UNIT 1 MICROWAVE TRANSMISSION LINES-I AND RECTANGULAR GUIDES

PART-A
SHORT QUESTIONS WITH SOLUTIONS

Q1. What is a microwave transmission line.

Ans: A transmission line that is commonly used for transmitting microwave energy is termed as a microwave transmission line. These lines are analyzed in terms of voltage, current and impedance by the distributed circuit theory or by Maxwell's field equations.

When the space between the transmission on lines is smaller than the wavelength of the transmitted signal, it is analyzed as a waveguide. Microwave transmission lines transmit signals in order to realize passive microwave circuits such as directional couples, quadrature hybrids and filters.

Q2. List the applications of microwaves. Model Paper-I, Q1(a)

Ans: The applications of microwaves are,

1. Microwave frequencies are used in Radars and Radio Astronomical Research of space.
2. They are used in communication links such as telephone,T.V, telemetry etc.
3. These frequencies are used in military applications in command and control warfare.
4. They are used in Jamming systems to confuse enemy by sending false signals.

Q3. What are rectangular waveguides.

Ans: Rectangular waveguides are a type of transmission lines that carry microwave signals. They support three modes of signal transmission. They are,

1. **Transverse Magnetic (TM) Mode:** In this, the magnetic field is transverse to the direction of propagation.

   i.e., $E_z = 0, H_z \neq 0$.

2. **Transverse Electric (TE) Mode:** In this, the electric field is transverse to the direction of propagation.

   i.e., $E_z \neq 0, H_z = 0$.

3. **Transverse Electromagnetic Mode (TEM):** In this, both electric and magnetic fields are transverse to the direction of propagation.

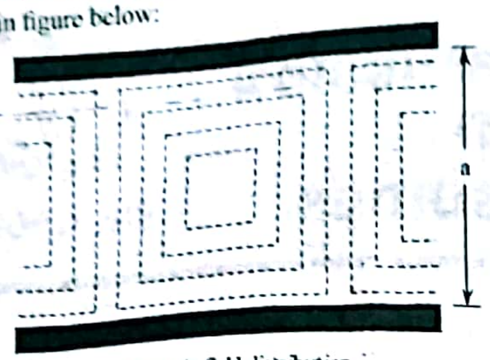
   i.e., $E_z = 0, H_z = 0$.

Q4. What does the suffixes m and n indicate in TEmn mode representation? Sketch the electric and magnetic field distributions for TE_{10} in rectangular waveguide.

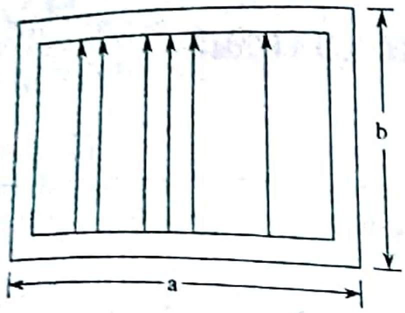
Ans:

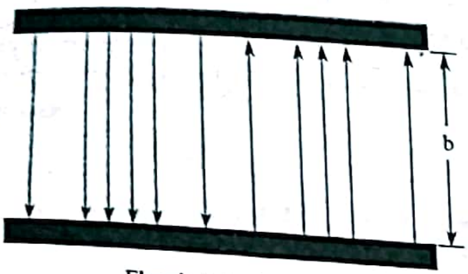
In transverse electric TEmn mode m represents the number of half wave variations of electric field over the wide dimensions of a waveguide and n represents the number of half wave variations over the narrow dimension of a wave guide.

The electric and magnetic field distributions for TE_{10} mode are shown in figure below:



Magnetic field distribution





Electric field distribution

Figure

Q5. What are dominant and degenerate modes?

Ans:

Model Paper-II, Q1(a)

Dominant Mode: The mode with lowest cut-off frequency or longest cut-off wavelength is called as the dominant mode in a rectangular waveguide.

Degenerate Mode: The higher order modes which have the same cut-off frequency are said to be degenerate modes in a rectangular waveguide.

Q6. Justify that TM_{11} is a dominant mode in rectangular waveguide for transverse magnetic propagation.

Ans:

Model Paper-III, Q1(a)

The mode with lowest cutoff frequency or longest cutoff wavelength is known as dominant mode in a rectangular waveguide. The cutoff frequency of rectangular waveguide is given by the expression.

$$f_c = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

Consider a wave is propagated through the transverse magnetic field.

If $m = 0, n = 1$, then

$$(f_c)_{01} = \frac{c}{2}\sqrt{0+\left(\frac{1}{b}\right)^2} = \frac{c}{2b} \quad \ldots (1)$$

If $m = 1, n = 0$, then

$$(f_c)_{10} = \frac{c}{2}\sqrt{\left(\frac{1}{a}\right)^2 + 0} = \frac{c}{2a} \quad \ldots (2)$$

If $m = 1, n = 1$, then,

$$(f_c)_{11} = \frac{c}{2}\sqrt{\left(\frac{1}{a}\right)^2 + \left(\frac{1}{b}\right)^2}$$

$$= \frac{c}{2}\sqrt{\frac{a^2+b^2}{a^2b^2}}$$

$$= \frac{c}{2ab}\sqrt{a^2+b^2}$$

$$\therefore \quad (f_c)_{11} = \frac{c}{2ab}\sqrt{a^2+b^2} \quad \ldots (3)$$

From equations (1), (2) and (3), it is clear that,

$(f_c)_{11} < (f_c)_{01}$

$(f_c)_{11} < (f_c)_{10}$

Therefore TM_{11} mode is referred as dominant mode in rectangular waveguides.

Q7. Define cut-off frequency and phase constant in a rectangular waveguide.

Ans:

Cut-off Frequency: The frequency above which the attenuation offered by the rectangular waveguide to a wave is zero is termed as cut-off frequency. It is denoted as 'f_c' and is given by,

$$f_c = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \text{ Hz}$$

Where,

c = Velocity of light

m = Number of halfwave variations of electric field over wide dimension of waveguide

n = Number of halfwave variations of electric field along narrow dimension of waveguide

c = Length of waveguide

b = Breath of waveguide.

Phase Constant: Phase constant 'β' is inversely proportional to the guide wavelength and is given by,

$$\beta = \frac{2\pi}{\lambda_g}$$

$$\Rightarrow \beta = \frac{\omega_0}{c}\sqrt{1-\left(\frac{\omega_c}{\omega_0}\right)^2} \text{ radians per meter}$$

Q8. Define phase velocity, group velocity and wavelength of a rectangular waveguide.

Model Paper-I, Q1(b)

Ans:

Phase Velocity: The rate at which phase of the wave is changed in terms of guide wavelength is known as phase velocity. It is denoted as V_p and is given by,

$$V_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

Where,

λ_0 = Fundamental cut-off wavelength

λ_c = Cut off wawelength for rectangular waveguide.

Group Velocity: The rate at which the wave propagates through the waveguide is known as group velocity. It is denoted as V_g and is given by,

$$V_g = \frac{d\omega}{d\beta} = c\sqrt{1+\left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

Wavelength: The expression for wavelength of a rectangular waveguide is defined as,

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

Q9. Give the expressions for wave impedance and power transmission in TE and TM waves in a rectangular waveguide.

Ans:

TE: The expression for wave impedance for TE wave in rectangular waveguide is given by,

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

The average power transmitted through a rectangular waveguide for TE wave is given by,

$$P_{tr(TE)} = \frac{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}{2\eta}\int_0^b\int_0^a (|E_x|^2+|E_y|^2)\,dx\,dy$$

TM: The expression for wave impedance for TM wave in rectangular waveguide is given by,

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

The average power transmitted through a rectangular waveguide for TE wave is given by,

$$P_{tr(TM)} = \frac{1}{2\eta\sqrt{1-\left(\frac{f_c}{f}\right)^2}}\int_0^a\int_0^b (|E_x|^2+|E_y|^2)\,dx\,dy$$

Q10. What is a microstrip line. Give its properties.

Model Paper-II, Q1(b)

Ans:

Microstrip line is a type of electrical transmission line which transfers the microwave frequency signals. It contains strip conductor which is separated from ground plane by dielectric layer called substrate, as shown in figure. The entire device looks like a pattern of metallization on the substrate. Therefore, microstrip is less costly when compared to traditional waveguide technology and in addition, it is very lighter and more compact.

