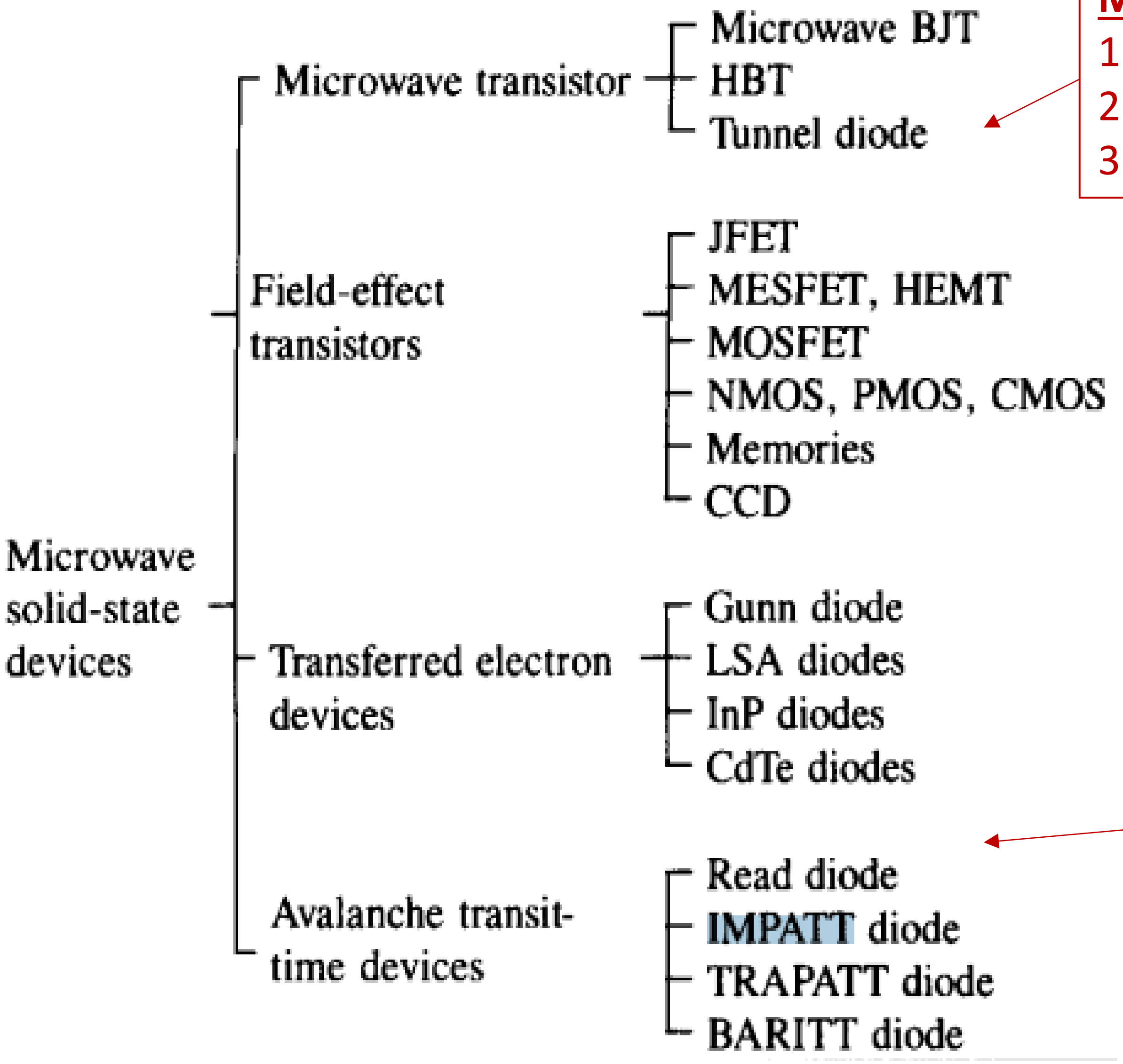
AVALANGE & TRANSIT-TIME DEVICES

EEEN 566 – MICROWAVE DEVICES

Friday, March 13, 2026

RECAP- TYPES OF SOLID-STATE DEVICES



Microwave Transistors & Diodes

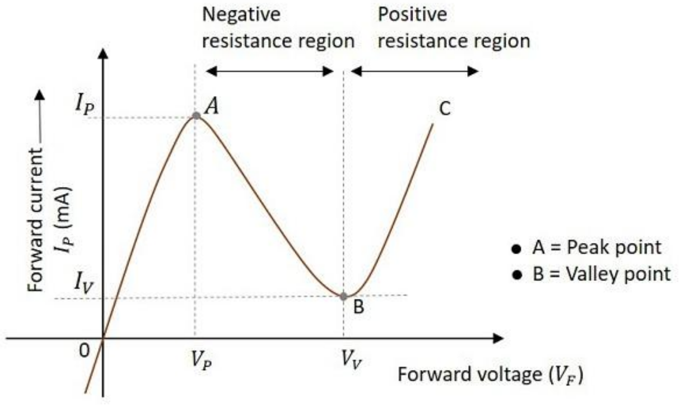
1. Microwave bipolar junction transistor (BJT)
2. Heterojunction bipolar transistor (HBT)
3. Tunnel diodes.

Avalanche effect of the semiconductor, are referred to as avalanche diodes:

1. **Read diode** theory was presented by Read in 1958
2. **Impact Ionization Avalanche Transit-Time (IMPATT)** diodes
3. **Trapped Plasma Avalanche Triggered Transit-Time(TRAPATT)** diodes
4. **BARrier Injected Transit-Time (BARITT)** diodes

POSITIVE & NEGATIVE RESISTANCE

