Dr. MAHALINGAM COLLEGE OF ENGINEERING AND TECHNOLOGY

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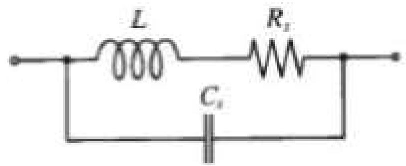
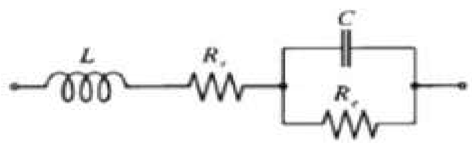
Question bank with answers – Unit 1&2

Name of Programme: BE-ECE

Course Code & Course Title: 16ECT72-RF and Microwave Engineering

UNIT1- Part- A Short Answer Questions (10X2=20 Marks)

Q. No	Question	CO No.	Revised Bloom's Cognitive Level	
			Question	CO
1	State the need for S Parameters in High frequency circuit analysis? 1. Equipment is not readily available to measure total voltage &total current at the ports of the network. 2. Short and open circuits are difficult to achieve over a broad band of frequencies. 3. Active devices, such as power transistor &tunnel diodes, frequently won't have stability for a short or open circuit.	CO1	U	An
2	List the Properties of s-matrix? 1. [S] is always a square matrix of order (n×n) 2. [S] is a symmetric matrix i.e. Sij =Sji 3. [S] is a unitary matrix i.e. [S] [S*] = [I] 4. Under perfect matched conditions, the diagonal elements of [S] are zero.	CO1	R	An
3	Define the S Matrix of a Two Port Network The scattering matrix is defined as the relationship between the forward and backward moving waves. For a two-port network, like any other set of two-port parameters, the scattering matrix is a 2×2 matrix. $\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$	CO1	R	An
4	Find insertion loss for s21=4 Insertion loss in db=-12.04	CO1	Ap	An
5	Differentiate Low frequency and High Frequency microwave circuits ✓ Large wavelength, no phase variation over the devices' physical dimension, circuit theory, lumped-element, R, L, C. ✓ Wavelength shorter than the device's physical dimension, transmission line theory needs to be introduced, distributed elements.	CO1	U	An
6	Analyze the inductor at radio frequency from its equivalent circuit. 	CO1	An	An
7	Analyze the capacitor at radio frequency from its equivalent circuit. 	CO1	An	An
8	List the different types of high frequency resistors. Wire wound Resistors Metal Film Resistors	CO1	R	An

	Thin Film Chip Resistor Thick Film Chip Resistors			
9.	Define skin effect Current density drops with decrease in *r* (proximity to the center) and skin depth decreases with increase in frequency current path conduction remains nearer to the periphery (skin effect) → means, current density towards center decreases with increase in frequency and increase in conductivity.	CO1	**R**	**An**
10.	List the characteristics of microwave ✓ Microwave Lengths are very small ✓ Microwave Pulses are very short so that they cab be used for distance or time measurement ✓ High frequency of microwave means very large bandwidth is available for communication ✓ Microwave Radiation penetrates fog and clouds, travels in straight lines and give reflections hence can be used for distance and direction measurement ✓ Microwaves are necessary for communication through satellite because they can pass through ionosphere which reflects low frequency waves ✓ Microwave Power is absorbed by water or another material containing water so that microwaves can be used for heating and drying	CO1	**R**	**An**
UNIT2- Part- A	**Short Answer Questions**	**(10X2=20 Marks)**		
1	State the applications of microwaves. i) Medical applications (ii) Domestic and industrial (iii)Navigation (iv) Communication	CO1	**R**	**An**
2	Define ferrites? Why is it needed in Isolators? Ferrites are the material having non reciprocal property. That is forward characteristics are different from reverse characteristics. It exhibit faradays rotation when waves pass through it. Ferrite isolator components are two-port passive RF or microwave devices made of magnets and ferrite material which is used to protect other RF components or microwave components from excessive signal reflection.	CO1	**R**	**An**
3	List the Microwave Frequency band	CO2	**R**	**U**
4	Draw the neat diagram of waveguide Bend and mention the design parameters	CO2	**R**	**U**

Microwaves Frequency Bands

Band	Frequency range
HF Band	3 to 30 MHz
VHF Band	30 to 300 MHz
UHF Band	300 to 1000 MHz
L Band	1 to 2 GHz
S Band	2 to 4 GHz
C Band	4 to 8 GHz
X Band	8 to 12 GHz
Ku Band	12 to 18 GHz
K Band	18 to 27 GHz
Ka Band	27 to 40 GHz
V Band	40 to 75 GHz
W Band	75 to 110 GHz
mm Band	110 to 300 GHz

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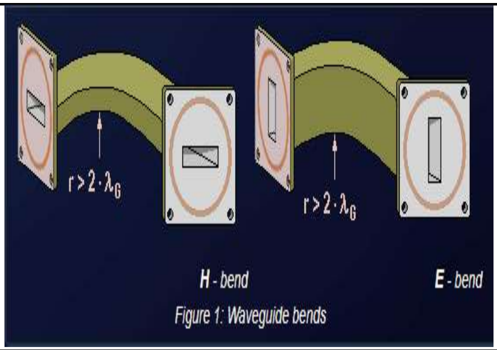
<tr><td></td><td>

