Microwave Semiconductor Devices

- Gunn Oscillator – Principle of operation, Characteristics
- Two valley model
- IMPATT Diodes
- TRAPATT Diodes
- BARITT Diode

Gunn Oscillator

- Gunn diode is a **Transferred Electronic Device**, which is composed of **only one type of semiconductor** i.e. **N-type** and utilizes the **Negative Resistance Characteristics** to generate current at high frequencies.
- It is used to generate RF and microwave frequencies.

- a type of diode even though it does not contain any typical PN diode junction like the other diodes, but it **consists of two electrodes**.
- This diode is also called as a Transferred Electronic Device (TED).
- It consists of only N-type semiconductor in which **electrons are the majority charge carriers**.
- To generate short radio waves such as microwaves, it utilizes the **Gunn Effect**.

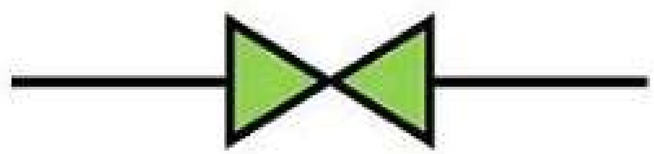
- similar function as Reflex Klystron Oscillators.
- In Gunn oscillators, the Gunn diode will be placed in a resonant cavity.
- A Gunn oscillator is comprised of **two major components**:
  (i) A DC bias and (ii) A tuning circuit.

Gunn Effect

- It was invented by John Battiscombe Gunn in 1960s; after his experiments on GaAs.
- He observed a noise in his experiments' results and owed this to the **generation of electrical oscillations at microwave frequencies by a steady electric field with a magnitude greater than the threshold value**.
- It was named as **Gunn Effect**.

Gunn diode symbol

- The most widely used Gunn diode symbol uses **two filled in triangles with points touching** is used.

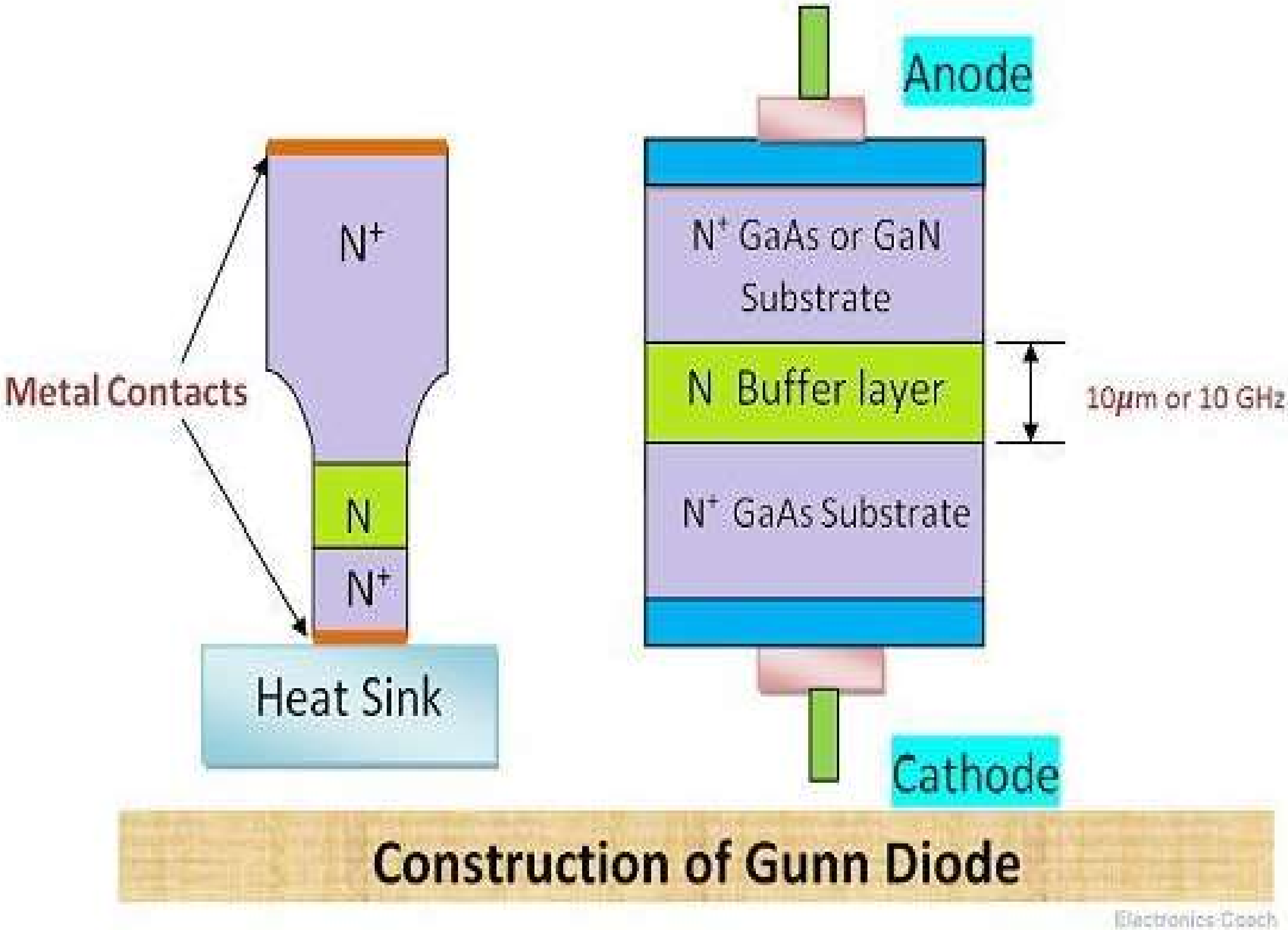


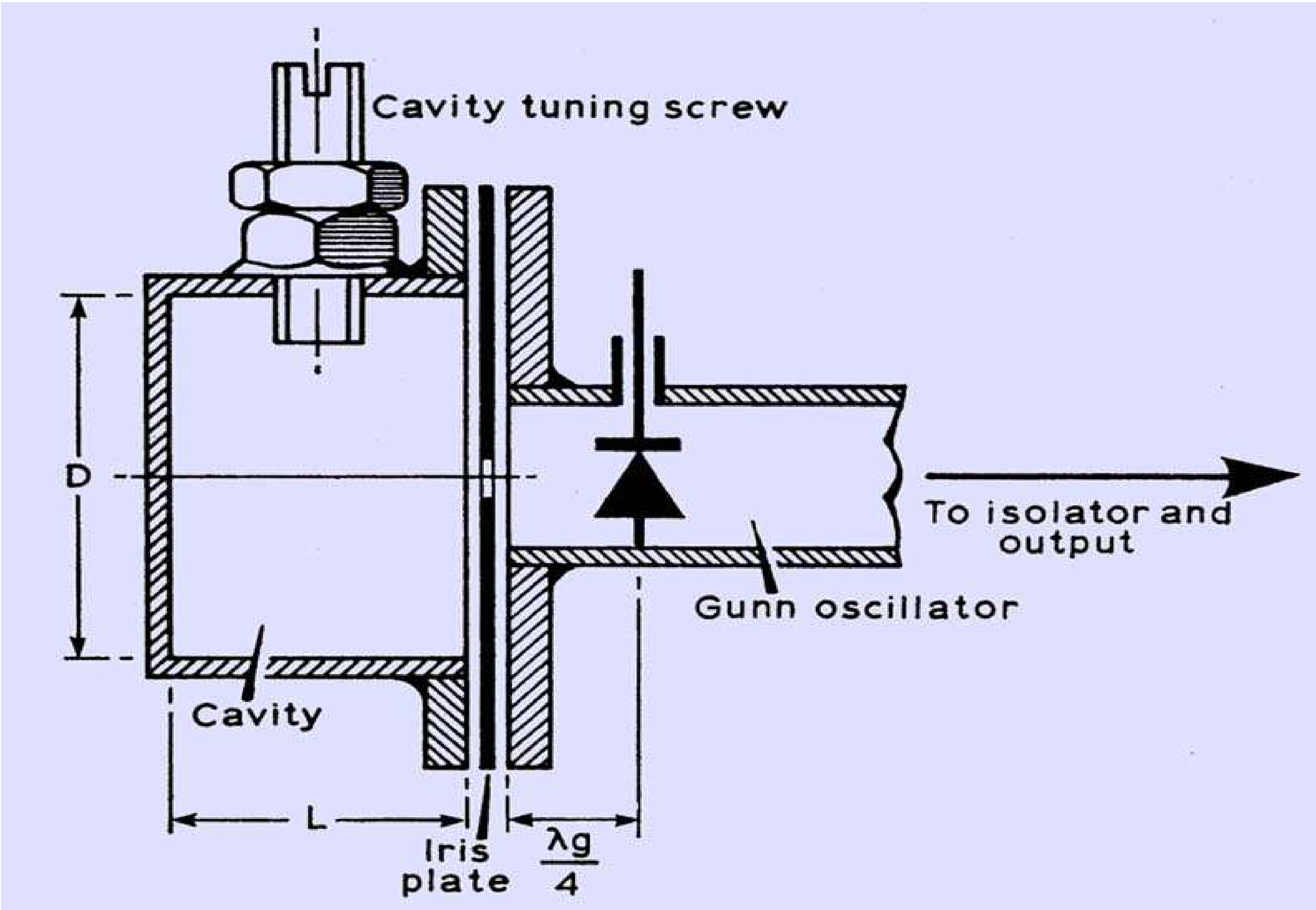
Symbol of Gunn Diode

Construction of Gunn Diode

- made up of **three layers of N-type semiconductor**.
- The semiconductors used in Gunn diodes are Gallium Arsenide (GaAs), Gallium Nitride (GaN), Cadmium Telluride (CdTe), Cadmium Sulphide (CdS), Indium Phosphide (InP), Indium Arsenide (InAs), Indium Antimonide (InSb) and Zinc Selenide (ZnSe).

- Among these three layers the **top most** and the **bottom** most are **heavily doped** while the **middle layer is lightly doped** in comparison to the extreme layers.
- The middle layer is an **epitaxial layer grown on the N-type substrate** and the **top most layer is formed by ion implantation technique**.
- The **metallic contacts are provided on extreme layers to facilitate biasing**. The **heat sink** is there so that the diode can **withstand excessive heat** and can be **prevented from damage**.


Anode
Metal Contacts
N+
N
N+
Heat Sink
N+ GaAs or GaN Substrate
N Buffer layer
10μm or 10 GHz
N+ GaAs Substrate
Cathode
Construction of Gunn Diode
Electronics Coach


Cavity tuning screw
D
To isolator and output
Gunn oscillator
Cavity
L
Iris plate
λg
4

Working of Gunn Diode

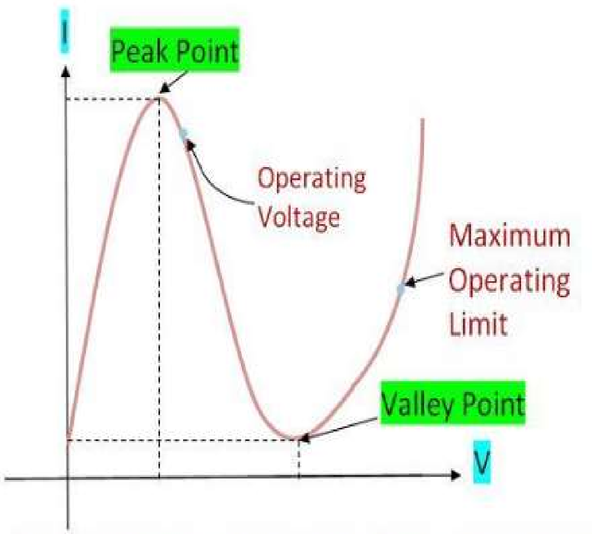
- The Gunn diode is **not actually a P-N junction diode** because there is **no P-region** and **no junction**.
- But still, it is called diode **because of involvement of two electrodes**.
- When biasing is applied to Gunn diode, the entire voltage appears across the active region.
- The active region is the middle layer of the device. The active region is 6-18m long.

- Due to which the current pulses start traversing the active region.
- The **potential gradient will fall when current pulse traverses in the active region** which **blocks another pulse to form**.
- The **next current pulse will form only when the previous current pulse has traversed the entire active region** or it will be on the **end of the active region**.
- In this way, the **thickness of active region modifies the frequency at which the device is working**.

- In Gunn diode, there is **valence band**, **conduction band** and **one more band near conduction band**.
- Thus, on initial DC bias the current through the device **increases because electrons move from valence band to conduction band**.
- After moving in conduction band the **current through the device starts decreasing because the electrons in conduction band move to band above the conduction band**.

- Due to this the **effective mass of electrons starts increasing and thus mobility starts decreasing due to which the current starts decreasing**, and this **creates the negative resistance region in the diode**.
- In this **negative resistance region**, the **current starts increasing with the fall in voltage** and **will starts decreasing with increase in voltage**.
- Thus, it generates pulses with phase reversal and thus this device is appropriate for the fabrication of amplifier and oscillator circuits.
- It generates **frequency ranging from 10 GHz to THz**.

V-I Characteristics of Gunn Diode



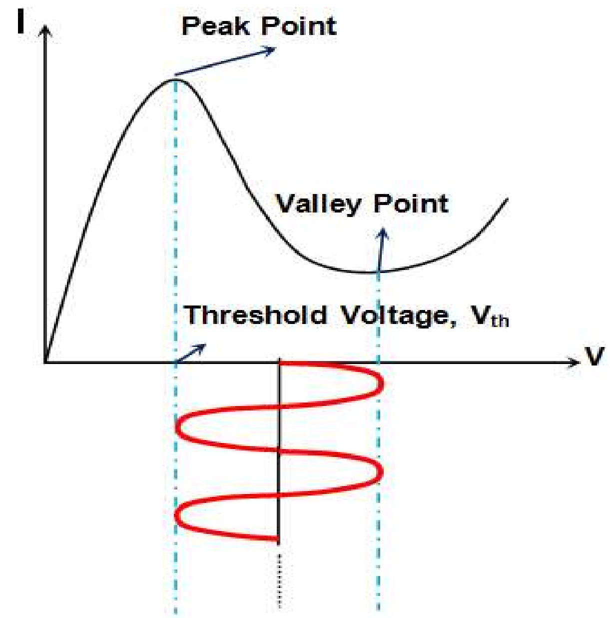


Figure 1 Gunn Diode Oscillations

Advantages of Gunn diode

- Portable and Small Size device.
- The cost of manufacturing of Gunn diode is low.
- It possesses better noise to signal ratio as it is immune from noise disturbance.
- The Gunn diode is reliable and stable at higher frequencies.
- It has a high bandwidth of operation.

