MICROWAVE DIODES

TRANSFER ELECTRON DEVICES

INTRODUCTION:

The application of two-terminal semiconductor devices at microwave frequencies has been increased usage during the past decades. The CW, average, and peak power outputs of these devices at higher microwave frequencies are much larger than those obtainable with the best power transistor. The common characteristic of all active two-terminal solid-state devices is their negative resistance. The real part of their impedance is negative over a range of frequencies. In a positive resistance the current through the resistance and the voltage across it are in phase. The voltage drop across a positive resistance is positive and a power of *(12 R)* is dissipated in the resistance.

In a negative resistance, however, the current and voltage are out of phase by 180°. The voltage drop across a negative resistance is negative, and a power of *(-I!R)* is generated by the power supply associated with the negative resistance. In positive resistances absorb. power (passive devices), whereas negative resistances generate power (active devices). In this chapter the transferred electron devices(TEDs) are analyzed.

The differences between microwave transistors and transferred electron devices (TEDs) are fundamental. Transistors operate with either junctions or gates, but TEDs are bulk devices having no junctions or gates. The majority of transistors are fabricated from elemental semiconductors, such as silicon or germanium, whereas 1tDs are fabricated from compound semiconductors, such as

gallium arsenide (r.As),indium phosphide (lnP), or cadmium telluride (CdTe). Transistors operate
As "warm" electrons whose energy is not much greater than the thermal energy 0.026eVat room temperature) of electrons in the semiconductors.

GUNN EFFECT DIODES – GaAs diode

Gunn effect are named after J. B. Gunn who is 1963 discovered a periodic fluctuation of current passing through the n- type gallium arsenide . when the applied voltage exceeded a certain critical value.

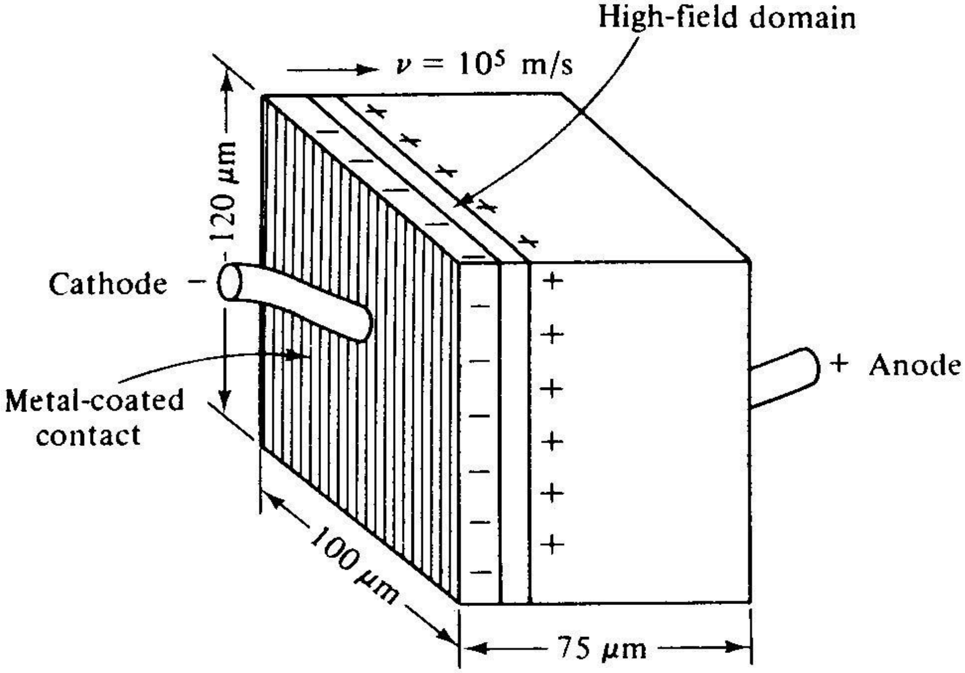
Shockley in 1954 suggested that the two terminal negative resistance devices using semiconductors had advantages over transistors at high frequencies.

In 1961 , Ridley and Watkins described a new method for obtaining negative differential mobility in semiconductors. The principle involved is to heat carriers in a light mass , low mobility , higher energy sub band when they have a high temperature.

Finally Kroemer stated that the origin of the negative differential mobility is Ridley Watkins Hilsum's mechanism of electron transfer into the valleys that occur in conduction bands.

Gunn effect:

The below figure shows the diagram of a uniform n-type GaAs diode with ohmic contacts at the end surfaces. Gunn stated that " Above some critical voltage , corresponding to an electric field of 2000 to 4000 Volts/cm, the current in every specimen became a fluctuating function of time.



Gunn Diodes

Single piece of GaAs or Inp and contains no junctions

Exhibits negative differential resistance

Applications:

- low-noise local oscillators for mixers (2 to 140 GHz).
- Low-power transmitters and wide band tunable sources

Continuous-wave (CW) power levels of up to several hundred mill watts can be obtained in the X-, Ku-, and Ka-bands. A power output of 30 mW can be achieved from commercially available devices at 94 GHz.

Higher power can be achieved by combining several devices in a power combiner.

Gunn oscillators exhibit very low dc-to-RF efficiency of 1 to 4%.

Gunn also discovered that the threshold electric field Eili varied with the length and type of material. He developed an elaborate capacitive probe for plotting the electric field distribution within a specimen of n-type GaAs of length *L* = 210 JLIll and cross-sectional area 3.5 x 10-3 cm2 with a low-field resistance of 16 n. Current instabilities occurred at specimen voltages above 59 V, which means that the threshold field is

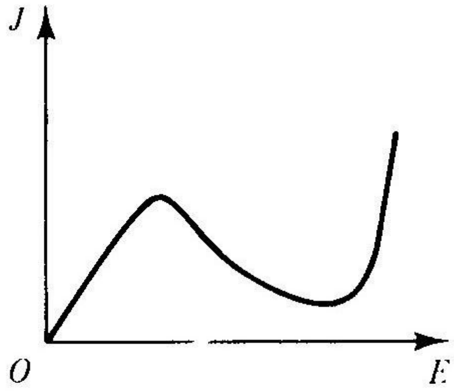
$$E_{th} = \frac{V}{L} = \frac{59}{210 \times 10^{-6} \times 10^{2}} = 2810 \text{ volts/cm}$$

RIDLEY WATKINS AND HILSUM THEORY:

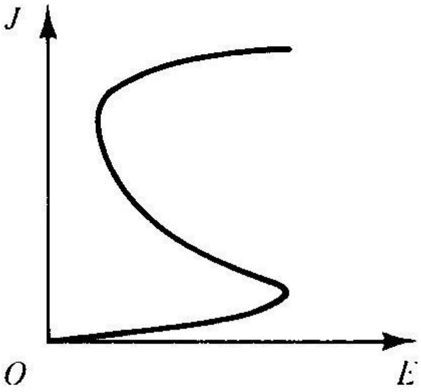
Many explanations have been offered for the Gunn effect. In 1964 Kroemer [6] suggested that Gunn' s observations were in complete agreement with the Ridley-Watkins-Hilsum (RWH) theory.

Differential Negative Resistance:

The fundamental concept of the Ridley-Watkins-Hilsum (RWH) theory is the differential negative resistance developed in a bulk solid-state III-V compound when either a voltage (or electric field) or a current is applied to the terminals of the sample. There are two modes of negative-resistance devices: voltage-controlled and current controlled Modes.

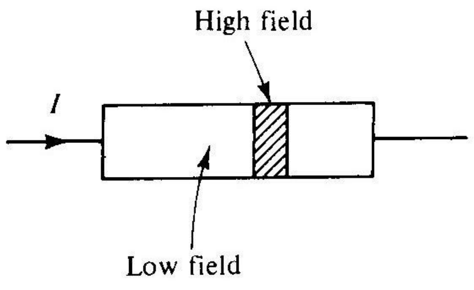


(a) Voltage-controlled mode

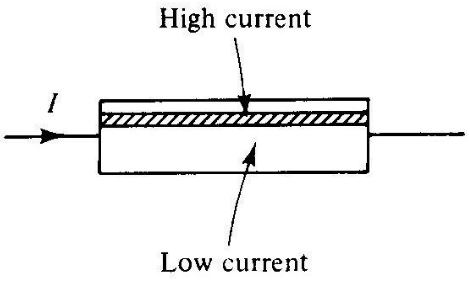


(b) Current-controlled mode

In the voltage-controlled mode the current density can be multivalued, whereas in the current-controlled mode the voltage can be multivalued. The major effect of the appearance of a differential negative-resistance region in the current density field curve is to render the sample electrically unstable. As a result, the initially homogeneous sample becomes electrically heterogeneous in an attempt to reach stability. In the voltage-controlled negative-resistance mode high-field domains are formed, separating two low-field regions. The interfaces separating low and high-field domains lie along equi potentials; thus they are in planes perpendicular to the current direction.



