Set - D (1)

Part - A

1(b)i) (b) A ~~f~~ high frequency semiconductor device operates in a material where the electron transit time is 2.5 ps. Calculate the fundamental frequency of the device.

ANS: To find the fundamental oscillation frequency of a high frequency device based on electron transit time;

$$f = \frac{1}{\tau} \quad [\tau = \text{Transit time}]$$

Given : $\tau = 2.5\,ps = 2.5 \times 10^{-12}\,s$ (picoseconds)

$$\therefore \quad f = \frac{1}{2.5 \times 10^{-12}}$$

$$= 4 \times 10^{11}\ Hz$$

$$= 400 \times 10^{9}\ Hz$$

$$= 400\,GHz$$

$\therefore$ The fundamental oscillation frequency of the device is 400 GHz.

ii) (b) The device is operating at 10 GHz has an input power of 2W at port 1. The power measured at port 2 is 1.6W, and the power measured at port 3 is 0.004W.

→ Calculate the insertion loss (in dB) between port 1 & port 2.

→ Calculate the isolation (in dB) between port 1 & port 3.

ANS: $f = 10\,GHz$

$$\text{Port } 1 = 2W$$
$$\text{Port } 2 = 1.6W$$
$$\text{Port } 3 = \cancel{0.04}\ 0.004W$$

→ Insertion loss (I_L) is the power loss during transmission from input to output.

$$I_L(dB) = -10\log_{10}(P_2/P_1)$$
$$= -10\log_{10}\left(\frac{1.6}{2}\right)$$
$$= -10\log_{10}(0.8)$$
$$= -10\times(-0.09691)$$
$$\simeq \boxed{0.97\ dB}$$

→ Isolation shows how much circulation surpresses unintended signal leakage at port 3.

$$\text{Isolation}(dB) = -10\log_{10}\left(\frac{P_3}{P_1}\right)$$
$$= -10\log_{10}\left(\frac{0.004}{2}\right)$$

$= -10 \times (-2.69897)$

$\simeq \boxed{26.99 \, dB}$

2 (b) A radar magnetron operates with an anode voltage of 40 kV and a cathode-anode separation of 3 cm. The required magnetic field is 0.25 T for proper operation.

i) Derive the equation for electron cyclotron frequency

ANS :

Lorentz force : $F = qvB$

$F \rightarrow$ Force

$q \rightarrow$ charge of electron $(q = -e)$

$v \rightarrow$ velocity

$B \rightarrow$ Mag. Field strength

Centripetal force required for circular motion :

$$F = mv^2/r$$

Equating both expressions :

$$qvB = mv^2/r$$

$$\Rightarrow r = mv/(qB)$$

Cyclotron angular frequency ω_c is :

$$\omega_c = v/r = qB/m$$

Cyclotron frequency (in Hz) : $f_c = \omega_c/(2\pi)$

$$= qB/(2\pi m)$$

For electron : $q = e = 1.6 \times 10^{-19}\, C$ & $m = 9.11 \times 10^{-31}\, Kg$

Final expression $\boxed{f_c = \dfrac{eB}{(2\pi m)}}$

(ii) Calculate cyclotron frequency for given magnetic field

ANS:

Mag. Field, $B = 0.25T$

charge of electron, $e = 1.6 \times 10^{-19} C$

Mass of electron, $m = 9.11 \times 10^{-31} Kg$

$$f_c = \frac{eB}{2\pi m}$$

$$= \frac{1.6 \times 10^{-19} \times 0.25}{2\pi \times 9.11 \times 10^{-31}}$$

$$= \frac{4 \times 10^{-20}}{5.722 \times 10^{-30}}$$

$$\simeq 6.99 \text{ GHz}$$

$$\therefore \boxed{f_c = 6.99 \text{GHz}}$$

3 (a) (i) S-Matrix Derivation

(ii) In an i/P power of 10 mW is applied at the horizontal input arm, how is the power distributed among the remaining three ports.

I/P Power = 10mW at Port 3 (H-Plane port)

From S-Matrix

$S_{31} = S_{32} = 1/\sqrt{2}$ → Power splits equally to Port 1 & Por 2

$S_{34} = 0$ → No power to Port 4

Power at Port 1 $= |S_{31}|^2 \times 10 = (1/\sqrt{2})^2 \times 10$

$= 0.5 \times 10$

$= 5mW$

Power at Port 2 $= |S_{32}|^2 \times 10 = (1/\sqrt{2})^2 \times 10$
$= 5mW$

Power at Port 4 $= 0mW$

Final Power Distribution:

→ Port 1 : 5mW

→ Port 2 : 5mW

→ Port 4 : 0mW

3(b) ii) An S-Parameter measurement shows $S_{21} = 0.89$ and $S_{11} = 0.25$.

(a) Calculate the insertion loss

(b) Calculate return loss

(c) Interpret the result in terms of system performance

Given : $S_{21} = 0.89$; $S_{11} = 0.25$

(a) Insertion loss (dB) $= -20 \log_{10} |S_{21}|$

$= -20 \log_{10} (0.89)$

$\simeq \boxed{1.01 dB}$

(b) Return loss (dB) $= -20 \log_{10} |S_{11}|$

$= -20 \log_{10} (0.25)$

$\simeq \boxed{12.04 dB}$

(c) Insertion Loss (1.01dB) : Indicates efficient transmission through the network with min power loss.

Return loss (12.04 dB) : Suggests about 6.3% of the power is reflected at Port 1. Matching is acceptable but could be improved.

4(b)

4(a) (ii) A microwave amplifier operates with a beam voltage of 5 kV and a beam current of 25 mA. Derive the formula for efficiency and calculate the efficiency if the RF output power is 120 W.

ANS: Beam voltage, $V_b = 5\,kV = 5\times10^3\,V$

Beam current, $I_b = 25\,mA = 25\times10^{-3}\,A$

RF output Power ; $P_{RF} = 120W$

$$\text{Efficiency}, \eta = \frac{\text{RF O/P Power}}{\text{I/P DC Power}} \times 100\%$$

$$= \frac{P_{RF}}{P_{DC}} \times 100\%$$

$$= \frac{P_{RF}}{V_b \times I_b} \times 100\% \quad [\because V_b \times I_b = P_{DC}]$$

$$= \frac{120}{5000 \times 0.25} \simeq 96\%$$

$$\therefore \boxed{\eta = 96\%}$$

4(b) ii) A non-reciprocal microwave device has the following S-Matrix:

$$S = \begin{bmatrix} 0 & 0.0001 \\ 1 & 0 \end{bmatrix}$$

(a) Calculate the insertion loss in dB for the forward direction

(b) Calculate the isolation in dB for the reverse direction

Ans: For a non-reciprocal microwave device,

$$S = \begin{bmatrix} 0 & 0.0001 \\ 1 & 0 \end{bmatrix}$$

Here; $S_{11} = S_{22} = 0$ [Matched]

$$S_{12} = 0.0001$$

$$S_{21} = 1$$

$\therefore S_{12} \neq S_{21}$ [Non-reciprocal]

(a) $\text{Insertion Loss(dB)} = -20 \log_{10} |S_{21}|$

$$= -20 \log_{10} (1)$$

$$\simeq 0\, dB$$

(b) Isolation (dB) (in Reverse direction) $= -20 \log_{10} |S_{12}|$

$$= -20 \log_{10} (0.0001)$$

$$= -20 \log_{10} (10^{-4})$$

$$= -20 \times (-4)$$

$$= 80\, dB$$