Disadvantages of Gunn Diode

- The Gunn diode has poor temperature stability.
- The device operating current is higher and therefore power dissipation is more.
- The efficiency of Gunn Diode is low below 10GHz.

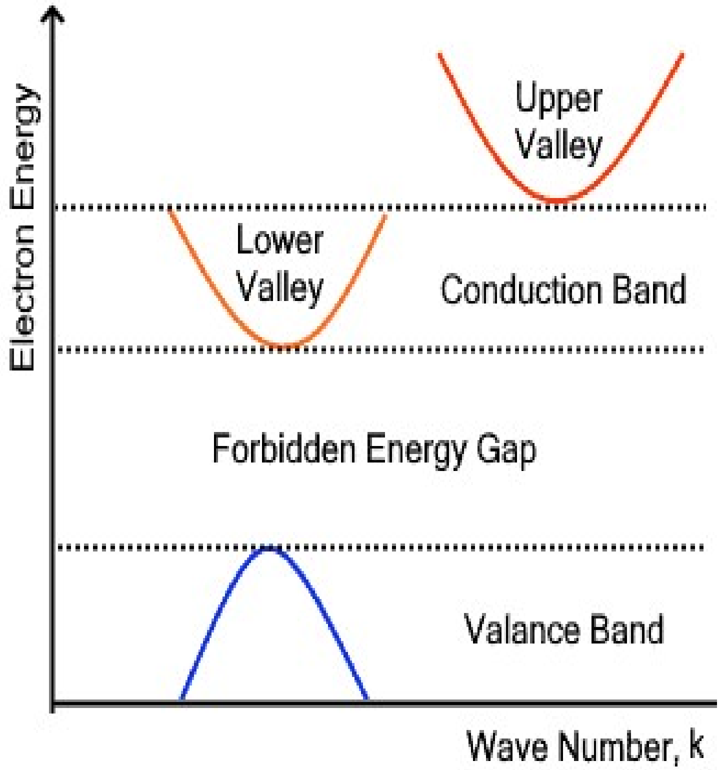
Applications of Gunn Diode

- Gunn Diodes are used as oscillators and Amplifiers.
- They are used in radio communication, military and commercial radar sources.
- Gunn diodes are used as fast controlling equipment in microelectronics for modulation of laser beams.
- It is used in tachometers.
- Gunn diode is used in sensors for detection in trespass detecting system, in-door opening system, pedestrian safety systems etc.
- It is also used extensively in microwave relay data link transmitters.

Two Valley Model Theory of Gunn Diode

- The Gunn oscillator uses the two-valley model (**Ridley-Watkins-Hilsum theory**), explaining how electrons transfer between a low-energy, high-mobility lower conduction valley (Γ valley) and a high-energy, low-mobility upper conduction valley (L valley) in materials like GaAs, causing negative differential resistance (NDR) and microwave oscillation.

- When a high electric field pushes electrons from the lower to the upper valley their velocity drops, leading to a current decrease despite voltage increase, creating high-field domains that drift and oscillate, functioning as microwave sources.
- This electron transfer (Gunn Effect) leads to the formation of high-field domains that move across the device, generating microwave signals.



Two valley model

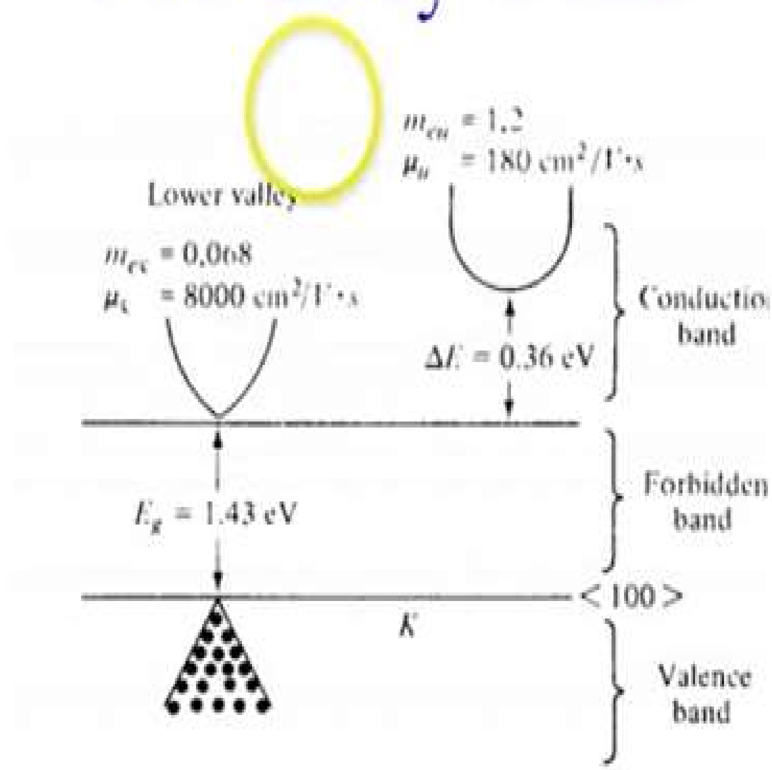


Fig: Two valley model electron energy Vs wave number for n type GaAs

- Lower Valley: Has low effective mass and high mobility (fast electrons).
- Upper Valley: Has high effective mass and low mobility (slow electrons)
- Energy Difference: The energy difference between these valleys (Delta E)) must be significantly larger than thermal energy (kT) but smaller than the band gap.

IMPATT Diodes

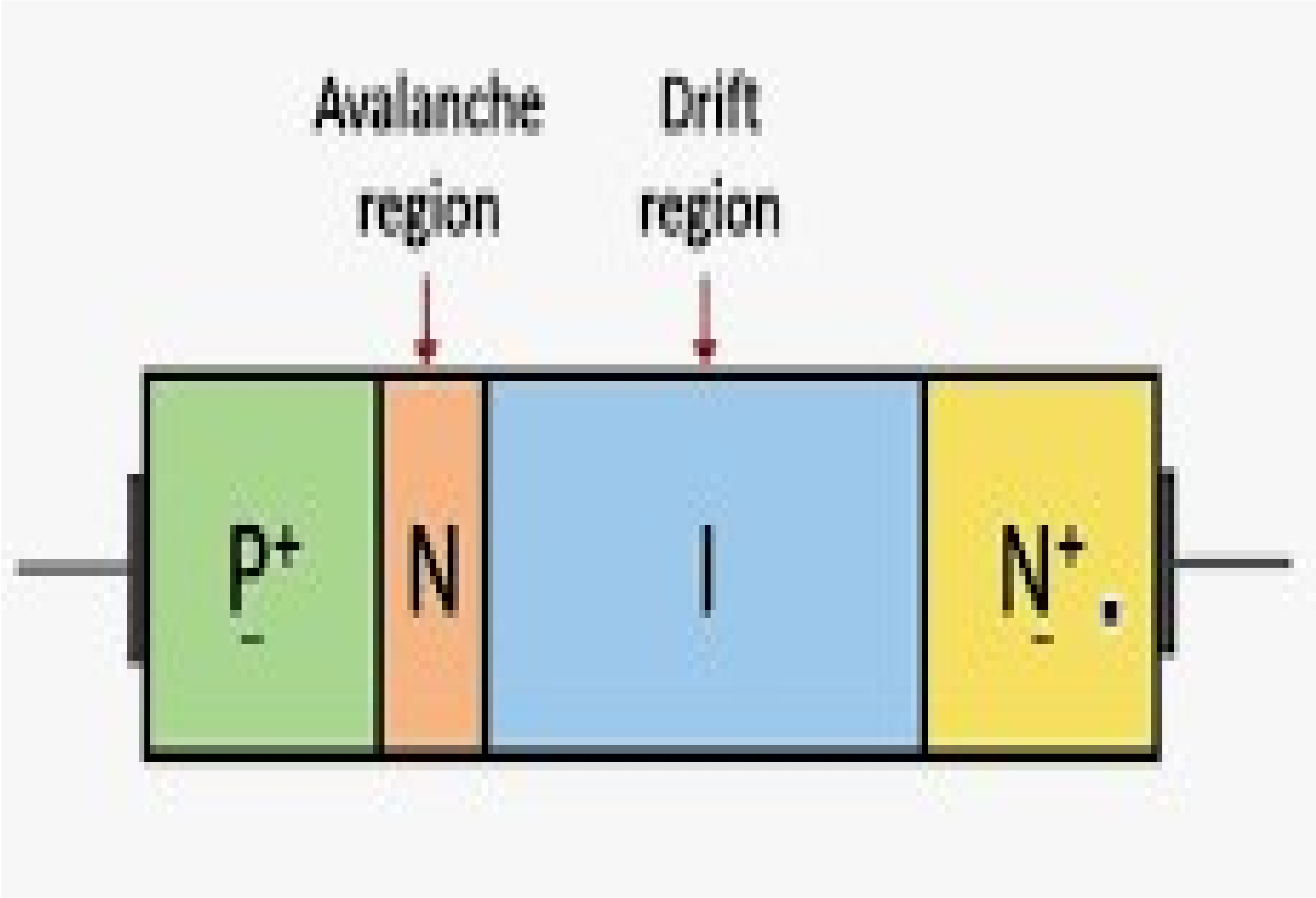
- **IMPact ionization Avalanche Transit-Time**.
- IMPATT diode is a **very high power semiconductor device** that is **utilized for microwave applications**.
- The operating range of the IMPATT diode lies in the range of **3 to 100 GHz**.
- it **Possesses Negative Resistance Characteristic** thus acts as an oscillator to generate signals at microwave frequencies.
- It is a **Reverse-Biased Diode** and **Avalanche condition is the basis of its operation**.

Principle

- These diodes function on the **idea of Avalanche Breakdown** and **Transit Time Effect**.

Construction

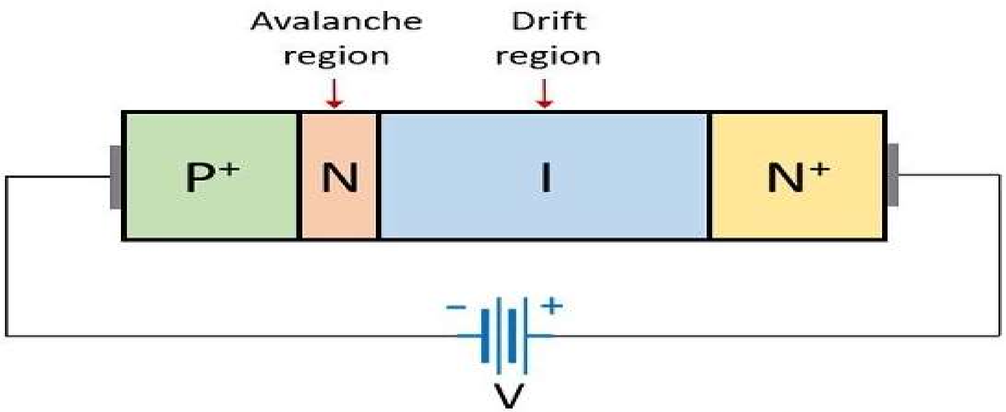
- The structure of the IMPATT diode is somewhat **similar to the PIN diode**.
- However, it operates on a **very high voltage gradient of around 400KV/cm**, so as **to produce avalanche current**.
- It consists of **4 regions** namely **P+-N-I-N+.**



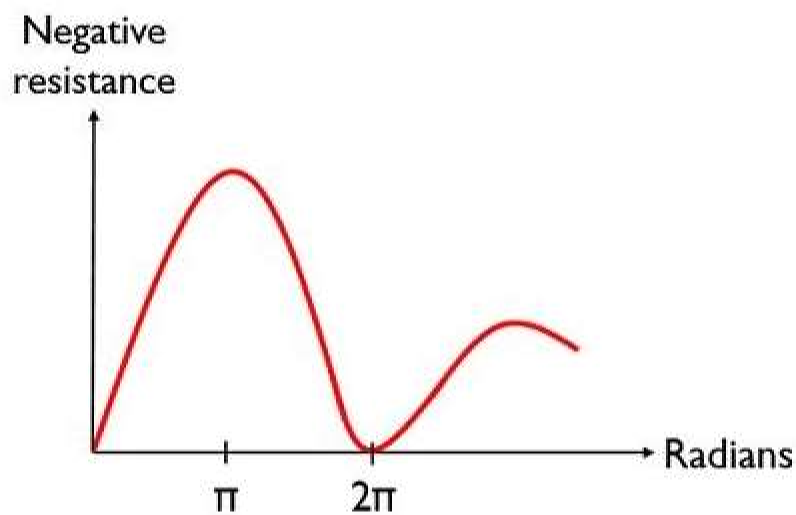
Avalanche region
Drift region
P+
N
I
N+

- In the depletion area, the diode experiences avalanche breakdown under reverse bias, producing electron-hole pairs.
- The transit time of the high-energy electrons through the depletion area is caused by the electric field.
- The frequency of the resulting microwave signal is largely determined by this **Transit Time Impact**.