Figure 1: Waveguide bends</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>Isolator is called as Uniline-Justify
An ideal isolator completely absorbs the power for propagation in one direction and provides lossless transmission in the opposite direction</td><td>CO2</td><td>U</td><td>U</td></tr>
<tr><td>6</td><td>Write the S-matrix of 3 port circulators?
Anticlockwise $[S]= \begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{matrix}$
Clockwise $[S]= \begin{matrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{matrix}$</td><td>CO3</td><td>R</td><td>An</td></tr>
<tr><td>7</td><td>Give the differences between Isolator and Circulator
<table>
<tr><td>Isolator</td><td>Circulator</td></tr>
<tr><td>2 port device</td><td>3 port device</td></tr>
<tr><td>It cannot be used as circulator</td><td>It is used as isolator by terminating one port</td></tr>
<tr><td>If input is given in port 1,output is obtained at port 2 and vice versa</td><td>Each terminal is connected only to the next terminal</td></tr>
</table></td><td>CO3</td><td>R</td><td>An</td></tr>
<tr><td>8</td><td>State the purpose of microwave terminators
They are used to absorb energy and prevent a signal from reflecting back from open-ended or unused ports.</td><td></td><td></td><td></td></tr>
<tr><td>9.</td><td>A waveguide termination having VSWR of 1.1 is used to dissipate 100 watts of power, Calculate the reflected power.
$T=S-1/S+1 = 1.1-1/1.1+1=0.04762$
$Pr=T^2 \ Pin =0.04762^2 \times 100= 0.2268W$</td><td>CO2</td><td>U</td><td>U</td></tr>
<tr><td>10</td><td>A waveguide termination having VSWR of 1.2 is used to dissipate 50 watts of power, Calculate the reflected power.
$T=S-1/S+1 = 1.2-1/1.2+1=0.0909$
$Pr=T^2 \ Pin =0.04762^2 \times 50= 0.4132W$</td><td>CO2</td><td>U</td><td>U</td></tr>
</table>

11. State and prove the various properties of S Parameters

1. S] is always a square matrix of order (n×n)
2. [S] is a symmetric matrix i.e. Sij =Sji
3. [S] is a unitary matrix i.e. [S] [S*] = [I]
4. Under perfect matched conditions, the diagonal elements of [S] are zero.

Property (1) : When any Z1h port is perfectly matched to the junction, then there are no reflections from that port. Thus S ..= O. If all the ports are perfectly matched, then the leading diagonal II elements will all be zero.

Property (2) : Symmetric Property of S-matrix:- If a microwave junction satisfies reciprocity condition and if there are no active *devices,* then S parameters are equal to their corresponding transposes.

$[S]$ is a symmetric matrix

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

$[S]$ is a unitary matrix

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

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

$$(k = 1, 2, 3, \ldots \; n) \; and \; (j = 1, 2, 3, \ldots \; n)$$

from port n. The scattering matrix, or $[S]$ matrix, is defined in relation to these incident and reflected voltage waves as

$$\begin{bmatrix} V_1^- \\ V_2^- \\ \vdots \\ V_N^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & & & \vdots \\ S_{N1} & \cdots & & S_{NN} \\ \vdots & & & \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \vdots \\ V_N^+ \end{bmatrix},$$

or

$$[V^-] = [S][V^+].$$

A specific element of the scattering matrix can be determined as

$$S_{ij} = \left. \frac{V_i^-}{V_j^+} \right|_{V_k^+ = 0 \text{ for } k \neq j}.$$

Phase shift property

$$V_n'^{+} = V_n^{+} e^{j\theta_n},$$
$$V_n'^{-} = V_n^{-} e^{-j\theta_n}.$$

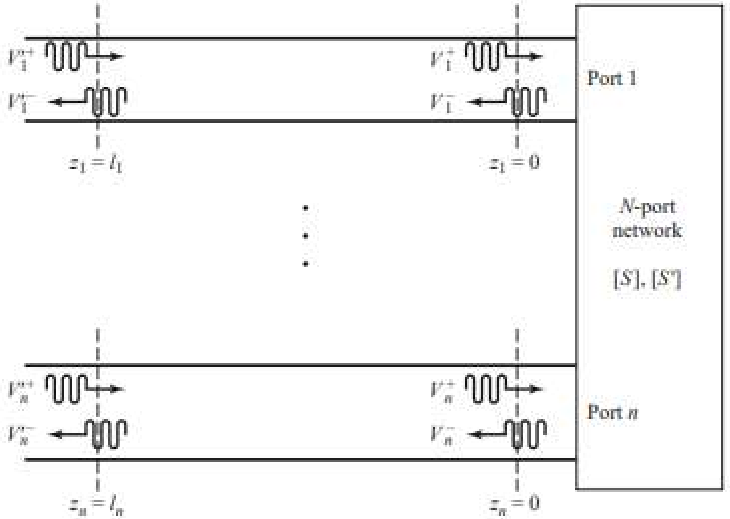


FIGURE 4.9 Shifting reference planes for an N-port network.

$$\begin{bmatrix} e^{j\theta_1} & & 0 \\ & e^{j\theta_2} & \\ & \ddots & \\ 0 & & e^{j\theta_N} \end{bmatrix} [V'^{-}] = [S] \begin{bmatrix} e^{-j\theta_1} & & 0 \\ & e^{-j\theta_2} & \\ & \ddots & \\ 0 & & e^{-j\theta_N} \end{bmatrix} [V'^{+}].$$

Multiplying by the inverse of the first matrix on the left gives

$$[V'^{-}] = \begin{bmatrix} e^{-j\theta_1} & & 0 \\ & e^{-j\theta_2} & \\ & \ddots & \\ 0 & & e^{-j\theta_N} \end{bmatrix} [S] \begin{bmatrix} e^{-j\theta_1} & & 0 \\ & e^{-j\theta_2} & \\ & \ddots & \\ 0 & & e^{-j\theta_N} \end{bmatrix} [V'^{+}].$$

Comparing with (4.54b) shows that

$$[S'] = \begin{bmatrix} e^{-j\theta_1} & & 0 \\ & e^{-j\theta_2} & \\ & \ddots & \\ 0 & & e^{-j\theta_N} \end{bmatrix} [S] \begin{bmatrix} e^{-j\theta_1} & & 0 \\ & e^{-j\theta_2} & \\ & \ddots & \\ 0 & & e^{-j\theta_N} \end{bmatrix}.$$

12a) A two-port network is known to have the following scattering matrix(6):

$$[S] = \begin{bmatrix} 0.15\angle 0^\circ & 0.85\angle -45^\circ \\ 0.85\angle 45^\circ & 0.2\angle 0^\circ \end{bmatrix}$$

Determine if the network is reciprocal and lossless. If port 2 is terminated with a matched load, what is the return loss seen at port 1? If port 2 is terminated with a short circuit, what is the return loss seen at port 1?

$$|S_{11}|^2 + |S_{21}|^2 = (0.15)^2 + (0.85)^2 = 0.745 \neq 1,$$

so the network is not lossless.

