UNIT-VII

Solid State Devices

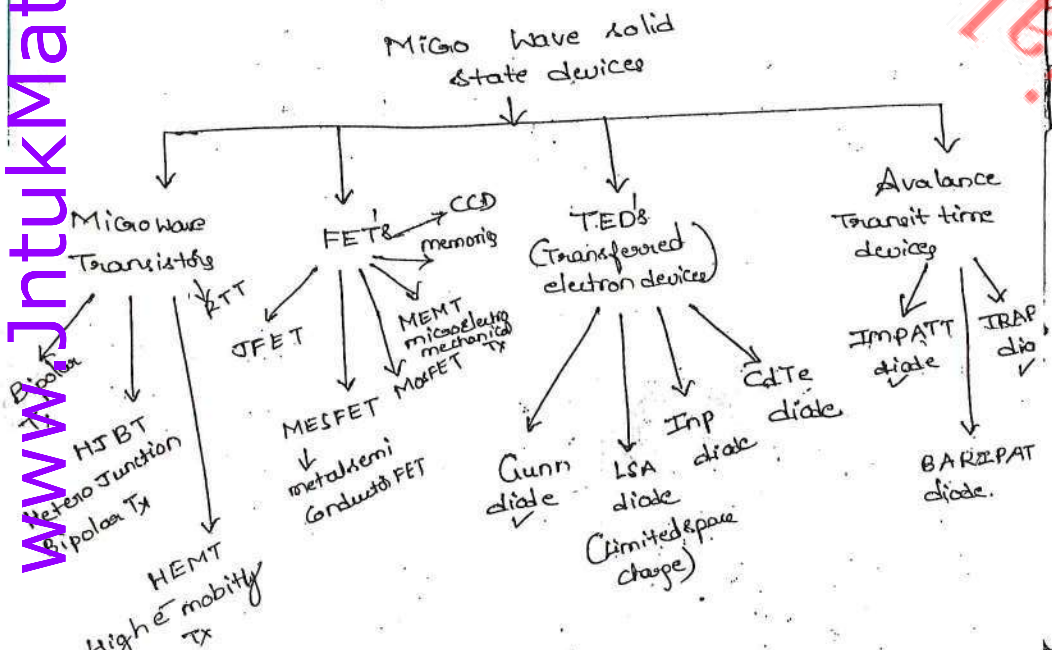
In order to meet the requirements such as low noise, high freq, greater b.w, less switching time, a tremendous research activity is done, which lead to development of semiconductor microwave devices, of two terminal & three terminal type.

Three terminal → Bipolars & FET's

Two terminal → TED's, Avalance transit time devices.

(1) Explain the classification of solid state devices.

Classification of Solid state devices:



RTT → Resonant Tunneling Tx

(2) Give Applications & Advantages of Solid state devices.

Applications of Solid state devices:

1) Amplification
2) Down Conversion
3) up Conversion
4) modulation
5) Switching
6) power generation.
7) phase shifting.

Devices	Applications	Advantages
Transistors & FET's	→ L-band Tx's. for Telemetry sys. Radar sys S-band Tx's for Communication sys	→ Low Cost. Low power supply reliable, high Carrier wave o/p, light weight.
TED's	→ C-band, X-band, ku-band, Amplifiers for wide band sys X- ku-band Txs for radar sys, such as traffic Control.	→ low power supply (uv) ~~low cost~~, reliable, ~~high power~~ CW light wt, Low noise, high gain.
IMPATT	→ Tx's for millimeter wave Communication sys	→ Low power supply, low cost, reliable, high CW power o/p, light wt.
TRAPATT	→ S band pulsed Tx's for Phased array radar sys	→ high peak & avg power, reliable Low power supply, Low Cost
BARITT	Local oscillators in Comm's & radar Rx	→ Low Cost, Low power supply, reliable, low noise,

What are TED's. Explain Gunn effect using two valley theory and draw I-E char of Gunn diode. (2)

Transferred Electron Devices (TED's)

* TED's are bulk devices having no junction (or) gates.
* These are fabricated from compound semiconductors such as GaAs, InP (Indium phosphate) (or) CdTe (Cadmium telluride) instead of SI & GE as that of normal transistors.
* TED's operate with hot electron whose energy is very much greater than thermal energy (0.026 eV at room temp), where as Transistors operate with warm electrons whose energy at room temp.
* TED's Exhibits negative resistance char's. ie, over a range of frequencies, the impedence is negative.
* Negative resistance char's means "I" & "V" are out of phase by 180°, and a power of $(-I^2R)$ is generated. The -ve resistance devices ~~Exhibit~~ generates power. (Active devices)
* +ve resistance has "I" & "V" in phase and a power (I^2R) is dissipated / absorbed (passive elements).
* Example of TED's is Gunn diode, LSA diode,

In TED's we observe bulk effect ~~of~~ ~~when~~ material, under the strong electric field, we observe a reduction of drift velocity, and thereby

Ing electric field above V_{th}, the electrons shift from high mobility state to low mobility state. This phenomena of transferring of electrons is Exhibited in TED's (Gunn diode).

Gunn diode:

Gunn diode are named after J.B. Gunn (1963) who discovered the current fluctuations of ~~when~~ current passing through the N type GaAs, when app Voltage applied Exceed a critical value (2-4 kV/cm).

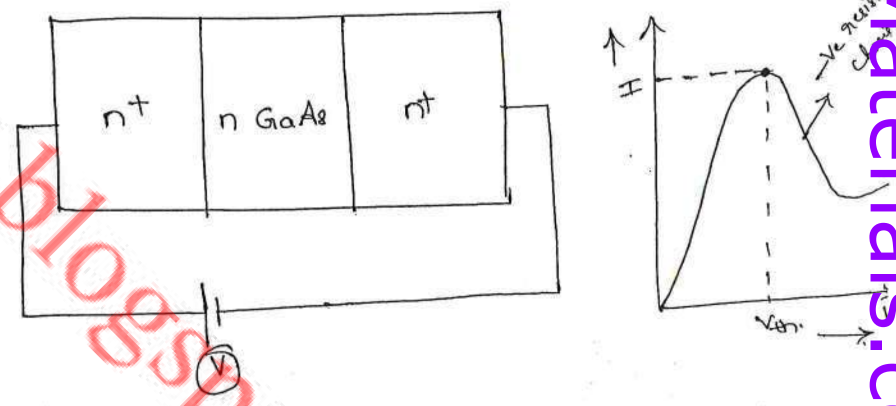
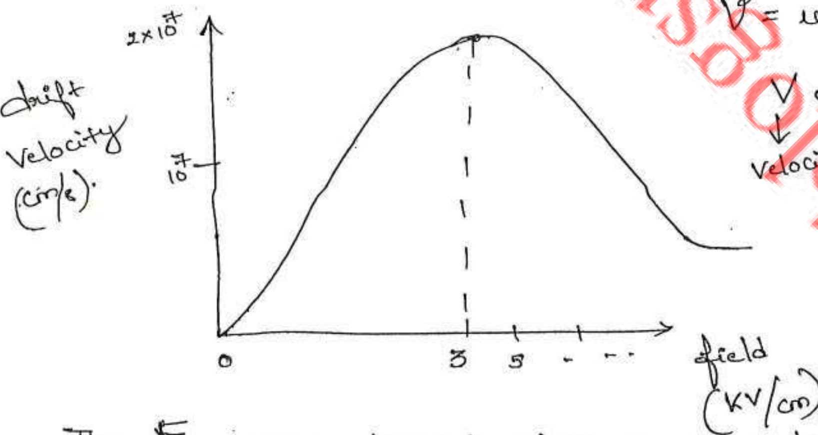


fig: Gunn diode structure & Char.

Gunn effect can be explained observed the carrier drift velocity is linearly ↑sed from zero to maximum, when electric field is varied from zero to a threshold value (3000 V/cm), After the E_{th}, the velocity is ↓sed and diode exhibite –ve resistance.



$v = \mu E$

$V \propto E$

velocity ↓ field ↓.

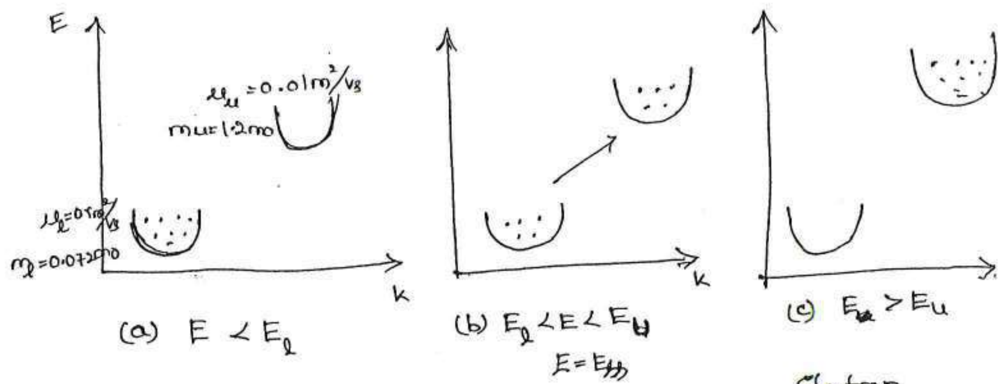
The E_{th} may vary with length & type of material

$\because E_{th} = V/L$

The Gunn effect is easily explained by using the two valley theory of Ridley Watkins – Hilsum (RWH) Theory (or) Transferred electron mechanism.

Principle: RWH / Two valley theory:

In this theory we consider two valleys in conduction band Lower valley, upper valley.



under ~~electron~~ Equilibrium Conditions, Electron density is constant,

When an electric field is applied, then the mobility, density of $\bar{e}$s vary.