1. **All active two-terminal solid-state devices have negative resistance**. The real part of their impedance is negative over a range of frequencies.
2. **Positive Resistance:** The current through the resistance and the voltage across it are in phase. Voltage drop across it is positive and a power (I^2 R) is dissipated.
3. **Negative Resistance:** Current and voltage are out of phase by 180°. Voltage drop across it is negative, and a power (I^2 R) is generated.



Summary:

Positive resistances absorb power (passive devices)

Negative resistances generate power (active devices).

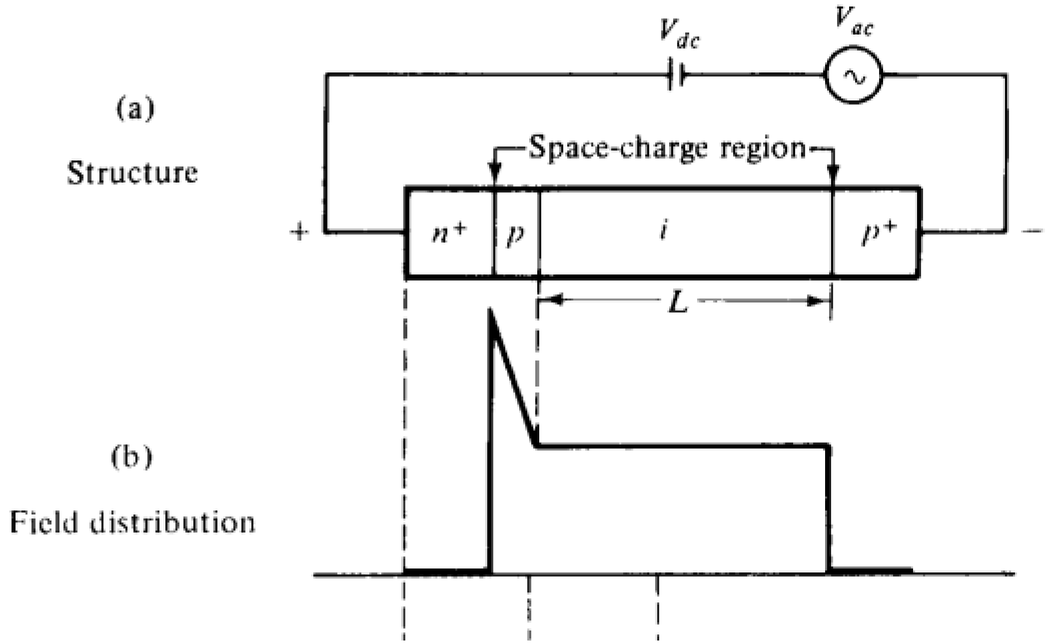
Further Reading: [Negative resistance: meaning and measurement]

WHAT ARE AVALANCHE TRANSIT-TIME?