When port 2 is terminated with a matched load, the reflection coefficient seen at port 1 is $\Gamma = S_{11} = 0.15$. So the return loss is

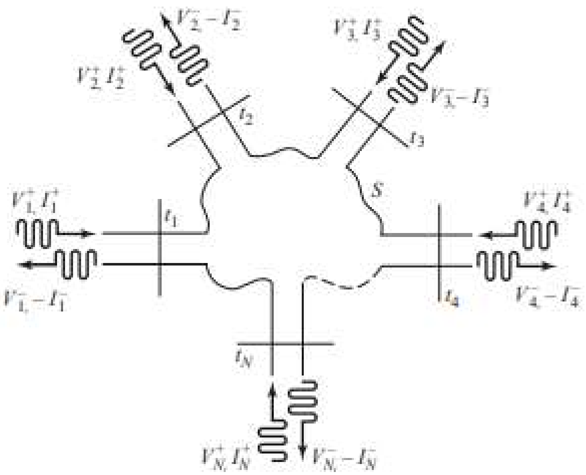
$$\mathrm{RL} = -20\log|\Gamma| = -20\log(0.15) = 16.5\ \mathrm{dB}.$$

$$\Gamma = \frac{V_1^-}{V_1^+} = S_{11} - S_{12}\frac{V_2^-}{V_1^+} = S_{11} - \frac{S_{12}S_{21}}{1 + S_{22}}$$

$$= 0.15 - \frac{(0.85\angle -45^\circ)(0.85\angle 45^\circ)}{1 + 0.2} = -0.452.$$

So the return loss is $\mathrm{RL} = -20\log|\Gamma| = -20\log(0.452) = 6.9\ \mathrm{dB}$.

12b Explain the formulation of N port S-matrix 10



An arbitrary N-port microwave network.

$$V_n = V_n^+ + V_n^-,$$
$$I_n = I_n^+ - I_n^-,$$

The impedance matrix $[Z]$ of the microwave network then relates these voltages and currents:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} \\ Z_{21} & & & \vdots \\ \vdots & & & \vdots \\ Z_{N1} & \cdots & \cdots & Z_{NN} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix},$$

$$[V] = [Z][I].$$

Similarly, we can define an admittance matrix [Y] as

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1N} \\ Y_{21} & & & \vdots \\ \vdots & & & \vdots \\ Y_{N1} & \cdots & \cdots & Y_{NN} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix},$$

or in matrix form as

$$[I] = [Y][V].$$

Of course, the $[Z]$ and $[Y]$ matrices are the inverses of each other:

$$[Y] = [Z]^{-1}.$$

Note that both the $[Z]$ and $[Y]$ matrices relate the total port voltages and currents.

From (4.25), we see that Z_{ij} can be found as

$$Z_{ij} = \left.\frac{V_i}{I_j}\right|_{I_k=0 \text{ for } k\neq j}. \qquad Y_{ij} = \left.\frac{I_i}{V_j}\right|_{V_k=0 \text{ for } k\neq j},$$

13. A four port network has the scattering matrix shown below

$$S= \begin{bmatrix} 0.1\angle 90^0 & 0.8\angle -45^0 & 0.3\angle 45^0 & 0 \\ 0.8\angle -45^0 & 0 & 0 & 0.4\angle 45^0 \\ 0.3\angle -45^0 & 0 & 0 & 0.6\angle -45^0 \\ 0 & 0.4\angle 45^0 & 0.6\angle -45^0 & 0 \end{bmatrix}$$

.

(i) Is this network lossless?

(ii) Is this network Reciprocal?

(iii) What is the return loss at port 1 when all other ports are terminated with matched loads?

(iv) What is the insertion loss between ports 2 and 4, when all other ports are terminated with matched loads?

(v) What is the reflection coefficient seen at port 1 in a short circuit is placed at the terminal plane of port 3, and all other ports are terminated with matched loads?

. (i) $[S11]^2 + [S12]^2 + [S13]^2 + [S14]^2 = 0.74 \neq 1$ so not lossless

(ii) reciprocal $[s]=[s]^T$

(iii) Return loss (dB) $= 10 \log \frac{P_i}{P_r} = 20 \log \frac{1}{|\Gamma|} = 20 \log \frac{1}{|S_{11}|}$ =20 db

(iv) insertion loss= $20 \log \frac{1}{|S_{21}|} = 20 \log \frac{1}{|S_{12}|}$ = 7.95dB

(v) reflection coefficient =0.1+j0.882

14. For the given S matrix,
(i) Verify the reciprocal and lossless property
(ii) Find the return loss at Port 1 when all other ports are terminated with matched load
(iii) Find the Insertion loss between Port 2 and Port 4 when all other ports are matched
(iv)Calculate the reflection coefficient at port 1 when port 3 is short circuited and all other ports are matched.

$$S = \begin{bmatrix} 0.1\angle 90^\circ & 0.6\angle -45^\circ & 0.6\angle 45^\circ & 0 \\ 0.6\angle -45^\circ & 0 & 0 & 0.6\angle 45^\circ \\ 0.6\angle 45^\circ & 0 & 0 & 0.6\angle -45^\circ \\ 0 & 0.6\angle 45^\circ & 0.6\angle -45^\circ & 0 \end{bmatrix}$$

(i) $[S11]^2 + [S12]^2 + [S13]^2 + [S14]^2 = 0.74 = 1$ so not lossless and Reciprocal $[s]=[s]^T$

(ii) Return loss (dB) $= 10 \log \frac{P_i}{P_r} = 20 \log \frac{1}{|\Gamma|} = 20 \log \frac{1}{|S_{11}|}$ =20

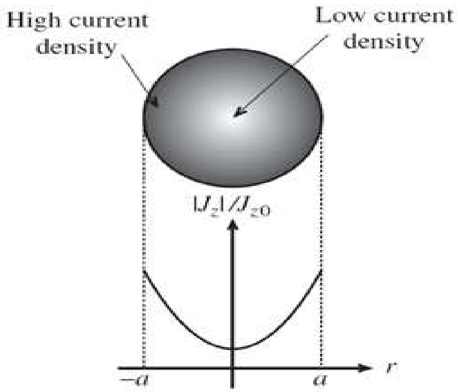
III) insertion loss= $20 \log \frac{1}{|S_{24}|} = 20 \log \frac{1}{|.6|}$ =4.45

(iv) reflection coefficient=.2595j

<u>**15. Explain the RF passive components**</u>

Wire-wound Resistors:

At DC, current flows uniformly distributed over the entire conductor cross-sectional area.
At AC, the alternating charge carrier flow establishes a magnetic field that induces an electric field (Faraday's Law) whose associated current density opposes the initial current flow → this effect is very strong at the center (r=0) where the impedance is substantially increased → as a result the current flow resides at the outer periphery with the increasing frequency.