Working of IMPATT Diode



IMPATT Diode



Negative resistance vs transit angle

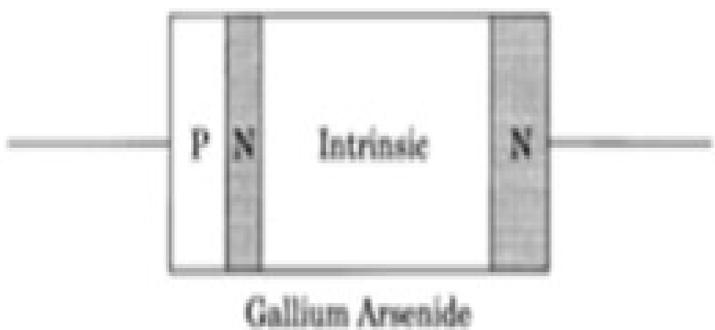
TRAPATT Diodes

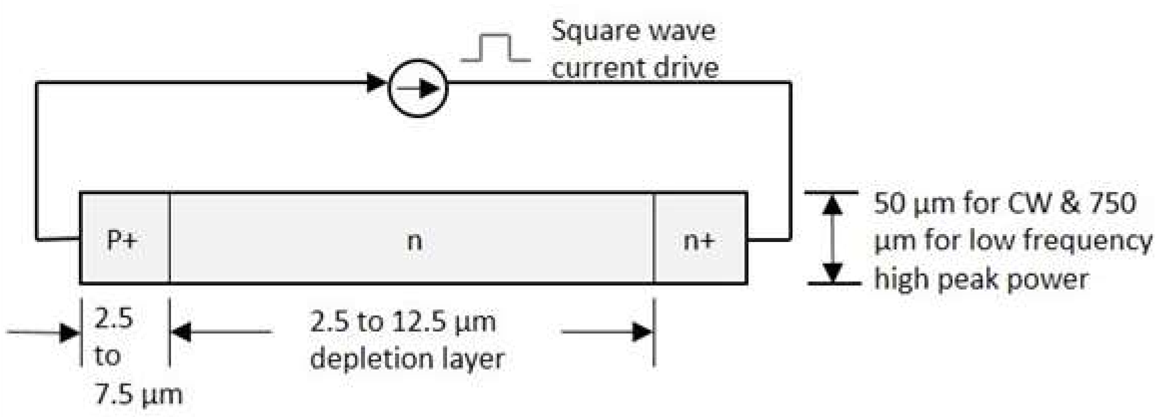
- **TRApped Plasma Avalanche Triggered Transit diode**.
- Microwave generator which operates between hundreds of MHz to GHz.

- The TRAPATT diode belongs to the **similar basic family of the IMPATT diode**.
- It has the advantage of a better level of efficiency normally the DC to RF signal alteration efficiency may be in the area of **20 to 60%.**

Construction

- the construction of the diode consists of a p+ n n+ which is used for high power levels an n+ p p+ construction is better.



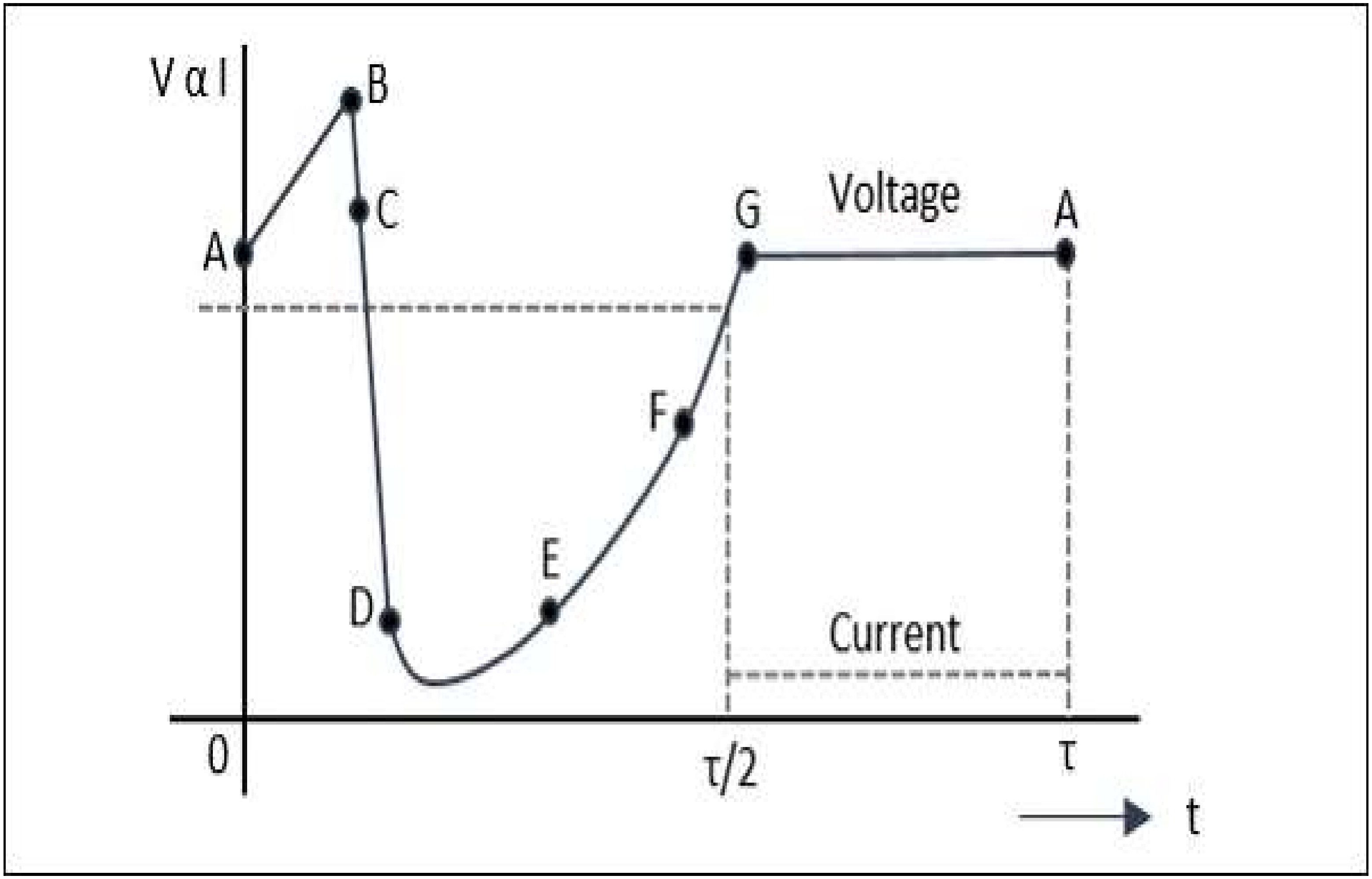


Arrangement in TRAPATT diode

Working Principle of TRAPATT Diode

- TRAPATT is energized using a current pulse which roots the electric field to **enhance to an important value where multiplication of avalanche occurs**.
- At this point the field fails nearby due to the produced plasma.

- The partition and flow of the holes and electrons are driven by a very much minor field.
- It almost shows that they have been ‘trapped’ behind with a velocity lesser than the velocity of saturation.
- After the plasma increases across the entire active region, the electrons and holes start to drift to the reverse terminals and then the electric field starts to rise again.


V α I
B
C
A
G
Voltage
A
F
E
D
Current
0
τ/2
τ
t

- A: The voltage at point A is not sufficient for the avalanche breakdown to occur. At A, charge carriers due to thermal generation results in charging of the diode like a linear capacitance.
- A-B: At this point, the magnitude of the electric field increases. When a sufficient number of carriers are generated, the electric field is depressed throughout the depletion region causing the voltage to decrease from B to C.
- C: This charge helps the avalanche to continue and a dense plasma of electrons and holes is created. The field is further depressed so as not to let the electrons or holes out of the depletion layer, and traps the remaining plasma.

- D: The voltage decreases at point D. A long time is required to clear the plasma as the total plasma charge is large compared to the charge per unit time in the external current.
- E: At point E, the plasma is removed. Residual charges of holes and electrons remain each at one end of the deflection layer.
- E to F: The voltage increases as the residual charge is removed.

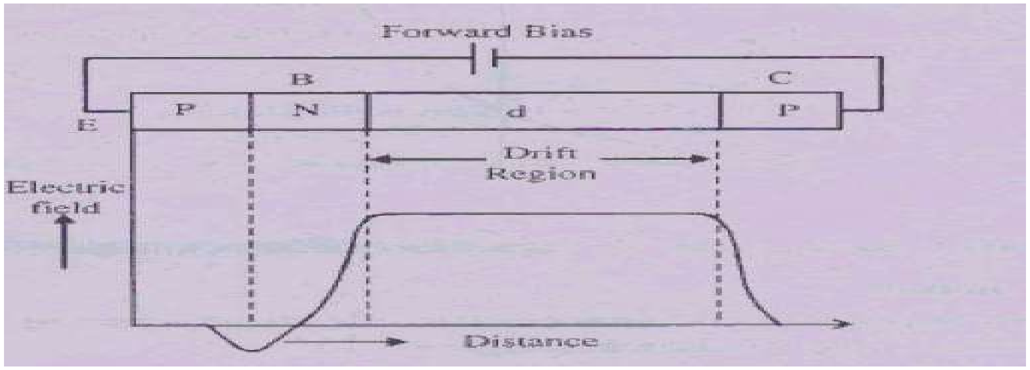
- F: At point F, all the charge generated internally is removed.
- F to G: The diode charges like a capacitor.
- G: At point G, the diode current comes to zero for half a period. The voltage remains constant as shown in the graph above. This state continues until the current comes back on and the cycle repeats.

Applications

- Low power Doppler radars
- Local oscillator for radars
- Microwave beacon landing system
- Radio altimeter
- Phased array radar, etc.

BARITT Diode

- **BARrier Injection Transit Time Diode**.
- Though these diodes have long drift regions like IMPATT diodes, the carrier injection in BARITT diodes is caused by forward biased junctions, **but not from the plasma of an avalanche region**.
- This diode is very similar with respect to the IMPATT diode, but the main difference between these two diodes is that the BARITT diode utilizes thermionic emission rather than multiplication of avalanche.


Forward Bias
B
C
E
P
N
d
P
Drift
Region
Electric
field
Distance

IMPATT Vs TRAPATT Diode Vs BARITT Diode

Properties	IMPATT Diode	TRAPATT Diode	BARITT Diode
Full name	Impact Ionisation Avalanche Transit Time	Trapped Plasma Avalanche Triggered Transit	Barrier Injection Transit Time
Developed by	RL Johnston in the year 1965	HJ Prager in the year 1967	D J Coleman in the year 1971
Operating Frequency range	4GHz to 200GHz	1 to 3GHz	4GHz to 8GHz
Principle of operation	Avalanche multiplication	Plasma avalanche	Thermionic emission
Output power	1Watt CW and > 400Watt pulsed	250 Watt at 3GHz , 550Watt at 1GHz	Just few milliwatts
Efficiency	3% CW and 60% pulsed below 1GHz,	35% at 3GHz and 60% pulsed at 1GHz	5% (low frequency) , 20%(high frequency)
Noise Figure	30dB	Very high NF of the order of about 60dB	Low NF about 15dB

Advantages	**·This microwave diode has high power capability compare to other diodes.** **· Output is reliable compared to other diodes**	**· Higher efficiency than Impatt** **· Very low power dissipation**	**· Less noisy than impatt diodes** **· NF of 15dB at C band using Baritt amplifier**
Disadvantages	· High noise figure · High operating current · High spurious AM/FM noise	· Not suitable for CW operation due to high power densities · High NF of about 60dB · Upper frequency is limited to below millimeter band	· Narrow bandwidth · Limited few mWatts of power output
Applications	· Voltage controlled Impatt oscillators · Low power radar system · Injection locked amplifiers · Cavity stabilized impatt diode oscillators	· Used in microwave beacons · Instrument landing systems • LO in radar	· Mixer · Oscillator · Small signal amplifier

UHF & Microwaves

Unit VI: Microwave Measurements

Contents

- Frequency Measurements
- Power Measurements
- Attenuation Measurements
- VSWR Measurements
- Impedance Measurements
- Insertion Loss Measurements
- Dielectric constant Measurements

Low Frequency Vs Microwave Measurements

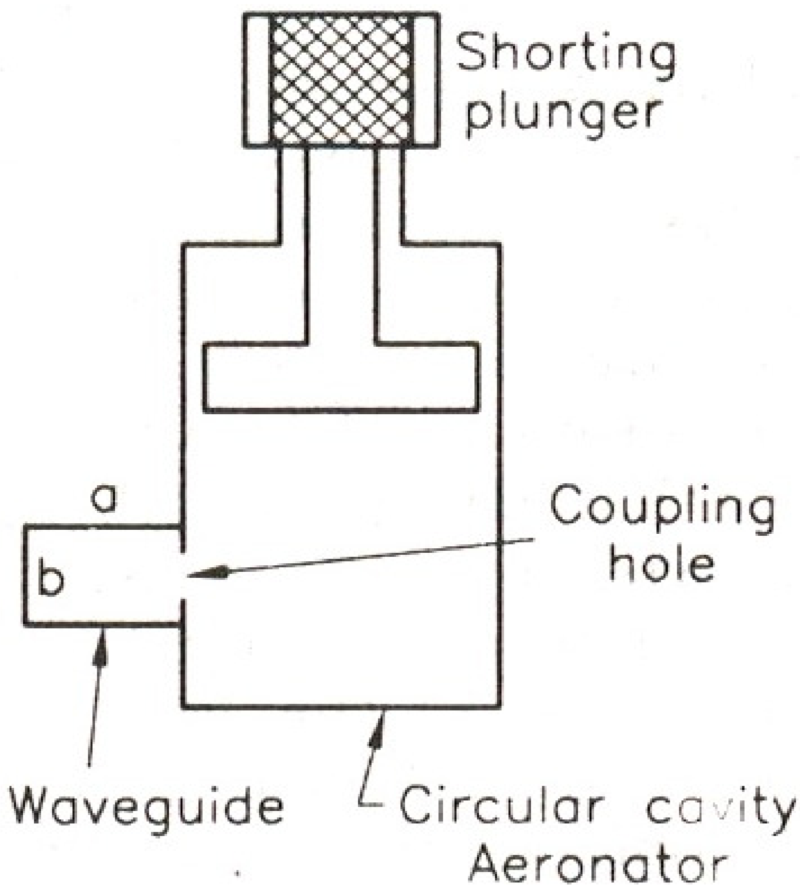
Terminologies	Low Frequency	Microwave Frequency
Power	Voltage and current can be measured hence is power	Difficult to measure V and I in transmission line hence is desirable to measure power directly.
Circuit Elements	Lumped elements hence can be identified and measured.	Distributed & impedance of whole circuitry can be measured.
Parameters	Can be exactly known.	Many parameters can not be measured for their absolute values i.e. relative measurements.