1. **Avalanche transit-time (ATT) is the delay between voltage and current in an avalanche together with transit time through the** material.
2. By using ATT, it is possible to make a **microwave diode which exhibits negative resistance**.
3. Devices using ATT are known as Avalanche transit time devices.
4. Examples of ATT devices are:
    a) **TRAPATT**
    b) **IMPATT**
    c) **BARITT**

WHAT ARE AVALANCHE TRANSIT-TIME DIODE OSCILLATORS?

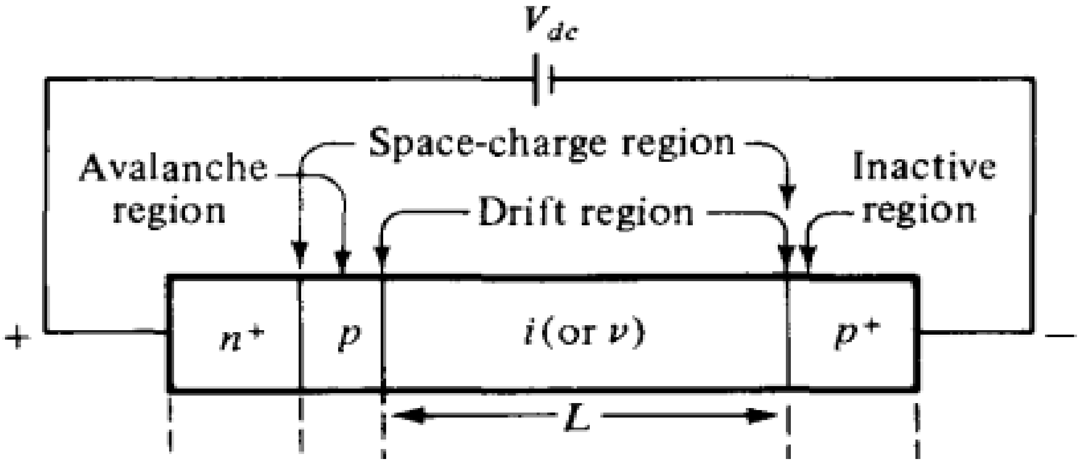
1. Avalanche transit-time diode oscillators **rely on the effect of voltage breakdown across a reverse-biased p-n junction** to produce a supply of holes and electrons and a delay in the transit region which creates negative resistance.



Further Reading:
microwave-devices-and-circuits-samuel-liao.pdf Read pages 303-308

READ DIODE - THE FOUNDATION OF ATT DIODES

1. **The operating principle of Avalanche Transit-Time (ATT)** diodes is based on the **read diode (1958).**
2. **A Read Diode is a microwave semiconductor diode consisting of an avalanching pn junction**, **biased to fields of several hundred thousand volts per centimeter**, at one end of a high-resistance carrier serving as a drift space for the charge carriers.



Further Reading:
microwave-devices-and-circuits-samuel-liao.pdf Read pages 303-308

IMPATT DIODE

ECE 524E – MICROWAVE ENGINEERING

Friday, March 13, 2026

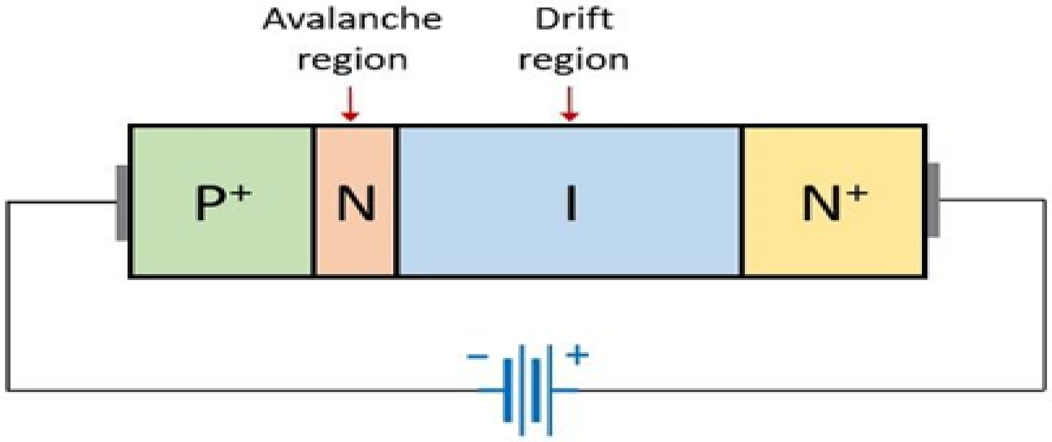
WHAT IS IMPATT DIODE?