DC Current Density: $\boxed{J_{z0} = \frac{I}{\pi a^2}}$.

- The current density at AC is given by: $J_z = \frac{pI}{2\pi a j\sqrt{r}} \exp\left(-(1+j)\frac{a-r}{\delta}\right)$

$$\boxed{p^2 = -j\omega\mu\sigma_{cond}}$$

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma_{cond}}}$$

Skin Depth

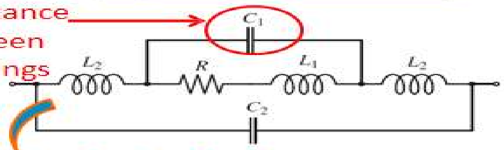
- J_z drops with decrease in r. (proximity to the center)
- δ decreases with increase in frequency (skin depth from periphery reduces with increased frequency) → means the path for current conduction remains nearer to the periphery (skin effect) → means, current density towards center decreases with increase in frequency and increase in conductivity

2. Wire-wound Resistors:

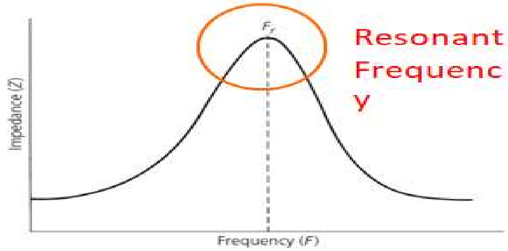
- Exhibit widely varying impedances over various frequencies.
- The inductor L is much larger here as compared to carbon-composition resistor.
- These resistors look like inductors → impedances will increase with increase in frequency.
- At some frequency F_r, the inductance will resonate with shunt capacitance →leads to decrease in impedance.

Equivalent Ckt Model:

Capacitance between Windings



L_2: lead inductance
L_1: inductance of resistive wires
C_2: Interlead Capacitance

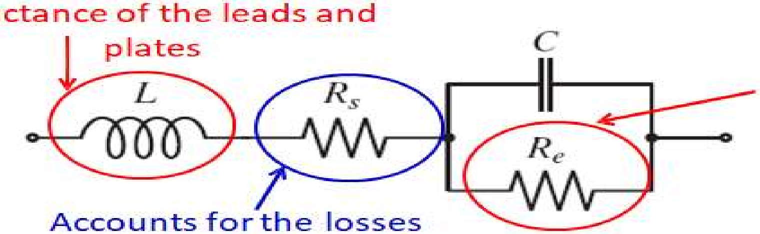


Resonant Frequency

Capacitors at High Frequencies

Equivalent Circuit Representation of a Capacitor → for a parallel-plate

Inductance of the leads and plates



Represents Insulation Resistance

Accounts for the losses in the leads

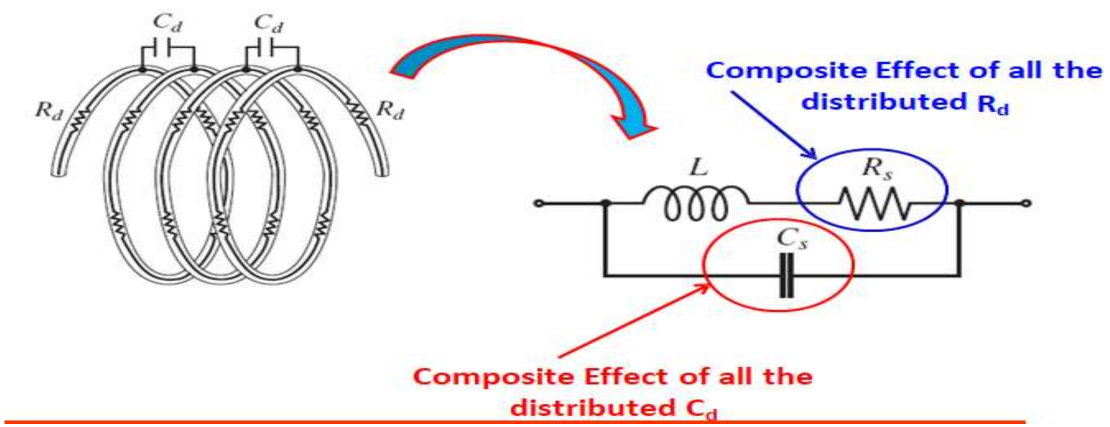
$$C=\frac{\varepsilon A}{d}=\varepsilon\varepsilon_r\frac{A}{d}$$

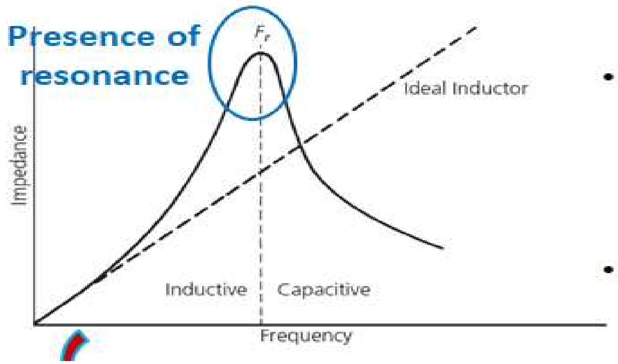
At high frequency, the dielectric become lossy i.e., there is conduction current through it

Then impedance of capacitor becomes a parallel combination of C and conductance G_e

- Above F_r, the capacitor behaves as an inductor.
- In general, larger-value capacitors tend to exhibit more internal inductance than smaller-value capacitors.
- Therefore, it may happen that a $0.1\mu F$ may not be as a good as a $300pF$ capacitor in a bypass application at $250\ MHz$.
- The issue is due to significance of lead inductances at higher frequencies.

