20ECD21

Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

July/August, 2023 | **Electronics & Communication Engineering**

Sixth Semester | **Microwave Engineering**

Time: Three Hours | **Maximum:** 70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**

Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	M
1	a)	What are the resonators used in microwave cavities?	CO1	L1	1M
	b)	What are the two types of waveguide tees used in microwave hybrid circuits?	CO1	L1	1M
	c)	What is the significance of scattering (S) parameters?	CO1	L2	1M
	d)	List the applications of directional couplers.	CO1	L1	1M
	e)	Write the applications of a TRAPATT diode.	CO2	L1	1M
	f)	List the characteristic of pin diodes	CO2	L1	1M
	g)	Write two modes of operation of a GUNN diode.	CO2	L1	1M
	h)	Define velocity modulation.	CO3	L1	1M
	i)	What is the primary operating principle of magnetron oscillators?	CO3	L2	1M
	j)	Explain the main amplification process in helix-traveling wave tubes.	CO3	L2	1M
	k)	Write the two main processes involved in velocity modulation in klystrons.	CO3	L1	1M
	l)	What is the primary method used for microwave frequency measurement?	CO4	L1	1M
	m)	What is the operation principle of a Thermistor?	CO4	L2	1M
	n)	Which is the common instrument used for scattering coefficient measurements?	CO4	L1	1M
		Unit-I			
2	a)	Demonstrate the working principle of a magic tee and its applications.	CO1	L2	7M
	b)	Explain the applications of circulators and isolators in microwave systems.	CO1	L1	7M
		(OR)			
3	a)	Demonstrate the working principle of waveguide corners, bends, and twists in microwave circuits.	CO1	L2	7M
	b)	Develop the scattering matrix equations for an H-plane tee.	CO1	L3	7M
		Unit-II			
4	a)	Explain the principle of operation of a microwave tunnel diode and discuss its advantages and limitations.	CO2	L2	7M
	b)	Illustrate the concept of varactor diodes and their applications in microwave circuits, particularly in frequency tuning and modulation.	CO2	L2	7M
		(OR)			
5	a)	With the help of two valley theory, explain how negative resistance can be created in the GUNN diode.	CO2	L2	7M
	b)	Compare the operation of IMPATT diodes and TRAPATT diodes in microwave circuits.	CO2	L4	7M
		Unit-III			
6	a)	Explain the principle of operation of a reflex klystron, focusing on the velocity modulation process and the role of resonant cavities in generating a high-power output.	CO3	L2	7M
	b)	Develop the Hull cut-off voltage equation for magnetron oscillators and explain its significance in achieving sustained oscillations.	CO3	L3	7M
		(OR)			
7	a)	Explain the concept of beam loading in klystrons and its effect on the output power and efficiency of the device.	CO3	L2	7M
	b)	Demonstrate the separation of the π mode in magnetron oscillators.	CO3	L2	7M
		Unit-IV			
8	a)	Explain the components typically found in a microwave bench setup, explaining the function and importance of each component in microwave measurements.	CO4	L2	7M
	b)	Explain the VSWR (Voltage Standing Wave Ratio) measurement technique and its significance in microwave measurements.	CO4	L3	7M
		(OR)			
9	a)	Explain the methods and instruments used for frequency measurement in microwave circuits.	CO4	L2	7M
	b)	Explain the techniques and methods used for impedance matching in microwave circuits.	CO4	L2	7M

I One mark questions (1*12=12)

a. Resonators used in microwave cavities are rectangular and circular.

b. E-plane Tee and H-plane Tee

c. Short and open circuits are difficult to achieve over a broad band of frequencies.So S parameters gained importance at higher frequencies

d. SWR measurements, power monitoring and source leveling , unidirectional power measurements

e. They are used in low-power Doppler radars, microwave beacon landing systems, phased array radars, and so on.

f. Low Capacitance, High breakdown voltage, Sensitive to photodetection,Charge carriers storage.

g.Gunn oscillation mode, Stable amplification mode, LSA oscillation mode, Bias-circuit oscillation mode(Any two)

h.The variation of electron velocity in drift space is known as ***velocity modulation***

i.The electric field and magnetic fields perpendicular to each other,the electron motion depends on both electric field and magnetic field

j.slow wave circuits are designed for producing large gain over a wide bandwidth.

k.Bunching process and Current modulation

l.Slotted line technique.

m.Thermistors have negative temperature coefficient of resistance and their resistance decrease with temperature.

n.Network Analyser

Unit I

2a) Diagrams,Explanation(3M+3M)

A magic tee is a combination of E-plane Tee and H-plane Tee. The magic tee has following characteristics.

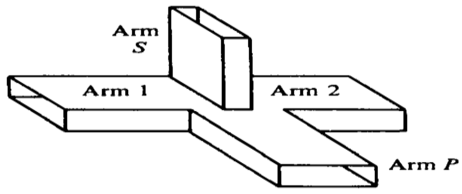
If two waves of equal magnitude and the same phase are fed into port 1 and port 2, the output will be zero at port 3 and additive at port 4.

If a wave is fed into port 4 (H arm), it will be divided equally between port 1 and port 2 of the collinear arms and will not appear at port 3 (E arm).

If a wave is fed into port 3 (E arm), it will produce an output of equal magnitude and opposite phase at port 1 and port 2. Output at port 4 is zero i.e $S_{43} = S_{34} = 0$.

If a wave is fed into one of the collinear arms at port 1 or port 2, it will not appear in the other collinear arm at port 2 or port 1 because the E arm causes a phase delay while the H arm causes the phase advance. i.e $S_{12} = S_{21} = 0$.

Applications: As an isolator, matching device, phase shifter, duplexer, and mixer, in measurement of impedance



(c) Magic tee

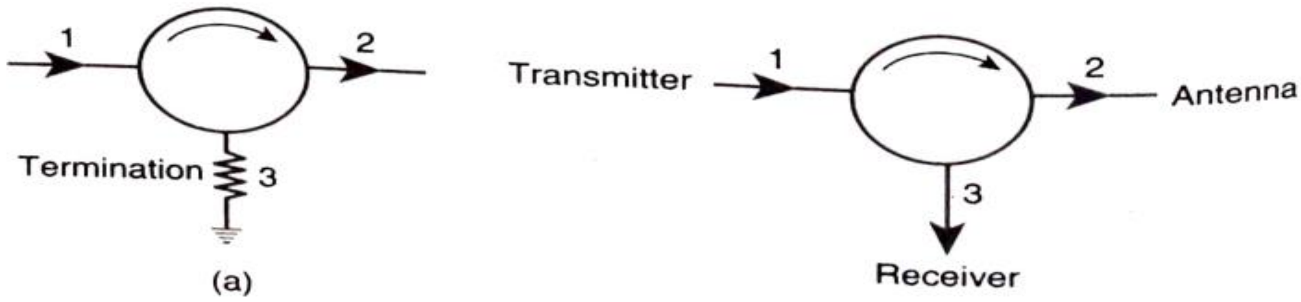
Measurement of Impedance Port 1:Known Impedance,Port 2:Unknown Impedance Port 3:Microwave source Port 4: Null detector