(a) High-field domain

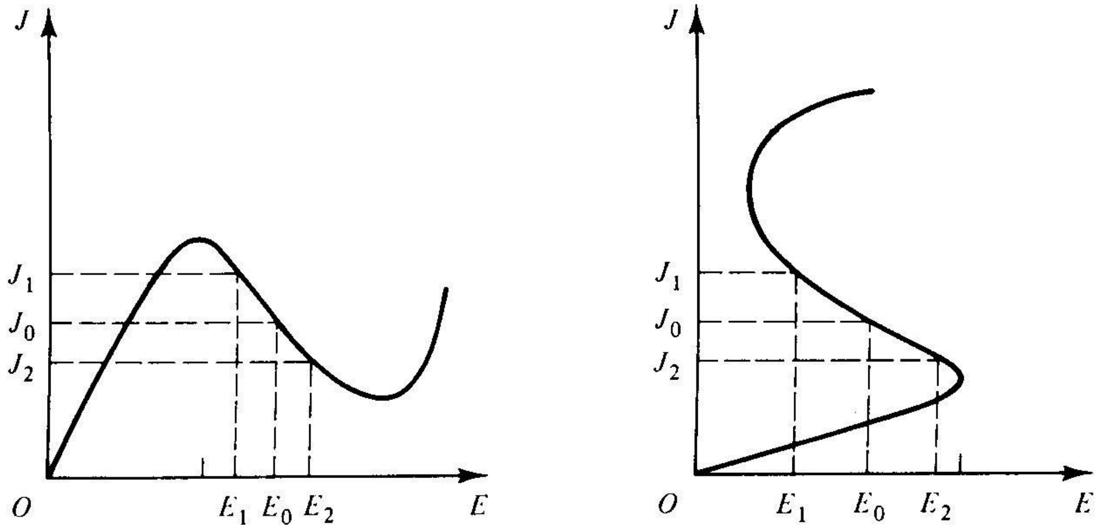


(b) High-current filament

Expressed mathematically, the negative resistance of the sample at a particular region is

$$\frac{dI}{dV} = \frac{dJ}{dE} = \text{negative resistance}$$

If an electric field *Eo* (or voltage *Vo)* is applied to the sample, for example, the current density 10is generated. As the applied field (or voltage) is increased to *E1* (or *V2),* the current density is decreased to 12. When the field (or voltage) is decr~ to £. (or *VI),* the current density is increased to 1, . These phenomena of the voltage controlled negative resistance are shown in Fig. 7-2-3(a). Similarly, for the current controlled mode, the negative-resistance profile is as shown below.

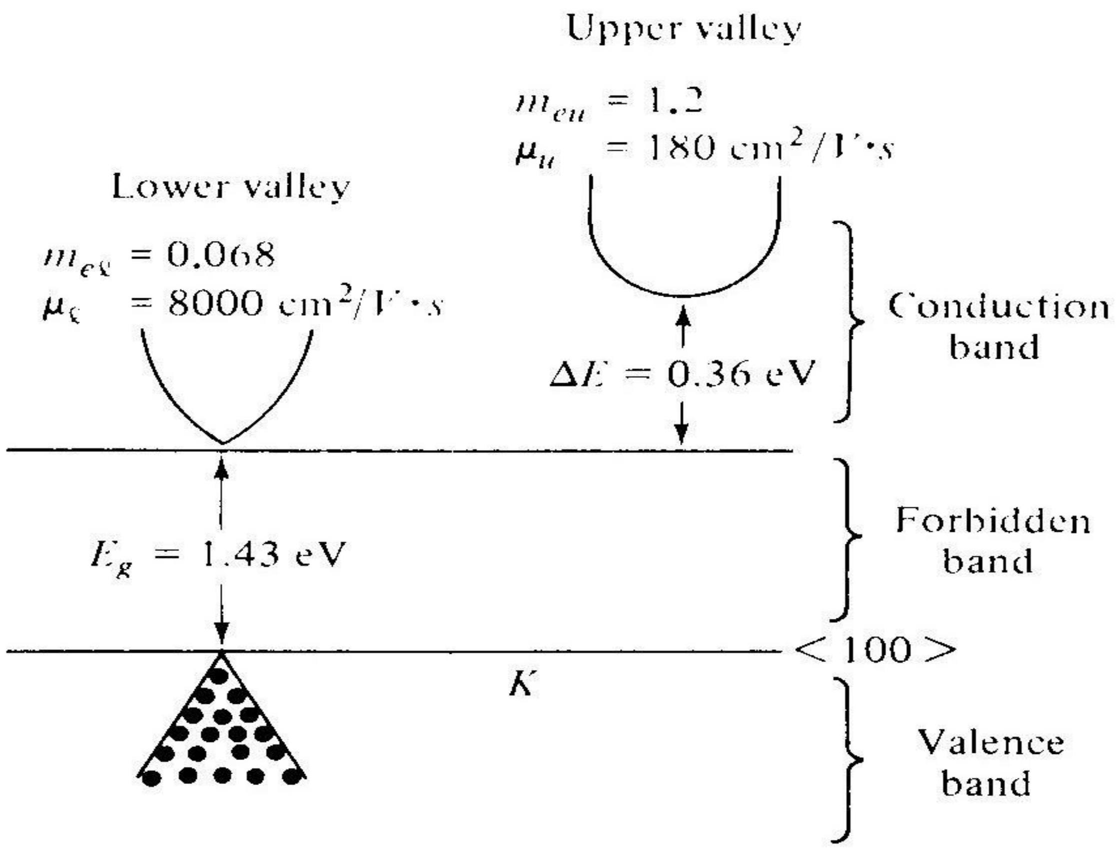


(a) Voltage-controlled mode

(b) Current-controlled mode

TWO VALLEY MODEL THEORY:

Kroemer proposed a negative mass microwave amplifier in 1958 [lO] and 1959 [II]. According *to* the energy band theory of the *n* -type GaAs, a high-mobility lower valley is separated by an energy of 0.36 eV from a low-mobility upper valley

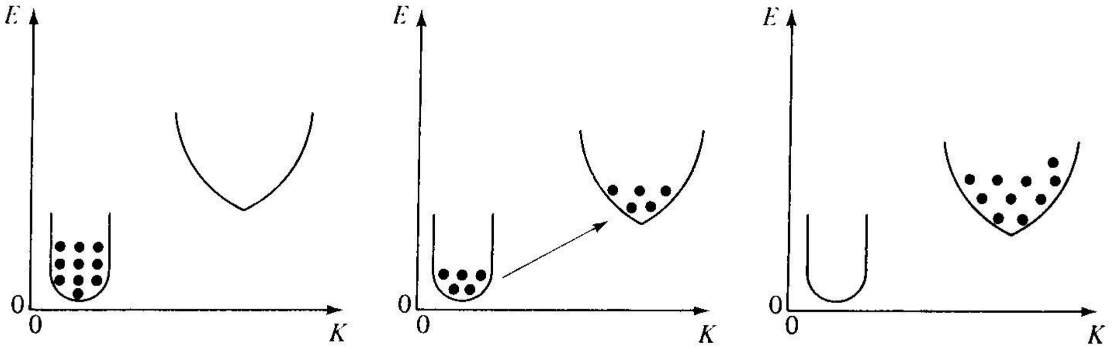


Electron densities in the lower and upper valleys remain the same under an Equilibrium condition. When the applied electric field is lower than the electric field of the lower valley *(E < Ee),* no electrons will transfer to the upper valley.

When the applied electric field is higher than that of the lower valley and lower than that of the upper valley *(Ee < E < Eu)),* electrons will begin to transfer to the upper valley.

when the applied electric field is higher than that of the upper valley *(Eu < E),* all electrons will transfer to the upper valley.

When a sufficiently high field *E* is applied to the specimen, electrons are accelerated and their effective temperature rises above the lattice temperature also increases. Thus electron density/I and are both functions of electric field *E*.



(a) $E < E_\ell$ (b) $E_\ell < E < E_u$ (c) $E_u < E$

Transfer of electron densities.

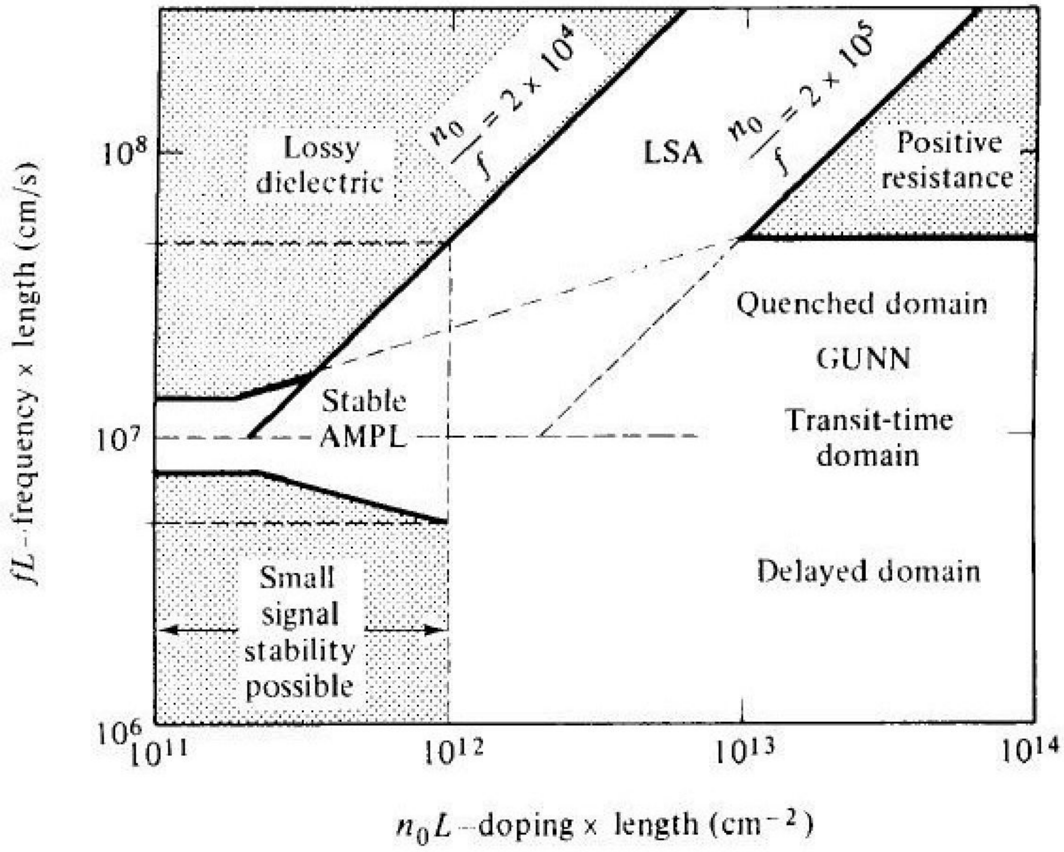
MODES OF OPERATION OF GUNN DIODE:

A gunn diode can operate in four modes:

1. Gunn oscillation mode
2. stable amplification mode
3. LSA oscillation mode
4. Bias circuit oscillation mode

Gunn oscillation mode: This mode is defined in the region where the product of frequency multiplied by length is about 107 cm/s and the product of doping multiplied by length is greater than 1012/cm2.In this region the device is unstable because of the cyclic formation of either the accumulation layer or the high field domain.

When the device is operated is a relatively high Q cavity and coupled properly to the load, the domain I quenched or delayed before nucleating.

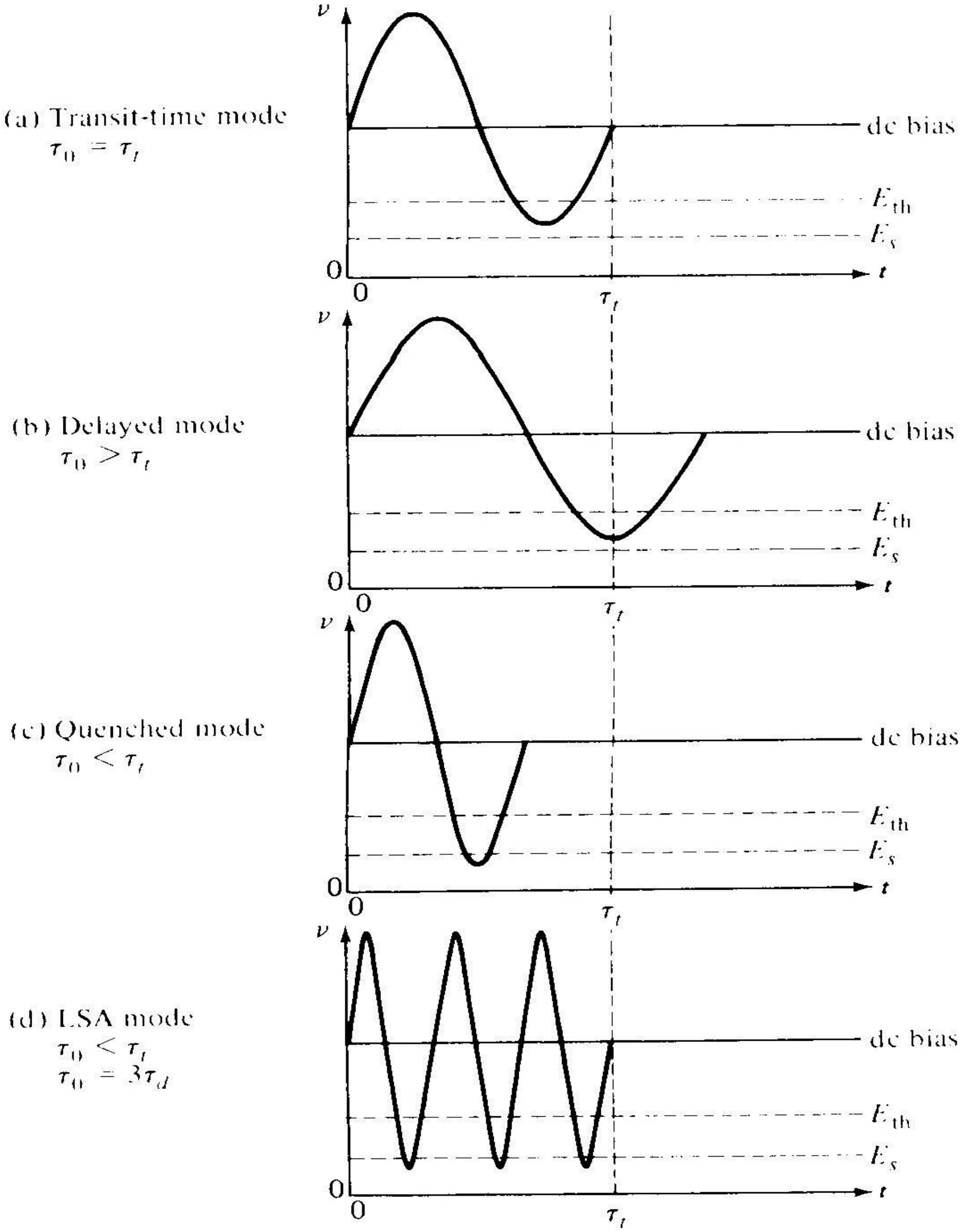


2.Stable amplification mode: This mode is defined in the region where the product of frequency times length is about 107 *cmls* and the product of doping times length is between $l0^{11}$and $1O^{12}/cm2$

.3. **LSA oscillation mode**: This mode is defined in the region where the product of frequency times length is above 10^7 *cmls* and the quotient of doping divided by frequency is between 2 x 10^4 and 2 x 10^5.

4. Bias-circuit oscillation mode: This mode occurs only when there is either Gunn or LSA oscillation. and it is usually at the region where the product of frequency times length is too small to appear in the figure. When a bulk diode is biased to threshold. the average current suddenly drops as Gunn oscillation begins.

The drop in current at the threshold can lead to oscillations in the bias circuit that are typically 1 kHz to 100 MHz .



Delayed domain mode (106 cm/s < *fL* < 107 cm/s). When the transit time is Chosen so that the domain is collected while *E* < Eth as shown in Fig. 7-3-4(b), a new domain cannot form until the field rises above threshold again. In this case, the oscillation period is greater than the transit time-that is, *To* > *T,*. This delayed mode is also called *inhibited mode.* The efficiency of this mode is about 20%.

Quenched domain mode (fL > 2 X 107 cm/s).

If the bias field drops below the sustaining field *Es* during the negative half-cycle as shown ,the domain collapses before it reaches the anode. When the bias field swings back above threshold ,a new domain is nucleated and the process repeats. Therefore the oscillations occur at the frequency of the resonant circuit rather than at the transit-time frequency, It has been found that the resonant frequency of the circuit is several times the transit-time frequency, since one dipole does not have enough time to readjust and absorb the voltage of the other dipoles . Theoretically, the efficiency of quenched domain oscillators can reach 13%