Equivalent Circuit Representation of an Inductor → coil type



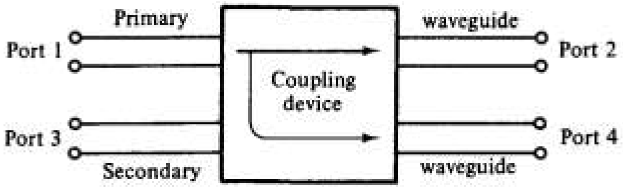


- Initially the reactance of inductor follows the ideal but soon departs from it and increases rapidly until it reaches a peak at the inductor's resonant frequency (F_r). **Why?**
- Above F_r, the inductor starts to behave as a capacitor.

UNIT2 - Part- B Descriptive – either or questions (2X15=30 Marks)

(11) (i) Explain the working of directional coupler and derive its S matrix --- 15

A directional coupler is a four-port waveguide junction as shown in Fig. 1. It consists of a primary waveguide 1-2 and a secondary waveguide 3-4. When all ports are terminated in their characteristic impedances, there is free transmission of power, without reflection, between port 1 and port 2, and there is no transmission of power between port 1 and port 3 or between port 2 and port 4 because no coupling exists between these two pairs of ports. The degree of coupling between port 1 and port 4 and between port 2 and port 3 depends on the structure of the coupler. The characteristics of a directional coupler can be expressed in terms of its coupling factor and its directivity. Assuming that the wave is propagating from port l to port 2 in the primary line, the coupling factor and the directivity are defined,



$$\text{Coupling factor (dB)} = 10 \log_{10} \frac{P_1}{P_4}$$

$$\text{Directivity (dB)} = 10 \log_{10} \frac{P_4}{P_3}$$

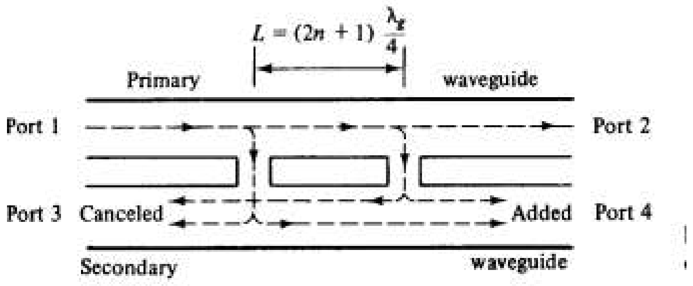
where P_1 = power input to port 1
P_3 = power output from port 3
P_4 = power output from port 4

Several types of directional couplers exist, such as a two-hole directional couler, four-hole directional coupler, reverse-coupling directional coupler (Schwinger coupler), and Bethe-hole directional coupler

Two-Hole Directional Couplers A two-hole directional coupler with traveling waves propagating in it is illustrated in Fig. 2. The spacing between the centers of two holes must be

$$L = (2n + 1)\frac{\lambda_g}{4}$$

where n is any positive integer.



A fraction of the wave energy entered into port 1 passes through the holes and is radiated into the secondary guide as the holes act as slot antennas. The forward waves in the secondary guide are in the same phase, regardless of the hole space, and are added at port 4. The backward waves in the secondary guide (waves are progressing from right to left) are out of phase by (2L/ A8)27T rad and are canceled at port 3.

In a directional coupler all four ports are completely matched. Thus the diagonal elements of the S matrix are zeros and

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

As noted, there is no coupling between port 1 and port 3 and between port 2 and port 4. Thus

$$S_{13} = S_{31} = S_{24} = S_{42} = 0$$

Consequently, the **S** matrix of a directional coupler becomes

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

zero property of the S matrix, so we have

$$S_{21}S_{23}^* + S_{41}S_{43}^* = 0$$

Also from the unity property of the **S** matrix, we can write

$$S_{12}S_{12}^* + S_{14}S_{14}^* = 1$$

Equations (4-5-7) and (4-5-8) can also be written

$$|S_{12}||S_{14}| = |S_{32}||S_{34}|$$

$$|S_{21}||S_{23}| = |S_{41}||S_{43}|$$

Since $S_{12} = S_{21}$, $S_{14} = S_{41}$, $S_{23} = S_{32}$, and $S_{34} = S_{43}$, then

$$|S_{12}| = |S_{34}|$$

$$|S_{14}| = |S_{23}|$$

Let

$$S_{12} = S_{34} = p$$

where p is positive and real. Then from Eq. (4-5-8)

$$p(S_{23}^* + S_{41}) = 0$$

Let

$$S_{23} = S_{41} = jq$$

where q is positive and real. Then from Eq. (4-5-9)

$$p^2 + q^2 = 1$$

$$S_{12}S_{14}^* + S_{32}S_{34}^* = 0$$

The **S** matrix of a directional coupler is reduced to

$$\mathbf{S} = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix}$$

This is S-matix of directional coupler.

12 (i) Explain the working of Magic Tee with neat diagram and derive its Scattering Matrix. –15M

A magic tee is a combination of the £-plane tee and H -plane tee and the magic tee has several characteristics:

1.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.

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

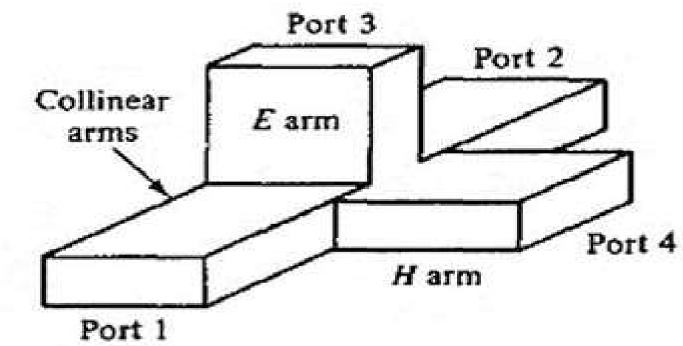
3. If a wave is fed into port 3 (the E arm), it will produce an output of equal magnitude and opposite phase at port 1 and port 2. The output at port 4 is zero. That is, 543 = S34 = 0.

4. 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 Harm causes a phase advance. That is, S12 = S21 = 0.

Therefore the S matrix of a magic tee can be expressed as

$$\mathbf{S} = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix}$$

The magic tee is commonly used for mixing, duplexing, and impedance measurements.