Duplexer: Port 1:Receiver Port 2:Transmitter 3: local Oscillator Port 4: Antenna

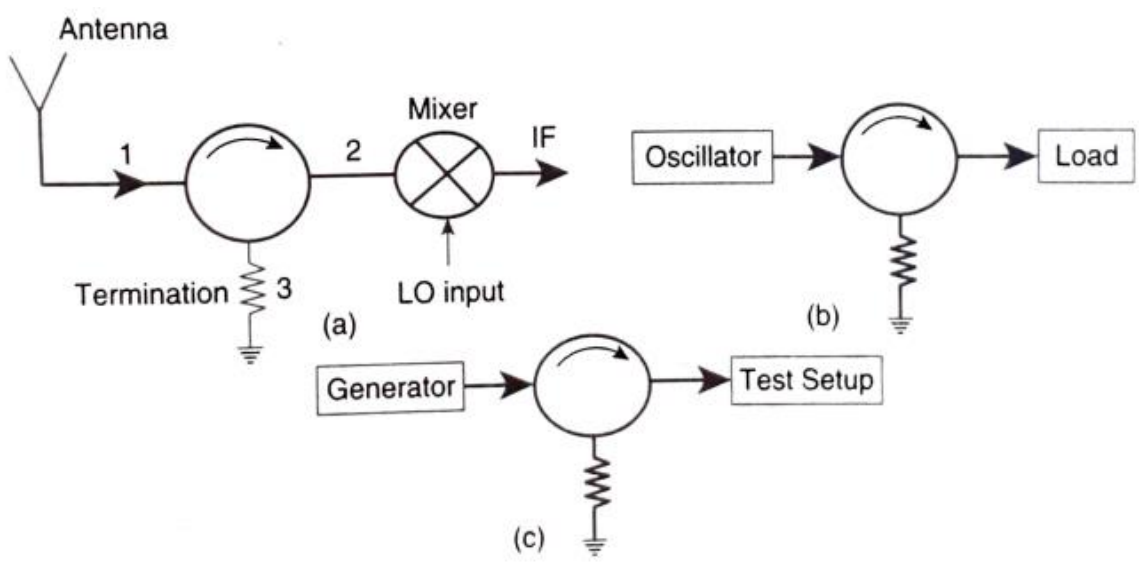
Duplexer: Port 1:Receiver Port 2:Matched Load Port 3: local Oscillator Port 4: Antenna

2b) Applications-7M

Circulator used as a two-port isolator, In this case, power flows from port 1 to port 2, while port 3 is terminated with the characteristic impedance. circulator used as a duplexer connect a receiver and a transmitter to a common antenna.



Applications of Isolator: To supply a constant load to an oscillator circuit,for testing

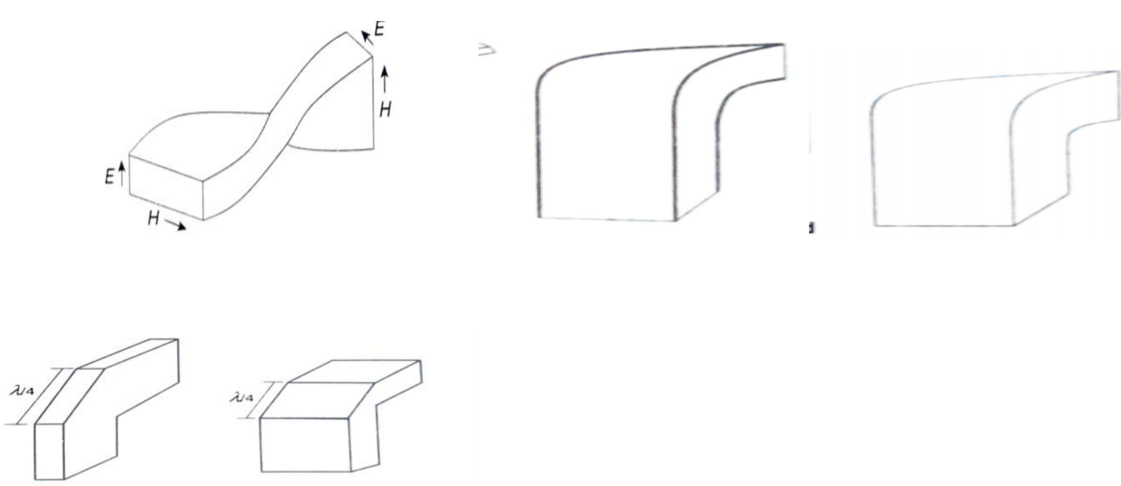


(OR)

3a) Diagrams-4M,Explanation-3M

Bends can be made in waveguides several ways that they do not cause reflections. A bend can be in either the narrow or wide dimension of the waveguide without changing the mode of operation.

Waveguide bends are of 3 types. They are twisted, gradual, and sharp bends.



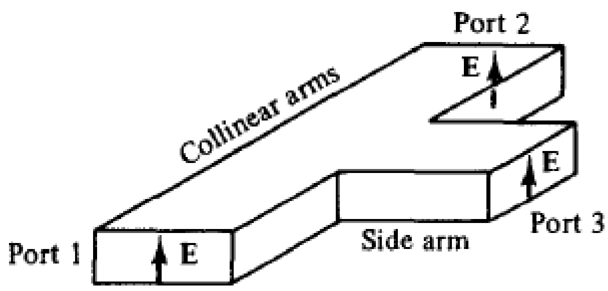
There are three basic types of waveguide joints. They are permanent, semi-permanent, rotating joints. Permanent joint is a factory-welded joint for which maintenance is not required.

Semi-permanent: The operation of choke joint is similar to an RF choke in a power supply. The choke joint keeps electromagnetic energy in the waveguide and the RF choke keeps RF energy in the circuit.

A rotating joint should be used whenever a stationary rectangular waveguide running from the transmitter is connected to a rotating antenna. A circular waveguide is generally used in a rotating joint.