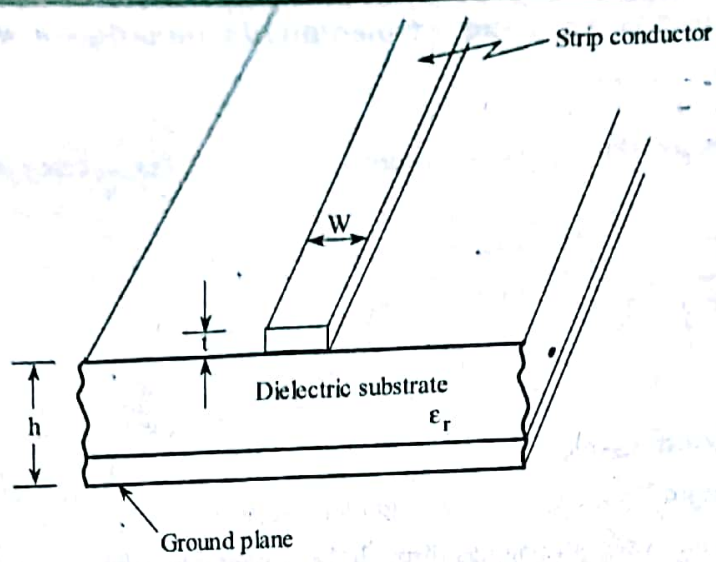


Figure: Microstrip Line

The properties of microstrip lines are,

1. EM waves propagating in microstrip lines lie partly in the dielectric substrate and partly in the air above it.
2. Microstrip lines will not support perfect TEM waves, it supports partial TEM waves referred as quasi TEM wave.
3. Microstrip lines are dispersive
4. The wave impedance of microstrip line changes across its cross-section.

The characteristic impedance of microstrip lines are known as quasi static characteristic impedance and is given by,

$$Z_{micr} = \frac{Z_o}{2\pi\sqrt{1+\varepsilon_r}} \ln\left[1+\frac{4h}{\omega_{eff}}\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\cdot\frac{4h}{\omega_{eff}}+\sqrt{\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\,\frac{4h}{\omega_{eff}}\right)+\pi^2\,\frac{1+\frac{1}{\varepsilon_r}}{2}}\right)\right]$$

Q11. What are the advantages of microstrip lines? *Model Paper-III, Q1(b)*

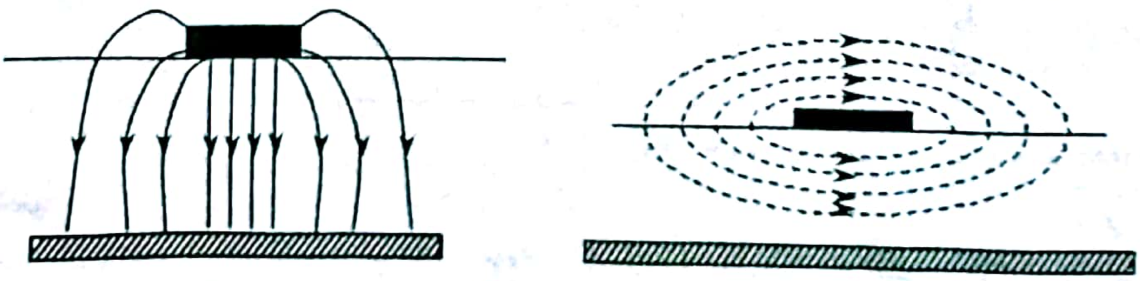
Ans: Microstrip lines find certain advantages over other transmission lines. They are,

1. Fabrication cost is low, because the total pattern is carried on a single dielectric substrate.
2. The packaged and unpackaged semiconductor chips, both can be attached to the microstrip element.
3. There is a scope for minor adjustments, even after completion of fabrication process.

Q12. Does microstrip line support TEM modes? Justify the answer.

Ans:

Microstrip line does not support TEM mode propagation, since it has an open structure and all its electric field lines are partially in air and partially in dielectric substrate of the strip. As a result, concentration of electric field lines increases in the region below the strip, which leads to energy concentration in that region. Thus, pure TEM mode propagation becomes impossible in microstrip line, instead a Quasi TEM propagation takes place. Below figure shows Quasi TEM mode of microstrip.



(a) Electric Field **(b) Magnetic Field**

Figure: Quasi TEM Mode of Microstrip Line

Q13. Give the expressions for quality factor, characteristic impedance and attenuation factor of a microstripline.

Ans: The expression for quality factor of a microstrip line is given by,

$$Q_c = 0.63\, h\sqrt{\sigma f}\ \text{GHz}$$

The expression for characteristic impedance of a microstripline is given by,

For wide microstrip line,

$$Z_0 = \frac{120\pi h}{w\sqrt{\varepsilon_r}}$$

For narrow microstrip line,

$$Z_0 = \frac{87.06}{\sqrt{\varepsilon_r + 1.041}} \ln\left(\frac{5.97h}{0.8\,w+t}\right)$$

The expression for attenuation factor of microstrip line is given by,

Dielectric Attenuation Factor

$$\alpha_d = 27.3\left(\frac{q\varepsilon_r}{\varepsilon_{re}}\right)\frac{\tan\theta}{\lambda_g}\ \text{dB/cm}$$

Ohmic Attenuation Factor

$$\alpha = 27.3\left(\frac{q\varepsilon_r}{\varepsilon_{re}}\right)\frac{\tan\theta}{\lambda_g} + \frac{8.686\,R_s}{z_0 w}$$

UNIT 2

CAVITY RESONATORS & WAVEGUIDE COMPONENTS AND APPLICATIONS

SIA GROUP

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Model Paper-I, Q1(c)

Q1. What is a cavity resonator.

Ans: When two shorting plates, one at one end of waveguide and the other at a distance "multiple of $\frac{\lambda_g}{2}$", are kept in order to terminate the waveguide a hollow space is formed. This hollow space supports the back and forth motion of a signal between the two shorting plates, which results in resonance. Thus, the hollow space is called a cavity and the resonator as the cavity resonator.

Generally, there are two types of cavity resonators.

1. Rectangular cavity resonator
2. Circular cavity resonator.

Q2. What are the most desirable properties of cavity resonators.

Ans: The properties of cavity resonator are,

1. The cavity resonator should resonate at only one particular frequency.
2. The shape of the cavity should be odd to ensure that the various oscillating frequencies are not harmonically related and hence these are attenuated.

Example

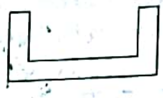


Figure (1)

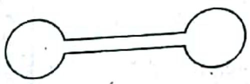


Figure (2)

3. Various TE_{mnp} and TM_{mnp} modes exist with in the cavity.
4. The energy dissipated by the finite conductivity of the cavity walls determine its equivalent resistance.
5. When frequency of an input signal is equal to resonant frequency, a maximum amplitude of the standing wave occurs and the peak energies stored in the electric and magnetic field are equal.
6. The mode with lowest resonant frequency is called the dominant mode.
7. They have high quality factor, Q.
8. They have high shunt impedance.
9. Theoretically infinite modes occur in a resonant cavity.
10. The plane of loop is rotated parallel to magnetic flux.

Model Paper-II, Q1(c)

Q3. Define Q factor of a cavity resonator.

Ans: The quantity which is a measure of the frequency selectivity of a resonant or non-resonant circuit is known as quality factor 'Q'.

Mathematically,

$$Q = 2\pi \times \frac{\text{Maximum energy stored}}{\text{Energy dissipated per cycle}}$$

i.e., $$\boxed{Q = \frac{\omega W}{P}} \quad \dots (1)$$

Where,

W = Maximum stored energy

P = Average power loss.

Q4. What is the significance of Q factor of a cavity resonator.

Ans: Significance of the Q in resonant circuits is to,

1. Q factor improves the frequency selectivity of the circuits.
2. It gives the relation between the capacity of resonant circuits for electromagnetic energy storage and energy dissipation.
3. It can be applicable to more complex lumped circuits.

Q5. Derive the expression for attenuation constant for dielectric loss.