Magic tee

The general matrix of the magic tee is given by,

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} ------(1)$$

From the property of Symmetry,

$S_{14} = S_{41}$,

$S_{13} = S_{31}$,

$S_{23} = S_{32}$ ---------------- (2)

Since port 3 acts as the E plane Tee,

$S_{13} = -S_{23}$ ------------------- (3)

Since port 4 acts as H plane Tee, $S_{14} = S_{24}$ ---------------- (4)

$S_{34} = -S_{43} = 0$ and
$S_{12} = -S_{21} = 0$ ---------------- (5)

If port 3 and port 4 are matched,
$S_{33} = S_{44} = 0$ ---------------- (6)

Applying equation (2) to (6) in equation (1)

$$S = \begin{bmatrix} S_{11} & 0 & S_{13} & S_{14} \\ 0 & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix} ------(7)$$

By unitary property, [S][S*] = I

$$\begin{bmatrix} S_{11} & 0 & S_{13} & S_{14} \\ 0 & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & 0 & S_{13}^* & S_{14}^* \\ 0 & S_{22}^* & -S_{13}^* & S_{14}^* \\ S_{13}^* & -S_{13}^* & 0 & 0 \\ S_{14}^* & S_{14}^* & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

R_1C_1 => $|S_{11}|^2+|S_{13}|^2+|S_{14}|^2 = 1$ -------------- (8)
R_2C_2 => $|S_{22}|^2+|S_{13}|^2+|S_{14}|^2 = 1$--------------- (9)

R_3C_3 => $2|S_{13}|^2 = 1$
$S_{13} = 1/\sqrt{2}$ -------------- (10)
R_4C_4 => $2|S_{14}|^2 = 1$
$S_{14} = 1/\sqrt{2}$ ----------------- (11)

Substitute, Equation (10) and (11) in equation (8)

$|S_{11}|^2 + (1/\sqrt{2})^2 + (1/\sqrt{2})^2 = 1$
$|S_{11}|^2 = 1 - 1$
=> $S_{11} = 0$

Equating equation (8) and (9)

We get, $S_{11} = S_{22}$

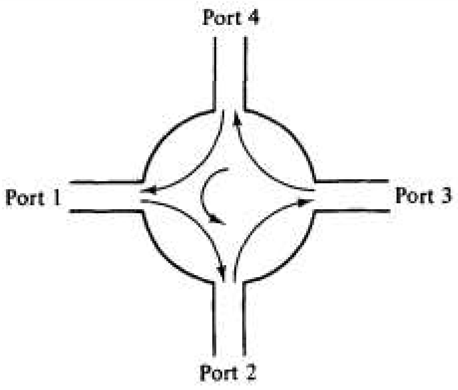
Therefore the s matrix of magic tee is,

$$S = \begin{bmatrix} 0 & 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & 0 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \end{bmatrix}$$

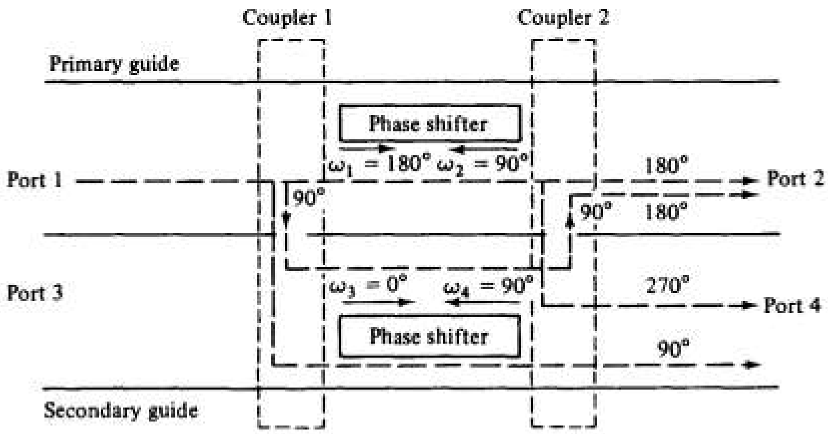
13. Explain the working of circulator and isolator with neat sketch and S Matrix -- 8+7M

Both microwave circulators and microwave isolators are nonreciprocal transmission devices that use the property of Faraday rotation in the ferrite material. In order to understand the operating principles of circulators and isolators,

Microwave Circulators A microwave circulator is a multiport waveguide junction in which the wave can flow only from the nth port to the (n + l)th port in one direction (see Fig. 4-6-2). Although there is no restriction on the number of ports, the four-port microwave circulator is the most common. One type of four-port microwave circulator is a combination of two 3-dB side-hole directional couplers and a rectangular waveguide with two nonreciprocal phase shifters



The symbol of a circulator.



Schematic diagram of four-port circulator.

- ✓ The operating principle of a typical microwave circulator can be analyzed with the aid of Fig.
- ✓ Each of the two 3-dB couplers in the circulator introduces a phase shift of 90°, and each of the two phase shifters produces a certain amount of phase change in a certain direction as indicated.
- ✓ When a wave is incident to port 1, the wave is split into two components by coupler 1. The wave in the primary guide arrives at port 2 with a relative phase change of 180°. The second wave propagates through the two couplers and the secondary guide and arrives at port 2 with a relative phase shift of 180°.

- ✓ Since the two waves reaching port 2 are in phase, the power transmission is obtained from port 1 to port 2. However, the wave propagates through the primary guide, phase shifter, and coupler 2 and arrives at port 4 with a phase change of 270°.
- ✓ The wave travels through coupler 1 and the secondary guide, and it arrives at port 4 with a phase shift of 90°.
- ✓ Since the two waves reaching port 4 are out of phase by 180°, the power transmission from port 1 to port 4 is zero.
- ✓ In general, the differential propagation constants in the two directions of propagation in a waveguide containing ferrite phase shifters should be