Frequency Measurements

- There are various ways for frequency measurements:
- Wave meter method.
- Slotted line method.
- Down conversion method.

➢Frequency Measurements: Wave meter method

- Typically constructed from cylindrical cavity resonator with a variable short circuit termination.
- Shorting plunger is used to change the resonance frequency of cavity by changing cavity length.



•TE_{011} mode is used because of its higher Q & absence of axial current.

•TM_{010} mode is excited in cavity through coupling hole by magnetic field coupling.

➢Frequency Measurements: Wave meter method

- Possible oscillation due to plunger can be avoided by placing a block of polytron at its back.
- Different plunger position results in different cavity resonant frequencies which can be calibrated by observing dip in power meter which connected by means of waveguide.
- For Q ranging from 1000-50,000 the accuracy of wavemeter is 1% to 0.005%.
- Since power is absorbed in wavemeter at resonance this is called as **absorption type wavemeter.**

➢ Frequency Measurements: Slotted Line Method

- Since distance between two minima $d_{min} = \lambda_g/2$ frequency can be determined from relations:

$$\frac{\lambda_g}{2} = d_{\min} \Rightarrow \lambda_g = 2.d_{\min}$$

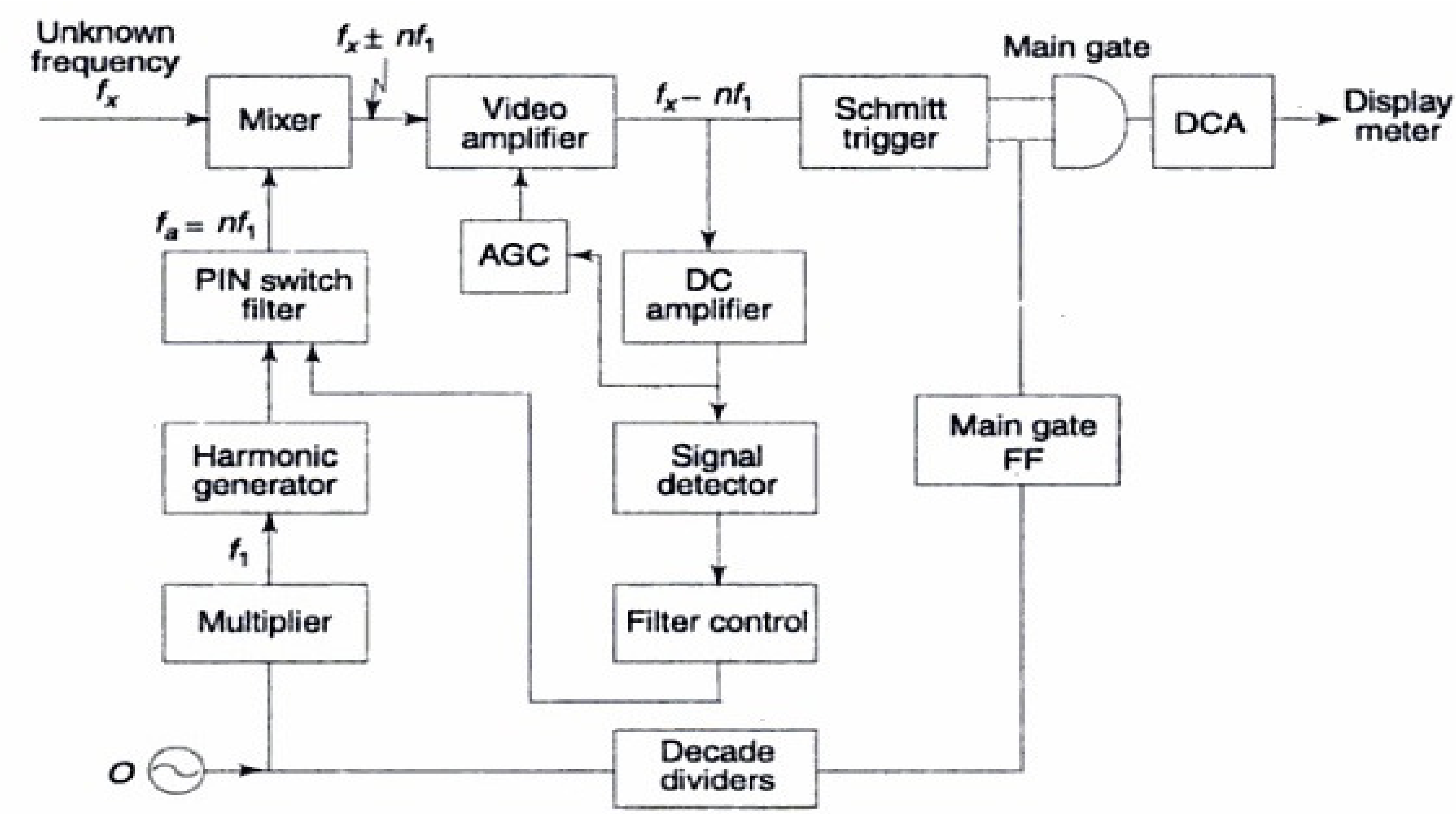
- For waveguide:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\left[1-\left(\lambda_0/\lambda_c\right)^2\right]}} \Rightarrow \lambda_g = \frac{\lambda_0}{\sqrt{\left[1-\left(\lambda_0/2a\right)^2\right]}}$$

- For coaxial line: $\lambda_g = \dfrac{\lambda_0}{\sqrt{\varepsilon_r}}$

➢Frequency Measurements: Down Conversion Method

- Accurate measurement using heterodyne converter.
- Unknown frequency f_x is down converted by mixing it with known f_a ($f_x - f_a = f_{IF}$) & is then amplified & measured by counter.



➢Frequency Measurements: Down Conversion Method

- f_a is obtained by = Local oscillator frequency X f_1
- Convenient frequency & is then passed through harmonic generator to give series of harmonics of f_1.
- Appropriate harmonics are then selected by tuning cavity such that f_a can be added with f_{IF} and displays unknown frequency f_x.
- Typical value for f_1 = 100 to 500 MHz for a range of f_x up to 20 GHz.

➢Measurement of Power

- Microwave power is average power & inside a waveguide it is invariant with measurement position.

- Following are the techniques used for power measurement:

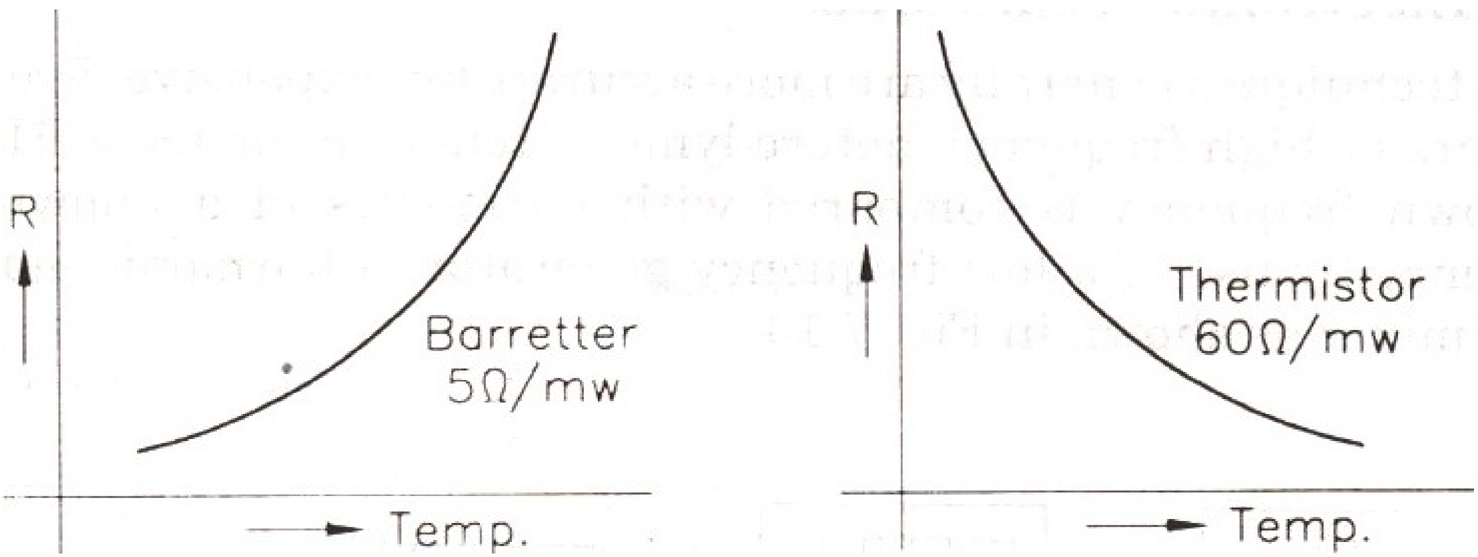
- Measurement of low microwave power (0.01 mW-10mW): Bolometer Technique.

- Measurement of medium microwave power (10 mW-1W): Calorimetric Technique.

- Measurement of high microwave power (> 10 W): Calorimetric Watt meter.

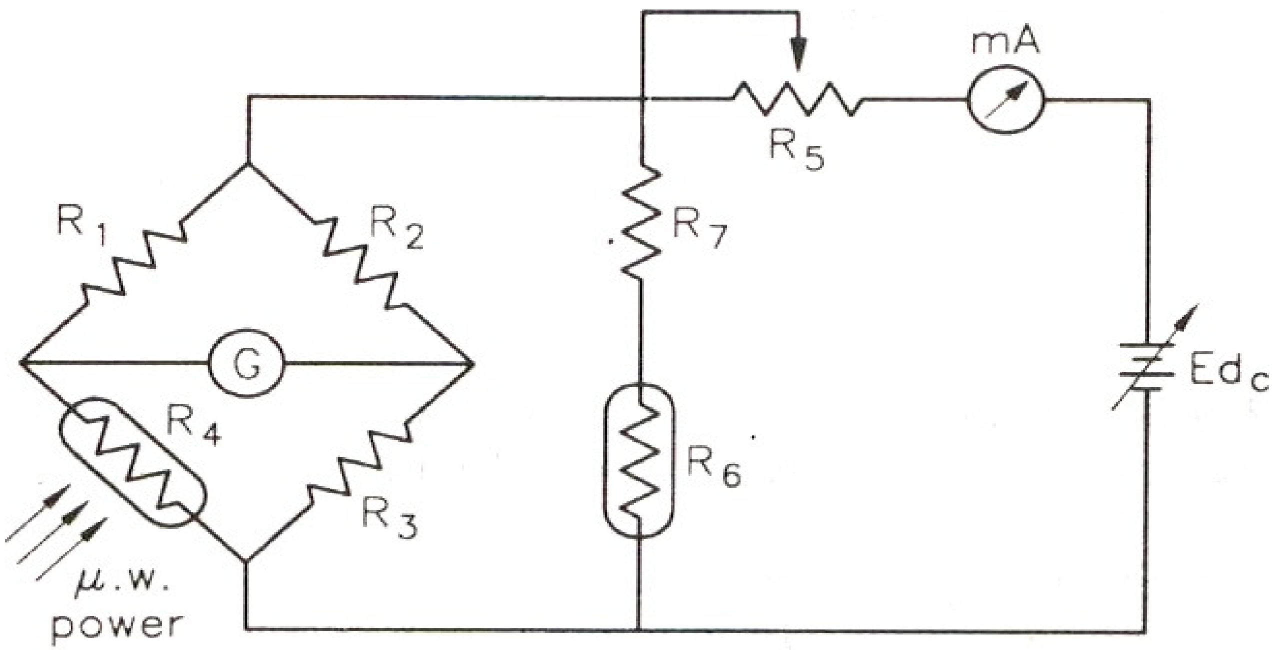
➢Measurement of Low Microwave Power

- Bolometer & thermocouples whose resistance changes with applied power are used measuring low microwave power.
- *Bolometer:* Simple temperature sensitive device whose resistance varies with temperature.
  - Barremeter and Thermistor.
- Barremeter have positive temperature coefficient & its resistance increases with increase in temperature.
- Consists of short platinum wire mounted in a cartridge like an ordinary fuse.