LSA MODE

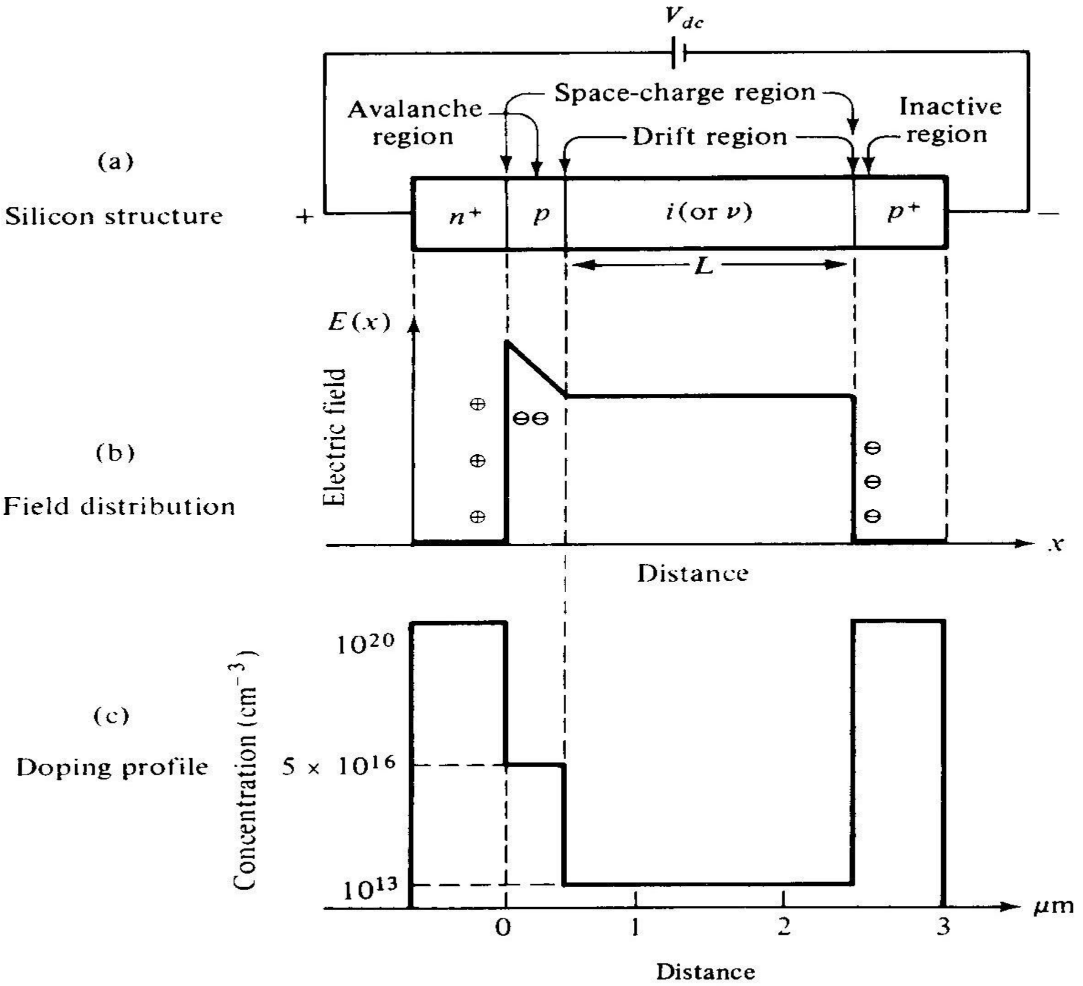
When the frequency is very high, the domains do not have sufficient time to form While the field is above threshold. As a result, most of the domains are maintained In the negative conductance state during a large fraction of the voltage cycle. Any Accumulation of electrons near the cathode has time to collapse while the signal is Below threshold. Thus the LSA mode *is* .the simplest mode of operation.

AVALANCHE TRANSIT TIEM DEVICES:

READ DIODE:

Read diode was the first proposed avalanche diode. The basic operating principles of IMPATT diode can be easily understood by first understanding the operation of read diode.

The basic read diode consists of four layers namely n+ p I p+ layers. The plus superscript refers to very high doping levels and ‘i’ denotes intrinsic layer.A large reverse bias is applied across diode . the avalanche multiplication occurs in the thin "p" region which is also called the high field region or avalanche region.



The holes generated during the avalanche process drift through the intrinsic region while moving towards p+ contact. The region between n+ p junction and the i-p+ junction is known as space charge region.

When this diode is reverse biased and placed inside an inductive microwave cavity microwave oscillations are produced due to the resonant action of the capacitive impedance of the diode and cavity inductance. The dc bias power is converted into microwave power by that read diode oscillator.

Avalanche multiplication occurs when the applied reverse bias voltage is greater then the breakdown voltage so that the space charge region extends from n+p junction through the p and I regions, to the i to p+ junction.

IMPATT DIODE:

lmpatt diodes are manufactured having different forms such as n+pip+, p+nin+, p+nn+ abrupt junction and p+ i n+ diode configuration. The material used for manufacture of these modes are either Germanium, Silicon, Gallium Arsenide (GaAs) or Indium Phosphide (In P).

Out of these materials, highest efficiency, higher operating frequency and lower noise is obtained with GaAs. But the disadvantage with GaAs is complex fabrication process and hence higher cost. The figure below shows a reverse biased n+ pi p+ diode with electric field variation, doping concentration versus distance plot, the microwave voltage swing and the current variation.

PRINICPLE OF OPERATION:

When a reverse bias voltage exceeding the breakdown voltage is applied, a high electric field appears across the n+ p junction. This high field intensity imparts sufficient energy to the valence electrons to raise themselves into the conduction band. This results avalanche multiplication of hole-electron pairs. With suitable doping profile design, it is possible to make electric field to have a very sharp peak in the close vicinity of the junction resulting in "impact avalanche multiplication". This is a cumulative process resulting in rapid increase of carrier density. To prevent the diode from burning, a constant bias source is used to maintain average current at safe limit 10, The diode current is contributed by the conduction electrons which move to the n+ region and the associated holes which drift through

the steady field and a.c. field.· The diode ~wings into and out of avalanche conditions under the influence of that reverse bias steady field and the a.c. field.

Due to the drift *time* of holes being' small, carriers drift to the end contacts before the a.c. voltage swings the diode out of the avalanche Due to building up of oscillations, the a.c. field takes energy from the applied bias lid the oscillations at microwave frequencies are sustained across the diode. Due to this a.c. field, the hole current grows exponentially to a maximum and again decays exponentially to Zero.

During this hole drifting process, a constant electron current is induced in the external Circuit which starts flowing when hole current reaches its peak and continues for half cycle Corresponding to negative swing of the a.c. voltage as shown in figure Thus a 180 degrees Phase shift between the external current and a.c. microwave voltage provides a negative Resistance for sustained oscillations.

The resonator is usually tuned to this frequency so that the IMPATI diodes provide a High power continuous wave (CW) and pulsed microwave signals.

$$\theta = \omega\tau = \omega\frac{L}{v_d}$$

$$\omega_r \equiv \left(\frac{2\alpha' v_d I_0}{\epsilon_s A}\right)^{1/2}$$

Applications of IMPATT Diodes

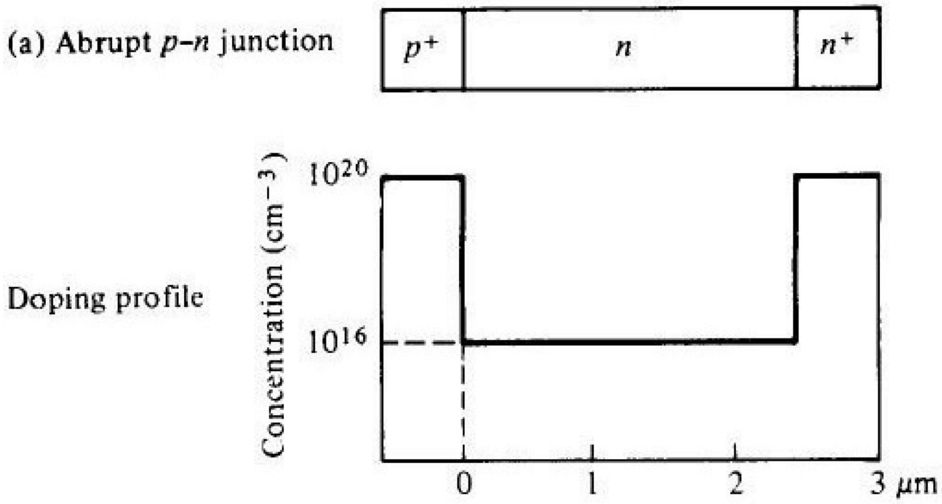
(i) Used in the final power stage of solid state microwave transmitters for communication purpose.

(ii) Used in the transmitter of TV system.

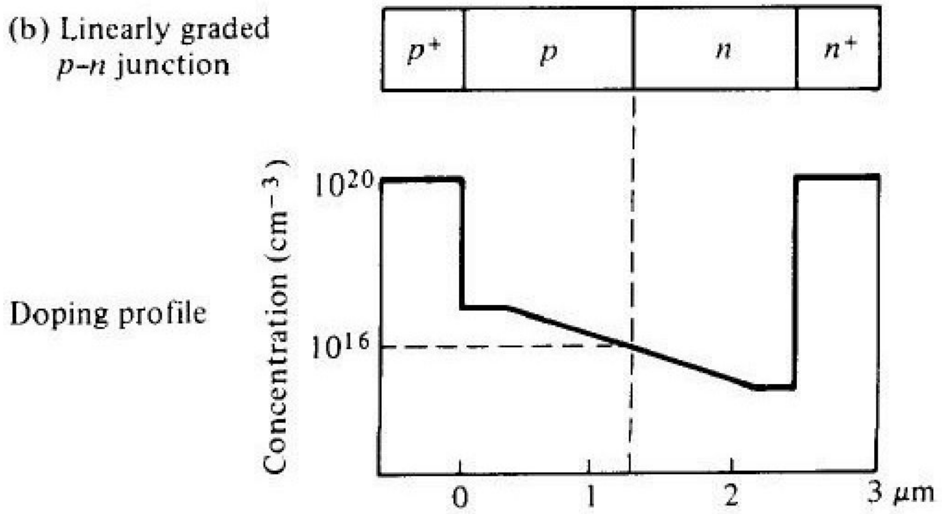
(iii) Used in FDM/TDM systems.

(iv) Used as a microwave source in laboratory for measurement purposes.