* When applied field (E) is lower than field of Lower Valley ($E < E_l$), there is no transfer of $\bar{e}$s from lower to upper valleys.
* When $E_l < E < E_u$, the electrons will begin to transfer to the upper valley.
* When $E > E_u$, then all the electrons will transfer to upper valley.

Let mobility of $\bar{e}$s in lower valley is

$\mu_l = 0.5\, m^2/Vs$, mass of $\bar{e}$ is $m_l = 0.072$

In upper valley $\mu_u = 0.01\, m^2/Vs$, mass of $\bar{e}$ is $m_U = 1.2$.

Let n_l, n_u be the electron density of lower and upper valleys.

* ie When $\bar{e}$s are in L valley, mobility (μ) is high, mass of $\bar{e}$ is low, hence current density J ↑sed.
* When a field is applied ↑sed, which is equal $E_{th} \simeq 3kV/cm$ at which $\bar{e}$s complete transfer to U valley takes place.
* In U - Valley mobility (μ_2) is low, mass of $\bar{e}$ ↑ses, hence current density J decreased.

$$J = \sigma E \qquad \sigma = (\mu_l n_l + \mu_u n_u)$$

$$\Rightarrow \boxed{J = (\mu_l n_l + \mu_u n_u)\, E}$$

$n = n_l + n_u$

= electron density

e = electron charge.

When $E > E_u \Rightarrow J = E\, n_u \mu_u$.

Modes of operation:

~~Depending on the material parameters & operating conditions, the Gunn diode operates in four frequency modes~~

(1)

Q: Determine conductivity of an n-type GaAs Gunn diode. Electron density $n = 10^{18}/cm^3$, n at lower valley $n_l = 10^{10}/cm^3$, n at upper valley $= 10^8/cm^3$, temp = T = 300°K

sol: $\sigma = e(\mu_l n_l + \mu_u n_u)$ $\qquad e = 1.6\times10^{-19}$

$= 1.6\times10^{-19}(0.5 \times 10^{10} +$

Explain the constructional details of Gunn diode. Explain modes of operation of Gunn diode. (5)

Construction:

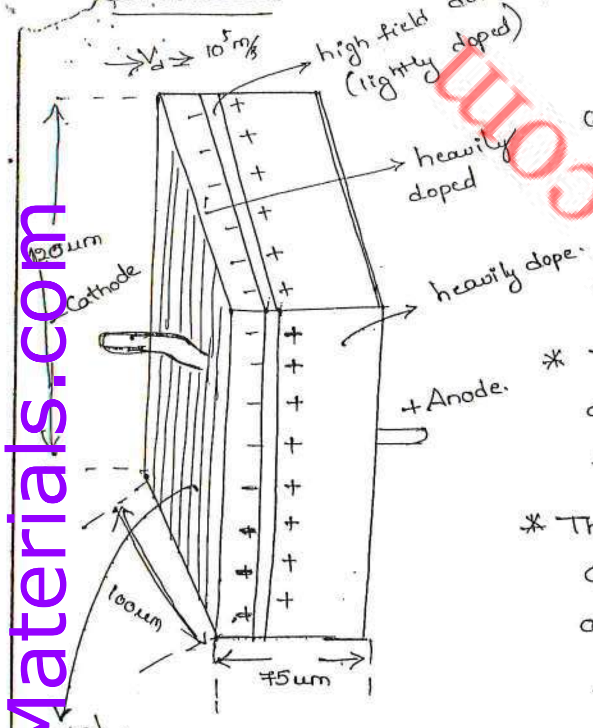
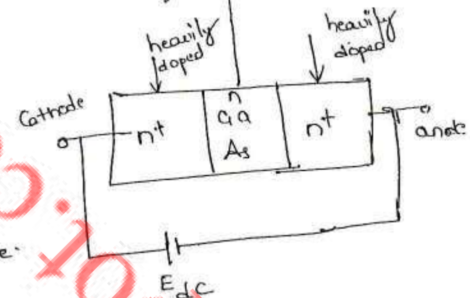


fig: Schematic diagram of n-type GA-As diode.



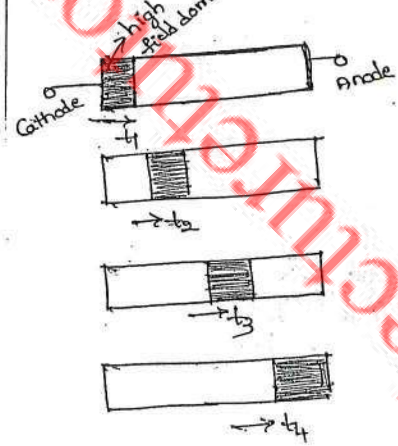
* Top & bottom areas of device are heavily doped to give n^+ material.
* The device mounted on a conducting base to which a wire connection is made
* It acts as heat sink for generated heat.

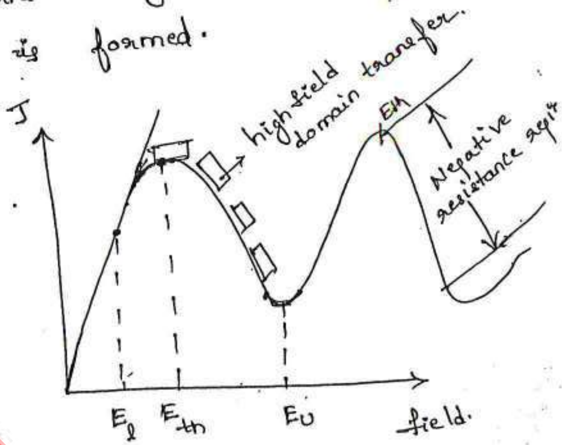
* The connection to other terminal of diode is made via Gold connection deposited on to the top surface. The center area is active region, hence all the voltage placed across device appears across this region.

(3) Explain about domain formation using relevant diagrams in Gunn diode.

<u>Operation of</u> <u>Gunn diode</u>: (High field domain formation)

* When voltage is applied across GaAs Crystal Exceeds E_{th}, $\bar{e}$s are transferred from Lower energy band (high mobility) to higher energy (low mobility) in which there electrons bunch together to form domain near the cathode.
* Due to this the electric field across domain ↑ses, but it is below E_{th} across the crystal, to prevent further domains.
* But upper band is low mobile, the velocity of the $\bar{e}$s is decreased, hence current present in domain also ↓ses.
* Hence the high field domain is travelled in to the end contact.
* After reaching end, due to change in voltage, current again returns to higher level, again a high field domain is formed.

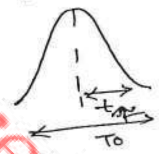




Each domain results a pulse of Current at the o/p. These Current fluctuations occurs at MW freq to Produce a o/p signal with a period Equal to Transit time.

Transit time (t_{tr}):

Time taken by the high field domain to travel from Cathode ~~and~~ to Anode is Called Transit time.



Oscillation frequency:

$f_o = 1/T_o$

T_o = oscillation ~~frequency~~ time period.

Basic modes of operation:

According to material parameters & operating Conditions, Gunn diodes ~~have~~ four modes

① Gunn oscillator mode:

Operating freq (f_o) × Length (L) = 10^7 cm/sec

Doping (n_o) × Length (L) $\ngtr 10^{12}/cm^2$
(n^+)

This is unstable mode. High freq oscillations achieved when device operated with high-Q Cavity resonator. The diode is mounted at center $\perp r$ to broad wall. The diode is mounted inside a Cavity formed by short ckt termination at one end by an iris at other inside. $f_o = V_d/l$.

② Stable Amplification mode: This mode is defined in region where.

$V_d = f_o \times L \cong 10^7$ cm/sec.

$n_o \times L \Rightarrow 10^{10} - 10^{12}/cm^2$

③ LSA oscillation mode:

$V_d = f_o \times L > 2 \times 10^7$ cm/sec

$f_o = \frac{1}{T_o} = \frac{1}{\text{oscillation period}}$.

In this mode Gunn diode placed in resonator which is tuned to a freq f_o.

④ Bias Circuit oscillation mode:

$f_o \times L$ = very small. The device is biased at threshold, f_o Can be obtain in range of 1k–100k

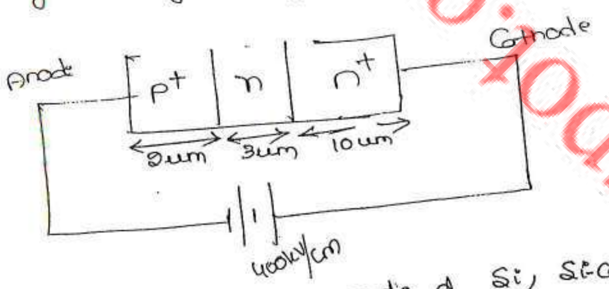
Gunn oscillation modes:

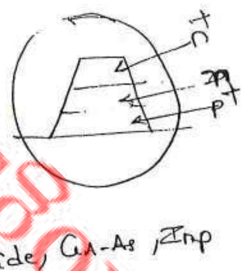
Refer Pg 15

Explain construction, schematic & working of IMPATT diode & draw the doping profile of typical IMPATT diode.

Impatt diode: [Impact ionization Avalance Transit time devices]

Impatt diode Exhibits -ve resistance chars which can be obtained by a junction diode of any doping profile.





→ Impatt diodes are made of Si, Si-Carbide, Ga-As, InP

The impatt diode Constructed on p+, N, N+ layers.

It operates at reverse bias.

→ Impact ionization happens when applied electric field cause a free e⁻s to hit an atom in lattice, and release an e⁻, hole pair.

→ Any diode Exhibits +ve resistance chars in forward bias region. The reverse chars exhibited in the Reverse bias.

→ The Impatt diodes are used as Amplifiers, oscillators.

→ They operate at high freq 3-100 GHz

→ Adv: High power Capability.

disadv: High level noise due to avalance transit chars.