Ans: The dielectric attenuation constant, when electric and magnetic fields are not in time phase is given by,

$$\alpha_d = \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}} \text{ Np/cm}$$

Where,

σ – Conductivity of the dielectric substrate in ℧/cm

The above equation is expressed in terms of dielectric loss tangent as,

$$\tan\theta = \frac{\sigma}{\omega\varepsilon}$$

$$\Rightarrow \quad \alpha_d = \frac{\omega}{2}\sqrt{\mu\varepsilon}\tan\theta \text{ Np/cm}$$

The attenuation constant provided by Welch and Prat is,

$$\alpha_d = 4.34\frac{q\sigma}{\sqrt{\varepsilon_{eff}}}\sqrt{\frac{\mu_0}{\varepsilon_0}} \text{ dB/cm}$$

$$= 1.634 \times 10^3 \frac{q\sigma}{\sqrt{\varepsilon_{eff}}} \text{ dB/cm}$$

Where,

$1 \text{ Np} = 8.686 \text{ dB}$

ε_{eff} – Effective dielectric constant of the substrate

q – Dielectric filling factor.

Dielectric filling factor is given as,

$$q = \frac{\varepsilon_{eff} - 1}{\varepsilon_r - 1}$$

$$\Rightarrow \alpha_d = 27.3\left(\frac{q\varepsilon_r}{\varepsilon_{eff}}\right)\frac{\tan\theta}{\lambda_g} \text{ dB}/\lambda_g$$

Where,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

Q6. Define,

(a) Coupling probe

(b) Coupling loop

(c) Aperture coupling.

Ans:

(a) **Coupling Probe:** Coupling probe is used to couple coaxial line to waveguide or resonator.

The coupling of a coaxial line at the mid-point of the broader walls of the guide, where the electric field is maximum is referred as coupling probe.

(b) **Coupling Loop:** Coupling loop is a metallic wire used to couple coaxial line to waveguide or resonator.

This implies the placing of a loop near a point where magnetic field strength is high.

(c) **Aperture Coupling:** The coupling of waveguide together using small aperture in a common wall to sample the field of main guide using another waveguide is referred as aperture coupling.

Q7. Write short notes on waveguide discontinuities.

Ans: *Model Paper-III, Q1(c)*

The structure of waveguide is a combination of uniform, non-uniform and discontinuity regions. Discontinuities can arise inside the waveguide or at the junction of the waveguide. The regions of the waveguide that present discontinuities in the cross-sectional shape are known as discontinuity regions.

For instance, when two waveguides are improperly joined, regularity of the waveguide is interrupted which is referred as discontinuity in the waveguide at the junction.

The fields within different regions of a waveguide are commonly described only by dominant propagating mode. However, to describe the fields in the discontinuous region of the waveguide, an infinite number of non-propagating modes are needed along with the dominant propagating mode.

Q8. What are tuning screw, posts and matched loads.

Ans:

Tuning Screw: Tuning screw is a metal rod which is inserted perpendicular into a rectangular waveguide in order to tune the device for impedance math in (based on its reactive nature).

Posts: Posts are thin cylindrical rods that extend completely across the narrow width of the wave guide at the centre of broad wall to provide inductive or capacitive susceptance.

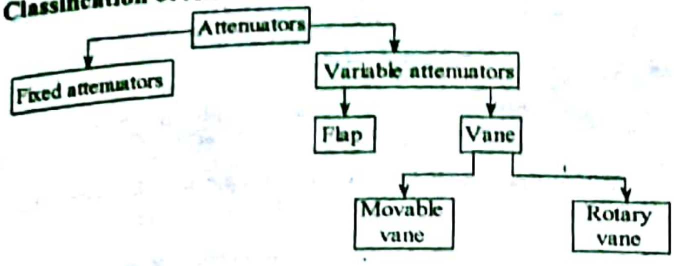
Matched Loads: Matched load implies short circuiting or open circuiting the loss less line to obtain the impedance of transmission line preferably used matched load is stub.

Q9. What is the need of attenuator and give their classification.

Ans: Attenuators are used for complete matching of microwave power in a wave guide without any reflection and intensity of frequency. These are commonly used for measuring power gain or loss in decibels for providing isolation between instruments, for reducing the power input to a particular stage to prevent overloading and also for providing the signal generators with a means of calibrating their outputs accurately.

Attenuators are classified as shown in figure below:

Classification of Attenuators



Figure

Q10. Give the applications of microwave phase shifters.

Model Paper-I, Q1(d)

Ans:

The applications of microwave phase shifters are,

1. It is used in phased array antenna system, in which the phase of a large number of radiating elements are controlled to force the electromagnetic wave to add up at a particular angle to the array. The total phase variation of a phase shifter requires only 360 degrees to control an ESA of Moderate bandwidth.
2. The high speed diode phase shifters are used in serrodyne systems where, shift phase changes result in nearly pure side band generation.
3. A microwave variable phase shifters of a coplanar waveguide is used to calculate the electric field. In this the electric wave propagation of the coplanar waveguide is confirmed.
4. The continuously variable phase shifters used for broadband, wireless local area networks, base stations, satellite communications phased-array radar and smart antennas.
5. Phase shifters are also adopted in frequency-agile systems where frequency and phase must change quickly.

Q11. Why do E-plane Tee and H-plane Tee are called as series and parallel Tees.

Model Paper-II, Q1(d)

Ans: In the *E*-plane Tee, high amount of energy is delivered to an auxiliary guide connected to a transmission line, if the auxiliary guide is connected in series with the main guide at a point of low voltage and high current. Hence, *E*-plane Tee is occasionally called as "series Tee".

In the *H*-plane Tee, high amount of energy is delivered to an auxiliary guide connected to a transmission line, if the auxiliary guide is connected in shunt with the main guide at a point of high voltage and low current. Hence, *H*-plane Tee is occasionally called as "parallel" or "shunt Tee".

Q12. A matched generator with a power of one watt is connected to the H-Arm of magic tee C (port-4). The E-arm (port-3) is match terminated and the length of the coplanar arms is the same. Compute the power delivered to the termination at port 1, 2 and 3 and the power reflected at port 4 when ports 1 and 2 are match terminated.

Ans:

May-19, Set-3, Q6(b)

According to the given data, we can obtain figure (1) based on the characteristics of magic tee.

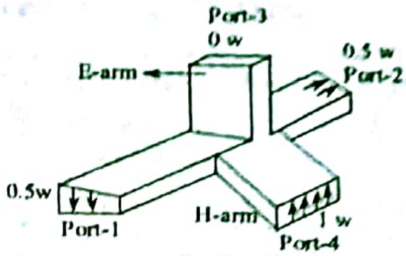


Figure (1)

We can say that, when a power of 1w is connected to H-arm, it is divided equally in port-1 and port-2, i.e., 0.5 w each and power in port-3 is zero.

When port-1 and port-2 are match terminated, then we obtain figure (2).

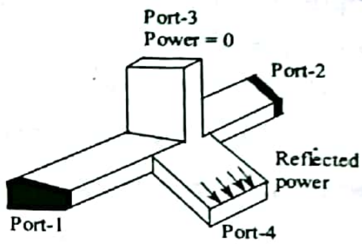


Figure (2)

As shown in the figure (2), when port-1 and port-2 are match terminated, the total power is reflected into port-4. i.e., 0.5 W + 0.5 W = 1 W.

Hence power reflected = 1 W.

Q13. Write a brief note on directional coupler.

Ans:

Directional couplers are the microwave devices that are specially designed for power measurements. These can be built by connecting two or more waveguides together.

The simple directional coupler is a four port device as shown in the figure below.

Directional coupler consists of two waveguides namely, primary main waveguide and secondary auxiliary waveguide.

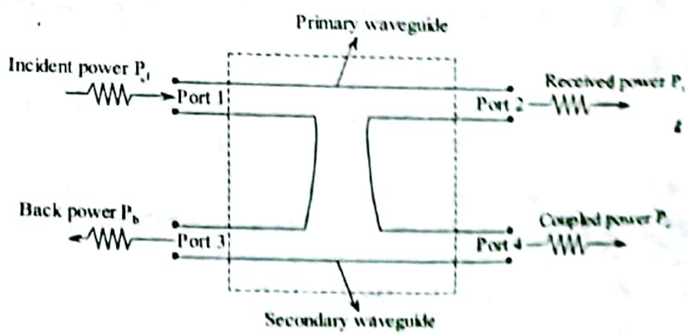


Figure: Directional Coupler

P_i is the power incident on port (1) which is the power to be transmitted.

P_r is the amount of power received, P_b is the back power and P_f is the coupled power (also called forward coupled power)

The 'P_b' is the unwanted component which should be avoided.

Operation of Directional Coupler: The working of an ideal directional coupler is as explained below.