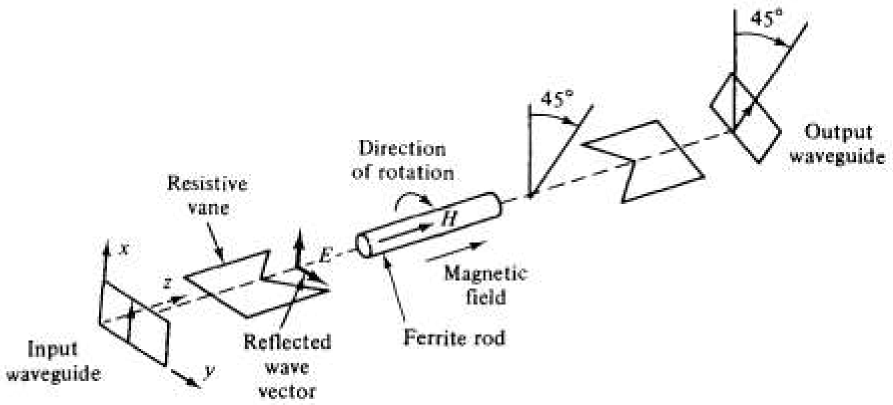
$$\omega_1 - \omega_3 = (2m + 1)\pi \qquad \text{rad/s}$$

$$\omega_2 - \omega_4 = 2n\pi \qquad \text{rad/s}$$

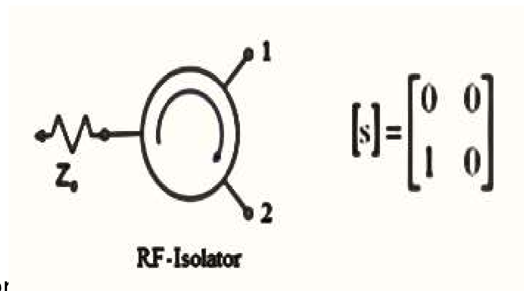
- ✓ A perfectly matched, lossless, and nonreciprocal four-port circulator has an S matrix of the form

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{21} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & S_{34} \\ S_{41} & S_{42} & S_{43} & 0 \end{bmatrix} \qquad \mathbf{S} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

- ✓
- ✓ An *isolator* is a nonreciprocal transmission device that is used to isolate one component from reflections of other components in the transmission line.
- ✓ An ideal isolator completely absorbs the power for propagation in one direction and provides lossless transmission in the opposite direction.
- ✓ Thus the isolator is usually called **uniline.**



- ✓ Faraday-rotation isolator

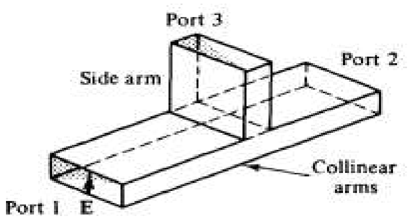


- ✓ Isolators are generally used to improve the frequency stability of microwave generators, such as klystrons and magnetrons, in which the reflection from the load affects the generating frequency.
- ✓ In such cases, the isolator placed between the generator and load prevents the reflected power from the unmatched load from returning to the generator.
- ✓ As a result, the isolator maintains the frequency stability of the generator. Isolators can be constructed in many ways

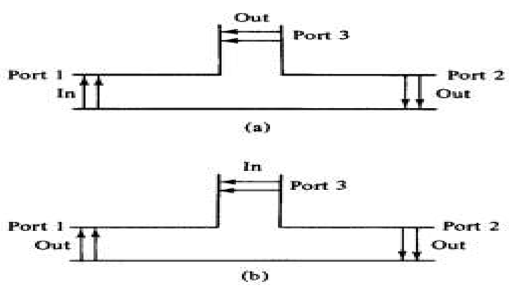
- ✓ They can be made by terminating ports 3 and 4 of a four-port circulator with matched loads.
- ✓ On the other hand, isolators can be made by inserting a ferrite rod along the axis of a rectangular waveguide
- ✓ The input resistive card is in the *y-z* plane, and the output resistive card is displaced 45° with respect to the input card. The de magnetic field, which is applied longitudinally to the ferrite rod, rotates the wave plane of polarization by 45°.
- ✓ The degrees of rotation depend on the length and diameter of the rod and on the applied de magnetic field. An input TE10 dominant mode is incident to the left end of the isolator.
- ✓ Since the TE10 mode wave is perpendicular to the input resistive card, the wave passes through the ferrite rod without attenuation. The wave in the ferrite rod section is rotated clockwise by 45° and is normal to the output resistive card. As a result of rotation, the wave arrives at the output end without attenuation at all
- ✓ On the contrary, a reflected wave from the output end is similarly rotated clockwise 45° by the ferrite rod. However, since the reflected wave is parallel to the input resistive card, the wave is thereby absorbed by the input card.
- ✓ The typical performance of these isolators is about 1-dB insertion loss in forward transmission and about 20- to 30-dB isolation in reverse attenuation.

14 a) Explain the E-plane and H-plane Tee with suitable sketch and its S-match -8M

E-plane tee {series tee). An £-plane tee is a waveguide tee in which the axis of its side arm is parallel to the E field of the main guide (see Fig. 4-4-4). If the collinear arms are symmetric about the side arm, there are two different transmission characteristics. if the E - plane tee is perfectly matched with the aid of screw tuners or inductive or capacitive windows at the junction, the diagonal components of the scattering matrix, S11, S22, and S33, are zero because there will be no reflection. When the waves are fed into the side arm (port 3), the waves appearing at port l and port 2 of the collinear arm will be in opposite phase and in the same magnitude. Therefore



$$S_{13} = -S_{23}$$



Two-way transmission of £-plane tee. (a) Input through main arm. (b) Input from side arm.

For a matched junction, the **S** matrix is given by

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

From the symmetry property of **S** matrix, the symmetric terms i equal and they are

$$S_{12} = S_{21} \qquad S_{13} = S_{31} \qquad S_{23} = S_{32}$$

From the zero property of **S** matrix, the sum of the products of each te column (or row) multiplied by the complex conjugate of the correspondin any other column (or row) is zero and it is

$$S_{11}S_{12}^* + S_{21}S_{22}^* + S_{31}S_{32}^* = 0$$

$$S_{21}S_{21}^* + S_{31}S_{31}^* = 1$$

$$S_{12}S_{12}^* + S_{32}S_{32}^* = 1$$

$$S_{13}S_{13}^* + S_{23}S_{23}^* = 1$$

Hence

$$S_{13}S_{23}^* = 0$$

$$S_{21}S_{21}^* + S_{31}S_{31}^* = 1 \tag{4-4-17}$$

$$S_{12}S_{12}^* + S_{32}S_{32}^* = 1 \tag{4-4-18}$$

$$S_{13}S_{13}^* + S_{23}S_{23}^* = 1 \tag{4-4-19}$$

Substitution of Eq. (4-4-14) in (4-4-17) results in

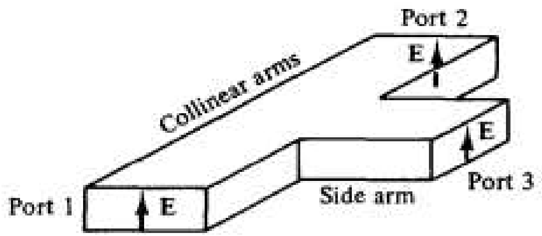
$$|S_{12}|^2 = 1 - |S_{13}|^2 = 1 - |S_{23}|^2 \tag{4-4-20}$$