3b)Derivation-(7M)

H-plane tee (shunt tee): An H-plane tee is a waveguide tee in which the axis of its side arm is "shunting" the *E* field or parallel to the *H* field of the main guide as shown below



Characteristics of H-plane Tee:

If the H plane junction is completely symmetrical and waves enter through side arm, the waves that leave through collinear ports are equal in magnitude and phase

Therefore $S_{13} = S_{23}$

S matrix is of order 3X3

$$[s] = \begin{matrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{matrix}$$

Because of plane of symmetry of the junction $S_{13} = S_{23}$

If port 3 is perfectly matched, $S_{33} = 0$

From symmetry property, $S_{ij} = S_{ji}$

$S_{12} = S_{21}$,$S_{13} = S_{31}$, $S_{23} = S_{32} = S_{13}$

With all above properties [S] becomes,

$$[s] = \begin{matrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{matrix}$$

From unitary property $[s][s]^* = [U]$

$$\begin{matrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{matrix} * \begin{matrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & S_{13}^* \\ S_{13}^* & S_{13}^* & 0 \end{matrix} = \begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$

R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1$

R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1$

R_3C_1: $S_{13}S_{11}^* + S_{13}S_{12}^* = 0$

$S_{11} = S_{22}$; $S_{13} = \frac{1}{\sqrt{2}}$;

$S_{13}(S_{11}^* + S_{12}^*) = 0$;$S_{13} \neq 0$;

$S_{11}^* = -S_{12}^*$

$S_{12} = -S_{11}$

$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} = 1$;$S_{11} = \frac{1}{2}$ $S_{12} = \frac{-1}{2}$ $S_{22} = \frac{1}{2}$

$$[S] = \begin{bmatrix} \frac{1}{2} & \frac{-1}{2} & \frac{1}{\sqrt{2}} \\ \frac{-1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

UNIT II

4a) **Diagrams-4M, Explanation-3M**

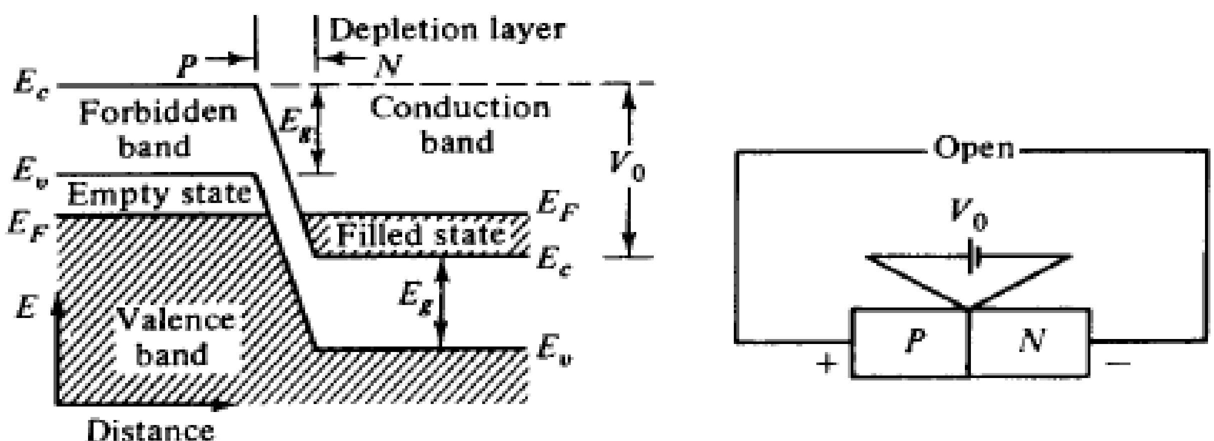
The tunnel diode is a negative resistance semiconductor p-n junction diode. According to quantum mechanics, if the barrier is thin, then there is a finite probability that electrons can tunnel through the potential barrier even though if they do not have enough kinetic energy to cross over the same barrier. There must be empty energy states on the other side of electrons which are tunneling.

Principle of Operation:

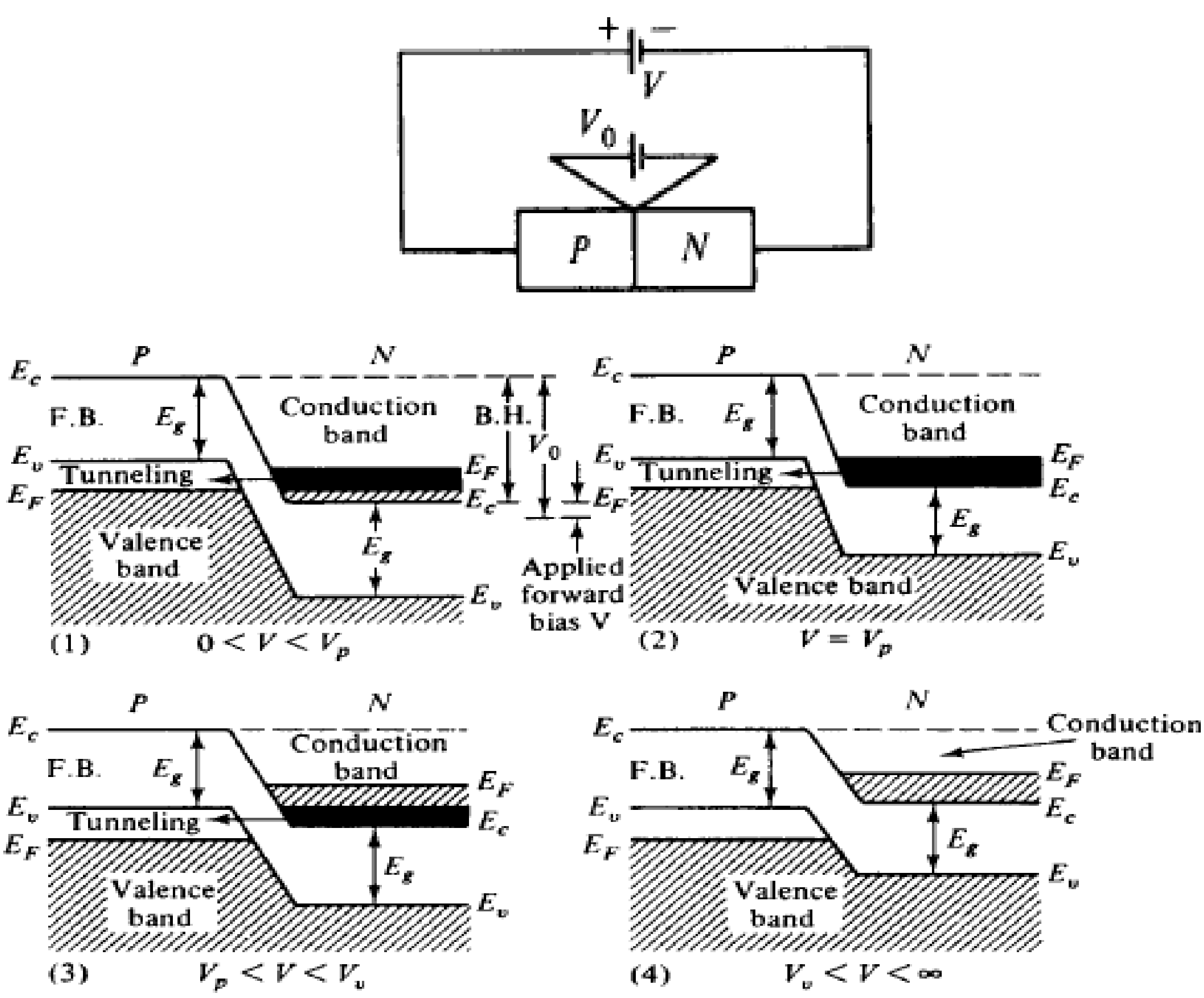
The operation of microwave tunnel diode can be understood with the help of energy band diagram.