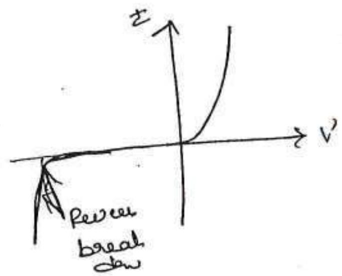
Impatt diode utilizes avalance breakdown combined with transit times of charge carriers to enable it to provide a -ve resistance region

Characteristics:

In forward direction it will Conduct, after it reached Conduction point.

In reverse direction it will block Current

How ever at Certain Voltage the diode break down and I will flow in reverse direction.



p+ = heavily doped P region

N+ = heavily doped region.

In Reverse bias,

the holes in P region, the e⁻s in n region are attracted to the Edge walls of the diode, leaving the minority carriers

After ↑se in voltage the velocity of carriers ↑ses & they knock the Crystal Structure from which e⁻s & holes are released. Again the majority carriers are attracted to walls, and so minority carriers ↑ses. Then for the movement of minority carriers the current peaks are observed.

→ The ↑se of e⁻s & holes due to V breakdown is called as Impact ionization.

In terms of operation Impatt diode has two regions (8)

① Avalance / Injection region

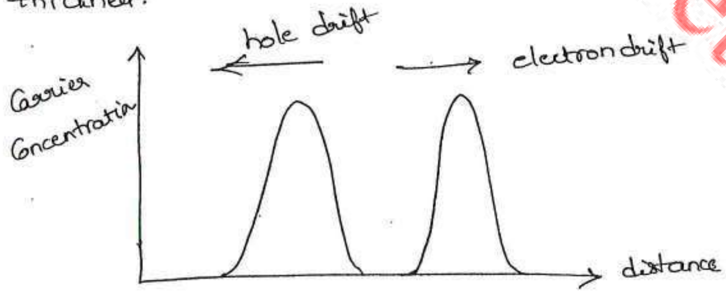
② Drift Region.

Injection Region:

It Creates the Carriers which may be holes / $\bar{e}$s.

Drift Region:

It is, where Carriers move across the diode taking a Certain amount of time dependent upon its thickness.



Charge Carriers movement with in Impatt diode.

* Majorly the drift effect is not seen for DC, but for AC we Can see the drift.

* When an AC signal applied the Current peaks are found to be 180° out of phase with the Voltage.

* This is due to two delays which occur in device.

① Injection delay

② Transit time delay.

ie Time taken for Carriers migrate & drift across the device is nothing but delay of Current peaks production.

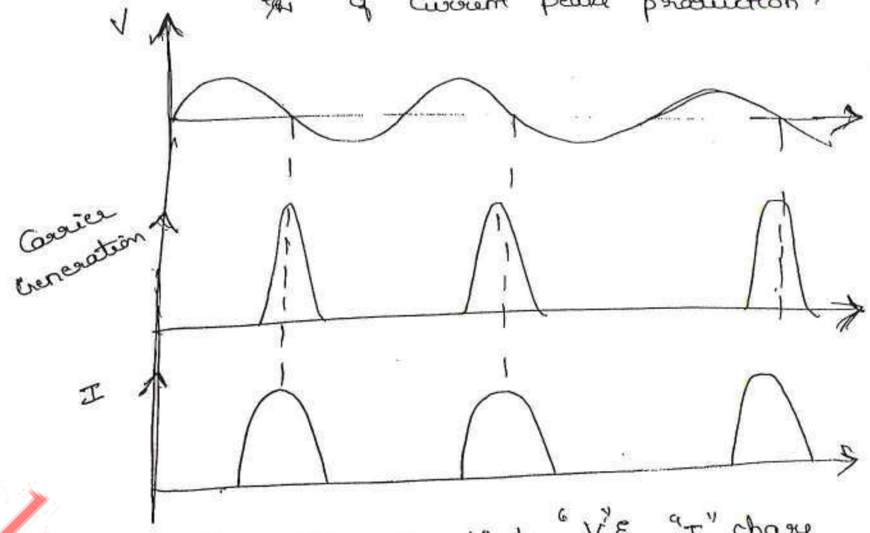


fig: Impatt diode "V" & "I" chars

* As electric field incs, no. of Carriers incs, when field reaches max also, the Carriers still Continues to grow as a result of no of Carriers already in Existance.

* As a result of this there is a phase lag of 90° b/w I & V. This is known as Injection phase delay.

* when $\bar{e}$s move across N^+ region an External Current is seen after a delay of another 90°.

By connecting a tuned circuit along with, Voltage (break down) oscillation will occur with a resonant frequency.

$$\text{Resonant frequency } (f_0) = \frac{V_d}{2L}$$

V_d = drift velocity
L = length of drift space region.

Disadvantages:

(1) It is very noisy because avalanche process is noisy process.
(Noise in db = 30db)

The devices based around Ga-As are better than Si.

(2) Tuning range is not good.

Performance characteristics:

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{V_a}{V_d}\left(\frac{I_a}{I_d}\right)$$

P_{ac} = ac power
P_{dc} = dc power
V_a, I_a = AC Voltage/Curr
V_d/I_d = dc Voltage/Curr

η = 30% (In practical)

15% for Si, 23% for Ga As

frequency : 1 – 300 GHz

max o/p power for single diode: 5W in x band
0.5W at 30GHz

max o/p power for several diodes combined:
40W at x band.

Pulsed power = 4kW.

Applications:

1) These are used as oscillators such as
(a) μw generators
(b) modulated o/p oscillators
(c) Receiver local oscillator

2) These are suitable for –ve resistance amplification.

3) High quality IMPATT diodes are used in
(a) Instrumentation alarams N/W
(b) police radar
(c) low power μw Tx's

Q: An IMPATT diode has following parameters.
Carrier drift velocity $V_d = 2\times10^7$ cm/s
drift region length $L = 6\mu m$
Max operating voltage $V_{0max} = 100V$
Max operating Current $I_{0max} = 200mA$
$\eta = 15\%$
Break down voltage $V_{bd} = 90V$

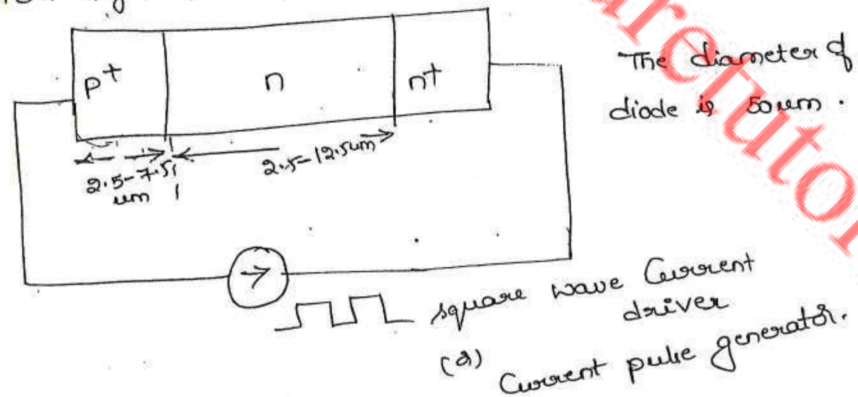
find (a) Max Carrier Wave o/p power in Watts
(b) Resonant freq in giga H.

sol: $\eta = \dfrac{P_{ac}}{P_{dc}} \Rightarrow$

What are avalanche TRAP? Explain schematic and working of TRAPATT diode use VI waveforms. Indicate typical values of power & eff.

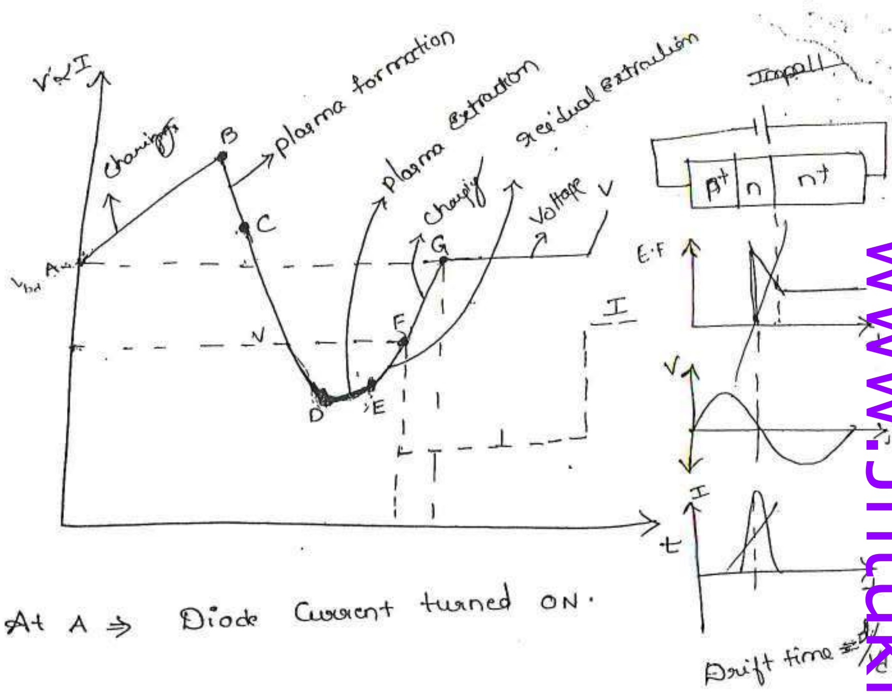
Trapatt diode: (Trapped plasma Avalance Transit time devices).

* Trapatt diode is similar to that of the Impatt diode, but it is advantageous in a way η is up to 20-60%.
* The construction of the device consits of p^+-n-n^+ layers, but the doping levels are $p^+ = 2.5$ to $7.5um$, $n = 2.5-12.5\,um$ depletion layer.
* Manufactured from Ge, Si, GA-As, Inp.
* For high peak power we use n^+-p-p^+ structure.