1. The power travelling from port (1) to port (2) is coupled to port (4) but not to port (3). In this case port (1) is the incident port and port (2) is the receiving port.
2. The power travelling from port (2) to port (1) is coupled to port (3) but not to port (4). Here, port (2) and port (1) are incident and receiving ports respectively.
3. Similarly, the power fed at port (3) can be transmitted to port (2), but not to port (1) and the power fed at port (4) can be transmitted to port (1) but not to port (2). In this way, a directional coupler works.

Q14. A 20 dB coupler has a directivity of 30 dB. Calculate the value of isolation.

Model Paper-II, Q1(a)

Ans:

Given that,

For a coupler,

Coupling factor, $C = 20$ dB

Directivity, $D = 30$ dB

Isolation, $I = ?$

The isolation can be defined as,

Isolation, I = Coupling factor (C) + Directivity (D)

On substituting corresponding values in the above equation, we get,

$I = 20 + 30 = 50$ dB.

$\boxed{\therefore \text{ Isolation}, I = 50 \text{ dB}}$

Q15. What are ferrites? List out their characteristics.

Ans:

Ferrites: A ferrite is a device, containing materials that are responsible for its magnetic properties.

Properties of Ferrites (Gyrator)

1. Ferrites possess strong magnetic properties.
2. They possess high resistivity, hence they can be used up to 100 GHz.
3. They exhibit non-reciprocal property.
4. The dielectric constant of ferrite materials is around 10 to 15.
5. They have relative permeabilities of the order of 1000.
6. The magnetic properties of these materials is similar to ferrous metals.

Q16. What is a ferrite isolator and ferrite phase shifter.

Ans:

Ferrite Isolator: Ferrite isolator is a ferrite device which allows microwave energy to pass in one direction only. Hence, it blocks the energy in the other direction in a waveguide.

Ferrite Phase Shirter: A ferrite phase shifter is an instrument that produces a change in the phase angle of the wave transmitted through it using a ferrite rod. An ideal phase shifter is perfectly matched to the input lines and output lines with zero attenuation of the wave.

UNIT 3

MICROWAVE TUBES AND HELLIX TWTs

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PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. What is a microwave tube? What are the limitations of conventional tubes at microwave frequencies.

Ans: Model Paper-I, Q1(a)

Microwave Tube: Microwave tubes are those whose principle is to use an electron beam on which the electric fields act on space charge waves to transfer energy to output circuit.

Limitations of Conventional Tubes at Microwave Frequencies: Conventional tubes cannot be used at microwave frequencies i.e., > 100 MHz due to the following effects.

1. Inter electrode capacitance effect
2. Lead inductance effect
3. Transit time effect
4. Gain-bandwidth limitation
5. Effect due to RF losses
6. Radiation losses.

Q2. What is a transit time effect?

Ans: The time taken for the electrons to travel from cathode to anode is known as transit time.

i.e., $\tau = d/V_0$ ... (1)

Where,

d – Distance between cathode and anode

V_0 – Electron velocity.

Under equilibrium, the static energy is equal to kinetic energy.

$$\Rightarrow \quad eV = \frac{1}{2}mV_0^2 \quad \ldots (2)$$

Where,

eV – Static energy

$\frac{1}{2}mV_0^2$ – Kinetic energy

$$\Rightarrow \quad V_0^2 = \frac{2eV}{m}$$

$$V_0 = \sqrt{\frac{2eV}{m}}$$

Substituting the value of V_0 in equation (1), we get,

$$\tau = \frac{d}{\sqrt{\frac{2eV}{m}}}$$

If the frequency is low, then the transit time is negligible.

Q3. Explain the transit-angle effects in conventional vacuum tubes.

Ans:

Transit Angle Effect in Conventional Vacuum Tubes: Transit angle effect is one of the limitation in the applications of conventional vacuum tubes . The electron transit angle of an conventional vacuum tubes is given by the expression.

$$\theta_g = \omega T_g = \frac{\omega d}{v_0}$$

Where, $T_g = \frac{d}{V_0}$ ⇒ Transit time across the gap

d – Seperation between cathode and grid

$v_0 = (0.593 \times 10^6 \sqrt{v_0})$ velocity of e^-

The effect of transit angle is negligible. Transit angle is large when the frequencies at microwave range. During electron transit, the voltage between the cathode and grid may be highly altered and it is in the range of 10-100 times of its original value. The final consequence of electron transit angle is to diminish the value of operating frequency of the vacuum tube. And this problem is very serious, when frequencies are above 1GHz.

Q4. What is velocity modulation? How is it different from normal modulation?

Model Paper-II, Q...

Ans:

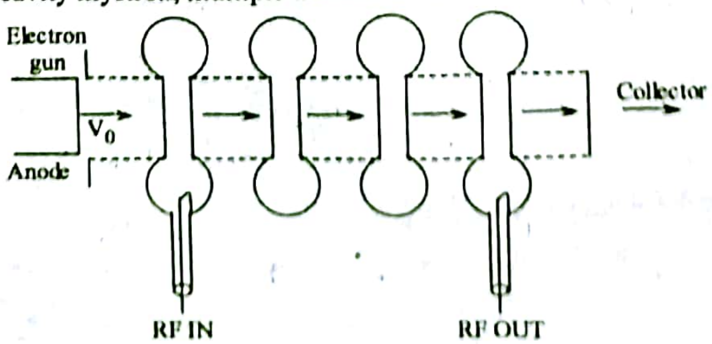
Velocity Modulation: The variation of electron velocity in the drift space region is known as velocity modulation. The differences between velocity modulation and normal modulation are listed below:

	Modulation		Velocity Modulation
1.	Modulation is a process in which the characteristics of the carrier signal i.e., amplitude or phase or frequency are varied according to the instantaneous value of the modulating or base band signal.	1.	Velocity modulation is the process of variation in electron velocity in the drift space region.
2.	This technique is used in signal transmission to avoid interference.	2.	This principle is employed in klystrons and magnetrons to avoid the effects at microwave frequencies.
3.	In this, depending on the varied characteristics of the carrier signal, the respective modulation technique is employed.	3.	In this, velocity of the electrons vary according to the amplitude of the RF input applied at the buncher cavity.
4.	Modulation technique is mainly used for proper transmission and reception of low frequency signals.	4.	Velocity modulation technique is mainly employed at microwave or high frequencies only.
5.	Efficiency of the system depends upon the type of modulation used.	5.	Efficiency of triode amplifier i.e., klystron using velocity modulation technique is approximately 40%.

Q5. Why do practical klystron amplifiers generally have more than two cavities? How can broadband operation be achieved in multicavity klystron?

Ans:

Multicavity Klystron: In a multicavity klystron, multiple number of cavities are used as shown in figure.



Figure

The two-cavity klystron will suffer for high gains of about 10 to 20 dB. So, a higher overall gain can be achieved by connecting multiple two cavity tubes in cascade, giving the output of each of the tubes to the input of the succeeding one.

In this, each of the intermediate cavities will act as a buncher with the passing electron beam inducing an enhanced RF voltage than the previous cavity. With four cavity Klystron, the power gains of around 50 dB can be obtained. For narrow-band operation, the cavities are tuned to the same frequency. An improved bandwidth can be achieved by staggering tuning of cavities up to 80 MHz.

Q6. What are the performance characteristics of a klystron amplifier?

Ans: Nov./Dec.-12, (R09), Q5(c)

The performance characteristics of a two-cavity klystron amplifier are as follows,

S.No	Parameter	Value
1.	Operating frequency	250 MHz- 100 GHz (60 GHz nominal)
2.	Power	10 kW - 500 kW (CW) 30 MW (pulsed)
3.	Power gain	15 dB - 70 dB (60 dB nominal)
4.	Bandwidth	10 - 60 MHz
5.	Noise figure	15 dB - 20 dB (sometimes > 25 dB)
6.	Theoretical efficiency	58% (30 - 40% nominal)

Table

Q7. What is a reflex klyston?

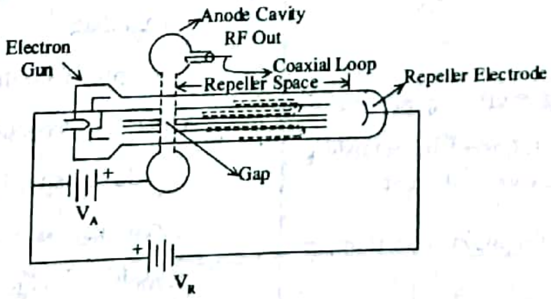
Ans: The reflex klystron is a single cavity variable frequency microwave generator oscillator. It has low power and low efficiency. It has electron gun similar to that of two-cavity klystron but of smaller size. As the size is small the beam does not require focusing. Reflex klystron has following characteristics,

Low power – 10-500 MW

Frequency range – 1-25 GHz.