Under Zero bias:

- The upper levels of electron energy of both p-type and n-type are at the same level i.e. Fermi level.
- The current is zero as there is no flow of charge carriers in either direction as shown in figure (a).



(a) Tunnel diode under zero-bias equilibrium



(b) Tunnel diode with applied forward bias

For applied voltage V(0<V<V_P):

- The potential barrier is decreased by the amount of forward bias voltage as shown in above figure.
- Due to applied forward bias voltage a difference in Fermi levels in both is created and there is filled states in the conduction band of the n-type are at the same energy level as the allowed empty states in the valance band.
- The electrons tunnel through the barrier from n-type to p-type giving rise to forward tunneling current as shown in figure above.

At V= V_P(peak voltage):

At applied forward voltage V equal to peak voltage V_p, maximum tunneling occurs as shown in figure (b)2 and corresponding peak current I_p

For V_P<V<V_V(Negative Resistive Region):

For the applied forward voltage between peak and valley voltage, the tunneling decreases.

For Large Forward voltage(V_V<V<∞):

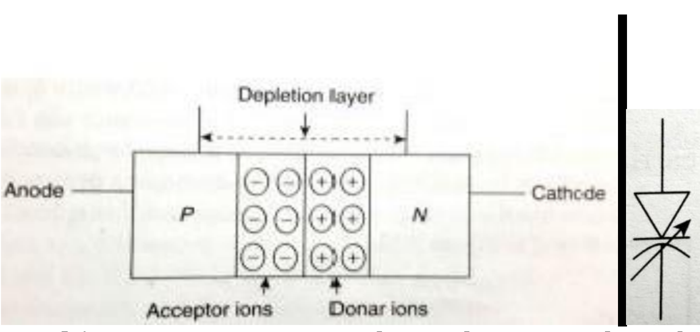
Since there are no allowed empty states in p-type at the same energy level as filled states in the n-type, no electrons can tunnel through the barrier and the tunneling current drops to zero.

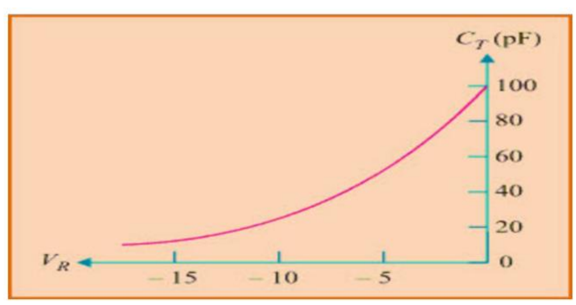
When forward voltage is increased above the valley voltage V_v, the ordinary injection current I at the p-n junction starts to flow. The total current given by the sum of tunneling current and the injection current results in V-I characteristics shown below.

The total current reaches a minimum value I_V(valley current) where the tunnel diode charecteristic meets the ordinary diode characteristic.

4a) **Diagrams-3M, Explanation-4M**

A varactor diode is a variable capacitor junction diode. These two terminal devices also called as varicaps. This is a special type of PN junction that is designed to operate in a microwave range. It works on the principle of voltage variable nature of the depletion capacitance.





Characteristics of Varactor Diode

Working: In a PN junction, due to density gradient, holes diffuse N side and Electrons diffuse P side. This causes a few ions on either side of the junction to be depleted of mobile charges. This region is known as depletion region or space charge region.
If forward bias is applied, the carriers move toward the junction which reduces the depletion width.
If reverse bias is applied, the carriers move away from the junction: as a result the depletion width increases.
The variation of width with voltage may be considered a capacitive effect with the depletion region as the dielectric, and P and N region as parallel plates. This capacitance is known as transition capacitance or junction capacitance.

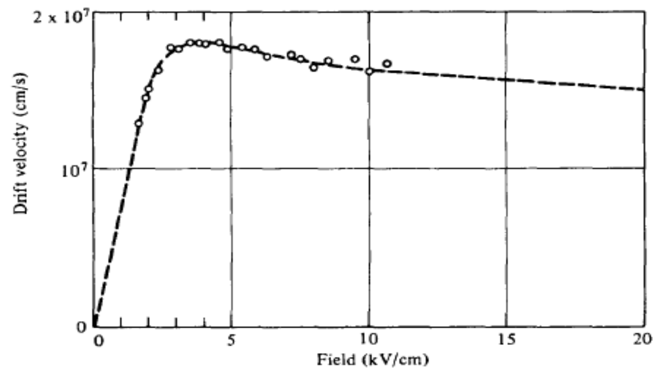
$$C_j = \frac{\varepsilon_s A}{W}$$

In the FM modulator, the output frequency changes depending on the modulation voltage of the Varactor diode. The varactor functions as a voltage condition capacitor whose desired frequency is selected by changing the age of the preload voltage on the varactor. By applying a reverse voltage, the electrostatic capacitance of the PN junction is changed. Therefore, it is used for automatic frequency control, sweep oscillation, frequency modulation, and tuning

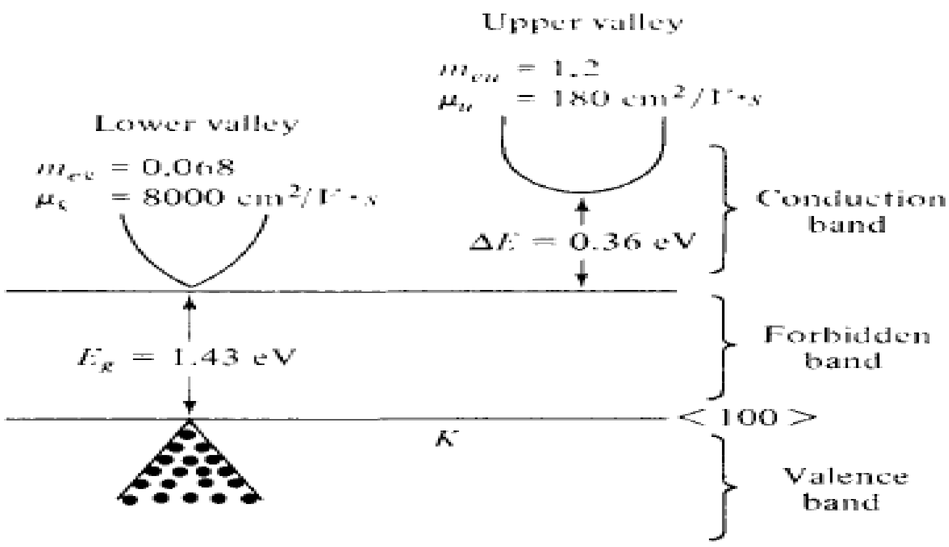
(OR)

5 a) **Gunn Effect**:

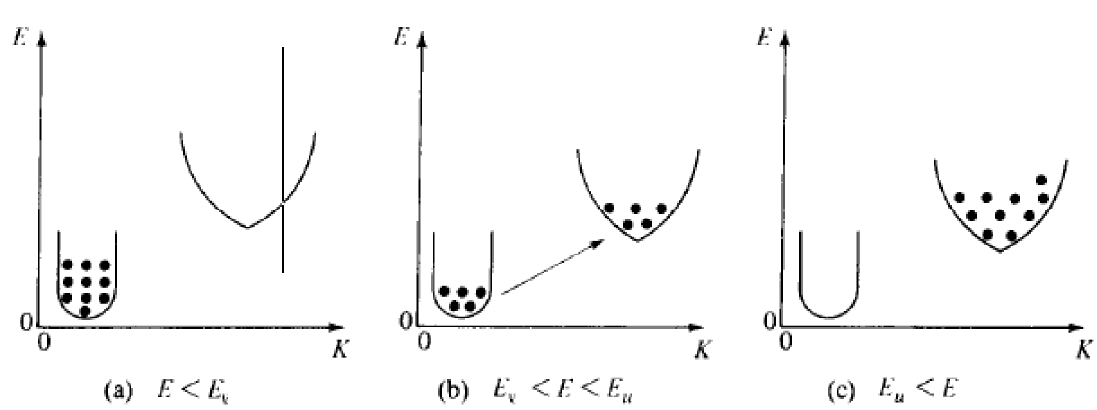
In some semiconductor materials, such as gallium arsenide(GaAs) or Indium Phosphide(InP), the mobility of electron decreases above the threshold value E_{th} (about 2000 – 4000v/cm) of the electric field strength. This is because as the field strength increases more and more electrons "transfer" to a state in which their "effective mass" becomes greater, thus decreasing their velocity. For field strength where E> E_{th} the electrons have a negative differential mobility i.e. an increase in the field strength results in decrease in the drift velocity.



Two valley model theory : 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 as shown in . And when the applied electric field is higher than that of the upper valley *(Eu < E),* all electrons will transfer to the upper valley



5b)

IMPATT diode	TRAPATT diode
1. It stands for Impact Avalanche and Transit Time	1. It stands for Trapped Plasma Avalanche Triggered Transit
2. Efficiency of operation is 30%	2. Efficiency is in between 15% and 40%
3. Frequency = 1 to 300 GHz	3. Frequency = 3 to 50 GHz
4. Pulsed power = 4 kW	4. Pulsed powers =1.2 kW at 1.1 GHz
5. It finds applications in microwave oscillators	5. They are used in low-power Doppler radars, phased array radars, radio altimeters, and so on

UNIT – III

6a) Explanation-4M,Expressions-3M

If the fraction of output power is fed back to the input cavity and if the loop gain has a magnitude of unity with a phase shift of multiple 2π, the klystron oscillate. The reflex klystron has been the most used source of microwave power in laboratory applications.The analysis of a reflex klystron is similar to that of a two-cavity klystron. For simplicity, the effect of space-charge forces on the electron motion will again be neglected. The electron entering the cavity gap from the cathode at z = 0 and time to is assumed to have uniform velocity On the assumption that the electron leaves the cavity gap at z = d and time t_1 with a velocity of v(t,) and returns to the gap at z

$$v_0 = 0.593 \times 10^6 \sqrt{V_0}$$

The same electron leaves the cavity gap at $z = d$ at time t_1 with velocity

$$v(t_1) = v_0\left[1 + \frac{\beta_1 V_1}{2V_0} \sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right]$$

This expression is identical to Eq. , for the problems up to this point are identical to those of a two-cavity klystron amplifier. The same electron is forced back to the cavity $z = d$ and time t_2 by the retarding electric field E, which is given by

$$E = \frac{V_r + V_0 + V_1 \sin(\omega t)}{L}$$

This retarding field E is assumed to be constant in the z direction. The force equation for one electron in the repeller region is

$$m\frac{d^2 z}{dt^2} = -eE = -e\frac{V_r + V_0}{L}$$

where $\mathbf{E} = -\nabla V$ is used in the z direction only, V_r is the magnitude of the repeller voltage, and $|V_1 \sin \omega t| \ll (V_r + V_0)$ is assumed.

$$\frac{dz}{dt} = \frac{-e(V_r + V_0)}{mL}\int_{t1}^{t} dt = \frac{-e(V_r + V_0)}{mL}(t - t_1) + K_1 \qquad (9\text{-}4\text{-}5)$$

at $t = t_1$, $dz/dt = v(t_1) = K_1$; then

$$z = \frac{-e(V_r + V_0)}{mL}\int_{t_1}^{t}(t - t_1)\,dt + v(t_1)\int_{t_1}^{t} dt$$

$$z = \frac{-e(V_r + V_0)}{2mL}(t - t_1)^2 + v(t_1)(t - t_1) + K_2$$

at $t = t_1$, $z = d = K_2$; then

$$z = \frac{-e(V_r + V_0)}{2mL}(t - t_1)^2 + v(t_1)(t - t_1) + d \qquad (9\text{-}4\text{-}6)$$

On the assumption that the electron leaves the cavity gap at $z = d$ and time t_1 with a velocity of $v(t_1)$ and returns to the gap at $z = d$ and time t_2, then, at $t = t_2$, $z = d$,

$$0 = \frac{-e(V_r + V_0)}{2mL}(t_2 - t_1)^2 + v(t_1)(t_2 - t_1)$$

The round-trip transit time in the repeller region is given by

$$T' = t_2 - t_1 = \frac{2mL}{e(V_r + V_0)}v(t_1) = T_0'\left[1 + \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right] \qquad (9\text{-}4\text{-}7)$$

where

$$T_0' = \frac{2mLv_0}{e(V_r + V_0)}$$

is the round-trip dc transit time of the center-of-the-bunch electron.

Multiplication of Eq. (9-4-7) through by a radian frequency results in

$$\omega(t_2 - t_1) = \theta_0' + X'\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)$$

where

$$\theta_0' = \omega T_0' \qquad ($$

9-4-2 that for a maximum energy transfer, the round-trip transit angle, referring to the center of the bunch, must be given by

$$\omega(t_2 - t_1) = \omega T_0' = \left(n - \frac{1}{4}\right)2\pi = N2\pi = 2\pi n - \frac{\pi}{2} \qquad (9\text{-}4\text{-}12)$$

The beam current injected into the cavity gap from the repeller region flows in negative Z direction.

$$i_{2t} = -I_0 - \sum_{n=1}^{\infty} 2I_0 J_n(nX')\cos\left[n(\omega t_2 - \theta_0' - \theta_g)\right]$$

6b) Derivation-7M

1. Write the equations of motion for electrons in cylindrical coordinates.

a.
$$\frac{d^2r}{dt^2} - r\left(\frac{d\phi}{dt}\right)^2 = +\frac{e}{m}E_r - \frac{e}{m}r\frac{d\phi}{dt}B_z$$

b.
$$\frac{1}{r}\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = \frac{e}{m}B_z\frac{dr}{dt}$$