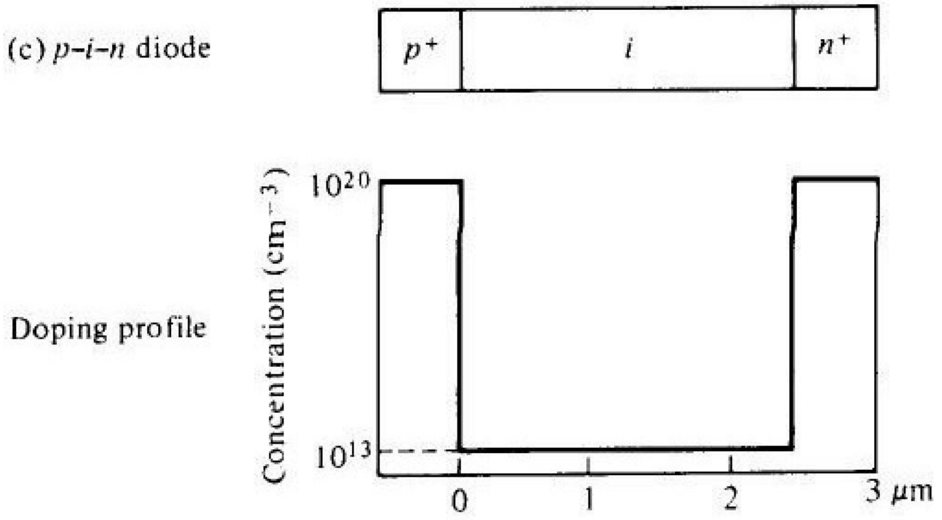
(a) Abrupt *p–n* junction



(b) Linearly graded *p–n* junction



(c) *p–i–n* diode



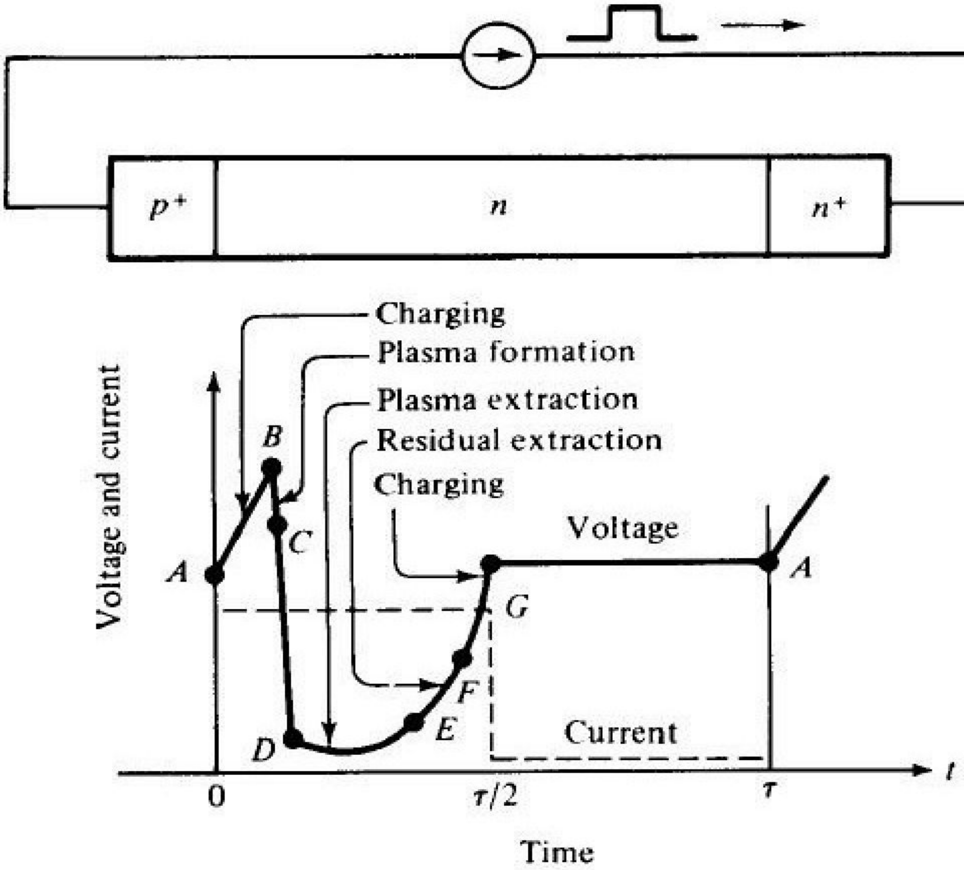
TRAPATT DIODE:

Silicon is usually used for the manufacture of TRAPATT diodes and have a configuration of p+ n n+ as shown .The p-N junction is reverse biased beyond the breakdown region, so that the current density is larger. This decreases the electric field in the space charge region and increases the carrier transit time. Due to this, the frequency of operation gets lowered to less than 10 GHz. But the efficiency gets increased due to low power dissipation.

Inside a co-axial resonator, the TRAPATT diode is normally mounted at a point where maximum RF voltage swing is obtained. When the combined dc bias and RF voltage exceeds breakdown voltage, avalanche occurs and a plasma of holes and electrons are generated which gets trapped. When the external circuit current flows, the voltage rises and the trapped plasma gets released producing current pulse across the drift space. The total transit time is the sum of the drift time and the delay introduced by the release of the trapped plasma. Due to this longer transit time, the operating frequency is limited to 10 GHz. Because the current pulse is associated with low voltage, the power dissipation is low resulting in higher efficiency.

The disadvantages of TRAPATT are high noise figure and generation of strong harmonics due to short duration of the current pulse.

TRAPATT diode finds application in S-band pulsed transmitters for pulsed array radar systems.



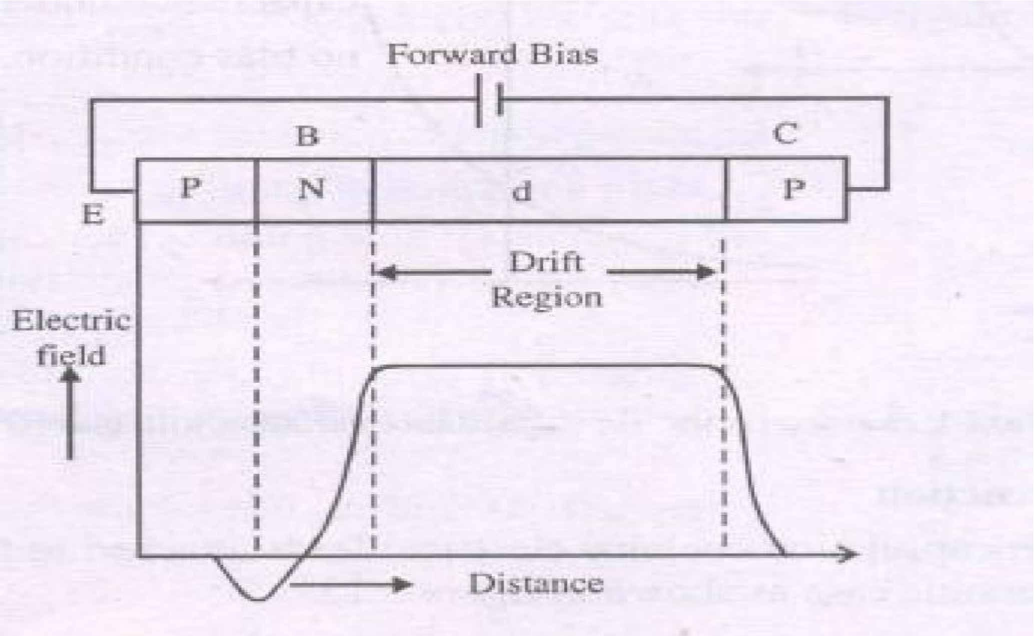
The electric field is expressed as

$$E(x, t) = E_m - \frac{qN_A}{\epsilon_s}x + \frac{Jt}{\epsilon_s}$$

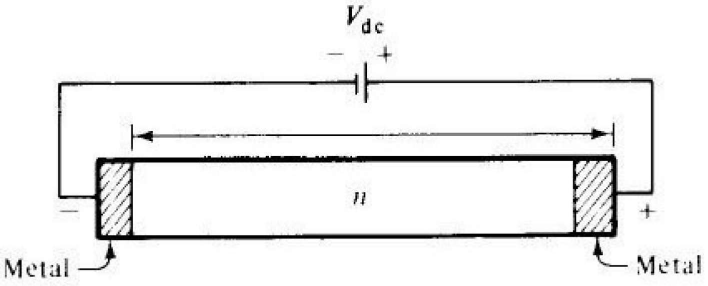
BARITT DIODE (Barrier injection transmit time devices):

BARITT devices are an improved version of IMPATT devices. IMPATT devices employ impact ionization techniques which is too noisy. Hence in order to achieve low noise figures, impact ionization is avoided in BARRITT devices. The minority injection is provided by punch-through of the intermediate region (depletion region). The process is basically of lower noise than impact ionization responsible for current injection in an IMPATT. The negative resistance is obtained on account of the drift of the injected holes to the collector end of the p-material.

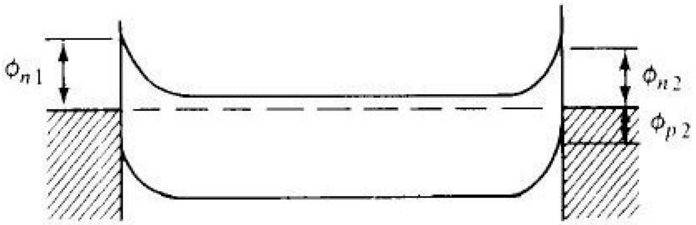
The construction of a BARITT device consisting of emitter, base,
intermediate or drift or depleted region and collector. An essential requirement for the BARITT device is therefore that the intermediate drift region be entirely depleted to cause punch through to the emitter-base junction without causing avalanche breakdown of the base-collector junction.