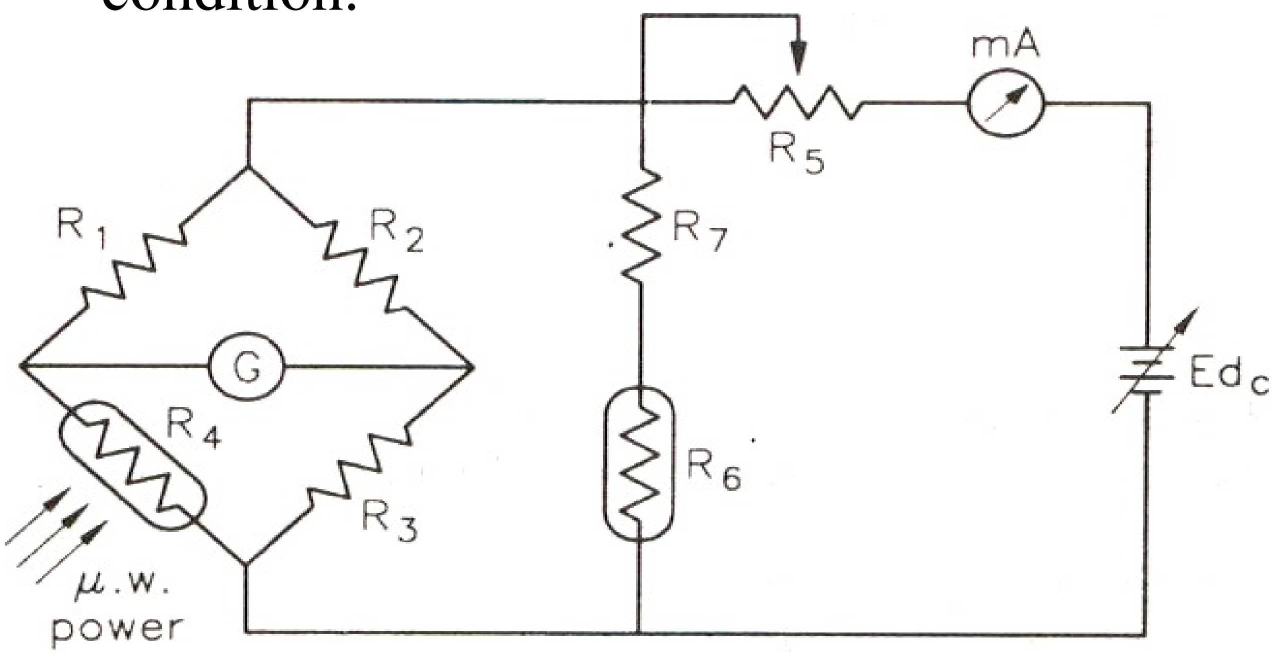
➢Balanced Bolometer Technique

- Bolometer is at one arm & initially bridge is balanced by adjusting R_5 which varies with DC power applied.
- Let E_1 be voltage of battery at balance, with microwave power applied bolometer heats up & changes its resistance. Hence bridge becomes unbalanced.
- New power E_2 is proportional to microwave power & detector 'G' can be directly calibrated in terms of microwave power.



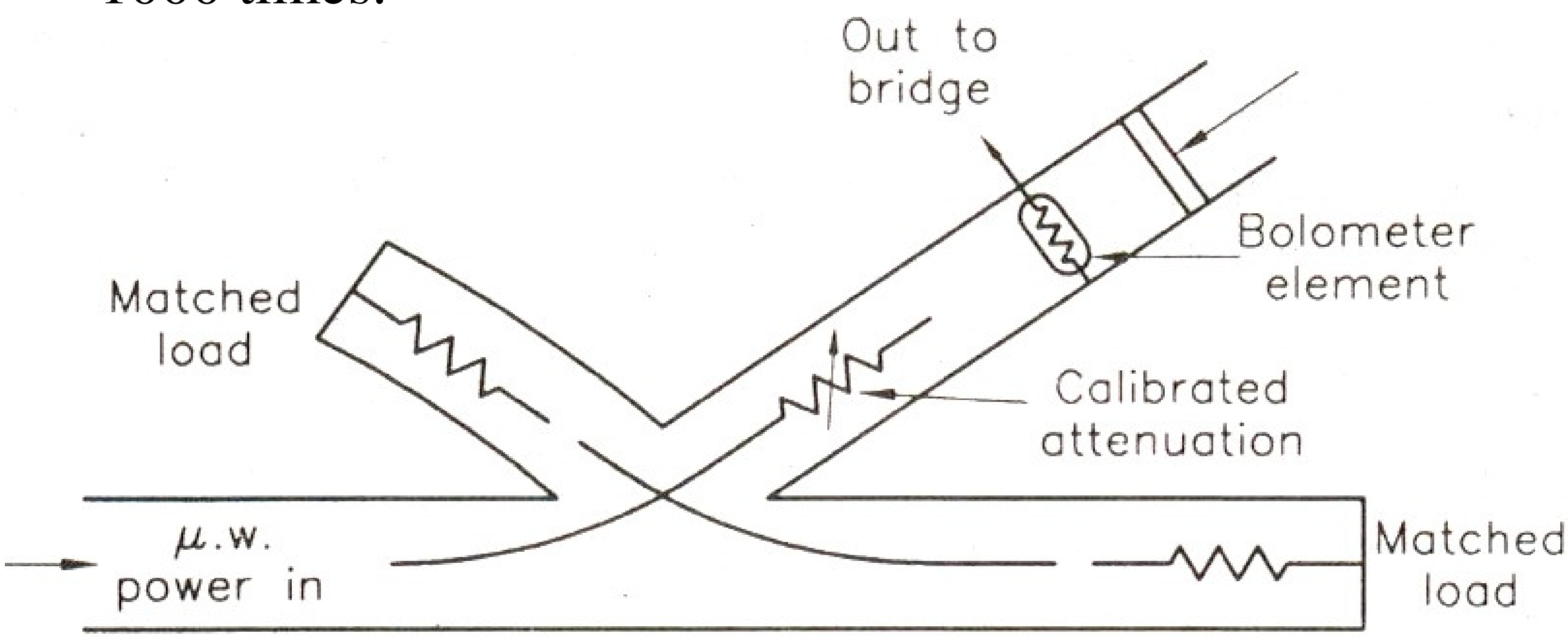
➢Balanced Bolometer Technique: Errors

- R_6 & R_7 are used for temperature compensation.
- R_6 & R_3 are identical and close to bolometer elements.
- If temp. is changed and R_3 is reduced then it will not be termed as microwave power change since R_6 will reduce.
- Thus more current will flow through R_6 and hence lesser amount through bridge and R_3 hence bridge will be restored for balanced condition.



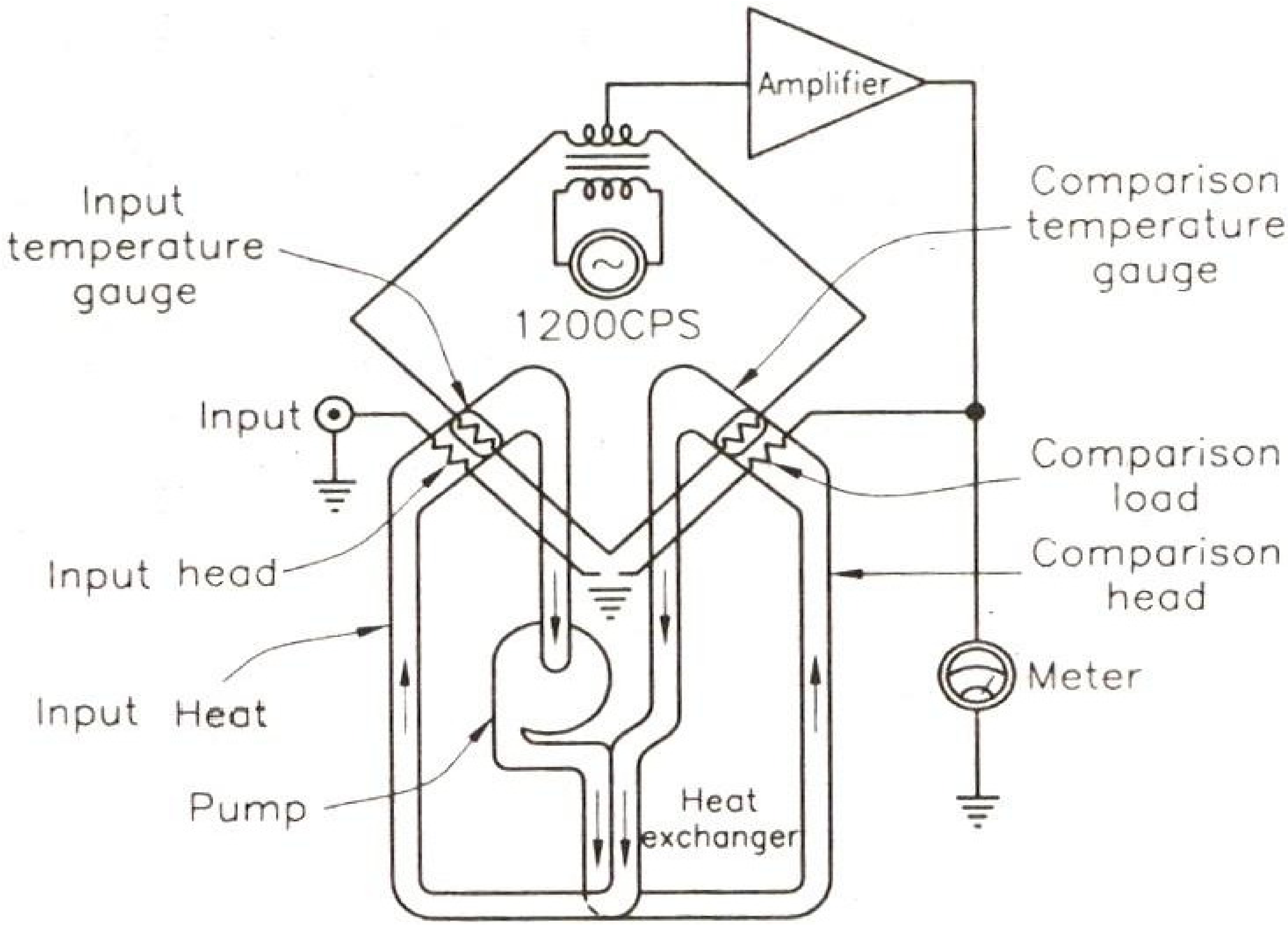
➢Balanced Bolometer Technique: Limitations

- Barremeter and Thermistor have limited power handling capability to 10 mW.
- Power measuring capability can be increased by using directional couplers.
- 20 dB directional coupler power + 10 dB attenuator power = 30 dB down power received by bolometer. This method extends its range by 1000 times.



➢Measurement of Medium Microwave Power: Calorimetric method

- Principle: Temp. rise in special load is monitored which is proportional to power responsible for its rise.



Calorimetric method : Working

- Water is used as a special load knowing its mass, specific heat and temp. rise and known rate of fluid flow the power can be measured.
- I/p load & I/p temp. gauge are closely placed so that temp. gauge will sense change in temp. making bridge unbalanced.
- Signal due to imbalance is then amplified & is given to comparison load resistor placed near to comparison gauge.
- Heat generated is transferred to comparison gauge making bridge rebalanced.

Calorimetric method : Characteristics

- For efficient and quick heat exchange components are immersed in oil.
- Power measurement accuracy is ± 5%.
- To maintain constant temp. streams are passed through parallel flow heat exchanger.
- 1200 Hz source and meter are separated by means of transformer.

➢Measurement of High Microwave Power : Calorimetric Watt Meter.

- Dry type or flow type.
- ***Dry type:*** Consists of coaxial cable filled with dielectric having high hysteresis loss.
- ***Flow type:*** Circulating water, oil or any liquid which is good absorber of microwaves.
- Fluid changes its temp. when it passes through load because of absorption of microwave power.
- Exact power is measured by using eq'n $P = \frac{RK\rho(T_2 - T_1)}{4.18}$

  where P = Power measured

  R = Rate of flow (cm^3/s) & (T_2-T_1) = Temp. diff. in ^0C

  K = Specific heat in cal/g & ρ = Specific gravity in g/cm^3

Attenuation Measurement

- Ratio of input power to output power expressed in dBs.

$$\text{Attenuation} = 10 \log \frac{P_{in}}{P_{out}}$$

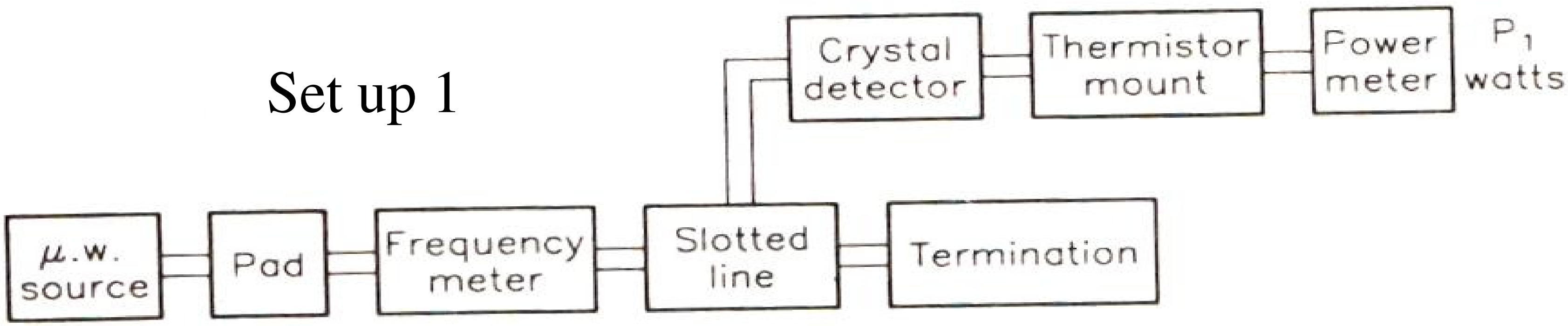
- The amount of attenuation can be measured by two methods:

1. Power ratio method.
2. RF substitution method.

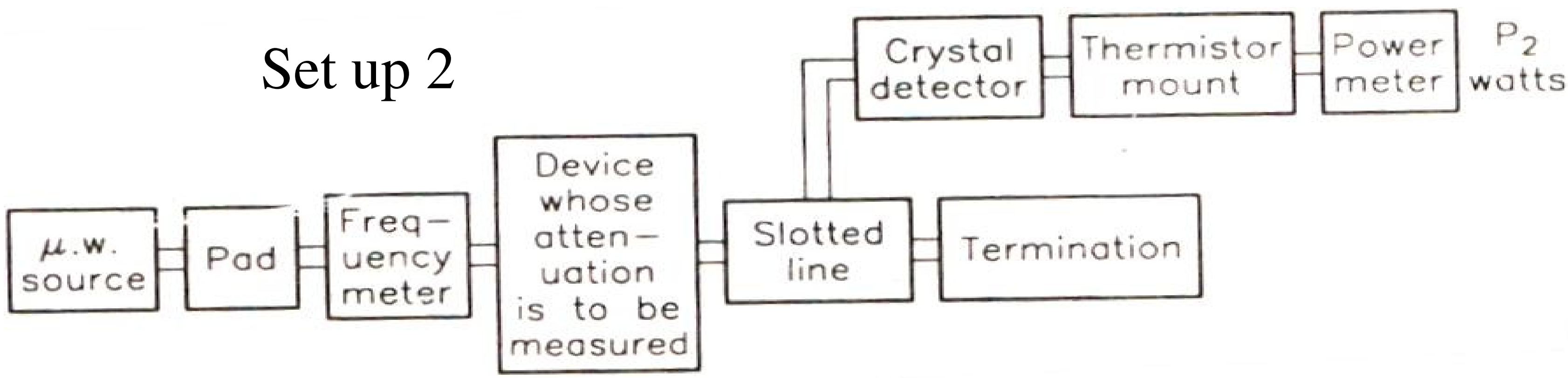
➢1. Power ratio method

- Measures the input power and output power with and without the device whose attenuation is to be measured.