1. **IMP**act ionization **A**valanche **T**ransit **T**ime (IMPATT) diode is semiconductor device that is used for generating microwave radio frequency signals.
2. Its main advantage over other microwave diodes is its **relatively high-power capability (often ten watts and more) when compared to other microwave diodes.**

HOW NEGATIVE RESISTANCE IS CREATED IN IMPATT DIODE

IMPATT diodes exhibit a differential negative resistance by two effects:

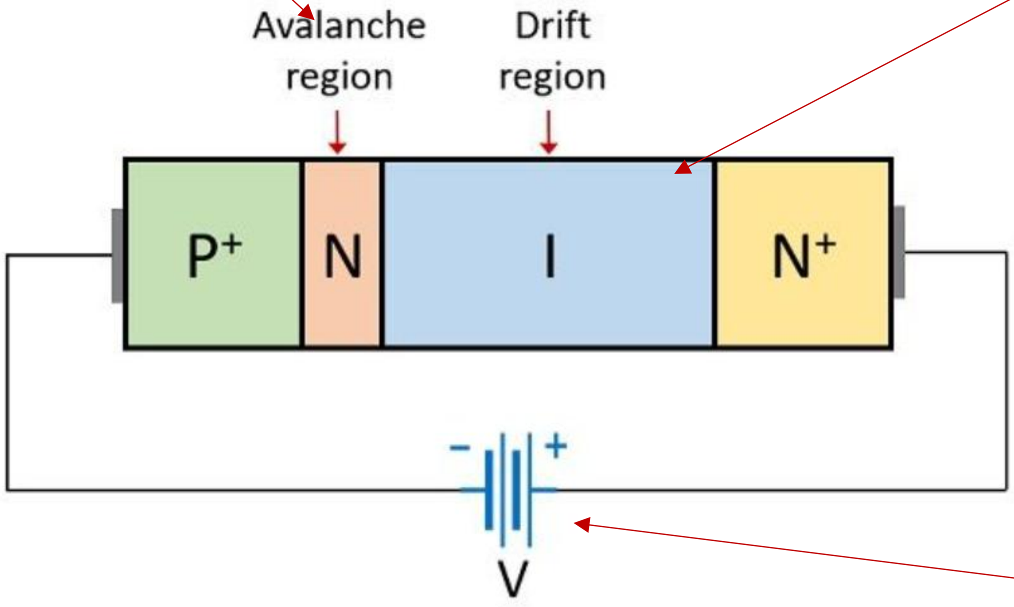
- **Impact ionization avalanche effect**, which causes the carrier current and the ac voltage to be out of phase by 90°
- **Transit-time effect**, which further delays the external current I.(t) relative to the ac voltage by 90°



STRUCTURE OF IMPATT DIODE

Avalanche region: High reverse voltage causes impact ionization, generating a large number of electron-hole pairs, leading to a pulsed carrier current that lags the external current by 90º, resulting in negative conductance and microwave oscillation.

Drift region: A lightly doped, high-resistivity area where avalanche-generated charge carriers (electrons or holes) drift towards the contacts causing a transit delay which promotes the diode's negative resistance behavior and microwave oscillation.

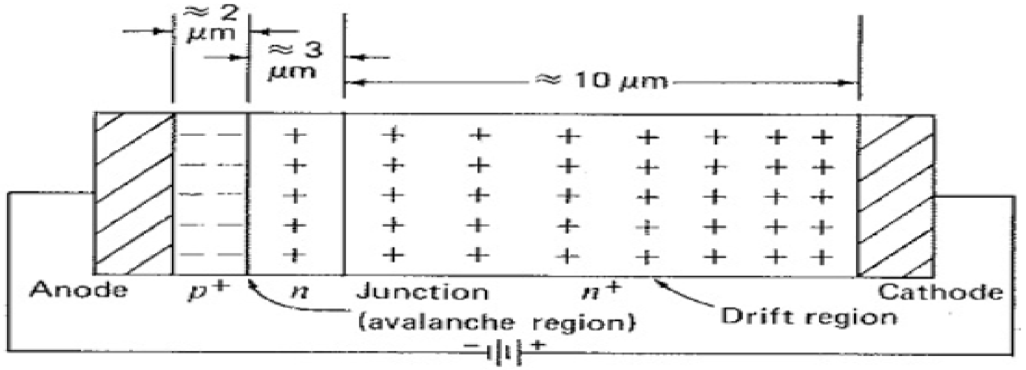


DC Source: creating a very high voltage gradient of around 400KV/cm, so as to produce avalanche current.