2. From (b)

$$\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = \frac{1}{2}\omega_c\frac{d}{dt}(r^2) \qquad \left(\text{where } \omega_c = \frac{e}{m}B_0\right)$$

$$r^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c r^2 + \text{constant}$$

3. Application of the boundary conditions: At $r = a$,

$$a^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c a^2 + \text{constant}$$

$$\frac{d\phi}{dt} = 0 \qquad \text{constant} = -\frac{1}{2}\omega_c a^2$$

Hence

$$r^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c(r^2 - a^2)$$

4. The magnetic field does no work on the electrons:

$$\frac{1}{2}m\upsilon^2 = eV$$

$$\upsilon^2 = \frac{2e}{m}V = \upsilon_r^2 + \upsilon_\phi^2 = \left(\frac{dr}{dt}\right)^2 + \left(r\frac{d\phi}{dt}\right)^2$$

5. For grazing the anode,

$$r = b \qquad V = V_0 \qquad \frac{dr}{dt} = 0$$

$$b^2\left(\frac{d\phi}{dt}\right)^2 = \frac{2e}{m}V_0 \quad \text{and} \quad b^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c(b^2 - a^2)$$

$$b^2\left[\frac{1}{2}\omega_c\left(1 - \frac{a^2}{b^2}\right)\right]^2 = \frac{2e}{m}V_0$$

6. The cutoff voltage is

$$V_{0c} = \frac{e}{8m}B_0^2b^2\left(1 - \frac{a^2}{b^2}\right)^2 \qquad (1\text{-}3\text{-}3d)$$

This means that if $V_0 < V_{0c}$ for a given B_0, the electrons will not reach the anode. Conversely, the cutoff magnetic field can be expressed in terms of V_0:

$$B_{0c} = \frac{(8V_0m/e)^{1/2}}{b(1 - a^2/b^2)} \qquad (1\text{-}3\text{-}4)$$

This implies that if $B_0 > B_{0c}$ for a given V_0, the electrons will not reach the anode.

(OR)

7a) Diagram,Expressions-4M, Explanation-3M

The maximum bunching should occur approximately midway between the catcher grids.The phase of the catcher gap voltage must be maintained in such a way that the bunched electrons, as they pass through the grids, encounter a retarding phase.When the bunched electron beam passes through the retarding phase, its kinetic energy is transferred to the field of the catcher cavity.When the electrons emerge from the grids, they have reduced velocity and are finally collected by the collector.

The current induced by the electron beam in the walls of the catcher cavity

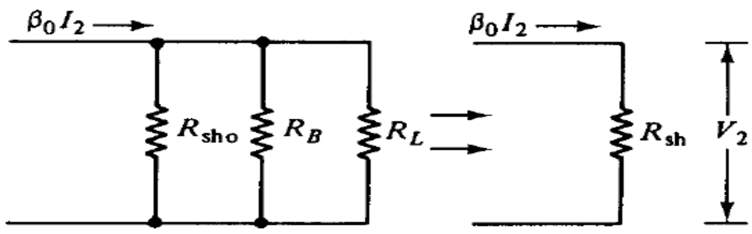
$$i_{2ind} = \beta_0 i_2 = \beta_0 2I_0J_1(X)\cos[\omega(t_2 - \tau - T_0)]$$

The fundamental component of the current induced in the catcher cavity then has the magnitude

$$I_{2ind} = \beta_0 I_2 = \beta_0 2 I_0 J_1(X)$$

The electronic efficiency of klystron is defined as the ratio of output power to input power.

$$\text{Efficiency} \equiv \frac{P_{out}}{P_{in}} = \frac{\beta_0 I_2 V_2}{2 I_0 V_0}$$



In which the power losses to the beam loading and cavity walls are included. If the coupling is perfect, $\beta_0 = 1$, the maximum beam current approaches $I_{2max} = 2I_0(0.582)$ and the voltage V_2 is equal to the V_0. The maximum electronic efficiency is about 58%.In practice, the electronic efficiency of a klystron amplifier is in the range of 15 to 30%.

7b) Diagram-3M, Explanation-4M

The number of bunches depends on the number of cavities in the magnetron and the mode of oscillations, in an eight cavity magnetron oscillating with π - mode, the electrons are bunched in four groups.Two identical resonant cavities will resonate at two frequencies when they are coupled together; this is due to the effect of mutual coupling.

Commonly separating the *pi mode* from adjacent modes is by a method called *strapping*. The straps consist of either circular or rectangular cross section connected to alternate segments of the anode block.

Disadvantages of strapping: Strapping may cause power loss in the conducting rings.Strapped resonators are very difficult.As the number of cavities increase (16 or 32), strapping has no effect on mode jumping

A magnetron that needs no strapping is the rising sun magnetron. Here, the anode cavities are designed to be dissimilar, and only the dominant mode 2π phase will be effective. The adjacent cavities oscillate at widely different frequencies separation will be quite effective.

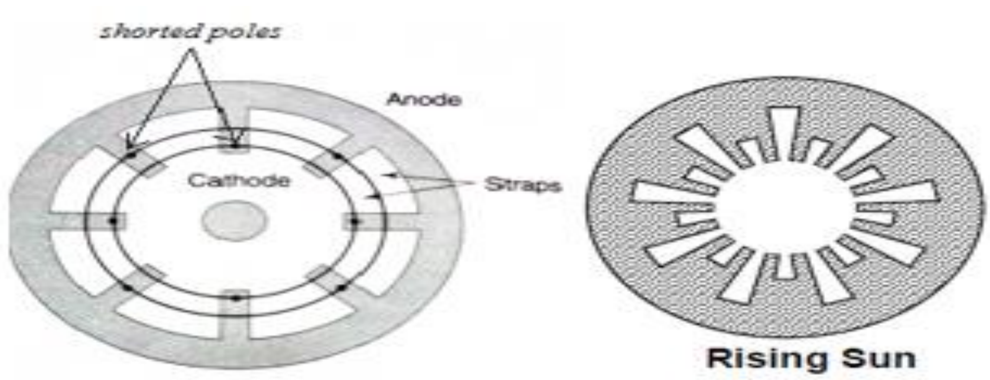
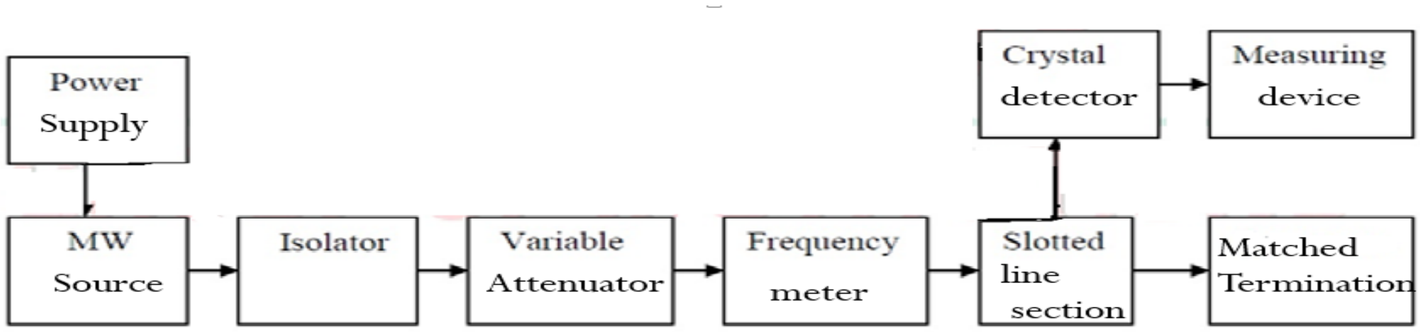