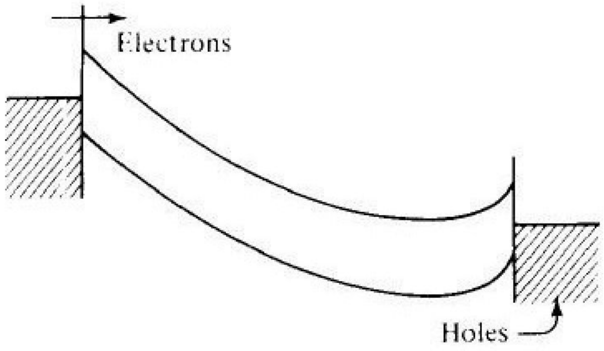
The parasitic should be kept as low as possible. The equivalent circuit depends on the type of encapsulation and mounting make. For many applications, there should be a large capacitance variation, small value of minimum capacitance and series resistance Rs' Operation is normally limited to f/l0 [25 GHz for *Si* and 90 GHz for GaAs]. Frequency of operation beyond (f /10) leads to increase in R, decrease in efficiency and increase in noise.



(a) M–n–M diode



(b) Energy band diagram in thermal equilibrium



(c) Energy band under bias condition

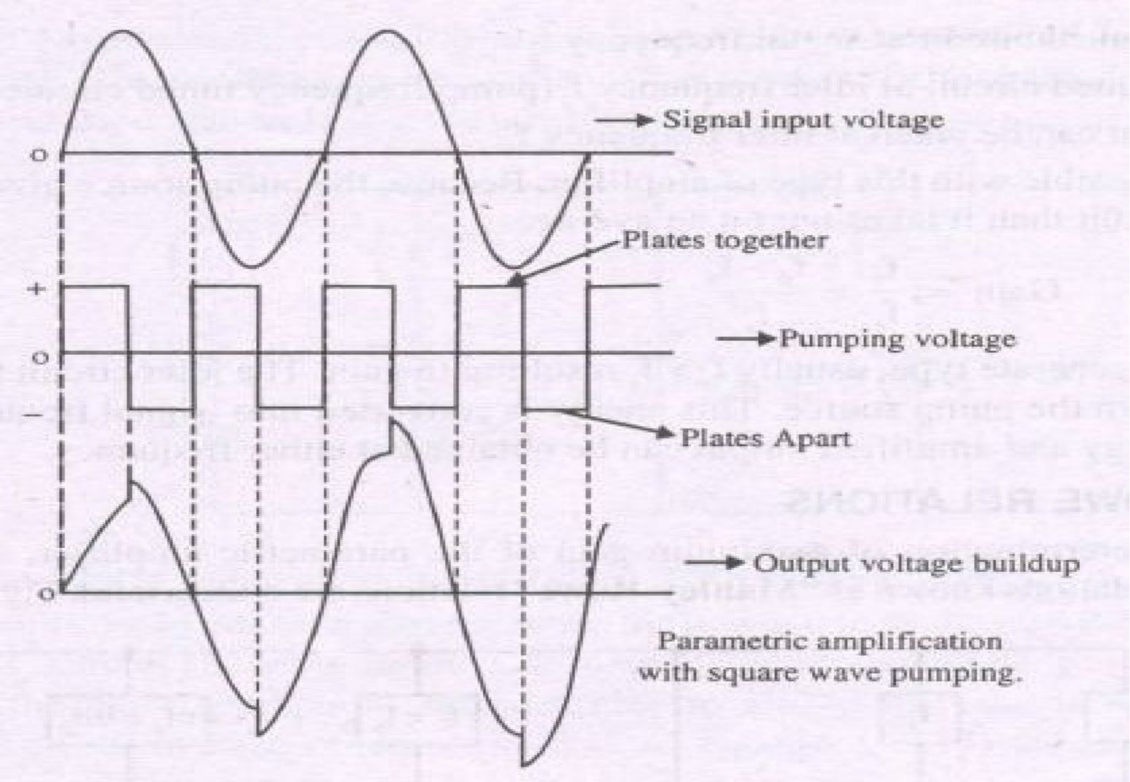
PARAMETRIC AMPLIFIERS:

The parametric amplifier is an amplifier using a device whose reactance is varied to produce amplification. Varactor diode is the most widely used active element in a parametric amplifier. It is a low noise amplifier because no resistance is involved in the amplifying process. There will be no thermal noise, as the active element used involved is reactive (capacitive). Amplification is obtained if the reactance is varied electronically in some predetermined fashion.

Due to the advantage of low noise amplification, parametric amplifiers are extensively used in systems such as long range radars, satellite ground stations, radio telescopes, artificial satellites, microwave ground communication stations, radio astronomy etc.

Basic **Parametric Amplifier**

A conventional amplifier uses a variable resistance and a d.c. power supply. For a parametric amplifier, a variable reactance and an ac power supply are needed. Pumping signal at frequency fp and a small amplitude signal at frequency fs are applied simultaneously to the device (varactor). The pump source supplies energy to the signal (at the signal frequency) resulting in amplification. This occurs at the active device where the capacitive reactance varies at the pump frequency.



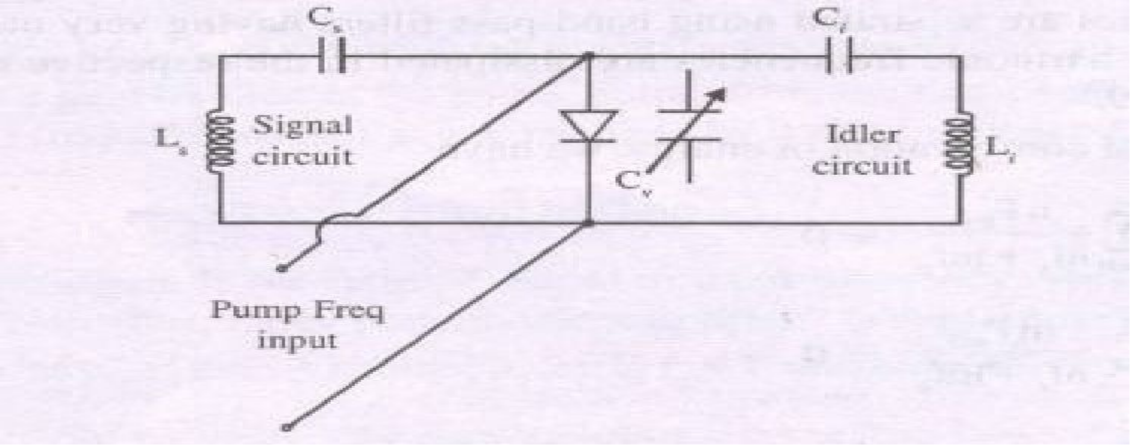
Parametric amplification with square wave pumping.

The voltage across the varactor is increased by the pumping signal at each signal voltage peak as shown above i.e., energy is taken from the pump source and added to the signal at the signal frequency. With an input circuit and load connected, amplification results.

One port non-degenerate amplifier is the most commonly used parametric amplifier. Only three frequencies are involved - the pump, the signal and the idler frequencies. If pump frequency is fp' the signal frequency is fs' then idler frequency is fj = fp - fs'

If fi = fs' then it is called Degenerate amplifier and

if fi is not equal to fs' then it is non-degenerate amplifier.



Ls Cs ~ tuned circuit at signal frequency fs

Lj Cj ~ tuned circuit at idler frequency fj (pump frequency tuned circuit is not shown),

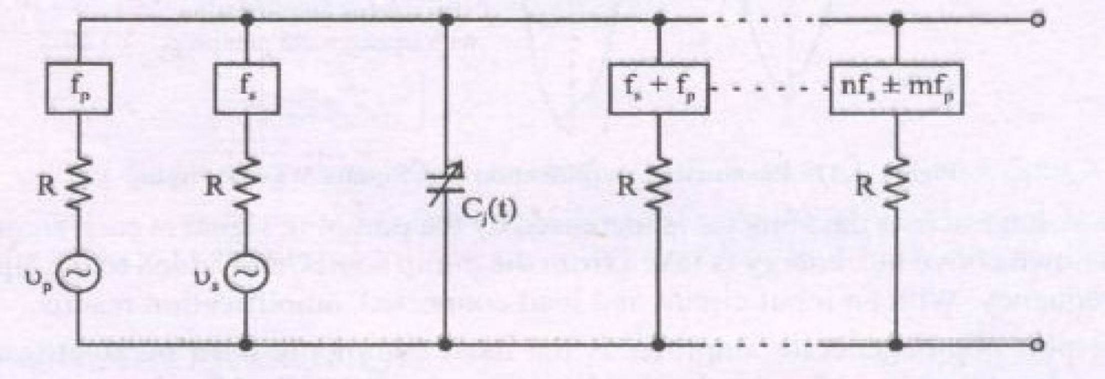
The output can be taken at idler frequency fr Gain is possible with this type of amplifier. Because the pump source gives more energy

$$\text{Gain} = \frac{f_i}{f_s} = \frac{f_p - f_s}{f_s}$$

In non-degenerate type, usually fj > fs resulting in gain. The idler circuit permits energy to be taken from the pump source. This energy is converted into signal frequency and idler frequency energy and amplified output can be obtained at either frequency.