FREQUENCY OF IMPATT DIODE

1. The frequency of an IMPATT diode oscillators depends on the drift velocity v_d and the length of the drift region L and is given by

$$f = \frac{v_d}{2L}$$



2. Typically operating frequency of the IMPATT oscillator is in the range of 3 GHz to 100 GHz

EFFICIENCY OF IMPATT DIODE

1. The efficiency, η of the IMPATT diode is the ratio of the power of the **continuous wave power output, P_{CW}** to the **input DC power**, **P_{DC}.**

$$\eta = \frac{P_{CW}}{P_{DC}}$$

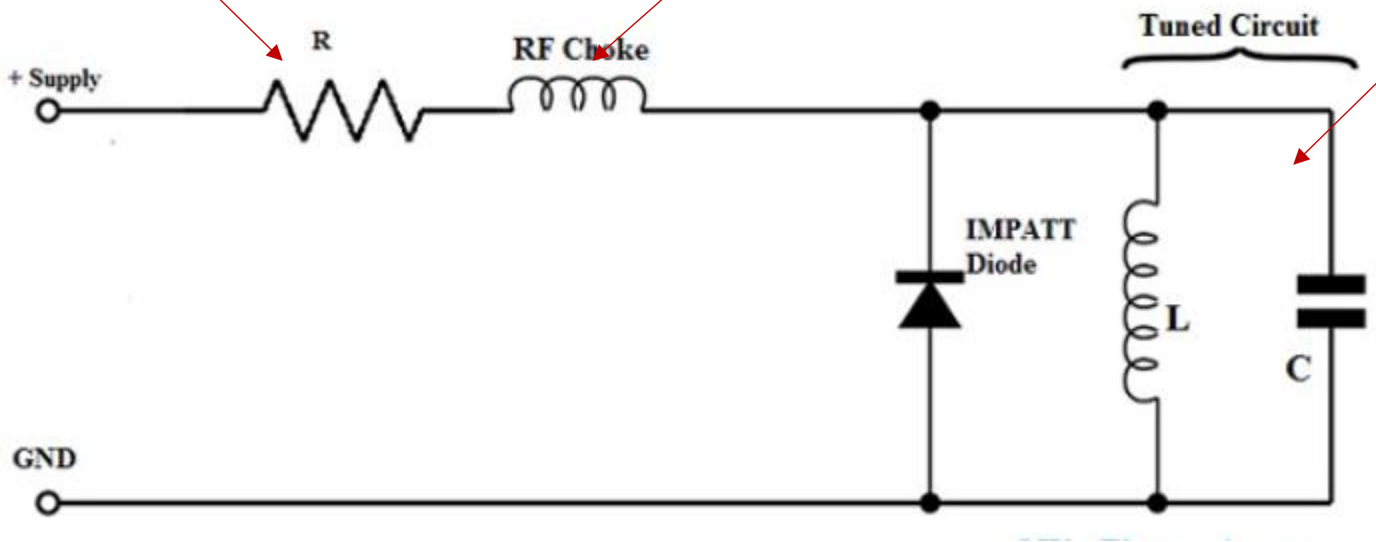
2. IMPATT diode efficiency typically ranges from about 10% to 20%.
3. Though some sources mention higher values, and it depends on factors like operating frequency and material used.

Further Reading:

microwave-devices-and-circuits-samuel-liao.pdf Read pages 303-313

CIRCUIT DIAGRAM OF IMPATT OSCILLATOR

A typical circuit of an IMPATT oscillators is shown below.



Resistor the flow of current to necessary value

RF choke to separate the DC from the RF signal.