Figure: Strapping Method

UNIT IV

8a) Bench set up-3M Explantion-4M



Signal Generator: As the name implies, it generates a microwave signal, in the order of a few millivolts. A Gunn diode oscillator or a Reflex Klystron tube could be an example for this microwave signal generator.

Isolator: It allows the signal to pass through the waveguide only in one direction.

Precision Attenuator: It adjusts the power flowing in a wave guide.They can be either fixed or variable attenuator

Frequency Meter: This is the device which measures the frequency of the signal. With this frequency meter, the signal can be adjusted to its resonance frequency.

Slotted line used for measuring standing wave ratio.A crystal detector is inserted in the probe and is used to adjust the modulated signal by sensing the relative field strength of standing wave pattern in the wave guide.

Tunable detector helps to detect the low frequency square wave modulated microwave signal.The detector can be point contact type or schottky barrier diode.

8b) Diagrams-3M Explantion-4M

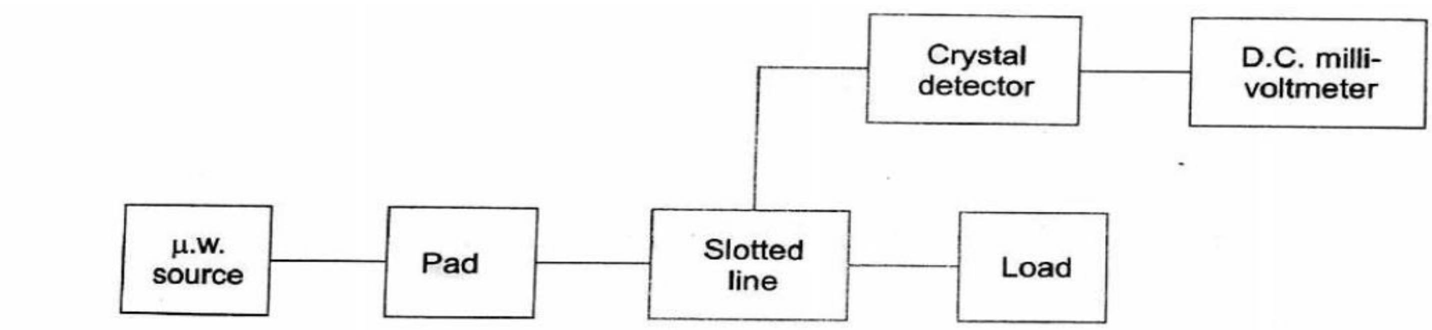
VSWR stands for voltage standing wave ratio. In a perfectly matched system, there is no variation in the field strength along the waveguide.A mismatch leads to reflected waves, there by leading to standing waves along the length of the guide. Standing guide are the indication of the quality of the transmission. VSWR = 1 for perfectly matched system. The ratio of maximum to the minimum voltage gives the VSWR

$$VSWR = \frac{V_{max}}{V_{min}} \qquad VSWR = \frac{1+\Gamma}{1-\Gamma}$$

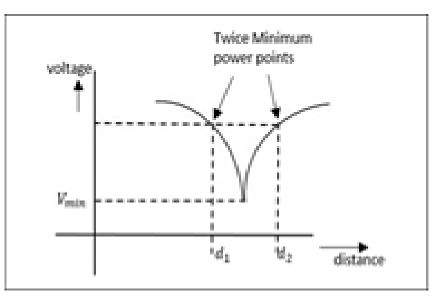
Measurement of Low VSWR $S < 10$

The measurement of low $VSWR$ can be done by adjusting the attenuator to get a reading on a DC millivoltmeter which is VSWR meter. The readings can be taken by adjusting the slotted line and the attenuator in such a way that the DC millivoltmeter shows a full scale reading as well as a minimum reading.

Now these two readings are calculated to find out the $VSWR$ of the network.



VSWR greater than 10 can be measured by double minimum method. In this method, the probe is inserted to a depth where the minimum value can be read easily. Then the probe should be moved to a point where the power is twice the minimum ($P_{min} = 2V^2_{min}/R_L$ i.e. $P_{min} = 2P$).
Let d_1 be the position. Then again, the probe is moved to twice the power point on the other side of the minimum(say d_2) as shown in fig below.For the dominant mode TE_{10} mode rectangular waveguide, λ_0, λ_g , and λ_c are related as below.



$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}$$

λ_0 is free space wavelength
λ_g is guide wavelength
λ_c is cutt off wavelength
For the TE_{10} mode $\lambda_c = 2a$ where “a” is the broad dimension of the waveguide.

(OR)

9a) Each technique(4+3M)

Microwave frequency can be measured by two methods: (i) slotted-line method; (ii) electronic technique.

11.5.1 Slotted-line Method (Mechanical Technique)

In this method, the measurement of wavelength in a waveguide will be made first and from that, frequency will be determined. A tunable resonator is required for this method, which has a known relation between a physical dimension and frequency, for example an absorption wave meter. The standing wave pattern appears only when the slotted line is terminated by a short circuit. The positions of two adjacent nulls are accurately positioned in two steps (i) moving the probe along a slotted line (ii) read the position of nulls in the vernier scale. The two positions are separated by half a guide wavelength $\lambda_g/2$.