Efficiency – 20-30%

Reflex klystron is used in microwave measurements and microwave receivers as local oscillators. Figure shows the schematic diagram of a reflex klystron.



Figure

Q8. Show that theoretical efficiency of reflex klystron is 27.78%.

Model Paper-III, Q1(e)

Ans: The efficiency of reflex klystron is the ratio of P_{ac} and P_{dc} and is given as,

$$\eta = \frac{P_{ac}}{P_{dc}}$$

Where,

$$P_{dc} = P_{in} = V_0 I_0$$

$$P_{ac} = P_{out} = I_0 V_1 J_1 (X') \text{ and } 'X' = \frac{V_1}{2V_0} \theta_0'$$

$'\theta_0'$ - Transit time $= 2\pi n + 3\pi/2$

$$\therefore \quad \eta = \frac{I_0 \times X' \times 2V_0 \times J_1(X')}{I_0 V_0 \theta_0'}$$

$$\eta = \frac{2X'J_1(X')}{\theta_0'}$$

$$\eta = \frac{2X'J_1(X')}{2\pi n + 3\pi/2}$$

$$\eta = \frac{X'J_1(X')}{\pi\left[n + \frac{3}{4}\right]}$$

$$\therefore \quad \eta_{max} = \frac{0.3980}{\left[n + \frac{3}{4}\right]}$$

For $n = 1, n + \frac{3}{4} = 1\frac{3}{4}$

Now, $(P_{ac})_{max}$ can be obtained as,

$$(P_{ac})_{max} = 0.278\, I_1 V_0$$

$$\eta_{max} = \frac{(P_{ac})_{max}}{P_{dc}}$$

$$= 0.227$$

$$\boxed{\therefore \eta_{max} = 22.7\%}$$

Hence, the theoritical efficiency of reflex klystron is 22.7%.

Q9. Derive the relation between accelerating voltage V_0, repeller voltage V_R and repeller space L.

Ans: In a klystron oscillator,

For $V_1 \ll V_0$

$$\omega t_2 = \omega t_1 + \theta_0'$$

Where,

t_1 = Time for electron leaving cavity gap at $x = d$

t_2 = Time for same electron returned by retarding field at $x = d$.

The mode cycles are $1\frac{3}{4}$ apart, for maximum transfer of energy, i.e., $2\pi(n - 1/4)$

Where,

$$n - \frac{1}{4} = \frac{3}{4}, 1\frac{3}{4},$$

$$\Rightarrow \quad (2\pi n - \pi/2) = \theta_0' \qquad \dots (1)$$

$$\text{But, } \frac{2mL\omega v_0}{e(V_R + V_0)} = \omega T_0' x = \theta_0'$$

Where,

v_0 – Velocity of electron in gun.

$$\Rightarrow \quad \theta_0' = \frac{2mL\omega v_0}{e(V_R + V_0)}$$

$$v_0 = \frac{e(V_R + V_0)}{2mL\omega}\,\theta_0'$$

$$v_0^2 = \frac{e(V_R + V_0)}{2mL\omega}(\theta_0')^2 \qquad \dots (2)$$

$$\text{and } \frac{1}{2}mv_0^2 = eV_0$$

$$\Rightarrow \quad V_0 = \frac{m}{2e}v_0^2 \qquad \dots (3)$$

Substituting equation (2), in equation (3), we get,

$$\therefore \quad V_0 = \frac{m}{2e}\left[\frac{e^2(V_R + V_0)^2}{4m^2L^2\omega^2}(\theta_0')^2\right]$$

Substituting equation (1) in equation (4), we get,

$$V_0 = \frac{m}{2e}\left[\frac{e^2(V_R + V_0)^2}{4m^2L^2\omega^2}(2\pi n - \pi/2)^2\right] \qquad \dots (4)$$

$$\Rightarrow \frac{V_0}{(V_R + V_0)^2} = \frac{m}{2e}\,\frac{e^2}{4m^2L^2\omega^2}\,(2\pi n - \pi/2)^2$$

$$\therefore \frac{V_0}{(V_R + V_0)^2} = \frac{1}{8}\,\frac{1}{\omega^2L^2}\,\frac{e}{m}\,[2\pi n - \pi/2]^2$$

Q10. A reflex klystron is operated at 5 GHz with an anode voltage of 1000 V and cavity gap of 2 mm. Find out the optimum length of the drift region. Assume N. V_R = 500 V.

Ans:

Given that,

For a reflex klystron,

Operating freequency, $f = 5$ GHz $= 5 \times 10^9$ Hz

Anode voltage, $V_0 = 1000$ V

Cavity gap, $m = 2$ mm $= 2 \times 10^{-3}$ m

Repeller voltage, $V_R = 500$ V

Optimum length of drift region, $L = ?$

Assume operating mode as $N = 1\frac{3}{4}$

The expression for repeller voltage of a reflex klystron is given by,

$$V_R = \frac{6.74 \times 10^{-6} \times f \times L \times m \times \sqrt{V_0}}{N} - V_0 \qquad \dots (1)$$

From equation (1), the optimum length of drift region (L) can be given as,

$$L = \frac{(V_R + V_0)N}{6.74 \times 10^{-6} \times f \times m \times \sqrt{V_0}} \qquad \dots (2)$$

On substituting corresponding valves in equation (2), we get,

$$L = \frac{(500+1000)\times 1.75}{6.74\times 10^{-6}\times 5\times 10^{9}\times 2\times 10^{-3}\times\sqrt{1000}}$$

$= 1.231$ m

$\therefore$ The optimum length of drift region is 1.231 m

Q11. A reflex klystron operates at the peak of the n = 2 mode. The dc power input is 40 mW and the ratio of V_1 over V_0 is 0.278. If 20% of power delivered by the beam is dissipated in the cavity walls, find the power delivered to the load. (V_1 = Signal voltage and V_0 = Beam voltage).

Ans: (Model Paper-I, Q1(f) | May-10, Set-2, Q6(b))

Given that,

For a reflex klystron,

Oscillating mode, $n = 2$

D.C power input, $P_{in} = 40$ mW

Power output, $P_{out} = ?$

With 20% power dissipated in the cavity,

Power delivered to load $P_L = ?$

The expresion for input power is given by,

$$P_{in} = V_0 I_0 = 40 \text{ mW}$$

The output power of reflex klystron is given by,

$$P_{out} = \frac{2V_0 I_0 \times J_1(X')}{2n\pi - \frac{\pi}{2}} = \frac{2P_{in}\, J_1(X')}{2n\pi - \frac{\pi}{2}} \quad \frac{2V_0 I_0\, J_1(X')}{2n\pi - \frac{\pi}{2}}$$

$$= \frac{2\times 40\times 10^{-3}\times 1.25}{2\times 2\times \pi - \frac{\pi}{2}}$$

$P_{out} = 9.09$ mW

Power delivered to load if 20% of the power delivered by beam is dissipated in cavity walls, implies 80% power is delivered to load,

$$\Rightarrow P_L = 9.09\times 10^{-3}\times\frac{80}{100}$$

$= 7.27$ mW

$$\boxed{\therefore \quad P_L = 7.27 \text{ mW}}$$

Q12. What is a slow wave structure? What is the use of them in TWT.

Ans: Model Paper-II, Q1(f)

Slow Wave Structure: Slow wave structures are the circuits which provides interaction between electron beam and signal wave by reducing the velocity of wave in particular direction.

Use of Slow Wave Structures in TWT: In TWT, the electron beam cannot accelerate faster than the waves travelling on wire. This is because of the waves travelling at the speed of light and increase in its amplitude along the length of TWT. Due to this drawback bunching process does not occur.

This drawback can be eliminated by using slow wave structures in TWT. These structures allows by bunching process to occur by reducing the speed of travelling waves below the electron beam speed. This setup also produces large gain over a wide bandwidth.

Q13. Mention the characteristics and applications of TWT.

Ans: Model Paper-III, Q1(f)

Characteristics of TWT: The principle characteristics of a basic travelling wave tube amplifier are listed below.

1. Frequency of operation : 300 MHz to 50 GHz
2. Efficiency : 20 to 40%
3. Power gain : 40 dB to 60 dB
4. Bandwidth : about 800 MHz
5. Power output : Upto 10 k Watts.