Tuned circuit can also use a waveguide cavity

APPLICATIONS OF IMPATT DIODE

IMPATT diodes are used as oscillators in the following applications:

1. **Low-power radar systems** including CW radars used for speed measurement
2. **Motion-sensitive Proximity alarms** and such as those used in intrusion alarm devices.
3. **High-frequency signal generation** in the frequency range of 3 – 100 GHz

ADVANTAGES & DISADVANTAGES OF IMPATT DIODE-BASED OSCILLATORS

ADVANTAGES	**DISADVANTAGES**
• Extremely high frequency operating range • Small size • Reliable at high temperatures • Excellent power output	• Small tuning range • Higher noise level compared with TRAPATT and BARITT

WORKED EXAMPLE

An IMPATT diode has the following parameters:

- Carrier drift velocity: $v_d = 2 \text{ x } 10^7$ cm/s
- Drift-region length: $L = 6\ \mu m$
- Maximum operating voltage: $V_{0max} = 100$ V
- Maximum operating current: $I_{omax} = 200$ mA
- Efficiency: $\eta = 15\%$
- Breakdown voltage: $v_{bd} = 90$ v

Compute the following:

(a) the maximum CW output power in watts;

(b) the resonant frequency in gigahertz.

SOLUTION TO WORKED EXAMPLE

(a) DC power, P_{DC} is given by

$P_{DC} = V_{0max} \text{ x } I_{omax} = 100 \text{ x } 0.2 = 20W$

CW output power P_{CW} is given by

$P_{CW} = \eta P_{DC} = 0.15 \text{ x } 20 = 3W$

(b) Resonant frequency f is given by:

$$f = \frac{v_d}{2L} = \frac{2 \times 10^5}{2 \times 6 \times 10^{-6}} = 16.67\ GHz$$

TRAPATT DIODE

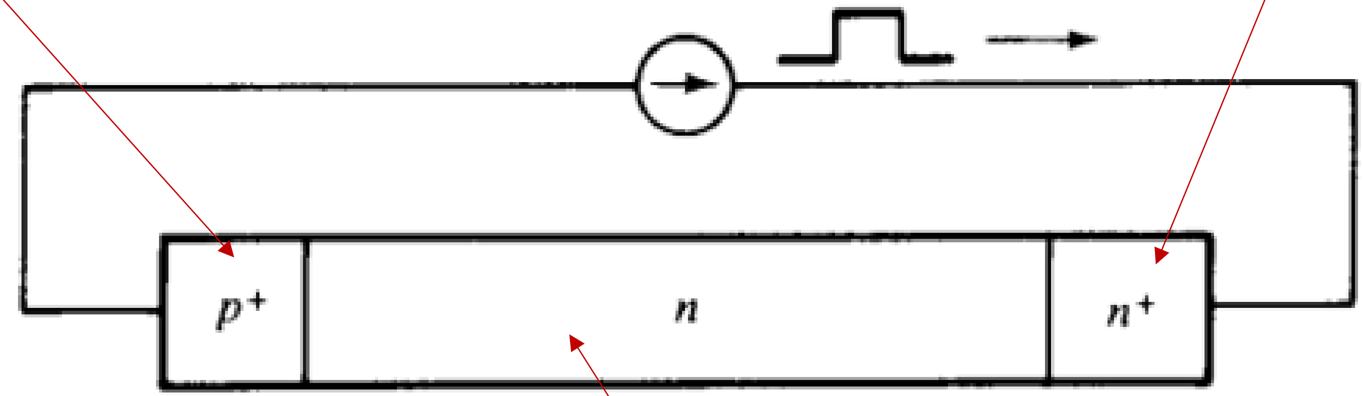
EEEN 566 – MICROWAVE ENGINEERING

Friday, March 13, 2026

WHAT IS TRAPATT DIODE?

1. **TRAPATT (TRApped Plasma Avalanche Triggered Transit)** diode is a microwave semiconductor device that **operates as an amplifier and oscillator**.
2. **TRAPATT consist of a three-layer P+ N N+ structure** (or N+ P P+ for higher power levels) fabricated using silicon.

STRUCTURE OF TRAPATT DIODE



P+ Region: A heavily doped P-type region (P+) is typically on one side of the junction.

N+ Region: A heavily doped N-type region (N+) is on the other side of the junction

N Region: A lightly doped N-type region (N) is between the P+ and N+ regions.