MANLEY – ROWE RELATIONS:

For the determination of maximum gain of the parametric amplifier, a set of power conservation relations known as "Manley-Rowe" relations are quite useful.



two sinusoidal signals fp and fs applied across a lossless time varying non-linear capacitance Cj (t). At the output of this varying capacitance, harmonics of the two frequencies fp and fs are generated.

These harmonics are separated using band-pass filters having very narrow bandwidth.

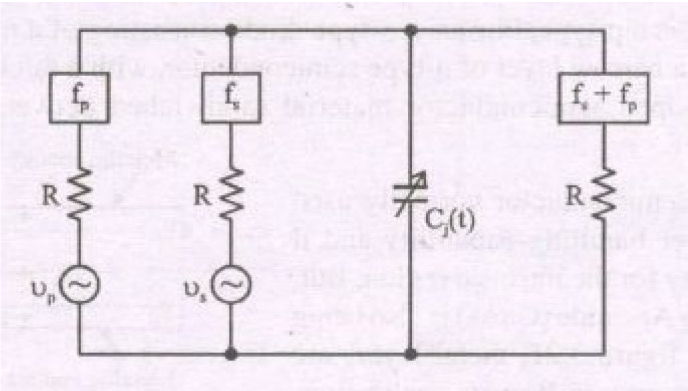
The power at these harmonic frequencies is dissipated in the respective resistive loads.

From the law of conservation of energy, we have

$$\sum_{m=-\infty}^{\infty} \sum_{n=0}^{\infty} \frac{n P_{mn}}{nf_s + mf_p} = 0$$

$$\sum_{m=0}^{\infty} \sum_{n=-\infty}^{\infty} \frac{m P_{mn}}{nf_s + mf_p} = 0$$

The above relations are called "Manley-Rowe" power conservation equations. When The power is supplied by the two generators, then Pmn is positive. In this case, power will flow into the non-linear capacitance. If it is the other way, then Pmn is negative.



As an example, let us consider the case when the power output flow is allowed at the sum frequency fp + fs only, with all the remaining harmonics being open circuited. With the above rest ructions, the quantities ‘m' and ‘n' can take on values -1,0 and respectively.

$$\frac{P_{01}}{f_s} + \frac{P_{11}}{f_s + f_p} = 0$$

$$\text{and } \frac{P_{10}}{f_p} + \frac{P_{11}}{f_s + f_p} = 0$$

The powers P01and P10 are considered positive, whereas P11 is considered negative. :. The power gain defined as the power output from the non-linear capacitor delivered to the load at sum frequency to that power received by it at a frequency fs is given by

$$G_p = \frac{P_{11}}{P_{01}} = \frac{f_s + f_p}{f_s} \text{ (for modulator)}$$

Thus the power gain is the ratio of output to input frequency. This type of parametric device is called "Sum-frequency parametric amplifier" or "up-converter".

On the other hand, if the signal frequency is fp + fs and output frequency is fs' then

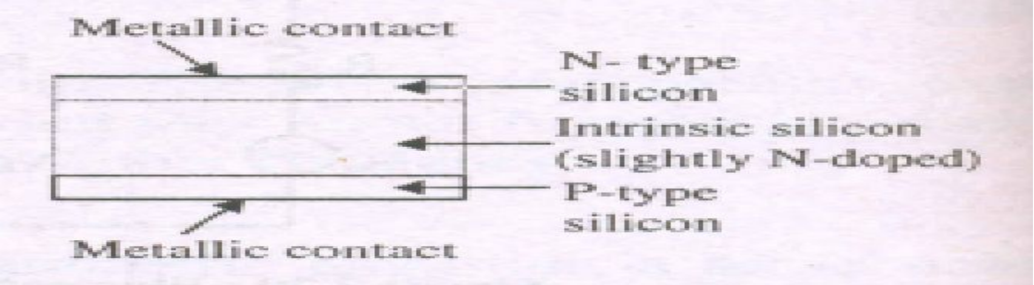
$$G_p = \frac{f_s}{f_p + f_s} \text{ (for demodulator)}$$

This type of parametric device will now be called "parametric down-converter" and the power gain becomes power attenuation.

PIN DIODE AND ITS APPLICATION:

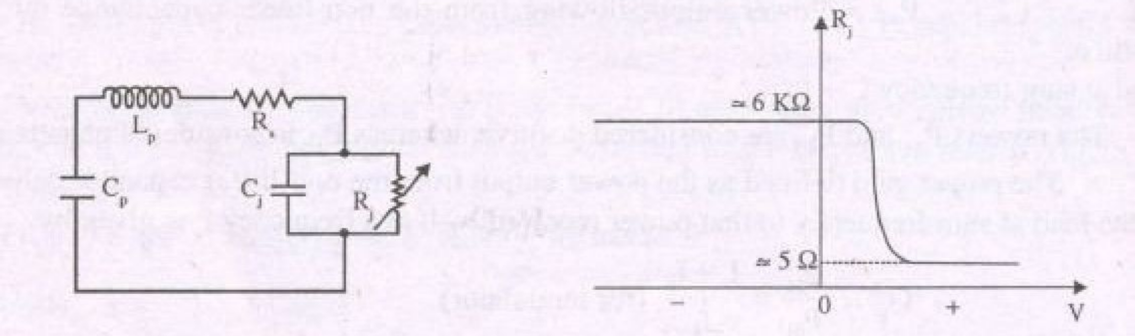
The PIN diode is a p-type, intrinsic, n-type diode consisting of a narrow layer of p-type semiconductor and a narrow layer of n-type semiconductor, with a thicker region of intrinsic or very lightly n-doped semiconductor material sandwiched between them.

Silicon is the semiconductor normally used because of its power handling capability and it offers high resistively for the intrinsic region. But, now-a-days Gallium Arsenide (GaAs) is also being used. Metal layers are attached for contact purposes. Its main applications are in microwave switching and modulation.



PIN diode acts as a more or less ordinary diode at frequencies upto about 100 MHz. At high frequencies, it ceases to rectify and then acts as a variable resistance with an equivalent circuit and a resistance-voltage characteristics .In 'the equivalent circuit, Land C represent the package inductance and capacitance p p respectively. R is the bulk semiconductor layer and contact resistance. R. and C. represent the respective junction resistance and capacitance of the intrinsic layer. When the bias is varied on the PIN diode, its microwave resistance R. changes from a typical value of 6 K under J

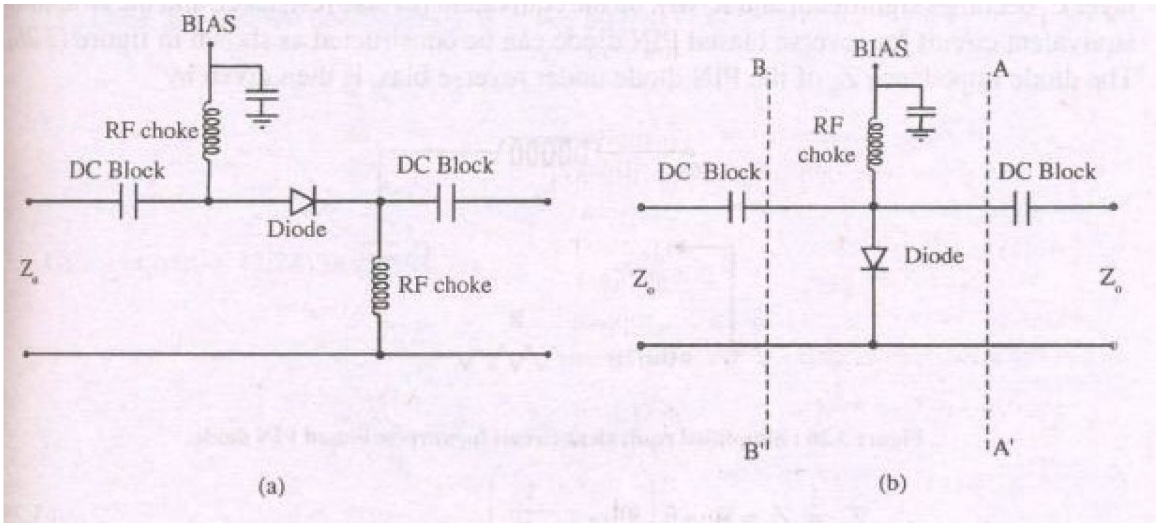
negative bias to perhaps 5 Q when the bias is positive .Thus, if the diode is mounted across a 50 Q co-axial line, it will not significantly load this line when it is back-biased, so that the power flow will not be interfered with. However, if the diode is now forward biased, its resistance drops significantly to 5Q, so that most of the power is reflected and hardly any is transmitted; the diode is acting as a switch.



APPLICATION OF PIN DIODE AS SINGLE POLE SWITCH:

A PIN diode can be used in either a series or a shunt configuration to form a single-pole, single-throw RF switch. These circuits are shown with bias networks below.