The diameter of diode is 50um.

* In trapatt diode, the mode does not depend on the Avalance phase delay.
* Because Avalance multiplication is faster than that of the drift velocity of the Carriers by a factor "3".
  Hence no delay for Avalance breakdown.
* To prevent burning of diode, a Current bias source is used to maintain an avg Current at safe limit I_0.
* The diode Current Contributed by $\bar{e}$ move from p^+ to drift space region and then to n^+.



At A ⇒ Diode Current turned ON.

A high field avalance zone propagates through diode and fills depletion layer with a dense plasma of $\bar{e}$s/holes become trapped in low field region behind zone.

* A typical 'V' wave form for Trapatt diode operation with square wave Current is assumed to be as below.

At A: Electric field is uniform through out the sample, its mag is large but less than of avalance BD.

Current density Expressed as $J =$

∴ At A ⇒ diode is turned ON.

Hence at 'A' the diode starting to charge like a linear capacitance, hence the electric field increases above the break down voltage.

→ At "B", when a sufficient no. of carriers are generated, the internal current exceeds the external current. Hence the voltage field is decreased through out the depletion region. Hence voltage decreased to "C" from "B"

$V = \frac{I_{in} - I_E}{R}$

→ At "C", we observe electric field voltage is still more than sufficient for avalance to continue, hence still dense plasma of $\bar{e}$'s & holes is created, hence internal current still increases, result in decrease of voltage further to "D".

→ Due to heavy release, some of $\bar{e}$'s, holes may drift out of the ends of the depletion region hence voltage decreases to "D".

→ A long time is required to remove the plasma because plasma charge is very large compared to charge per unit area in external current

"$i_i = \frac{q_p}{t}$" "$i_e = \frac{q}{t}$"

$i_i > i_E$.

Hence in order to reduce i_i, the plasma charge should be removed.

Hence after removal of plasma i_i will be reduced, the voltage will be rised from D to "E"

* After removal of plasma a residual charge is observed, where a residual charge of $\bar{e}$'s is on one side, residual charge of holes on other side.

* As the residual charge is removed, voltage rises from "E" to "F".

ie., At "F" all the charge that was generated will be removed.

* From "F" the diode charges up again like a fixed capacitor.

Avalance zone velocity $V_Z = \frac{dx}{dt} = \frac{J}{qN_A}$

J = Current density

q = electron charge

N_A = doping concentration.

Q: A TrapaTT diode has $N_A = 2\times10^{15}/cm^3$ & $J = 20kA/cm^2$. Calculate V_Z.

$$V_Z = \frac{J}{q \cdot N_A} = \frac{20\times10^3}{1.6\times10^{-19} \times 2\times10^{15}}$$

$$V_Z = 6.25\times10^7 \text{ cm/s}$$

TrapaTT diode:

Specifications / chars:

1) CW power = 1–3W b/w 8GHz to 0.5GHz
2) pulsed power = 1.2kW at 1.1GHz
3) operating voltage = 60–150V.
4) η = up to 40%.

5) Noise figure > 30db

6) frequency : 3-50GHz

Limitations

* Sensitive to harmonics
* more noisy due to avalanche process

Applications

1) used in low power doppler radars
2) Local oscillators for radars.
3) radio Altimeter
4) MW beacon landing sys.
5) phased array Radar.

Q: A Impatt diode had L (drift ~~velocity~~ length) of 2um.
find (a) drift time of Carriers (2) operating freq fo

$V_d = 10^5$ m/sec

$\therefore V_d = f \cdot L$

$f_0 = \frac{1}{2\tau} = \frac{V_d}{2L}$

$f = \frac{V_d}{L}$

$T_1 = T_2$

$T_1 + T_2 = T_0$

(a) drift time $\tau = \frac{L}{V_d} = \frac{2\times10^{-6}}{10^5}$

$= 2\times10^{-11}$ sec

$\tau = \frac{L}{V_d}$

(b) $f_0 = \frac{1}{2\tau} = \frac{1}{2\tau} = \frac{1}{2\times2\times10^{-11}\text{ sec}} = 0.25\times10^{11}$ Hz

$= 25$ GHz

Q: An Impatt diode has following parameters.

$V_d = 2\times10^{5}$ cm/s, drift length $L = 6\mu m$,
drift velocity

max operating voltage $V_{0\,max} = 100V$, max operating Current $I_{0\,max} = 200$

Efficiency $\eta = 15\%$, breakdown voltage $V_{bd} = 90V$.

find (a) Max Carrier o/p power in watts.

(b) The resonant freq f_0.

Sol: (a) $\eta = \frac{P_{ac}}{P_{dc}}$

$P_{ac} = \eta P_{dc} = 0.15\times20$

$= 3W$

$P_{dc} = V_0 \times I_0$

$= 100\times200\times10^{-3}$

$= 20$

$\eta = \frac{15}{100} = 0.15$

(b) $f_0 = \frac{1}{2\tau} = \frac{1}{2\cdot L}\cdot V_D$

$= \frac{2\times10^5}{2\times6\times10^{-6}}$

$= 1.67$ GHz

$f = \frac{1}{2T}$

$V_d = fL$

$f = \frac{V_D}{L}$

$\tau = \frac{L}{V_D}$

$\tau = \frac{V_D}{2L}$

f

Q: A ku band IMPATT diode has pulse operating Voltage of 100V & Current of 0.9A, η is of 10%. Calculate.

① o/p power ② duty Cycle of pulse width of 0.01ns & freq is 16GHz

(a) % power $P_{ac} = \eta P_{dc}$

$= \frac{10}{100}\times(V_0\times I_0) = 0.1\times100\times0.9$

$= 9W$

(b) duty cycle = $\frac{\text{pulse duration}}{\text{pulse repetition period}} = \frac{\tau}{T}$

$= \frac{0.01\times10^{-9}}{T} = 0.01\times10^{-9}\times16\times10^{9}$

$= 0.16$

$= 16\%$

$f = \frac{1}{T}$

In a gunn diode active length of 20um, drift velocity of $\bar{e}$ = 2×10^7 cm/s. Calculate natural freq. & critical voltage of diode.

Sol:

$$f = \frac{V_d}{L} = \frac{2\times10^7}{2\times10^{-6}} = 1\times10^{12} = 1000\ \text{GHz}.$$

Critical voltage: $V = l \times \text{Critical field}$

$$= 20\times10^{-6} \times 3.3\times10^{3}\ V = 6.6\ V$$

$V_d \propto I \propto V$

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The avalanche zone velocity,

$$v_z = \frac{dx}{dt} = \frac{J}{q N_A}$$

where N_A = Doping concentration

The highest pulse power of 1.2 kW has been obtained at 1.1 GHz, and the highest efficiency 75% has been achieved at 0.6 GHz. The TRAPATT diode generally exhibits a higher noise figure than the IMPATT mode and the upper operating frequency appears to be practically limited to below the millimeter wave region.

6) A TRAPATT diode has the following parameters: Doping concentration, $N_A = 2\times10^{5}/cm^3$ and current density, $J = 20\ kA/cm^2$. Calculate the avalanche zone velocity.

Sol: $v_z = \frac{J}{q N_A}$

$$= \frac{20\times10^3}{1.6\times10^{-19}\times 2\times10^{15}}$$

$$v_z = 6.25\times10^{7}\ cm/s$$

This means that the avalanche zone velocity is much larger than the scattering-limited velocity.

IMPATT diode :-

Performance characteristics :-

1) η = 30% and 15% for Si, 23% for GaAs.
2) Frequency : 1 to 300 GHz
3) Max. o/p power for single diode : 5W in X band to 0.5W at 30 GHz.
Several diodes combined : 40W at X band.
4) pulsed powers ≃ 4 kW.

Disadv :-

1) it is very noise because avalanche is a noisy process (30dB)
2) Tuning range is not good.

Applications

→ These are used as oscillators such as
1) m/w generators 2) modulated o/p oscillators 3) receiver local oscillator 4) Par amp. pumps.
→ These diodes are also suitable for negative resistance amplification.
→ high quality IMPATT diodes are used in
a) Intrusion alarms N/W
b) police radar
c) Low power M/W Tx'er
→ FM Telecomm. Tx'ers
→ CW doppler radar Tx'er.

TRAPATT diode :-

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Specifications:-

1) CW power : 1-3W b/w 8GHz to 0.5GHz
2) pulsed power : 1.2 KW at 1.1GHz
3) operating voltage : 60–150 V
4) η : 15 to 40%.
5) Noise figure > 30dB
6) Frequency : 3 to 50 GHz.

Limitations:

✓ These diodes are very sensitive to harmonics.
✓ more noisy. because of avalanche.

Applications:

1) used in low power doppler radars
2) local oscillators for radars
3) radio altimeter
4) phased array radar
5) N/w beacon landing system etc.

4, 5, 11, 12, 15, 16, 17, 18, 23, 24, 25, 28, 29, 30, 32, 33, 34, 36, 39, 40, 42, 43, 45, 46, 50, 51, 52-54, 55, 57, 58.— 08 — 462
13/4/13

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Hyderabad

Ashok

19/4/14 : 3, 7, 18, 24, 29, 30, 32, 35, 37, 42, 43, 44, 45, 46, 49, 51, 52, 54, 55, 58.

(13)

High field domain formation :-

When the voltage applied across $n^+ n n^+$ GaAs crystal exceeds a threshold level, electrons are transferred from the low energy, high mobility conduction band to a higher energy, low mobility sub conduction band, where these heavier electrons bunch together to form a electric field dipole domain near the cathode. Since the applied voltage remains constant, the electric field across the domain is greater than the average field. The consequent E field remains below the threshold level across rest of the crystal. This prevents the formation of further domains.

All the conduction band electrons drift across the crystal at the same velocity and the less mobile bunched electrons have reduced velocity. The current in the presence of domain also decreases. After the high field domain had travelled into the end contact, the current returns to its higher level and high field domain is again formed.