OPERATION OF TRAPATT DIODE OSCILLATOR

1. **Avalanche Breakdown:** When a high voltage is applied, an avalanche breakdown occurs in the depletion region, creating a plasma of electrons and holes.
2. **Plasma Trapping:** The avalanche-generated plasma is "trapped" within the depletion region due to the electric field, hence the name "trapped plasma".
3. **RF Power Generation:** The trapped plasma oscillates, allowing the diode to efficiently deliver RF power to an external load.

ADVANTAGES OF TRAPATT

1. **High Efficiency:** TRAPATT diodes achieve DC to RF signal conversion efficiencies in the range of 20% to 60%.
2. **Low Power Dissipation:** The current pulse associated with the trapped plasma results in low voltage, leading to low power dissipation and thus higher efficiency.

APPLICATIONS OF TRAPATT DIODES

1. **Low-Power Doppler Radars:** They are suitable for low-power Doppler radar applications.
2. **Pulsed Transmitters:** TRAPATT diodes are used in S-band pulsed transmitters for phased array radar systems.
3. **Radio Altimeters:** TRAPATT diodes are used in radio altimeters.
4. **Microwave Beacon Landing Systems:** They find use in microwave beacon landing systems.

BARITT DIODE

EEEN 566 – MICROWAVE ENGINEERING

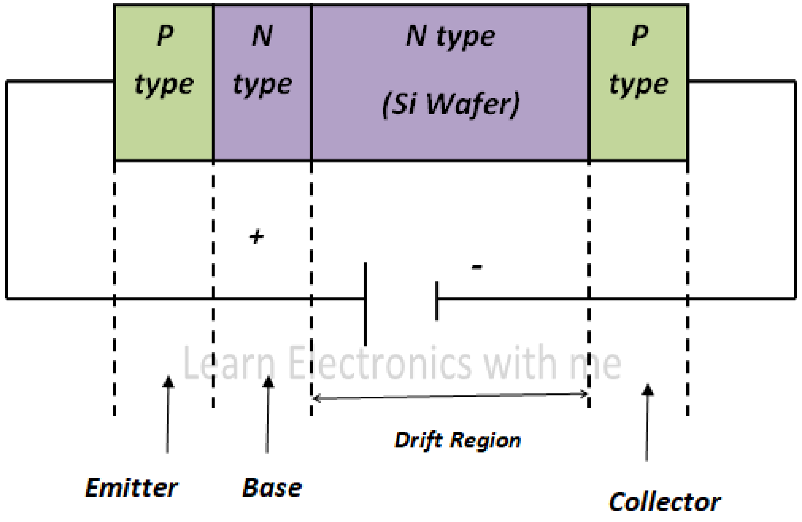
Friday, March 13, 2026

WHAT IS A BARITT DIODE?

1. **BArrier Injected Transit-Time diodes (BARITT)** is a microwave semiconductor device that uses minority carrier injection and transit-time effects to produce a negative resistance at microwave frequencies**.**
2. They have long drift regions similar to those of IMPATT diodes.
3. The carriers traversing the drift regions of BARITT diodes, however, are generated by minority carrier injection from forward-biased junctions instead of being extracted from the plasma of an avalanche region.

WORKING PRINCIPLE OF BARITT DIODE

- **Baritt diode consists of two back-to-back diodes** it can be P type and N type or Metal and semiconductor or combination of two.
- **N type region is larger than the both P type leading to punch-through-effect between these regions.** "Punch through effect" is the effect which happens when the depletion region expands from one junction to the other junction.



Learn Electronics with me

MERITS & DEMERITS OF BARITT DIODE

Advantages

- low noise.

Disadvantages

- When the frequency is increased, the efficiency decreases.
- It produces low power output.
- Narrow bandwidth

APPLICATIONS OF BARITT DIODE

1. **Microwave Signal Generation:** BARITT diodes, like IMPATT diodes, are used to generate microwave signals due to their ability to produce a negative resistance at microwave frequencies.
2. **Oscillators:** They are used as oscillators in electronic circuits, generating continuous wave (CW) microwave signals.
3. **CW Radar Speed Guns:** BARITT diodes can be used in radar speed guns to measure the speed of moving objects using microwave signals.
4. **Microwave Relay Data Link Transmitters: U**sed in transmitters in microwave relay data link systems as carrier signal generators.