Applications of TWT

1. In broadband microwave receivers, travelling wave tubes are used as low noise RF amplifiers.
2. These are used as repeater amplifier in wide band communication links and long distance telephony.
3. Travelling wave tubes are used as output power tubes in communication satellites because of its long tube life i.e., 50,000 hrs.
4. Due to larger power and bandwidth, continuous wave high power TWT's are used in troposcatter links.
5. Travelling wave tubes are also used in airborne and shipborne pulsed high power radars and ECM ground based radars.

Q14. A TWT operates with following parameters, V_b = 2.5 kV, I_b = 25 mA, Z_0 = 10 Ω, circuit length L = 50, f = 9 GHz.

Find the gain parameter and power gain.

Ans: May-10, Set-1, Q2(b)

Given that,

For a TWT,

$V_b = 2.5$ kV

$I_b = 25$ mA

$Z_0 = 10\ \Omega$

$L = 50$

$f = 9$ GHz

Gain parameter, $C = ?$

Power gain, $A_p = ?$

The gain parametern of a TWT is given by the equation,

$$C = \left[\frac{I_0 Z_0}{4V_0}\right]^{1/3}$$

$$\Rightarrow \quad C = \left[\frac{I_b Z_0}{4V_b}\right]^{1/3}$$

On substituting corresponding values in above equation, we get,

$$C = \left[\frac{25\times10^{-3}\times10}{4\times2.5\times10^{3}}\right]^{1/3}$$

$$= 2.92 \times 10^{-2}$$

$$\boxed{\therefore C = 2.92\times10^{-2}}$$

The expression for power gain of TWT is given by,

$$A_p = -9.54 + 47.3\, NC$$

$$= -9.54 + 47.3 \times 50 \times 2.92 \times 10^{-2}$$

$$= 59.52$$

$$\boxed{\therefore A_p = 59.52 \text{ dB}}$$

Q15. What are the gain considerations and nature of four propagation constants of TWT.

Ans:

Gain Considerations: The output gain of a TWT is defined as,

$$A_p = 10 \log\left|\frac{V(l)}{V(o)}\right|^2$$

$$\boxed{\therefore A_p = -9.54 + 47.3\, NC \text{ dB}}$$

Where, $V(l)$ = Output signal voltage

$V(o)$ = Input signal voltage

N = Circuit length

C = Gain parameter.

Nature of Four Propagation Constants: The four propagation constants that determine the wave modes of helix type travelling wave tube is given by,

$$\gamma_1 = -\beta_e C\frac{\sqrt{3}}{2} + j\beta_e\left(1+\frac{C}{2}\right)$$

$$\gamma_2 = -\beta_e C\frac{\sqrt{3}}{2} + j\beta_e\left(1+\frac{C}{2}\right)$$

$$\gamma_3 = -j\beta_e(1-C)$$

$$\gamma_4 = -j\beta_e\left(1-\frac{C^3}{4}\right)$$

UNIT 4

M-TYPE TUBES AND MICROWAVE SOLID STATE DEVICES

SIA GROUP

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Model Paper-I, Q1(g)

Q1. Write about the classification of magnetrons.

Ans: M-type tubes are microwave tubes in which the electric and magnetic fields are perpendicular to each other. Hence these tubes are also known as cross field tubes. In M-type tubes, the principal tube is magnetron. M-type tubes are classified into following three categories they are as follows,

1. Negative resistance type
2. Cyclotron frequency type
3. Travelling wave (or) cavity type.

1. Negative Resistance Type Tubes

Negative resistance M-type tubes employ the negative resistance between the two anode segments. They possess very low efficiency and suitable only at low frequencies i.e., <500 MHz.

2. Cyclotron Frequency Type Tubes

Cyclotron frequency M-type tubes rely on the phenomenon of cyclotron frequency synchronism between the two alternating components of electric and oscillation of electrons in the direction parallel to this field. Their tubes are suitable for frequencies higher than 100 MHz.

3. Travelling Wave (or) Cavity Type Tubes

Travelling M-type tubes produce oscillations depending upon the interaction of electrons with rotating electromagnetic field with constant angular velocity. These oscillations are of very high peak power and therefore these tubes are widely used in RADAR applications.

Model Paper-II, Q1(g)

Q2. Define crossed field effect in magnetron.

Ans: Magnetron is a self excited high power microwave oscillator in which it is used to interact magnetic and electric fields of a cavity to provide oscillations.

M-types or cross field devices are those devices whose electric field between anode and cathode is radial. Since magnetic field is perpendicular to plane of radial electric field, magnetron is also referred as cross field device.

Crossed Field Effect: If the orientation of electric and magnetic fields are perpendicular to each other the motion of electrons depend on electric or magnetic fields respectively. This field is called as cross field. Hence, the magnetic field exerts no force on electrons when the direction of electric and magnetic fields are same or opposite.

Q3. Compare the performance characteristics of magnetron and Klystron oscillator.

Ans:

The performance characteristics of magnetron and klystron oscillator are given below:

	Magnetron		Klystron
1.	The frequency range of magnetron is upto 10 GHz.	1.	The frequency range of klystron is 4 GHz to 200 GHz.
2.	The power output for magnetron is 800 kW.	2.	The power output for klystron is 10 mW to 2.5 W.
3.	The efficiency of magnetron is 40 to 70%.	3.	The efficiency of klystron is 20%.

Q4. Explain the terms frequency pulling and frequency pushing with reference to magnetron.

Ans:

Frequency Pulling: Frequency pulling is the variation of frequency due to the changes in load impedance of magnetron. The load variations can be either resistive or reactive.

It is also defined as the difference between maximum and minimum frequencies at VSWR = 1.5 and phase angle change is through 360°.

Frequency pulling can be avoided by using a stabilized power supply.

Frequency Pushing: Frequency pushing is the variation of frequency of the magnetron due to the change in anode voltage current, in particular anode voltage. The change in anode current for a fixed load produces changes in velocity of electron orbital. This in turn produces changes in oscillator frequency.

A plot of frequency versus current represents pushing characteristic whose slope is referred as pushing figure.

Frequency pushing can be minimized by avoiding backward flow of energy which is done by placing a circulator waveguide before the waveguide connector at the output.

Q5. Compare the performance characteristics of TWT amplifier and magnetron.

Ans: The Comparison between the performance characteristics of TWT and magnetron is shown below:

	Travelling Wave Tube (TWT)		Magnetron
1.	In TWT, the electrons interact with a travelling wave.	1.	In magnetron the electron carrying energy are made to interact with RF field for a long duration.
2.	The efficiency of TWT is in the range of 5 to 20%.	2.	The efficiency provided by magnetron is in the range of 40 to 70%.
3.	The operating frequency of TWT is greater than 3 GHz.	3.	The operating frequency of magnetron is upto 10 GHz.
4.	The average power output of TWT is 10 kW.	4.	The power output of magnetron is 800 kW (Pulsed).

Q6. The parameters of linear magnetron are:

V_o = 15 kV

I_o = 1.2 A

B_o = 0.16 T

Separation between cathode and anode = 4 cm.

Find the Hull's cut-off voltage.

Ans:

Given that,

For a linear magnetron,

Anode voltage, V_o = 15 kV

Cathode current, I_o = 1.2 A

Magnetic flux density, B_o = 0.16 T

Distance between cathode and anode, d = 4 cm

Hull's cutoff voltage, V_{oc} = ?