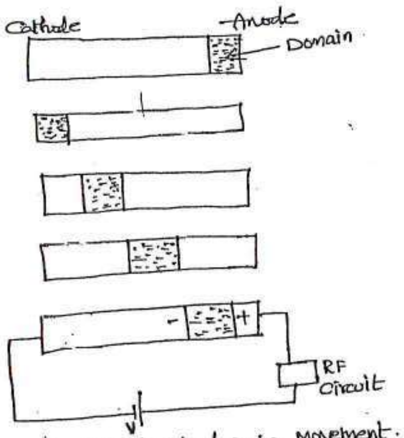


Fig. High field domain Movement.

Each domain results in a pulse of current at the o/p. These current fluctuations occurs at MW freq's.to produce a o/p signal with a period equal to the transit time.

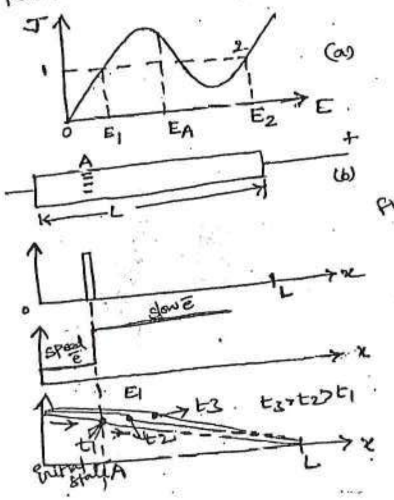


Fig. Formation of E accumulation (excess) layer in n-type GaAs

" High field domain properties "

(283)

Gunn diode modes

Basic Modes of operation :-

According to material parameters & operating conditions Gunn diode can be used in four basic Modes.

1) Gunn oscillator mode (Transit-time Mode) 2) stable amplification mode
3) LSA oscillation Mode 4) Bias ckt oscillation Mode.

1) Gunn oscillator Mode :-

operating frequency (f) x length (L) ≅ 10^7 cm/sec

& Doping (n_0) x length (L) > $10^{12}/cm^2$

In this mode the device is unstable because of the cyclic formation of either accumulation layer or high field domain. Higher oscillation frequency can be obtained when the device is operated with a high Q cavity resonator.

2) stable Amplification Mode :-

$fxL = 10^7$ cm/sec

$n_0xL = 10^{11}$ to $10^{12}/cm^2$

3) LSA oscillation Mode :-

$fxL > 2\times10^7$ cm/sec.

LSA mode is the simplest mode of operation.

In LSA Mode, The Gunn diode is placed in a resonator which is tuned to an oscillation frequency of f_0.

$f_0 = \frac{1}{T_0} = \frac{1}{\text{oscillation period.}}$

• In this mode The device can be biased to several times The Threshold voltage. As the i/p RF voltage increases, above the Threshold voltage, the device remains in the negative resistance region. The oscillating frequency is determined by the external components only & not by transit carrier time.

o/p power = 400 watts to 6kW in pulsed Mode.

Limitations of LSA Mode :-

1) it is very sensitive to load
2) sensitive to operating Temperature
3) variation in doping concentration affects the stability.

Bias circuit oscillator :-

✓ ∴ fxL is very small.
✓ The device is biased at Threshold
✓ The oscillating freq can be obtained in the range of 1KHz to 100 MHz.

Typical characteristics :-

1) CW Power : 25mW to 250mW
x band (5-15GHz)
100 mW at 18 – 26.5GHz
40mW at 26.5 – 40 GHz
2) pulsed power : 5W (5-12GHz)
3) η = 2% to 12%.

Applications :-

1)

2)

$v = d/t$

$= f.L$

1) Transit-time domain mode ($fL \simeq 10^7$ cm/s) :

When the electron drift velocity v_d is equal to the sustain velocity v_s, the high field domain is stable. In other words, the electron drift velocity is given by

$$v_d = v_s = fL \simeq 10^7 \text{ cm/s}.$$

Then the oscillation period is equal to the transit time — that is, $\tau_o = \tau_t$. This situation is shown in fig. The efficiency is below 10% because the current is collected only when the domain arrives at the anode.

2) Delay domain mode (10^6 cm/s $< fL < 10^7$ cm/s) :

when the transit time is chosen so that the domain is collected while $E < E_{th}$ as shown in fig., a new domain

53 56,58 67,

77, 80, 87/88

UNIT-8 (17)

MICROWAVE MEASUREMENTS

MicroWave measurem

Difference between low frequency Measurment & Microwave frequency Measurme

1) At lower frequency's power is obtained by multiplication of measured voltage & Current. At high frequency power is obtained directly.

2) At low frequency circuit is consists of lumped elements (R, L, where as at high frequency consists of distributive elements, impedance of the circuit is measured.

3) Ratio of maximum to minimum Power is Calculated at high frequencies instead of input & output power.

4) Parameters at high frequency are power, frequency, phase, impedance, attenuation, VSWR & quality factor.

Q)(7) Draw the block schematic of a typical Microwave Test-bench and explain functionality of Each Component.

Discription of Microwave Bench :-

The general setup for measurment of any parameter in microwaves is normally done by a microwave bench. It has different blocks those are

1) Signal Generator
2) Variable Precision Attenuator
3) Variable Flap Attenuator
4) Frequency Meter
5) Slotted line
6) crystal detector probe
7) Standing wave indicator.

Let us discuss each of them ...

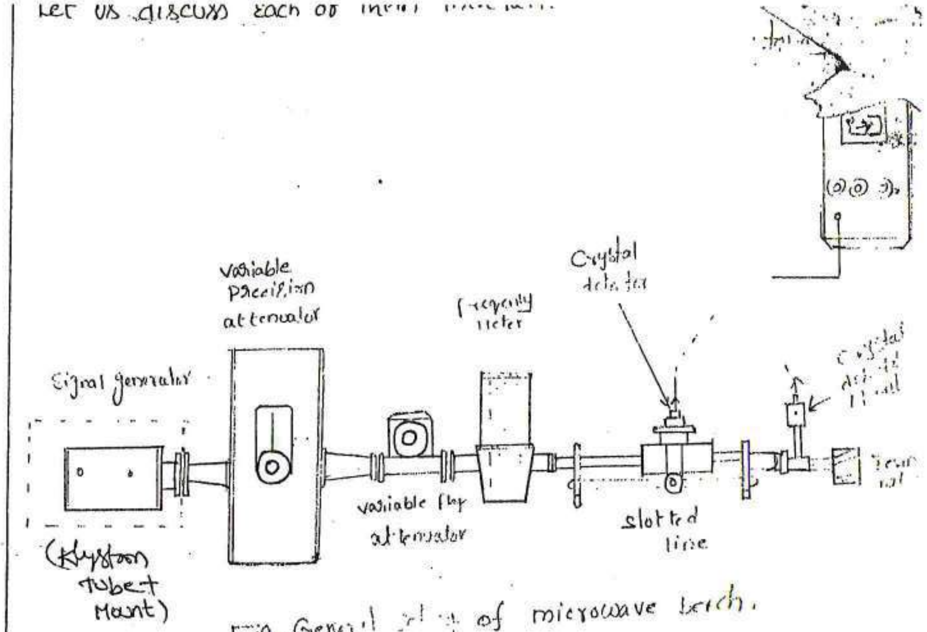


Fig. General ... of microwave bench.

Signal generator :-

It is a microwave source whose output is of the order of millia... It could be Gunn diode oscillator, a backward wave oscillator or a reflex klystron tube.

a) Klystron tube :- It makes use of velocity modulation to transfer c... Continuous beam into microwave power. Electrons emitted from the cathode are accelerated and passes through the positive resonator towards negative reflector, which retards and finally reflects the elect... and the electrons turn back through the resonator.

b) Klystron Power Supply :- It basically generates necessary frequency whic... is to be transmitted through the waveguide. It provides the beam voltage (anode) and reples voltage (cathode) to the klystron mount.

The mode switch is kept to CW position. Keep the beam voltage control knob to fully anti clockwise and reflector voltage control knob to clockwise direction. The ranges for beam voltage 240V–400V and repel voltage 25V–247V. In some cases it may have provision for sweep oscillator which allows the output frequency to be varied periodic.

Variable precision Attenuator :-

It provide 0 to 50dB attenuation above its insertion loss.

Variable Flap Attenuator :-

It is also used to check its calibration against readings of the precision attenuator.

Frequency Meter :-

It is used for direct reading of frequency that consists of single cylindrical cavity which can be adjusted to resonance and is slot coupled to the waveguide. It helps to read the frequency of signal passing through the waveguide setup. It is read at the intersection of horizontal and vertical red lines.

Slotted section :-

In this section the waveguide is slotted by a gap and it is done so that wavelength as to adjust the amount of clock cycles of signal with respect to which it can be measured using vernier scale.

Crystal Detector :-

Crystal detector probe is inserted in the E probe of the slotted line is contained in the crystal detector mount at the end of the waveguide run, is used to detect the modulated signal.

VSWR meter :-

This indicator is basically a sensitive tuned voltmeter that provides direct reading of the SWR as its equivalent value in decibles.

Precautions :-

1) Components should be connected tightly for avoiding power leakage.
2) Air cooling is required for reflex klystron oscillator.
3) M/W power should not be measured directly as it effects the vision (harmful to eyes).

(Q) 12) Explain the frequency measurement Techniques,

(i) Frequency Measurement :-

Microwave frequency can be measured by either electronic & mechanical Techniques.

Electronic Techniques :-

These techniques generally more accurate and expensive. Frequency counters or high frequency hetrodyne systems can be used. Here the unknown frequency is compared with harmonics of a known lower frequency by use of a low frequency generator, a harmonic generator and mixer.

Fig. Measurment of frequency – electronic method.