The free space wavelength is given by $\lambda_0 = \dfrac{C}{f} \Rightarrow c = f\lambda_0 \Rightarrow f = \dfrac{C}{\lambda_0}$

The guided wavelength in the air-filled rectangular waveguide,

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-(\lambda_0/\lambda_c)^2}} \tag{11.3}$$

and

$$\frac{1}{\lambda_0} = \sqrt{\left(\frac{1}{\lambda_g^2}+\frac{1}{\lambda_c^2}\right)} \tag{11.4}$$

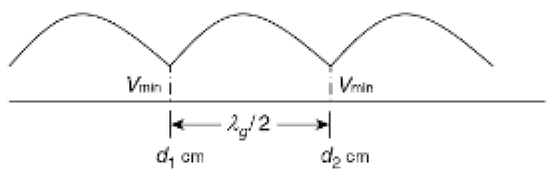


Figure 11.19 *Standing wave*

The distance between two successive voltage minima as shown in Figure 11.19 is given by

$$\lambda_g/2 = (d_2 - d_1).$$

The cutoff wavelength, $\lambda_c = 2a$ (for the dominant TE_{10} mode), where "a" is the broad dimension of the waveguide

Therefore,

$$f = \frac{c}{\lambda_0} = c\sqrt{\left(\frac{1}{\lambda_g^2}+\frac{1}{\lambda_c^2}\right)} \tag{11.5}$$

where c - speed of light in free space (3×10^8 m/s)

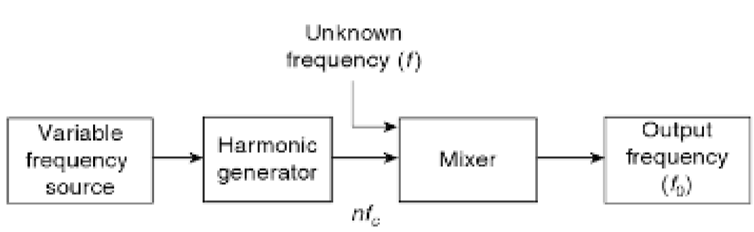
f – frequency, (Hz)
λ_0 – wavelength in free space, (m)
λ_g – wavelength of waveguide, (m)
λ_c – cutoff wavelength of waveguide (m)

In this method, the guided wavelength (λ_g) in a waveguide is measured by creating standing waves in a slotted-line section. The distance between a maxima and minima of the standing wave ($d_2 - d_1$) corresponds to ($\lambda_g/2$); hence, frequency can be determined from the measurement of (λ_g).

Electronic technique

This method uses frequency heterodyne system. This system compares the unknown microwave frequency with a harmonic of the known standard frequency as shown in Figure 11.20. The unknown frequency f can be calculated as below from the output frequency f_0 and frequency nf_c.

$$f = nf_c - f_0 \tag{11.6}$$

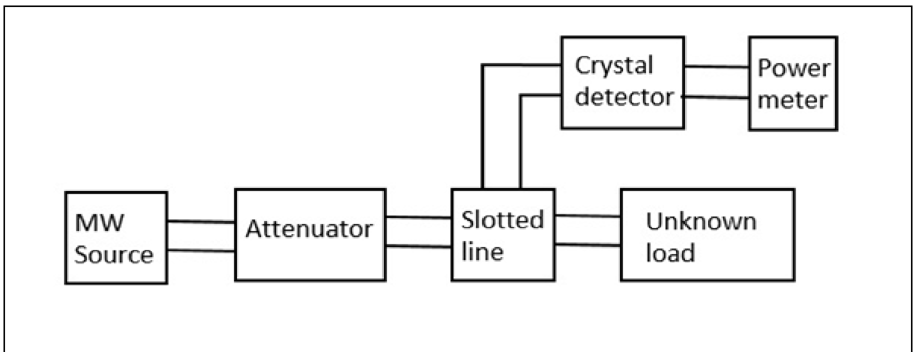


9b) Any two technique(4+3M)

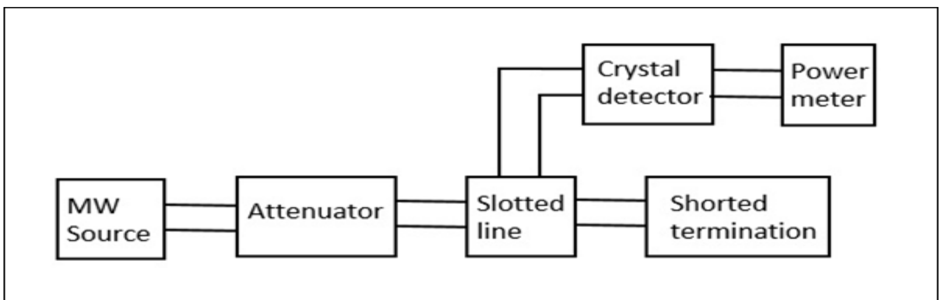
Measurement of load impedance using Slotted line

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 V_{max} and V_{min} can be accurately determined.

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \Gamma = \frac{VSWR - 1}{VSWR + 1}$$



Set up 1, Impedance measurement using slotted line

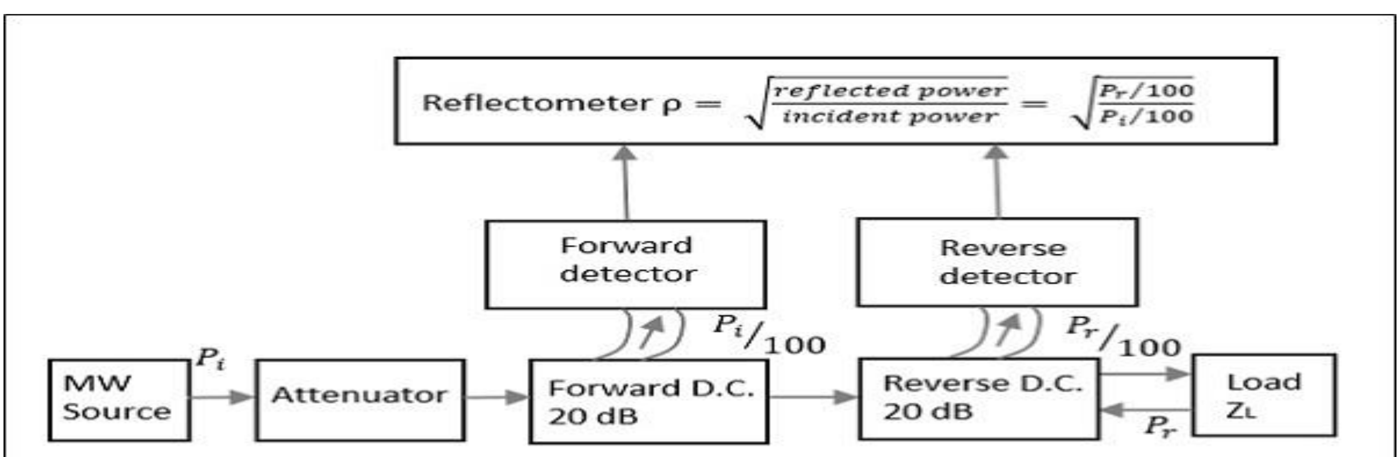


Set up 2, Impedance measurement using slotted line

From the above diagrams it is noted that the load is replaced by short circuit and the shift minimum is measured.If the minimum is shifted to the left the impedance is inductive and if it shifts to the right it is capacitive.

Measurement of Impedance using MagicTee.

Measurement of load impedance using Reflectometer Technique



Set up for measuring impedance using reflectometer

From the reflectometer reading, we have

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

From the value of ρ , the $VSWR$, i.e. S and the impedance can be calculated by

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