In the series configuration the switch is ON when thel diode is forward Biased and OFF when it is reverse biased. But, in shunt configuration of forward biasing the diode *"cuts-off'* the transmission and reverse biasing the diode ensures transmission from input to output. The DC blocks should have a very low impedance at RF operating frequency and RF choke inductors should have very high RF impedance.

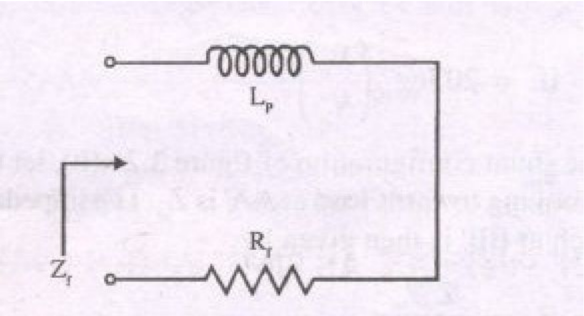


(a) Series configuration **(b) Shunt configuration.**

Ideally, a switch should have zero insertion loss in the ON state and infinite attenuation in the OFF state. Realistic switching elements, of course, result in some insertion loss for the ON state and finite attenuation for the OFF state due to non-zero forward bias resistance.

Similarly, for reverse bias shunt capacitor is not infinite & non-zero insertion loss results. Because of the large breakdown voltage (=500 volts) compared to an ordinary diode, PIN diode can be biased at high negative region so that large a.c. signal, superimposed on d.c. cannot make the device forward biased.

Forward Bias: When the PIN diode is forward biased, the capacitors C and C. almost behave as open circuits so that the equivalent circuit can now be simplified where Rf is the total forward resistance of the PIN diode given by



$$R_f = R_s + R_j$$

.. The diode impedance Zd of the PIN diode is given by

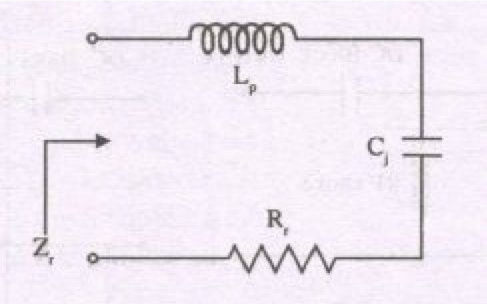
$$Z_d = Z_f = R_f + j\omega L_p$$

Reverse bias: When the PIN diode is reverse biased, the capacitance of the intrinsic layer C. becomes significant and Rr will be the equivalent reverse resistance and the simplified equivalent circuit for reverse biased PIN diode can be constructed as shown.

The diode impedance Zd of the PIN diode under reverse bias, is then given by

Reverse bias: When the PIN diode is reverse biased, the capacitance of the intrinsic layer C. becomes significant and Rr will be the equivalent reverse resistance and the simplified equivalent circuit for reverse biased PIN diode can be constructed ;

The diode impedance Zd of the PIN diode under reverse bias, is then given by

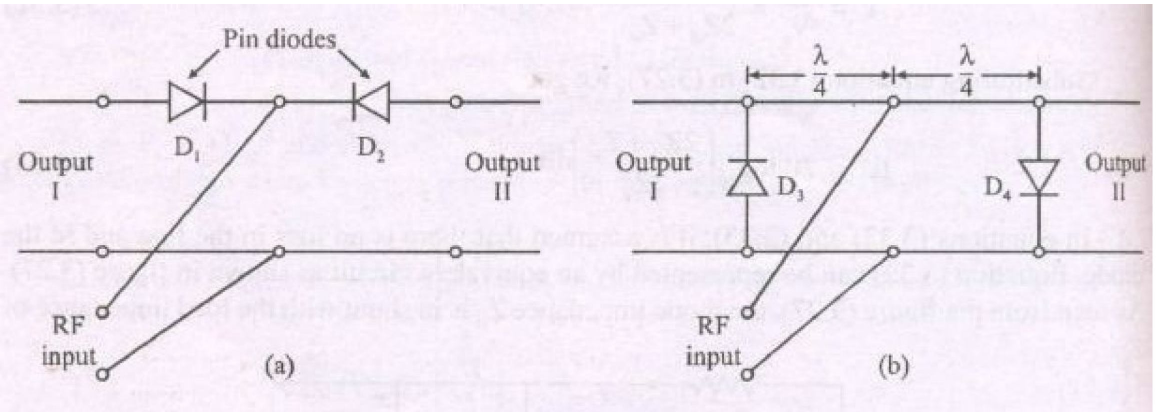


$$Z_d = Z_r = R_r + j\left(\omega L_p - \frac{1}{\omega C_j}\right)$$

PIN DIODE AS SPDT SWITCH:

Single-pole double throw (SPDT) action can be obtained by using a pair of PIN diodes either in series configuration or in shunt configuration as shown .In the series configuration of figure 3.29(a), when DI is forward biased and *Dz* reverse biased, connection is established between RF input and output I and no output at OUTPUT II.

When the biasing condition is reversed (D(reverse biased and *Dz* forward biased), connection is established between RF input and output II.



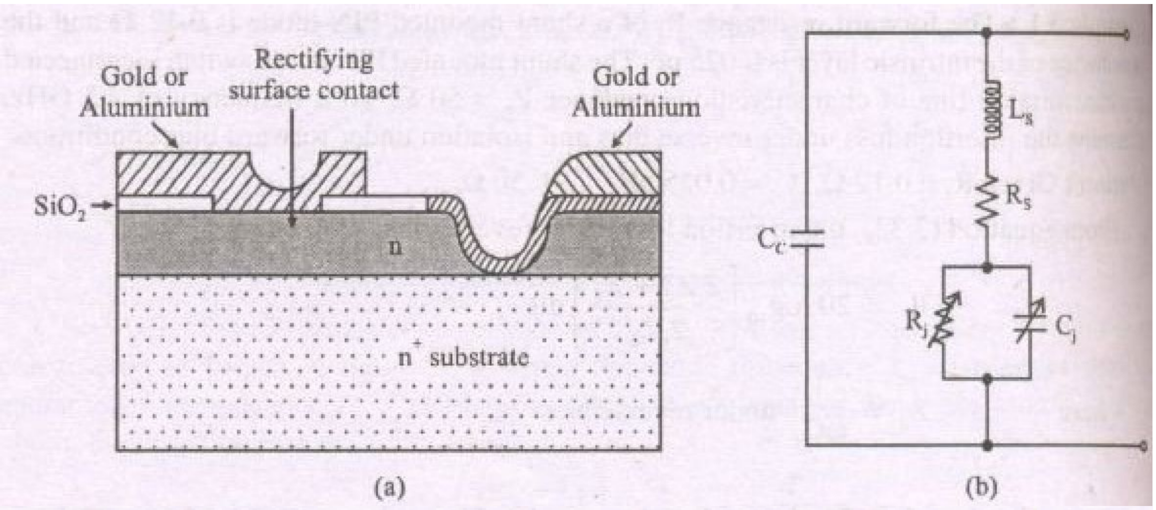
(a) Series configuration (b) Shunt configuration

In the shunt configuration when D3 is forward biased, it becomes short circuited throwing an open circuit at RF input line junction due to *(AI* 4) section. D4 is reverse biased so that it becomes open circuit (high impedance state) and connection is established between RF input and output II. When D3 is reverse biased and D4 forward biased, connection is established between RF input and output I.

SCHOTTKY BARRIER DIODE:

Schottky barrier diode is a sophisticated version of the point-contact silicon crystal diode, wherein the metal-semiconductor junction so formed is a surface rather than a point contact.

The advantage of schottky diode over point contact crystal diode is the elimination of minority carrier flow in the reverse-biased condition of the diode. Due to this elimination of holes, there is no delay due to hole-electron recombination (which is present in junction diodes) and hence the operation is faster. Because of larger contact area of rectifying contact compared to crystal diode, the forward resistance is lower as also noise. Noise figures as low as 3dB have been obtained with these diodes. Just like crystal diodes, the schottky diodes are also used in detection and mixing.



(a) Schottky barrier diode (b) Its equivalent circuit

The construction of schottky diode is illustrated in figure 3.30(a). The diode consists of n+ silicon substrate upon which a thin layer of silicon of 2 to 3 micron thickness is epitaxially grown. Then a thin insulating layer of silicon dioxide is grown thermally. After opening a window through masking process, a metal-semiconductor junction is formed by depositing metal over SiO_2. schottky diode which is almost identical with that of crystal diode.

RECOMMENDED QUESTIONS ON UNIT- 3

1. What is " Gunn Effect"? with a neat diagram explain the constructional details of GUNN diode.
2. Explain the different modes of operation of Gunn diode oscillator.
3. Explain RWH theory for Transfer electron devices.
4. Explain the two valley theory model.
5. What are modes of operation of Gunn diode, explain.
6. With neat diagram explain the construction and operation of READ diode.
7. With neat diagram explain the construction and operation of IMPATT diode.
8. With neat diagram explain the construction and operation of TRAPATT diode.
9. With neat diagram explain the construction and operation of BARITT diode.
10. With neat diagram explain the construction and operation of SCHOTTKY barrier diode.
11. Explain the operation of a basic parametric amplifier with square wave pumping.
12. What are MANLEY –ROWE relations? How are they useful in understanding parametric amplifiers.