Measurement of power:

The microwave power inside waveguide does not ~~depends~~ vary on position of measurement. ~~&~~ ~~power~~ P

The technique used to measure power depends on, whether Power is low/high.

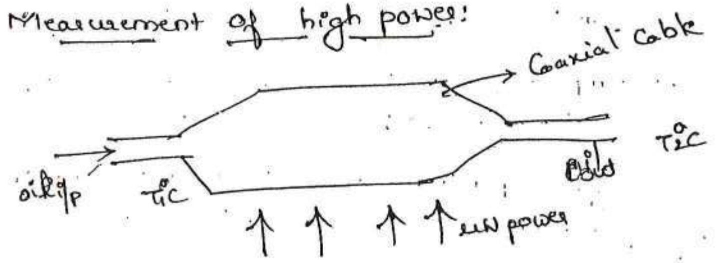
∴ The measurement techniques are of 3 types

① Measurement of low power (0.01mW – 10mW)
 — Bolometer

② " Medium power (10mW – 1W)
 — Calorimetric Technique.

③ " high power (>10 W)
 — Calorimetric Watt meter.

Measurement of high power:



Any power b/w 10W – 50kW is considered to be high power. These are measured using calorimetric Watt meter method.

It consists of a coaxial cable which is filled with circulating water/oil which is good absorber of microwaves. The cable subjected to micro wave power. The fluid after flowing through the load experiences a temp rise due to μW energy. The difference b/w $T_1°C$ of known liquid before entering load and the $T_2°C$ after it emerges is a measure of power it absorbs.

$$\therefore P = \frac{R \cdot k e\,(T_2 - T_1)}{4.18}$$

P = measured power in watts
R = rate of flow (cm^3/s)
k = specific ~~gravity~~ heat in Cal/g
e = specific gravity in g/cm^3

Measurement of Low power:

Bolometers / Thermocouples are devices whose resistance changes with applied power and are capable of measuring low power.

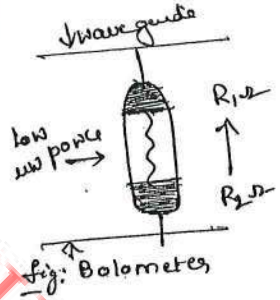
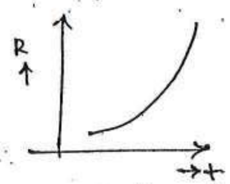


fig: Bolometer

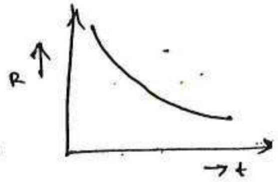
Bolometer simple temp sensitive device, whose Resistance varies wrt temp.

They are of 2 types

① Barretters



② Thermistors



→ Barretters have +ve temp coeff. R ↑ses with ↑se in temp.
→ Thermistors " –ve " " . R ↓ses " ↑se " " .
→ Barretters ~~It~~ consists of a fine platinum wire mounted in catridge, like an ordinary fuse. Thermistors are semiconductor material

→ Bolometer is a square law device, it produces current ie proportional to applied power. Bolometer is mounted inside a wave guide, whose operation resistance is $R_1\Omega$.

→ Now a low μW power applied, ~~to~~ some power is absorbed by bolometer load and dissipated as heat, its resistance changes to R_2.

∴ Change in R ∝ microwave power.

(4) In the balanced bolometer bridge techniqe, the bolometer itself is made to be one of the arms of the bridge.

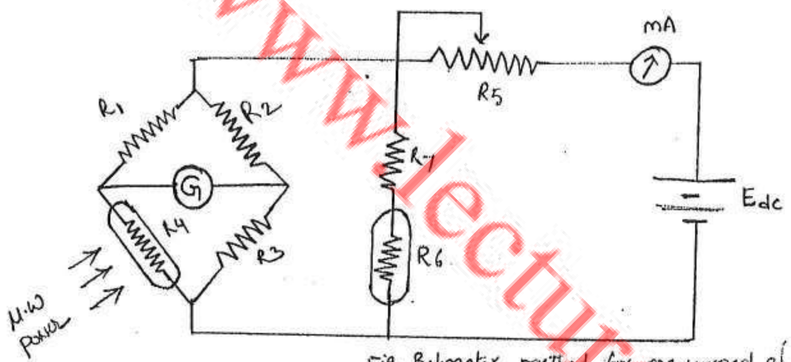


Fig. Bolometer method for measurement of power.

Initially, The bridge is balanced by adjusting R_5, which varies the dc power applied to the bridge and the bolometer element is brought to a predetermined operating resistance before microwave power is applied. Let The voltage of the battery be E_1 at balance. The microwave power is now applied and This power gets dissipated in the bolometer. The bolometer heats up and it changes its resistance. Therefore the bridge becomes unbalanced and the applied dc power is changed to E_2 to get back the balance. The change in dc battery voltage $(E_1 \sim E_2)$ will be proportional to the microwave power. Alternatively the detector 'G' can be directly calibrated interms of microwave power so that when the bridge is unbalanced, the detector reads the microwave power directly.

Errors since bolometers are temperature sensitive, so some ~~form of~~ temperature compensation has to be used to avoid Errors. By R_6 and R_7 resistors This can be achieved.

Attenuation Measurment :-

Microwave Components and devices almost always provide some degree of attenuation. Attenuation is the ratio of input power to the output power and is normally expressed as in decibles.

i.e $\text{Attenuation (in dB's)} = 10 \log \frac{P_{in}}{P_{out}}$

where P_{in} = input power and
P_{out} = output power.

the amount of attenuation can be measured by two methods.

(a) power Ratio method
(b) RF Substitution method.

Power Ratio method :-

This method involves measuring the input power and output power with and with out the device whose attenuation is to be measured as shown in set up 1 and set up 2. The powers are measured in set up as P_1 and P_2. The ratio of powers P_1/P_2 expressed in decibles gives the attenuation.

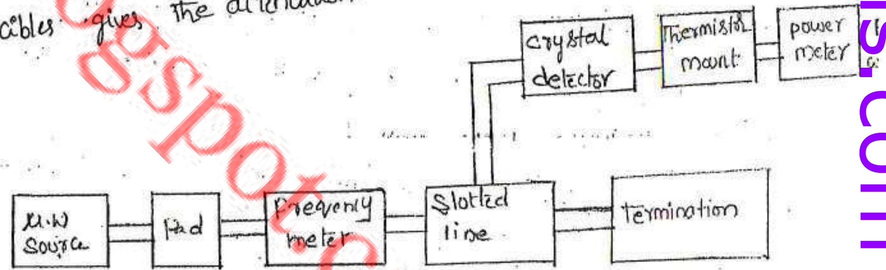


Fig. Setup 1, power Ratio method.

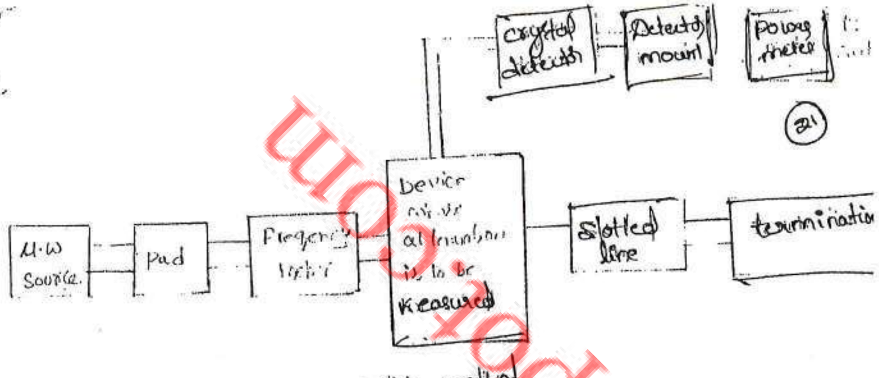


Fig. Setup2, power ratio method

The drawback of this method is that the attenuation measured correspond to two power positions on the power meter with a square law crystal detector characteristics. Due to nonlinear characteristics the two powers measu and the attenuation calculated will not be accurately particularly if the attenuation of the network is large and if the input power is low.

RF Substitution method :-

This method overcomes the drawback of power ratio method since there are measure attenuation at single power position. the method consists of measuring the output power say 'p' by including the networ whose attenuation is to be measured in set up1 as shown in fig.

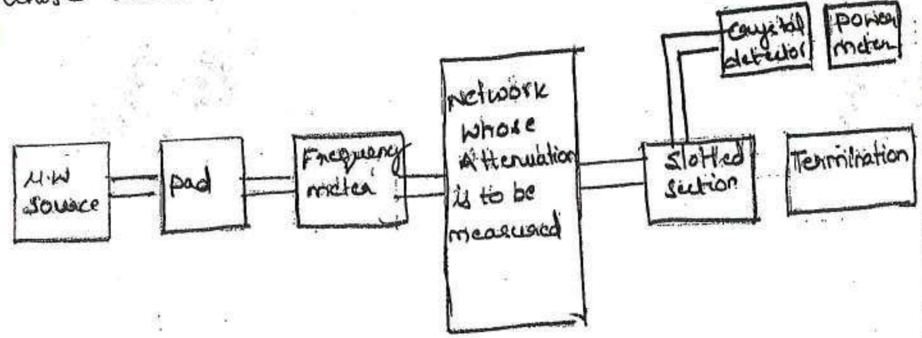


Fig. Setup1, RF Substitution method

In Set up 2 this network is replaced by a ... attenuator which can be adjusted to obtain the same power 'P' as measured in set up 1. under this condition the attenuation read on the precision attenuator could give attenuation of the network directly.

