ-wave oscillations.



IMPATT Diode operates in Reverse Bias Condition. In reverse resistance, V↑ I↓, recombination is very high, switching will be much faster.

Why Reverse Bias?

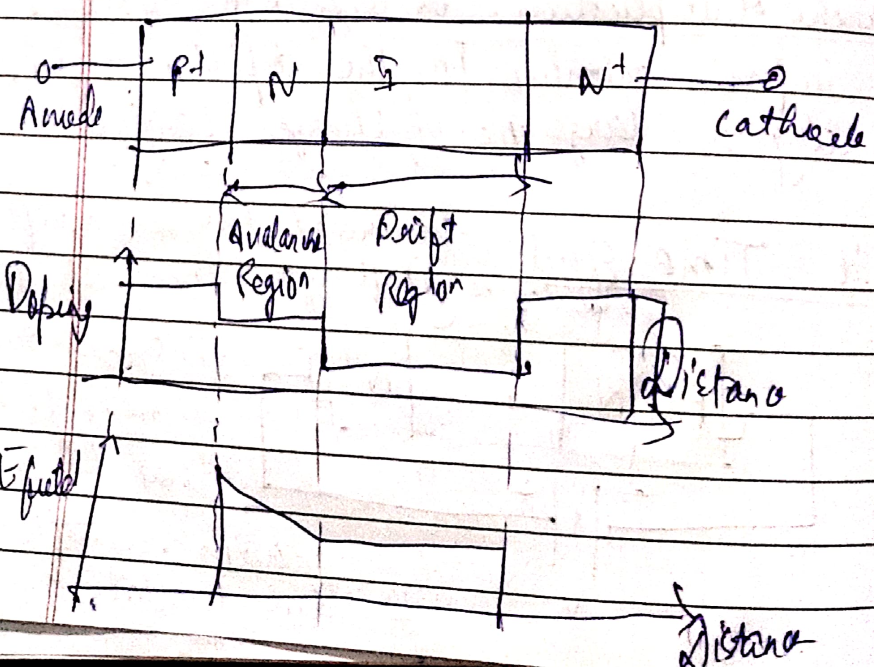
Characteristics.



Structure and Working.

Huge current flows after breakdown, because of Avalanche effect (charge carrier multiplication)

More layers) High power handling ca[pability]

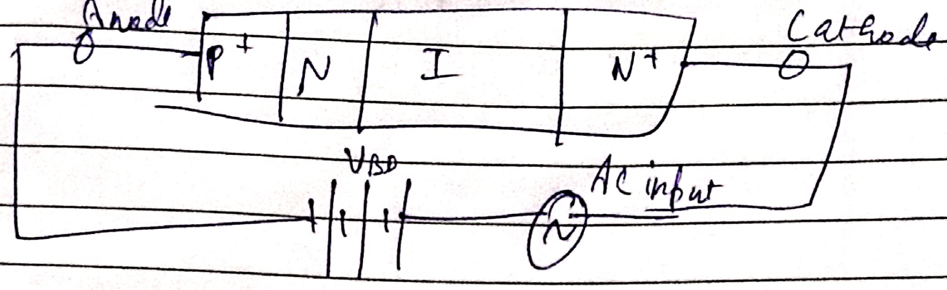


IMPATT can be fabricated using GaAs, Si, InP

Avalanche region – High E-field, charge multiplication happens in reverse bias condition.

After Reverse breakdown, electrons move towards N^+ region, holes move towards P^+ region.

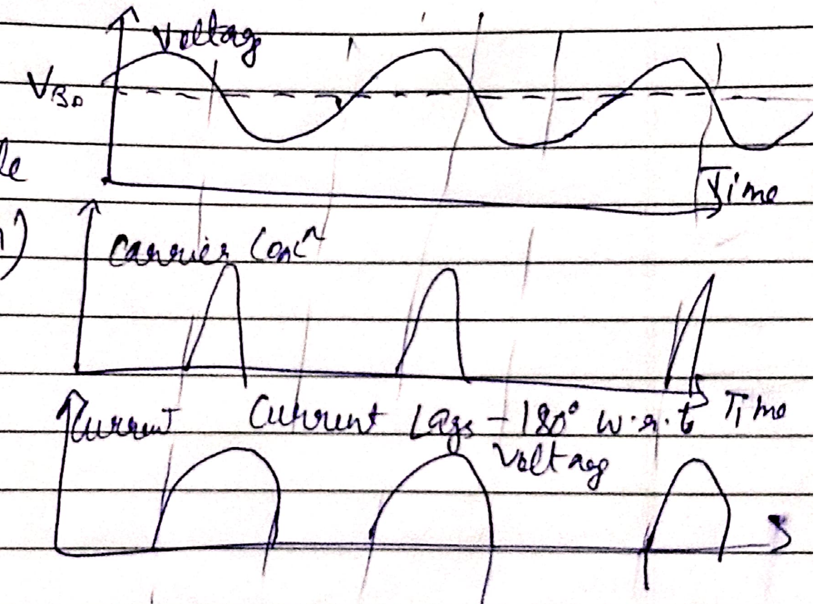
Working:



$e^- \to$ P side

holes → N side

(Recombinatⁿ)



Anode → (−)ve terminal of DC.

Cathode to (+)ve terminal of DC.

Diode – R.B.

Voltage – V_{BO} (Breakdown Voltage)

i/p – Sinusoidal AC

Reference – V_{BO}

1· Below V_{BD}) Break down occurs

Applications :

1. μ- wave comm^n systems
2. Radar and missile guidance
3. Industrial and medical heating
4. mm-wave imaging.