Set up 1

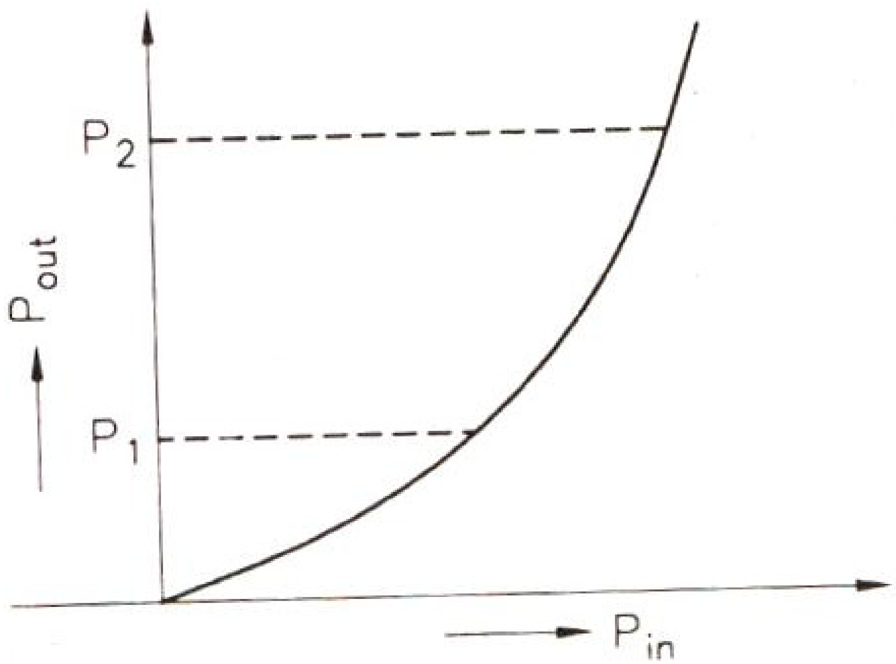


Set up 2



1. Power ratio method: Disadvantage

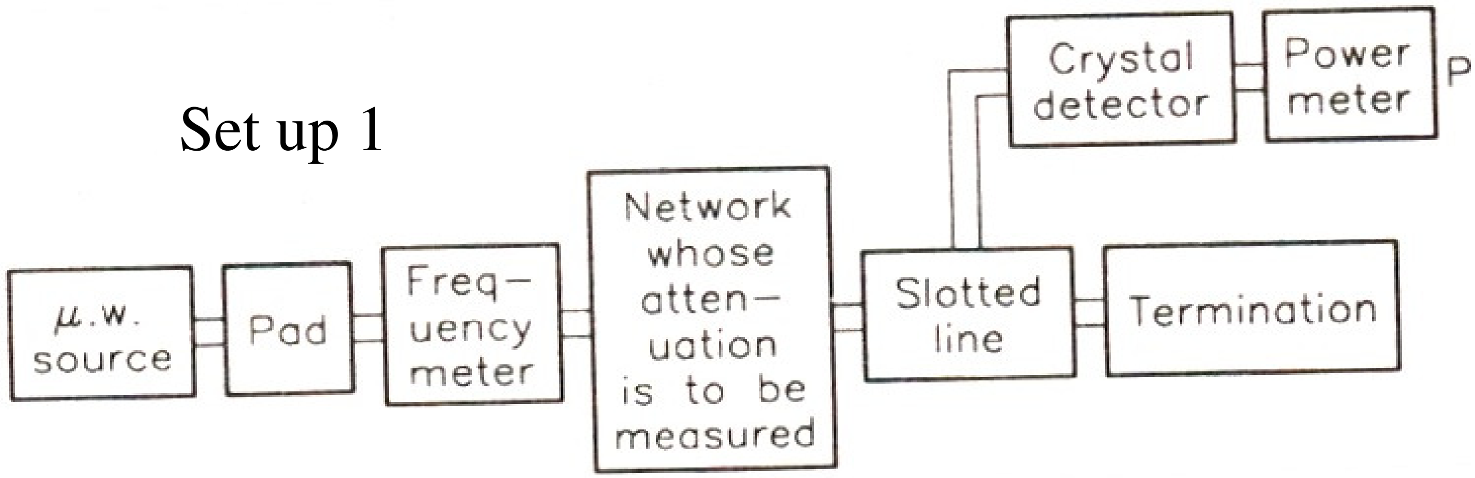
- Measured attenuation corresponds to two power positions on power meter with square law crystal detector chars.
- Results will not be accurate if attenuation of n/w is large and if input power is low.



➢2. RF Substitution Method

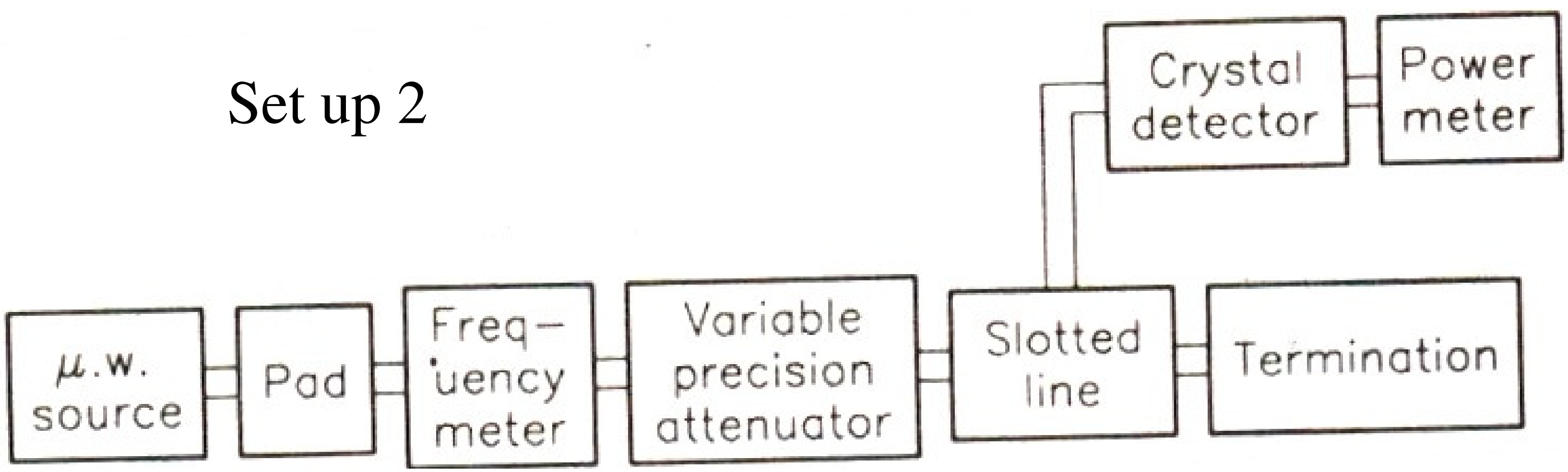
- Attenuation at single power position is measured.
- Set up 1: Includes network whose attenuation is to be measured.

Set up 1



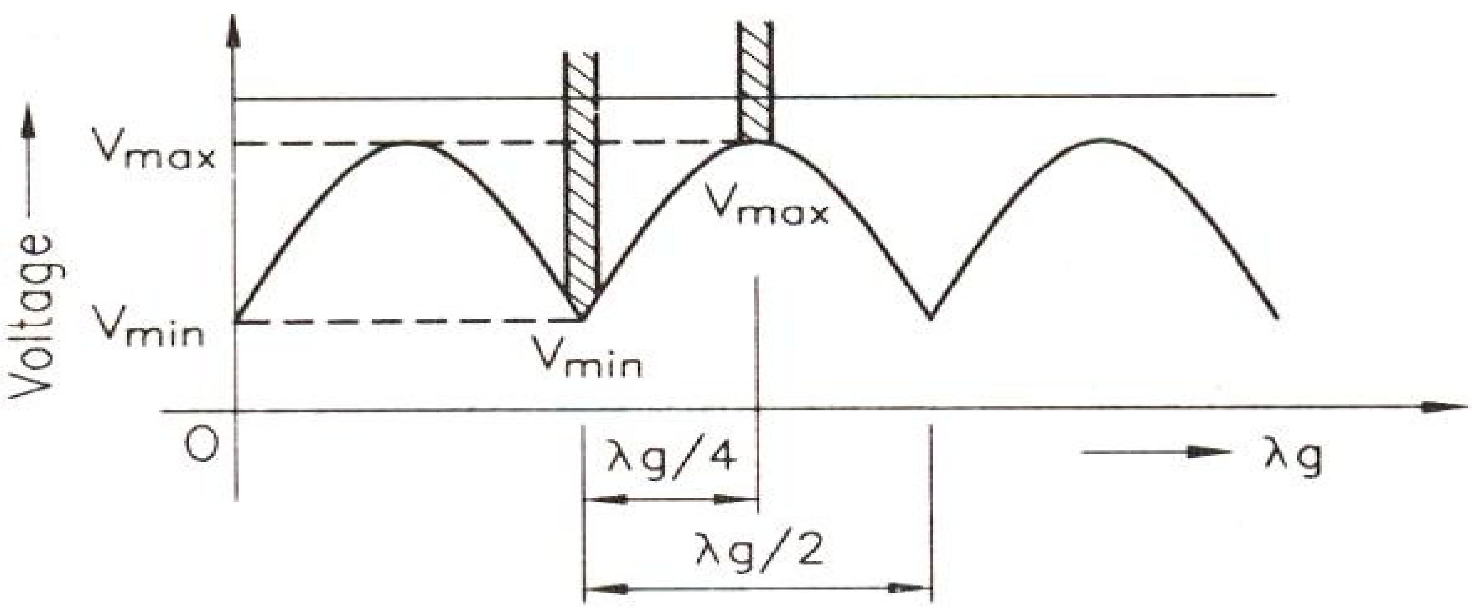
- Set up 2: Network is replaced by precision attenuator.

Set up 2



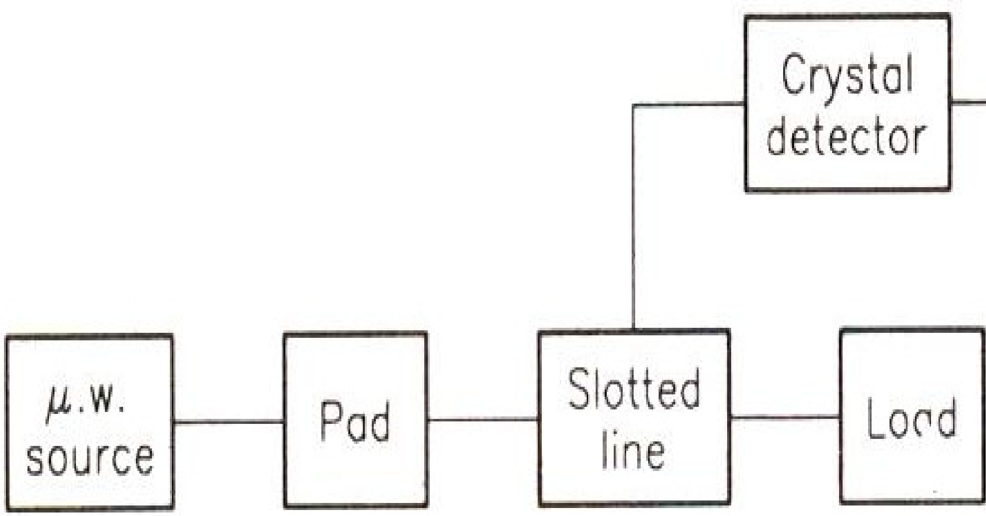
➢Measurement of VSWR

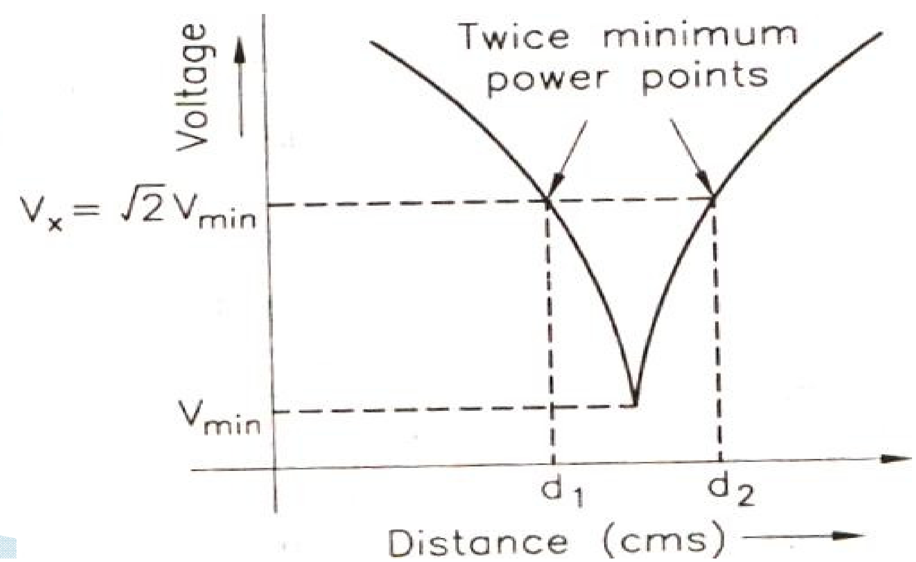
- Mismatched load, leads to reflected waves resulting in standing waves.
- Ratio of max. to min. voltage gives the VSWR. $S = \frac{V_{\max}}{V_{\min}} = \frac{1+\rho}{1-\rho}$
- Where ρ = reflection coefficient $= \frac{P_{reflcetd}}{P_{incident}}$
- S varied from 1 to ∞ as ρ varies from 0 to ∞