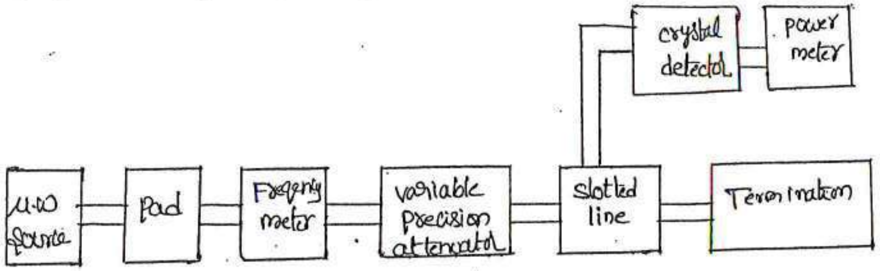
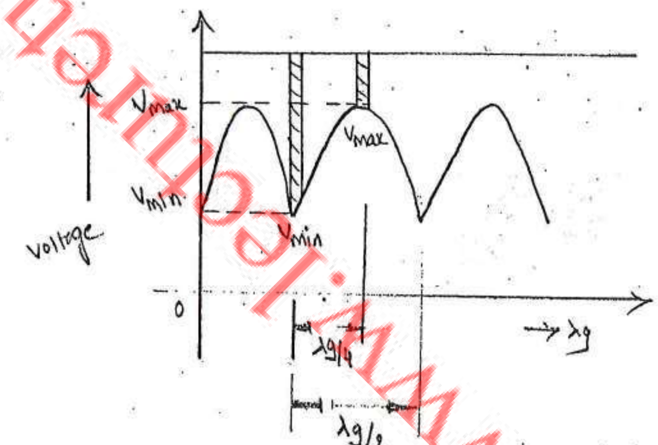


Fig. Setup2, RF Substitution method.

Measurement of VSWR :-

Any mismatched load leads to reflected waves resulting in standing waves along the length of the line. the ratio of maxim to minimum voltage gives the VSWR.



i.e $S = \frac{V_{max}}{V_{min}} = \frac{1+\rho}{1-\rho}$

if $\rho = 0$, $S = 1$

$\rho = 1$, $S = \infty$

Where, ρ = reflection coefficient = $\frac{P_{reflected}}{P_{incident}}$

S varies from 1 to ∞

as ρ varies from 0 to ∞

Hence minimum value of S is unity.

→ Measurment of Low VSWR's ($S<10$) :-

Values of VSWR not exceeding 10 are very easily measured with the set up and can be read off directly on the VSWR meter calibrat as show in fig.

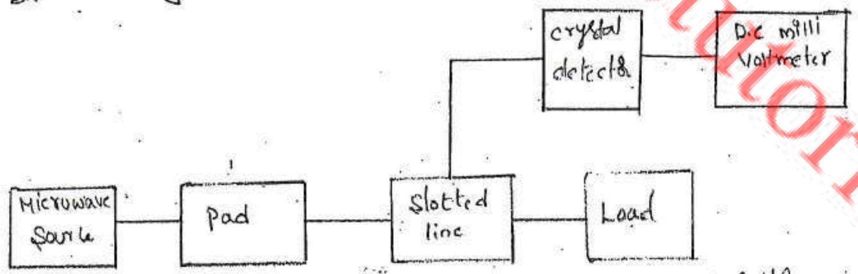


Fig. Microwave test bench for measuring VSWR<10.

The measurment basically consists of simply adjusting the attenuator to give an adequate reading on the meter, which is a DC millivolt meter. the probe on the slotted waveguide is moved to get maximum reading on the meter (corresponding to Vmax), the attenuation is now adjusted to get full scal reading. this full scale reading is noted down. Next the probe on the slotted line is adjusted to get minimum reading on the meter (corresponding to Vmin). the ratio of first reading to the second (i.e Vmax/Vmin) gives the VSWR.

The meter itself can be calibrated in terms of vswr. in this case, the probe carriage is moved to give maximum deflection, the VSWR meter by adjusting the pad. This Full Scale Deflection (FSD) corresponds to a VSWR of 1.

for example, for a full scale deflection of 10mV, If the minimum reading on the meter is 1mV then

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{10mV}{1mV} = 10$$

If the minimum reading on the meter is 2.5mV then

$$VSWR = \frac{10mV}{2.5mV} = 4$$

If the minimum reading on the meter is 3.3mV. then

$$VSWR = \frac{10mV}{3.3mV} = 3$$

If the minimum reading on the meter is 5mV then

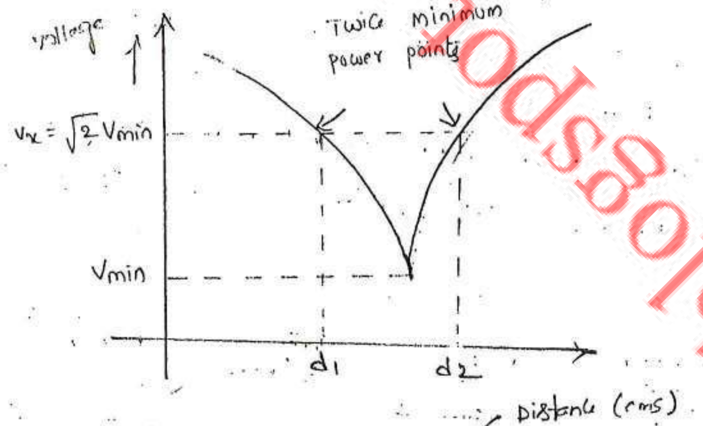
$$VSWR = \frac{10mV}{5mV} = 2$$

when VSWR >10, the meter will be congested and accurate measurment is not possible. so, the above method is not suitable for VSWR >10.

→ High VSWR Measurment ($S>10$):

The method which is used to measure high VSWR i.e greater than 10 is called as double minimum method. In this method, the probe is inserted to a depth where the minimum power can be read without difficulty. The probe is then moved

To a point where the power is twice the minimum. Let this position be noted by d_1. The probe is then moved to twice the power point on the other side of the minimum (say d_2) as shown in fig. we get $P_{min} \propto V_{min}^2 \longrightarrow (1)$



& $P_{min} \propto V_x^2 \longrightarrow (2)$

$$\frac{eqn(1)}{eqn(2)} \Rightarrow \frac{1}{2} = \frac{(V_{min})^2}{V_x^2}$$

$$V_x^2 = 2\,(V_{min})^2$$

& $$V_x = \sqrt{2}\, V_{min}$$

Further for TE_{10} mode, $\lambda_c \doteq 2a$

$$\lambda_0 = c/f$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

Then VSWR can be calculated using the empirical relation,

$$\boxed{VSWR = \frac{\lambda_g}{\pi(d_2-d_1)}}$$

Measurement of Q of a Cavity Resonator :-

There are several methods for measuring the Q of a cavity resonator.

1. Transmission method
2. Impedance measurement
3. Transient decay or decrement method.

Among these, Transmission method is the simplest and is described here in detail.

The set up for Transmission method of measuring Q is shown in fig. In this method, the cavity resonator is used as a transmission device a

Fig. Set up for measurement of Q of a Cavity resonator using Transmission method.

The output signal is measured as a function of the frequency resulting in the resonance curve as shown in fig.

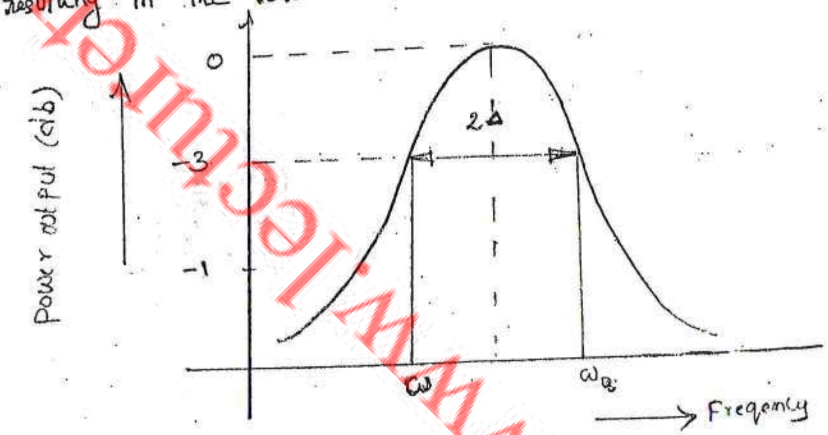


Fig. Resonance Curve

By varying the frequency of microwave source and keeping signal level constant, the output power is measured. Alternatively cavi can be tuned by keeping both signal level and frequency constant and output power measured. From the resonance curve half power bandwidth (2Δ) can be measured.

(24)

i.e $2\Delta = \pm \frac{1}{Q_L}$

where Q_L = loaded value,

or $Q_L = \pm \frac{1}{2\Delta} = \pm \frac{\omega}{2(\omega-\omega_0)}$

If the coupling between microwave source and cavity and that between detector and cavity are neglected, $Q_L = Q_0$ (unloaded Q). However, the accuracy of this method is poor, particularly in case of very high Q systems due to narrow band of operation.

Measurement of Impedance:-

Impedance at microwave frequencies can be measured using any of the following 3 methods.

a) using magic tee
b) using slotted line and
c) using reflectometer.

Measurement of Impedance using slotted line:-

Incident and reflected waves will be present proportional to the mismatch of the load under test (whose impedance is to be measured) resulting in standing waves. using slotted waveguide and with the load Z_L in the circuit. given by its ... position of V_{max} and V_{min} can be accurately determined.

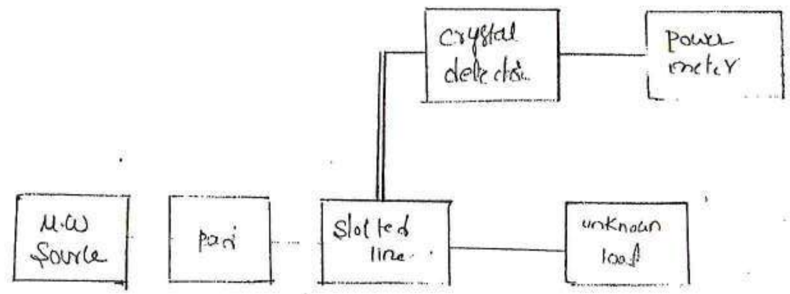


Fig. Set up 1, Impedance measurement using slotted line.