The Hull's cut off voltage for linear magnetron is given by,

$$V_{oc} = \frac{1}{2}\frac{e}{m}B_o^2 d^2$$

$$V_{oc} = \frac{1}{2}(1.759 \times 10^{11}) \times (0.16)^2 \times (4 \times 10^{-2})^2$$

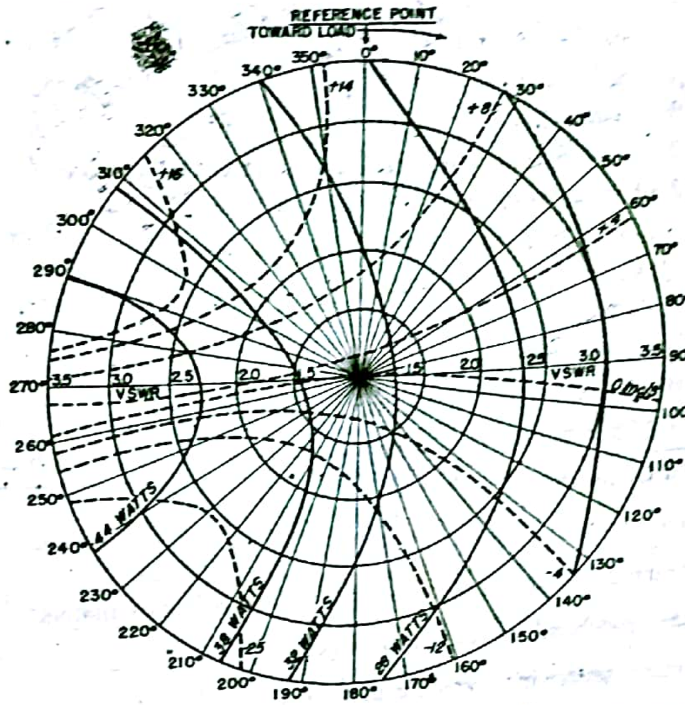
$$= 3.6 \times 10^6$$

$$\therefore \quad V_{oc} = 3.6 \text{ MV}.$$

Q7. Write short notes on Rieke diagram.

Model Paper-III, Q1(g)

Ans: Rieke diagram is a smith chart which represents the load admittance on magnetron at a launch-waveguide flange (convenient reference plane). It illustrates the performance of the magnetron over the range of load admittance. When anode current is applied to an electromagnetic winding to generate anode current, the magnetron is said to be operated in series-fed configuration. The smith chart that represents the load admittance of magnetron which is a function of constant output frequency and constant output power or efficiency is as shown in figure below:



The region or zone where the power output is maximum is referred as sink as the frequency contours are crowded at this point.

The Rieke diagram represents the location of reference plane, the magnetic field, the anode voltage and current. Since the magnetron is operated in a constant-anode-current system, the anode voltage or magnetic field is recorded.

Q8. What are microwave solid state devices. Give its applications.

Ans:

Microwave Solid State Devices: Microwave solid state devices are those which are used for low power microwave applications. These are of small size, light weight with high reliability.

Microwave solid state devices are classified into two types. They are,

1. Transferred-electron devices
2. Avalanche transit-time devices.

Applications: The applications of solid state microwave devices are,

1. They are used in radio transmitters, such as CW doppler radar.
2. They are used in broadband linear amplifiers.
3. They are used as pump sources in parametric amplifiers.
4. They find application in transponders.
5. They are used in both the combinational and sequential logic circuits.
6. They are used in microwave receivers.

Q9. What is Gunn effect?

Model Paper-I, Q1(h)

Ans: Basically, Gunn diode is a piece of doped semiconductor containing electrical contacts on opposite ends. In the year 1963, John B. Gunn discovered the Gunn diode, while performing experiment with semiconductor compounds like Gallium Arsenide (GaAS) where, Gunn observed that when bias voltage increases above threshold level the current pulse gets unstable. Thus, according to the estimation of John B. Gunn the unusual behaviour of diode is due to the negative resistance effect, which is named as Gunn effect.

Q10. What are the operating modes that exist in Gunn diode.

Ans: There are four basic operating modes of Gunn diode based on material parameters and operating conditions. They are,

1. **Gunn Oscillator Mode:** Gunn oscillation mode exists in the region where,

$$fL \simeq 10^7 \text{ cm/sec and } n_0L > 10^{12}/\text{cm}^2$$

Where,

f = Operating frequency

L = Length

n_0 = Doping.

Gunn diode is unstable in this mode.

2. **Stable Amplification Mode:** Stable amplification mode exists in the region where,

$$fL = 2 \times 10^7 \text{ cm/s and } n_0L = 10^{11} \text{ to } 10^{12}/\text{cm}^2$$

In this mode, Gunn diode exhibits amplification at the transit time frequency.

3. **LSA Mode:** LSA oscillation mode exists in the region.

Where,

$$fL = 2 \times 10^7 \text{ cm/s and } 2 \times 10^5 > \frac{n_0}{L} > 2 \times 10^4$$

In this mode, the device remains in the negative resistance region with increasing RF voltage beyond threshold voltage.

4. **Bias Circuit Oscillation Mode:** Bias circuit oscillation mode exists for every less values of 'fL".

Q11. List the applications of Gunn diode. Model Paper-II, Q1(h)

Ans: The applications of Gunn diode are,

1. In microwave receivers, Gunn diodes are used as low and medium power oscillators.
2. They are used in radars and broadband microwave amplifiers.
3. Gunn diodes are used as pump source in parametric amplifiers.
4. They are used as motion detectors for door openers and security alarms.
5. These are used as transmitters for millimeter-wave communication.

Q12. A GaAs GUNN diode has an active region of 10 micrometers. If the electron drift velocity is 10^5 m/sec. Calculate the natural frequency and the threshold voltage. The critical electric field is 3 kv/cm.

Ans:

Given that,

For a GaAs Gunn diode,

$L = 10\ \mu\text{m} = 10 \times 10^{-4}$ cm

Electron drift velocity, $V_d = 10^5$ m/sec $= 10^7$ cm/sec

Critical electric field, $E_c = 3$ kV/cm

Natural frequency, $f = ?$

Threshold voltage, $v = ?$

The expression for frequency of oscillation in Gunn diode is given by,

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

$$\Rightarrow \quad f = \frac{10^7}{10 \times 10^{-4}} = 10^{10}$$

$$\boxed{\therefore f = 10 \text{ GHz}}$$

And its critical voltage is given by, $v = L \times E_c$

$$\Rightarrow \quad v = 10 \times 10^{-4} \times 3 \times 10^3 = 3 \text{ V}$$

$$\boxed{\therefore v = 3 \text{ V}}$$

Q13. What are avalanche transit time devices.

Ans: The junction devices which give the negative resistance by suitable combination of impact avalanche breakdown and charge carrier transit time effects is referred as "Avalanche transit time devices". There are three types of avalanche transit time devices. There are three types of avalanche transit time devices. They are,

1. IMPATT (Impact ionization avalanche transit time)
2. TRAPATT (Trapped plasma avalanche triggered transit)
3. BARITT (Barrier injected transit time).

Q14. Compare IMPATT and TRAPATT diodes. Model Paper-III, Q1(h)

Ans: The comparison between IMPATT and TRAPATT diodes is mentioned below:

	IMPATT Diode		TRAPATT Diode
1.	IMPATT stands for Impact Avalanche and Transit Time.	1.	TRAPATT stands for Trapped Plasma Avalanche Triggered Transit.
2.	They exhibit negative resistance.	2.	They are derived from IMPATT diode in order to overcome the limitation of the same.
3.	Efficiency of Impatt didoe is 30%.	3.	Efficiency is in between 15% to 40%.
4.	It's pulsed powers is 4 kW.	4.	It's pulsed powers is 1.2 kW at 1.1 GHz.
5.	It's frequency range is 1 to 300 GHz.	5.	It's frequency range from 3 to 50 GHz.
6.	It finds its applications in microwave oscillators.	6.	They are used in low power Doppler radars, phased array radars, radio altimeter, etc.

Table

Q15. An IMPATT diode has drift length of 2 μm. Determine,

(i) Drift time of the carriers

(ii) Operating frequency of IMPATT diode.

Ans: Given that,

For an IMPATT diode,

Drift length, $L = 2\ \mu m$

(i) The expression for drift time of carrier is given by,

$$\tau = \frac{L}{v_d} = \frac{2\times10^{-6}}{10^5} \qquad \text{[Let, } v_d = 10^5 \text{ cm/sec]}$$

$$= 2 \times 10^{-11}$$

$$\boxed{\therefore \tau = 2\times10^{-11} \text{ sec}}$$

(ii) The expression for operating frequency of IMPATT diode is given by,

$$f = \frac{1}{2\tau} = \frac{1}{2\times2\times10^{-11}}$$

$$\Rightarrow f = 0.25 \times 10^{11} \text{ Hz}$$

$$\boxed{\therefore f = 25 \text{ GHz}}$$

UNIT 5

MICROWAVE MEASUREMENTS

Marketed by: SIA GROUP

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. Define S-matrix and mention its properties.

Ans:

S-Matrix: The S-matrix (or) a scattering matrix is a matrix which is used to represent all inputs,which are applied to the ports of a given network in a matrix form. This is a square matrix which it gives all the relations of power input and output ports of a microwave junction. The elements in this matrix are known as 'scattering coefficients' (or) 'scattering parameters'.