➢Measurement of Low VSWR (S < 10)

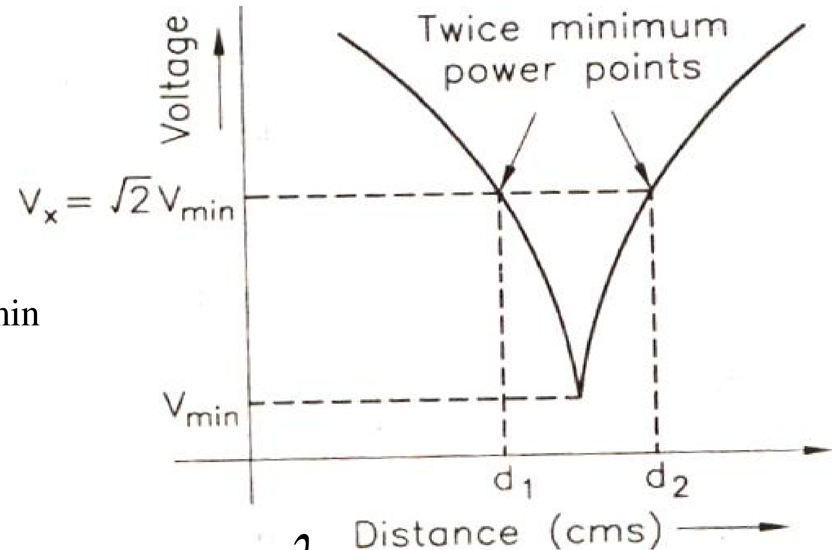
- Adjusting attenuator to give adequate reading on meter.
- Probe of slotted line is moved to get max. reading where attenuation is adjusted to get full meter reading & it is noted down.
- Then probe of slotted line is moved to get min. reading & ratio of max to min reading is taken.
- Full scale deflection corresponds to VSWR of 1.





➢Measurement of High VSWR (S > 10)

- *Double minimum method* is used.
- Probe is moved to a point where power is twice the min. and denoted by d_1.
- Probe is then again moved for twice the power point on other side of min. say d_2.



$$2P_{\min} \alpha V_x^2$$

$$\frac{1}{2} = \frac{V_{\min}^2}{V_x^2} \Rightarrow V_x^2 = 2.V_{\min}^2 \Rightarrow V_x = \sqrt{2}V_{\min}$$

$$\lambda_c = 2a \;\&\; \lambda_o = c/f$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{1-\left(\lambda_o/\lambda_c\right)^2}} \Rightarrow VSWR = \frac{\lambda_g}{\pi(d_2 - d_1)}$$

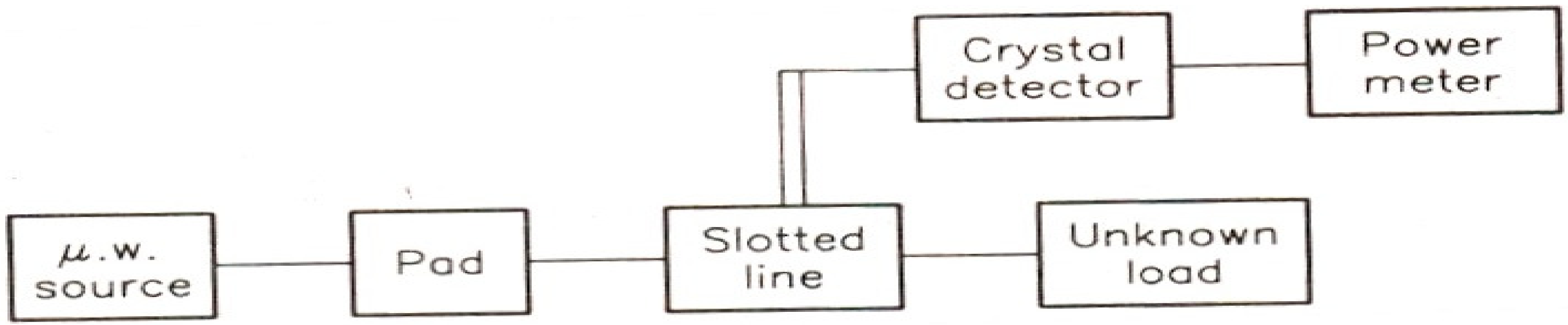
➢Measurement of Impedance

- It can be measured by using any of the following method:

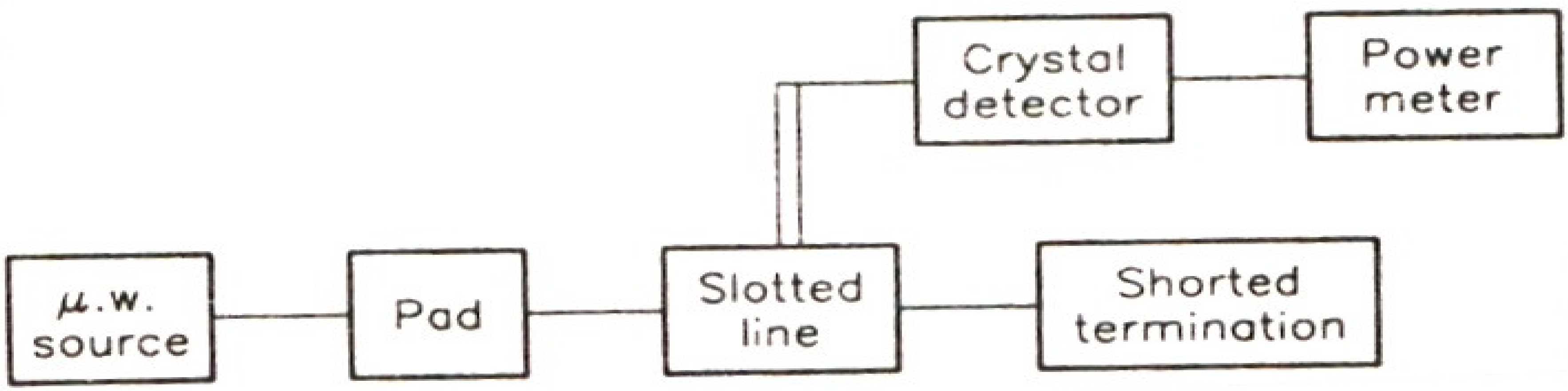
- Using magic T
- Using slotted line
- Using reflectometer

➢Measurement of Impedance using slotted line

- Incident and reflected waves are due to mismatch of load under test whose impedance is to be measured giving standing waves.
- Set up 1: With Z_L giving V_{max} and V_{min} is shown:

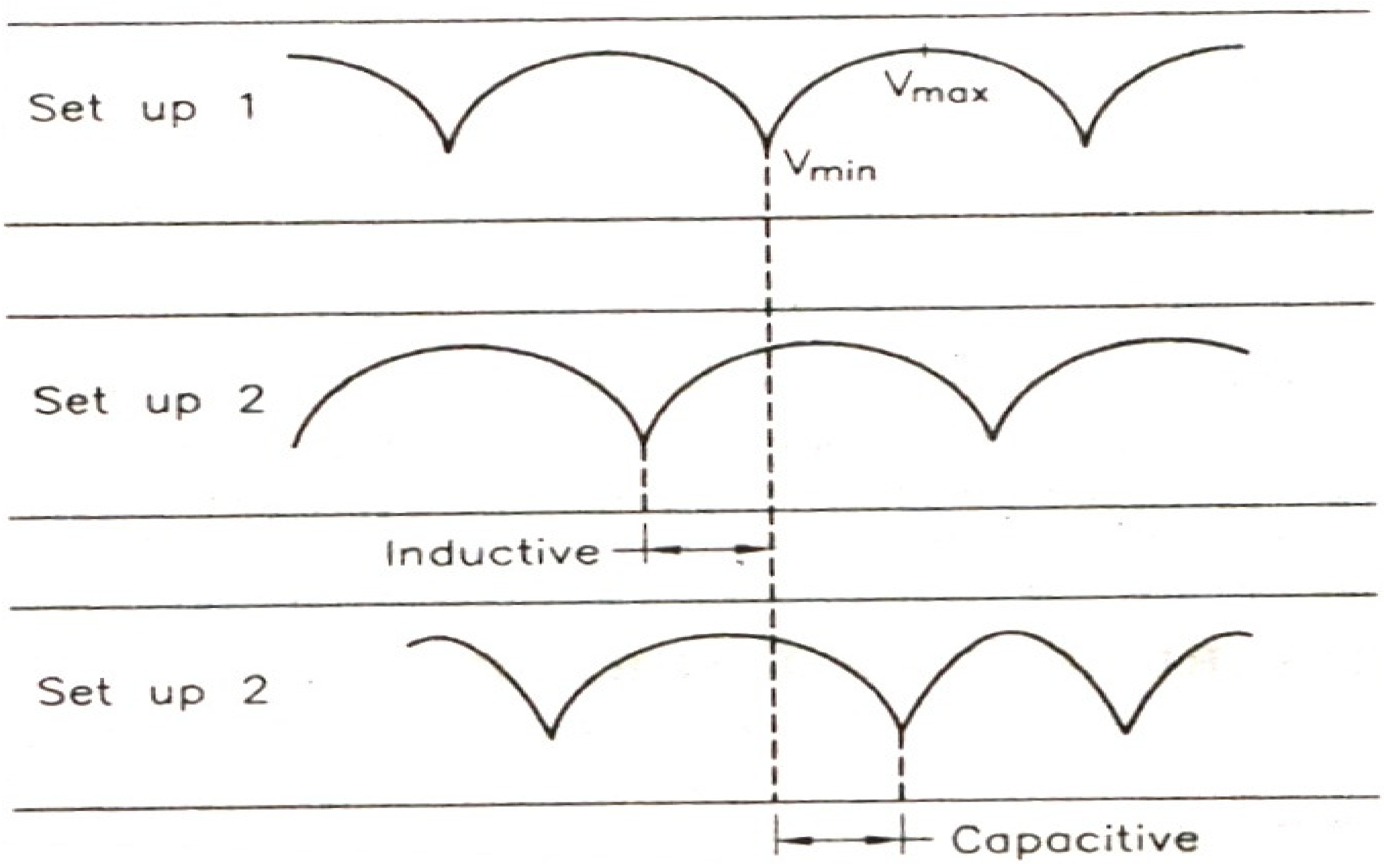


- Set up 2: Z_L is replaced & shift in V_{max} and V_{min} is measured.



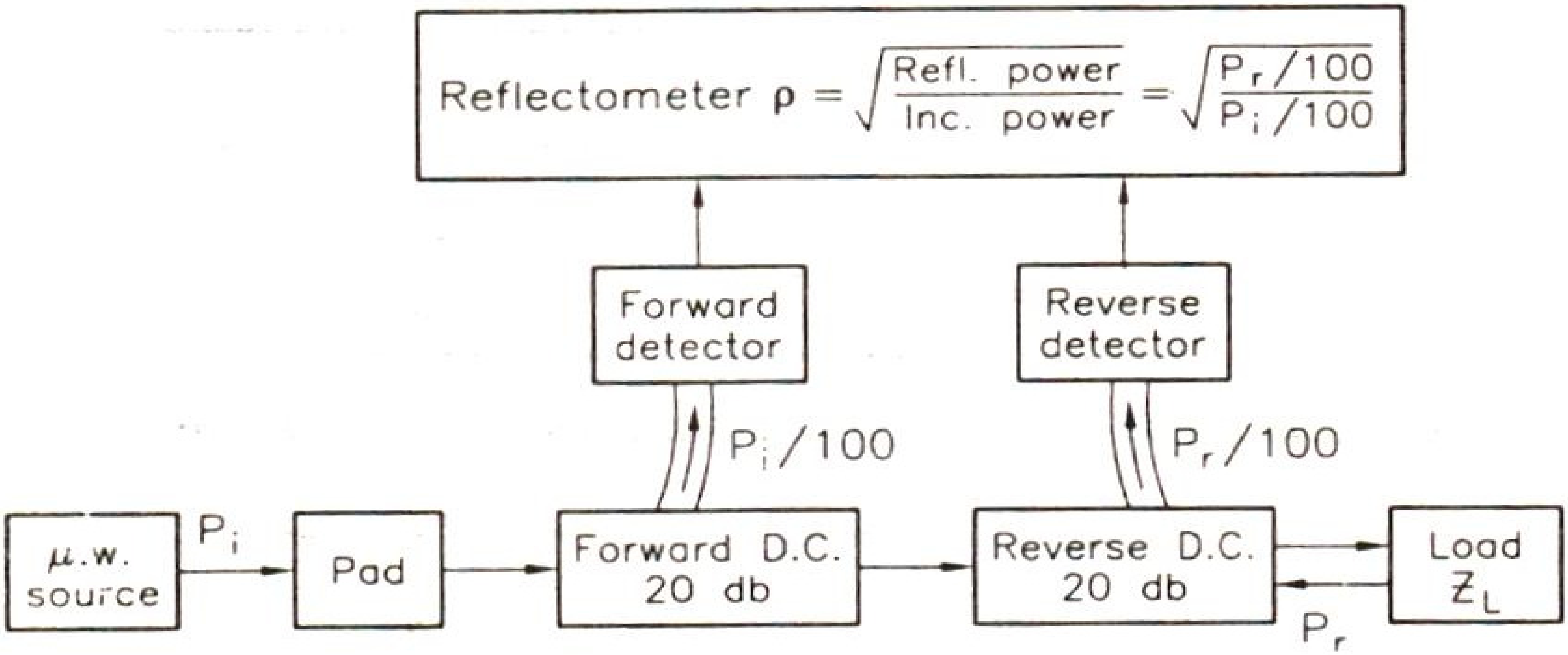
➢Measurement of Impedance using slotted line

- If minimum shifted to left then impedance is inductive.
- If minimum shifted to right then impedance is capacitive.
- Both impedance and reflection coefficient can be obtained in magnitude and phase.