Now the load Z_L is replaced by a short circuit as shown in below. and the shift in minimum is measured. If the minimum is shifted to the left, then the impedance is inductive and if is shift to the right, it is capacitive. unknown impedance can obtained by usual methods using the data recorded and a smith chart. Both impedance and reflection coefficient can be obtained in magnitude and phase.

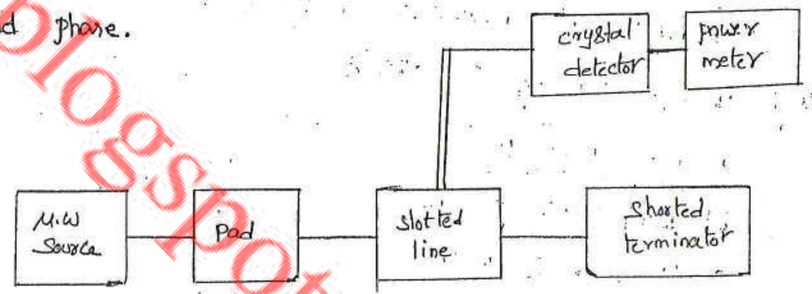


Fig. Setup 2, Impedance measurment using slotted line.

~~Now the load Z_L is replaced by a short circuit and the shift minimum is measured. If the minimum is shifted to the left, then The impedance is jX~~

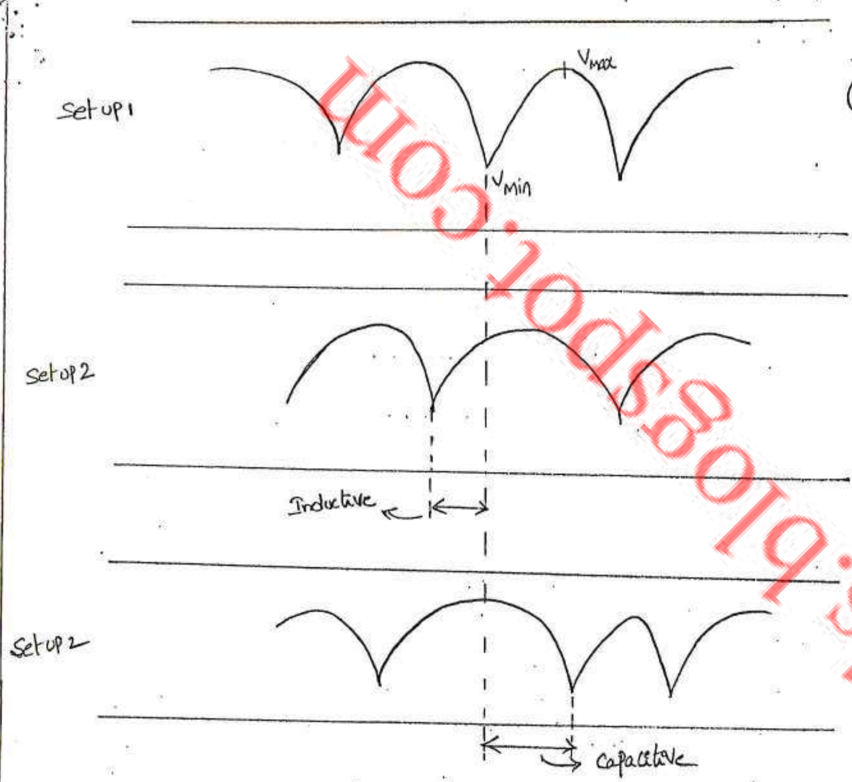


Fig. output standing waves of setup 1 & setup2.

Measurement of Impedance using Reflectometer:-

The reflectometer indicates magnitude of impedance but not the phase angle, whereas a slotted line waveguide measurement gives both. A typical setup for reflectometer technique is shown below. where two directional couplers are used to sample the incident power P_i and the reflected power from load. But the directional coupler are coefficient ρ, can be directly obtained on the reflectometer from which impedance can be calculated.

From reflectometer reading wave we have,

$$\rho = \sqrt{\frac{P_r}{P_i}}$$

Knowing ρ we can calculate VSWR and impedance by using the relations,

$$S = \frac{1+\rho}{1-\rho} \quad \text{and} \quad \frac{z-z_g}{z+z_g} = \rho.$$

where z_g is the wave impedance

z is unknown impedance.

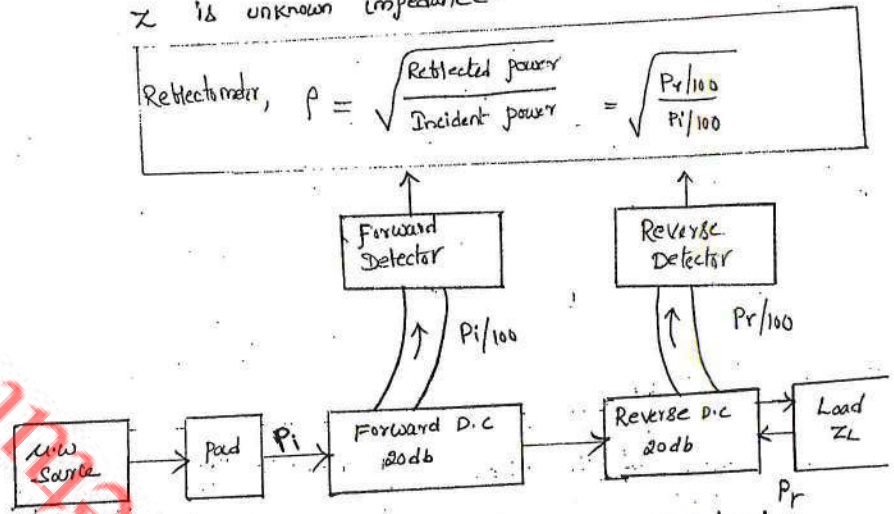


Fig. setup for measuring impedance using reflectometer

Due to directional property of the couplers, there will be no interference between forward and reverse waves. The input power is kept to a low level by means of pad. the reflectometer accuracy is greatest at low VSWR (i.e reflection coefficient).

26

1. Calculate the SWR of a transmission system operating at 10GHz. Assume TE_{10} wave Tx'ion inside a waveguide of dimensions $a = 4cm$, $b = 2.5cm$. The distance measured between twice minimum power point is 1mm on a slotted line.

Ans:

Given, $f = 10\,GHz$,

$a = 4cm$, $b = 2.5cm$

$$\lambda_0 = \frac{c}{f} = \frac{3\times10^{10}}{10\times10^9} = 3cm$$

$d_2 - d_1 = 1mm$

We know, $$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} = \frac{3}{\sqrt{1-(3/8)^2}} = 3.2\,cm$$

For double minimum method VSWR is given by

$$VSWR = \frac{\lambda_g}{\pi(d_2-d_1)} = \frac{3.2}{\pi(1\times10^{-1})} = 10.3$$

2) Two identical directional couplers are used in a waveguide to sample the incident and reflected powers. The output of the couplers is found to be 2.5 mW and 0.15 mW. Find the value of VSWR in the waveguide?

Ans:

Given $P_i = 2.5mW$

$P_r = 0.15mW$

Reflection Coefficient, $\rho = \sqrt{P_r/P_i} = 0.244$

$$\therefore VSWR = \frac{1+\rho}{1-\rho} = \frac{1.244}{0.756} = 1.64$$

3) If we have two directional couplers (20dB) in the ... The incident and reflected ~~waves~~ powers; the outputs of couplers are 3mW and 0.1mW respectively. What is the value VSWR in the main waveguide? What is the value of reflected power?

Sol:

Given $P_f = \frac{P_i}{100} = 3mW \Rightarrow P_i = 300mW$

$P_b = \frac{P_r}{100} = 0.1mW \Rightarrow P_r = 10mW$

$$\left[\rho = \sqrt{P_r/P_i}\right]$$

$$\rho = \sqrt{\frac{10}{300}} = 0.1816$$

$$VSWR\ (S) = \frac{1+\rho}{1-\rho} = \frac{1.18}{0.82} = 1.44$$

4) Two identical 30dB directional coupler are used to sample incident and reflected power in a waveguide. VSWR = 2 and the output of the coupler sampling incident power is 4.5mW. What is the value of reflected power?

Ans:

Given, $VSWR = \frac{1+\rho}{1-\rho} = 2$

$2 - 2\rho = 1+\rho \Rightarrow \rho = \frac{1}{3} = 0.33$

We know, $C = 10\log\frac{P_i}{P_f}$

$30 = 10\log\frac{P_i}{P_f} \Rightarrow \frac{P_i}{P_f} = 10^3$

$P_f = \frac{P_i}{10^3} = P_i/1000$

Given $\frac{P_i}{1000} = 4.5mW$ or $P_i = 4.5mW$.

$$\rho = \sqrt{\frac{P_r/10^3}{P_i/10^3}} = \sqrt{\frac{P_r}{P_i}} \text{ or } \rho^2 = \frac{P_r}{P_i}$$

$P_r = \rho^2 \cdot P_i = 0.5W$

$\therefore C = 20dB$

$C = 10\log_{10}\frac{P_i}{P_f}$

~~$20 = 10\log$~~ $\frac{P_i}{P_f} = 10^2$

$P_f = P_i/100 \rightarrow (1)$

$D = 10\log\frac{P_f}{P_r}$

$20 = 10\log_{10} P_i/P_r$

$\frac{P_f}{P_r} = 10^2$

$P_f = P_i/100 \rightarrow (2)$