The properties of S-matrix are,

1. Scattering matrix is always a square matrix.

   i.e., the order of s-matrix is $n \times n$.

2. It is a unitary matrix.

   i.e., $[S][S^*] = [I]$

3. It holds symmetrical property.

   i.e., $S_{ij} = S_{ji}$

   For, $k = 1, 2, \ldots, n$ and

   $j = 1, 2, \ldots, n$

   $\sum_{i=1}^{n} S_{ik} \cdot S_{ij}^* = 0$ for $k \neq j$

Q2. List the advantages of S-matrix

Model Paper-I, Q1(i)

Ans:

The advantages of S-matrix are,

1. The check unitary property of $[S]$ is used to the power of balance of lossless structure.
2. The [S]-parameters change only in phase if reference planes are changed.
3. The $[S]$ matrix describes the properties of the component (as, if it were a black box).
4. The properties of a $[S]$ matrix gives us a clear idea of what can be achieved and what cannot be achieved.

Q3. Explain why h, Y and Z parameters cannot be measured at microwave frequencies.

Model Paper-I, Q1(j)

Ans:

Z, Y and h-parameters are used in the analysis of low frequency circuits. Because at low frequencies, the total voltages and total currents are measured in the network analysis. But at microwave frequencies, travelling waves come into the analysis. For this we need to calculate the microwave powers associated with travelling waves. Due to this reason sealtering parameters are used at microwave frequencies instead of Z, Y and h-parameters.

Q4. How are microwave measurements different from low frequency measurements?

May-10, Set-3, Q2(b) M[8]

Ans:

The differences between low frequency and microwave measurements is mentioned below:

Low Frequency Measurement		Microwave Measurement	
1.	In order to measure the power, first we have to calculate voltage and current.	1.	Power is measured directly without calculating the current and the voltage.
2.	In case of power measurement, both input and output power must be known.	2.	Ratio of powers is enough.
3.	Circuits are lumped elements.	3.	Circuits are distributed.
4.	Exact values must be known.	4.	Exact values are not necessary.

Table

Q5. Define slotted line carriage, VSWR meter and bolometer.

Ans:

Slotted Line Carriage: Slotted line carriage is a microwave instrument which measure the wavelength, standing wave pattern along with its ratio, impedance, reflection coefficient and return loss measurement.

VSWR Meter: A VSWR meter is a high gain, high Q, low noise amplifier which is tuned normally to a fixed frequency a modulated microwave signal.

Bolometer: Bolometer is a simple temperature sensitive device, whose resistance varies with temperature. It is also called as square law device, since it produces a current which is proportional to the applied power i.e., square of the applied voltage.

Q6. What are the characteristics of detectors used in microwave measurements?

Ans:

Model Paper-II, Q1(l)

The characteristics of detectors used in microwave measurements are,

1. In order to detect low frequency square wave modulated microwave signal, a non-reciprocal detector diode must be mounted in the transmission line.

   Examples of these diodes are point contact diodes or Schottky barrier diodes.

2. To detect the modulated signal, a crystal detector is connected at one end of the waveguide.

3. In order to avoid amplitude and phase variations and to get perfect detection, a tunable stub is used to match the detector to the microwave transmission system and that tunable stub may be,

   (i) Tunable waveguide detector

   (ii) Tunable probe detector

   (iii) Tunable coaxial detector.

4. Schottky detector can be used in which the output is proportional to the input power.

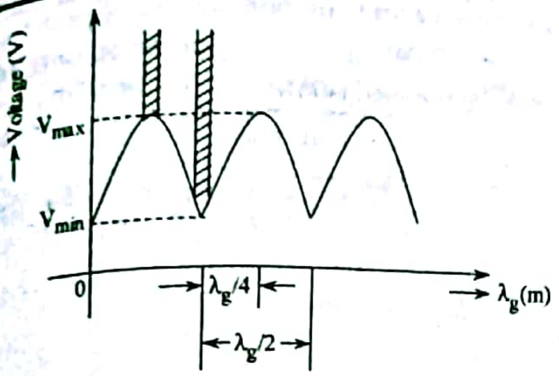
Q7. Define VSWR.

Model Paper-III, Q1(l)

Ans: Voltage standing wave ratio is defined as the ratio of maximum to minimum voltage on a line having standing waves i.e.,

$$\text{VSWR}, S = \left|\frac{V_{max}}{V_{min}}\right|$$

Figure shows the standing waves along the length of the line, which are due to the mismatch of load at the termination.



Figure

And, the expression for VSWR is given by,

$$S = \left|\frac{V_{max}}{V_{min}}\right| = \frac{1+|K|}{1-|K|}$$

Where,

K = Reflection coefficient = $\frac{V_r}{V_i}$

When $K = 0$, $S = 1$

When $K = 1$, $S = \infty$

When $K = \infty$, $S = 1$

Q8. Account for the different types of errors associated with the measurement of VSWR using a slotted line setup.

Ans: (Model Paper-II, Q1(j) | April-11, Set-4, Q4(b) M[8])

Following are the different types of errors associated with the measurement of *VSWR* using a slotted line setup.

1. Linearity error.
2. There is no accuracy in obtained results because of the limited dynamic range of detectors.
3. This process desires the manual interaction which, ultimately leads to an error.

Q9. Write short notes on reflection coefficient.

Ans: The reflection coefficient can be directly measured from the VSWR measurement using formulae given below.

$$K = \begin{cases} \left|\frac{S-1}{S+1}\right| \underline{4\pi\frac{d_1}{\lambda} - n\pi} \text{ , } n \text{ is odd} \\ \left|\frac{S-1}{S+1}\right| \underline{4\pi\frac{d_2}{\lambda} - n\pi} \text{ , } n \text{ is even} \end{cases}$$

Where,

d_1, d_2 = Distances in the standing wave pattern.

S = Voltage standing wave ratio.

λ = Length along the slotted line i.e., twice the distance between adjacent minima.

n = An integer value.

Q10. Two identical directional couplers are placed in a waveguide to sample the incident and the reflected power. The meter readings show that the power level of the reverse coupler is 10 dB down from the level of the forward coupler. What is the value of the SWR on the waveguide?

Ans: May-10, Set-3, Q2(a)

Given that,

For an arrangement of two identical directional couplers.

$$P_{reflected}(\text{dB}) = -10 \text{ dB} + P_{forward}(\text{dB})$$

SWR on the waveguide, ρ = ?

Then, converting above power relation into normal form as,

$$P_{reflected} = \left[\frac{P_{forward}}{10}\right] \quad \ldots (1)$$

But, the reflection coefficient is defined as, $\Gamma = \frac{P_{reflected}}{P_{forward}}$

Then, using equation (1), we get value of Γ as,

$$\Gamma = \frac{1}{10} = 0.1 \quad \ldots (2)$$

The SWR value (ρ) and reflection coefficient Γ are related as,

$$\Gamma = \frac{\rho-1}{\rho+1}$$

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

$$\Rightarrow \Gamma\rho - \rho = -1 - \Gamma$$

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

$$\Rightarrow \rho = \frac{1+\Gamma}{1-\Gamma}$$

$$\Rightarrow \rho = \frac{1+0.1}{1-0.1}$$

$$\Rightarrow \rho = \frac{1.1}{0.9}$$

$$= \frac{11}{9}$$

$$= 1.22$$

$$\boxed{\therefore \rho = 1.22}$$

Q11. An unmodulated microwave source is connected to a bolometer mount and an appropriate power meter. The microwave power level reads as 25 mW. When an attenuating device is inserted between the source and the bolometer, the power reading falls to 5 mW. What is amount of attenuation (in decibels) provided by the device?

Ans: (Model Paper-III, Q1(j) | May-10, Set-1, Q5(a) M[8])

Given that,

For an unmodulated microwave source connected to a bolometer,

Initial power, $P_1 = 25$ mW

Power after inserting attenuating device, $P_2 = 5$ mW

Attenuation, dB = ?

Attenuation in decibels can be calculated by using the following relation,

$$\text{Attenuation, dB} = 10 \log_{10}\left(\frac{P_1}{P_2}\right)$$

$$= 10 \log_{10}\left(\frac{25\,\text{mW}}{5\,\text{mW}}\right)$$

$$= 10 \log_{10}(5)$$

$$= 6.989$$

$$\boxed{\therefore \text{Attenuation} = 6.99\,\text{dB}}$$