➢Measurement of Impedance using reflectometer

- Gives only magnitude of impedance but not phase angle.
- Employs two directional couplers to sample Pi and Pr from load.



➢ Measurement of Impedance using reflectometer

- The magnitude of reflection coefficient is given from

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

- Knowing reflection coefficient VSWR and reflection coefficient can be calculated from

$$S = \frac{1+\rho}{1-\rho} \; \& \; \rho = \frac{z - z_g}{z + z_g}$$

- Where Z_g = Known impedance & Z = Unknown impedance.

- Due to directional coupler there will be no interference between forward and reverse waves.

➢Measurement of Insertion Loss

- Insertion Loss = Reflected power from device due to mismatch + Power attenuated.
- Reflected power is measured using reflectometer technique.
- Attenuated power is measured using RF substitution method hence insertion loss can be measured.

Measurement of Dielectric Constant

- EM property of non-magnetic material or medium is defined by its permeability (μ), conductivity (σ) & dielectric constant (ε).
- *Permeability (μ)* : Gives efficiency of transfer of magnetic force.
- *Conductivity (σ)* : Gives efficiency of transfer of electric charge.
- *Dielectric constant (ε)* : Gives efficiency of transfer of electric force.
- Complex dielectric constant is given by $\varepsilon = \varepsilon_0(\varepsilon' - j\varepsilon'')$

  ε = Dielectric constant in free space = $\varepsilon_r \varepsilon_0$

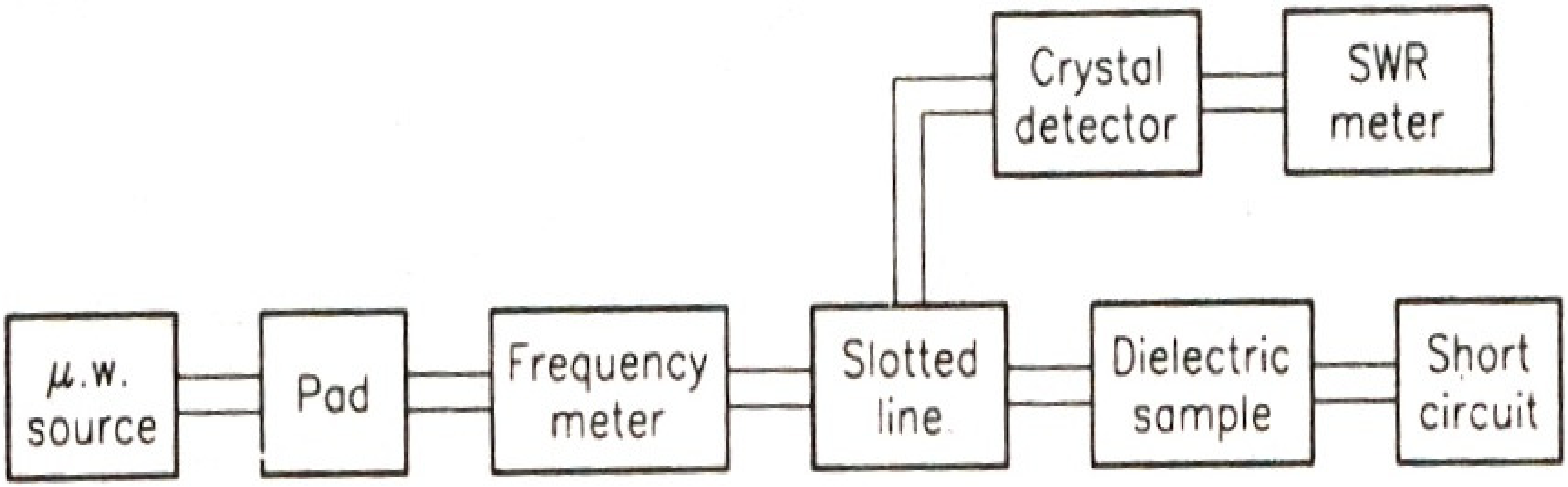
  ε' = Ability of dielectric to store energy &

  ε'' = Energy dissipation in medium.

Where ε_r = Relative permittivity $\varepsilon_r = \dfrac{\varepsilon}{\varepsilon_o} = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - j\tan\delta)$

➢Measurement of Dielectric Constant

- Loss tangent tan δ : Ratio of power dissipated to power stored/cycle i.e. it is a measure of energy lost in the form of heat.
- *Roberts and Von Hippel method* is employed.
- Shift in minima of standing wave produced by a short circuit when a dielectric sample is placed at its front.



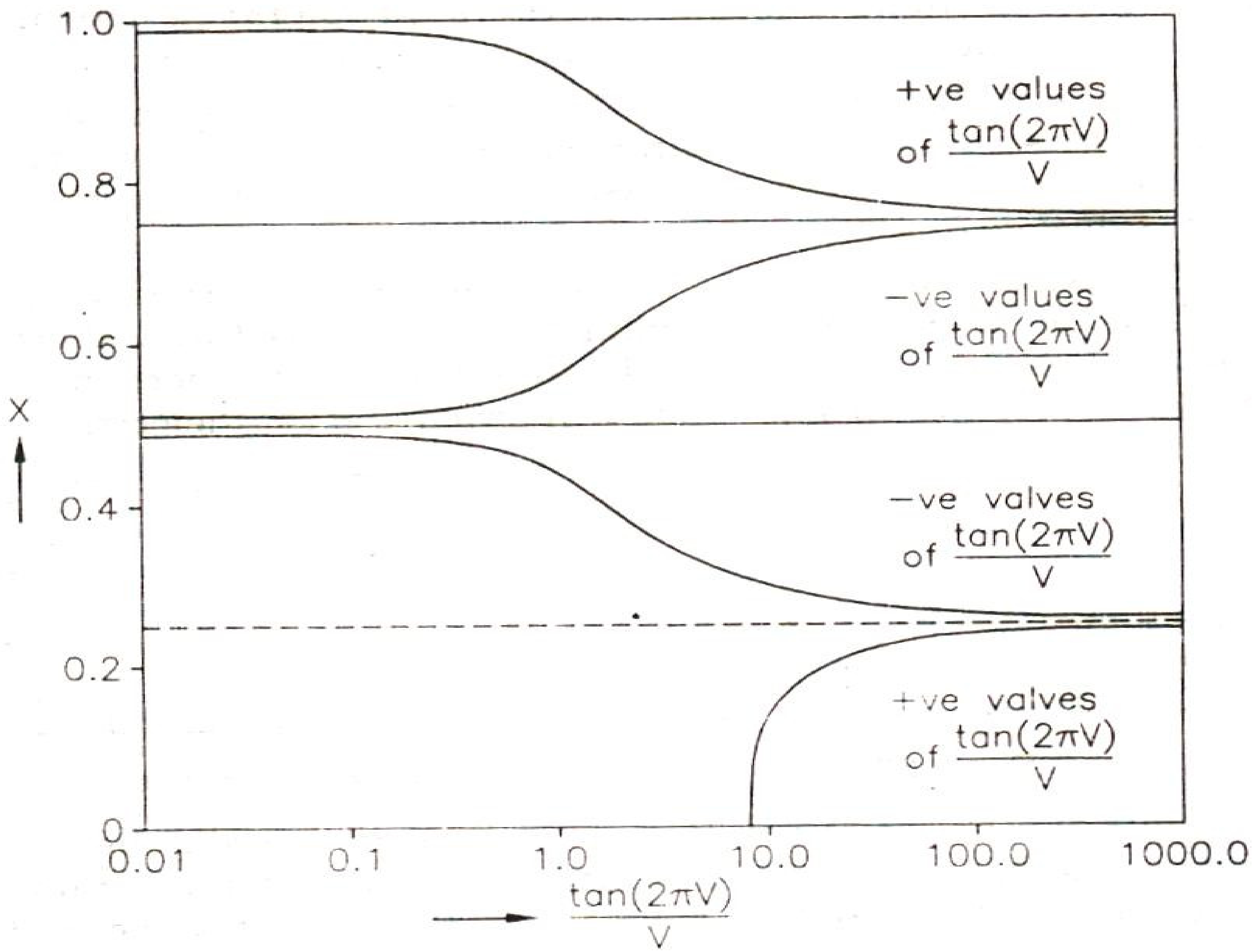
➢Measurement of Dielectric Constant

- Guide wavelength is measured using frequency meter & dielectric thickness is measured using micrometer accurately.
- Micrometer of short circuit is adjusted to read same value as thickness of dielectric.
- Exact position of two successive minima's are measured from SWR meter.
- Short circuit is removed and dielectric sample is then inserted into aperture of short circuit.
- Dielectric filled short circuit on SWR meter is then replaced & position of first minima from SWR meter is measured, which will give shift in minima.

$$X = \frac{\lambda_g}{d}\tan\left(\frac{2\pi(\Delta s + d)}{\lambda_g}\right)$$

➢Measurement of Dielectric Constant

- For calculating dielectric constant *Roberts and Von Hippel* developed a plot X vs V as shown in fig.



Measurement of Dielectric Constant

- Unknown quantity $X = \frac{\tan(2\pi V)}{V}$
- Where V = No. of wavelengths of microwave radiation in distance 'd' of dielectric filled guide.
- For X values value V are read from plot & Dielectric constant is measured from formula

$$\varepsilon_r = 1 - \left(\frac{\lambda_o}{\lambda_g}\right)^2 + \left(\frac{\lambda_o V}{d}\right)^2$$

- If ε_r is unknown repeat above procedure to get ε_{rs}, the average of these two will give dielectric constant.

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

- Ans:
- Given: f = 10GHz ;a = 4cm; b = 2.5cm
- For TE_{10} mode, $\lambda_C = 2a = 2x4 = 8cm$

$$\lambda_o = \frac{c}{f} \Rightarrow \frac{3\times10^{10}}{10\times10^{9}} = 3\,\text{cm} \Rightarrow \boxed{\lambda_o = 3\,\text{cm}}$$

- Also given d_2-d_1 = 1 mm

- We know $\lambda_g = \dfrac{\lambda_o}{\sqrt{1-\left(\lambda_o/\lambda_c\right)^2}} \Rightarrow \lambda_g = \dfrac{3}{\sqrt{1-\left(3/8\right)^2}} \Rightarrow \boxed{\lambda_g = 3.236\,\text{cm}}$

1.

- Ans:
- For double minimum method VSWR is given by;
- $$VSWR = \frac{\lambda_g}{\pi(d_2 - d_1)}$$

$$VSWR = \frac{3.236}{\pi(1 \times 10^{-1})}$$

$$\boxed{VSWR = 10.3}$$

2.You have two directional couplers (20 dB) in a guide to sample the incident and reflected powers. The outputs of the two couplers are 3 mW and 0.1 mW respectively. What is the value of VSWR in, the main waveguide? What is the value of reflected power.

- Ans:
- Given: $\frac{P_i}{100} = 3\,\text{mW} \Rightarrow P_i = 3 \times 100\,\text{mW} \Rightarrow \boxed{P_i = 300\,\text{mW}}$

$$\frac{P_r}{100} = 0.1\,\text{mW} \Rightarrow P_r = 0.1 \times 100\,\text{mW} \Rightarrow \boxed{P_r = 10\,\text{mW}}$$

- Reflection coefficient

$$\rho = \sqrt{\frac{P_r}{P_i}} \Rightarrow \rho = \sqrt{\frac{10}{300}} \Rightarrow \rho = \sqrt{0.033} \Rightarrow \boxed{\rho = 0.1816}$$

- VSWRs $= \frac{1+\rho}{1-\rho} = \frac{1+0.1816}{1-0.1816} \Rightarrow \boxed{VSWRs = 1.44}$

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

- Ans:
- We know that,
- Reflection coefficient $\rho = \sqrt{\dfrac{P_r}{P_i}}$

$$\Rightarrow \rho = \sqrt{\frac{0.15}{2.5}}$$

$$\Rightarrow \rho = \sqrt{0.06} \qquad \Rightarrow \boxed{\rho = 0.244}$$

- Now VSWR $= \dfrac{1+\rho}{1-\rho} = \dfrac{1+0.244}{1-0.244} \Rightarrow \boxed{VSWRs = 1.64}$

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

- Ans:
- We know that,
- Now VSWR $= \dfrac{1+\rho}{1-\rho} = 2 \Rightarrow (1+\rho) = 2(1-\rho)$

$$\Rightarrow (1+\rho) = 2 - 2\rho$$

$$\Rightarrow 3\rho = 1 \quad \text{Hence } \boxed{\rho = 0.333}$$

- Now Coupling Factor $C = 10\log\dfrac{P_i}{P_f} = 30$

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

4.

- Given $\frac{P_i}{10^3} = 4.5mW$ or $P_i = 4.5W$
- Reflection coefficient $\rho = \sqrt{\frac{P_r / 10^3}{P_i / 10^3}}$

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

$$\Rightarrow \rho^2 = \frac{P_r}{P_i}$$

$$\Rightarrow P_r = \rho^2 \times P_i$$

$$\Rightarrow P_r = (0.333)^2 \times 4.5 = 0.499W$$

$$\Rightarrow \boxed{P_r \cong 0.5\,W}$$

Wish You Good Luck…

Refer:

1. ***Microwave and Radar Engineering by M. Kulkarni***
2. ***Microwave Engineering by Annapurna Das***