Equations (4-4-19) and (4-4-20) are contradictory, for if $S_{13} = 0$, then S_{23} is also

when an £-plane tee is constructed of an empty waveguide, it is poorly matched at the tee junction. Hence SiJ * 0 if i = j. However, since the collinear arm is usually symmetric about the side arm, [S13] = [S23] and S11 = S22. Then the S matrix can be simplified t

$$\mathbf{S} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & -S_{13} \\ S_{13} & -S_{13} & S_{33} \end{bmatrix}$$

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 in fig



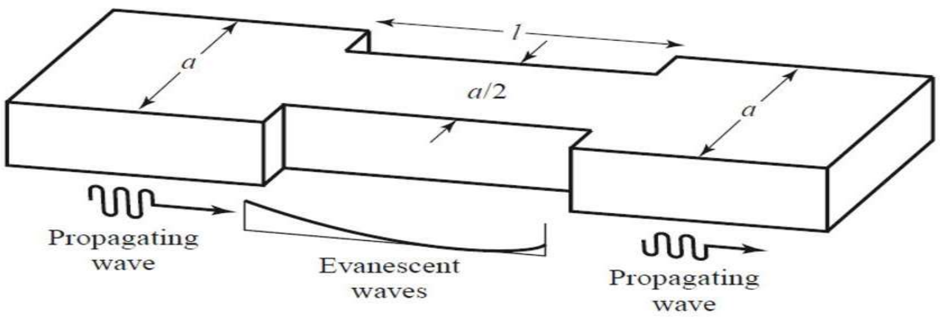
It can be seen that if two input waves are fed into port 1 and port 2 of the collinear arm, the output wave at port 3 will be in phase and additive. On the other hand, if the input is fed into port 3, the wave will split equally into port 1 and port 2 in phase and in the same magnitude. Therefore the S matrix of the H-plane tee is similar to except that $S_{13} = S_{23}$

15 (i) Explain the working of attenuator with neat diagram and also explain precision type variable attenuator. 12M

The attenuators are basically passive devices which control power levels in microwave system by absorption of the signal. Attenuator which attenuates the RF signal in a waveguide system is referred as **waveguide attenuator.** They are achieved by insertion of resistive films (aquadag).

- Waveguide attenuation is often based on the cut off principle where a section of the waveguide is operating frequency far below the cut off frequency — a frequency that directly correlated with the dimensions of the waveguide, below which the waveguide is unable to carry signals.

For a rectangular waveguide, the length of the broadwall is generally equal ½ wavelength of the lower cut off frequency



- Microwave energy will therefore dissipate very rapidly in sections where the H-plane is shunted as shown in ***Figure 1***. This rate of decay is exponential along the transmission path of the signal. As the cut off frequency increases, so does the rate of attenuation of the modes below cut off frequency. And since waveguides can operate with many modes existing simultaneously, the dominant mode is used; the mode with the lowest decay rate and lowest cut off frequency There are two main types of attenuators
- Fixed Attenuator
- Variable Attenuator

<u>Precision type Variable Attenuators</u>

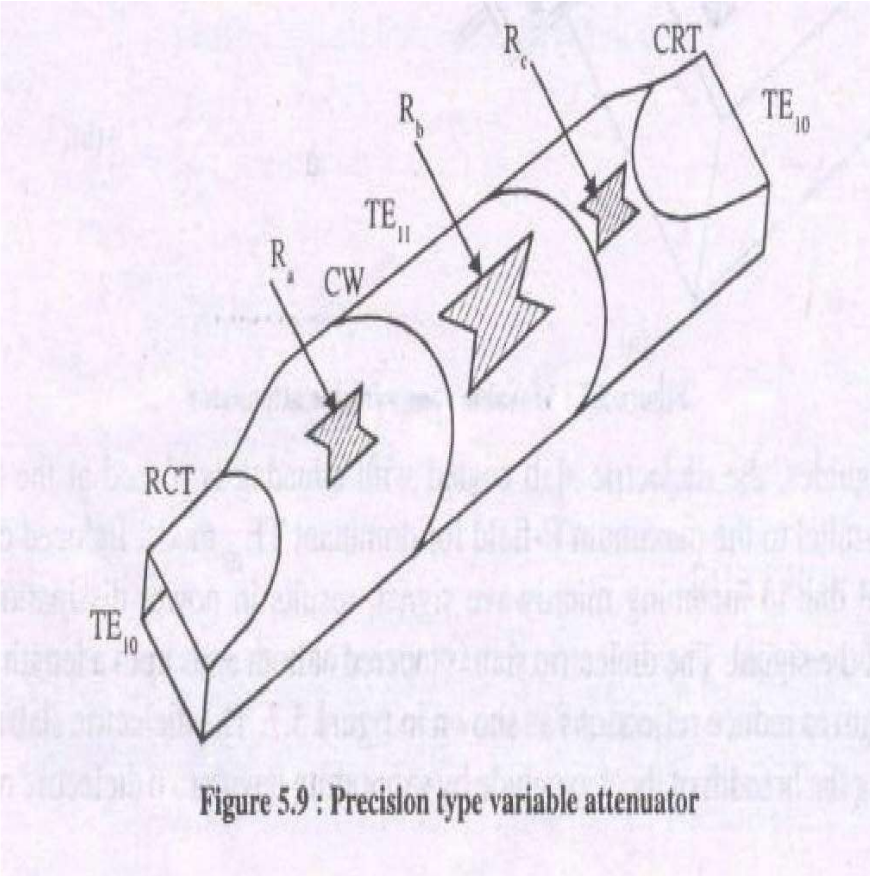


Figure 5.9 : Precision type variable attenuator

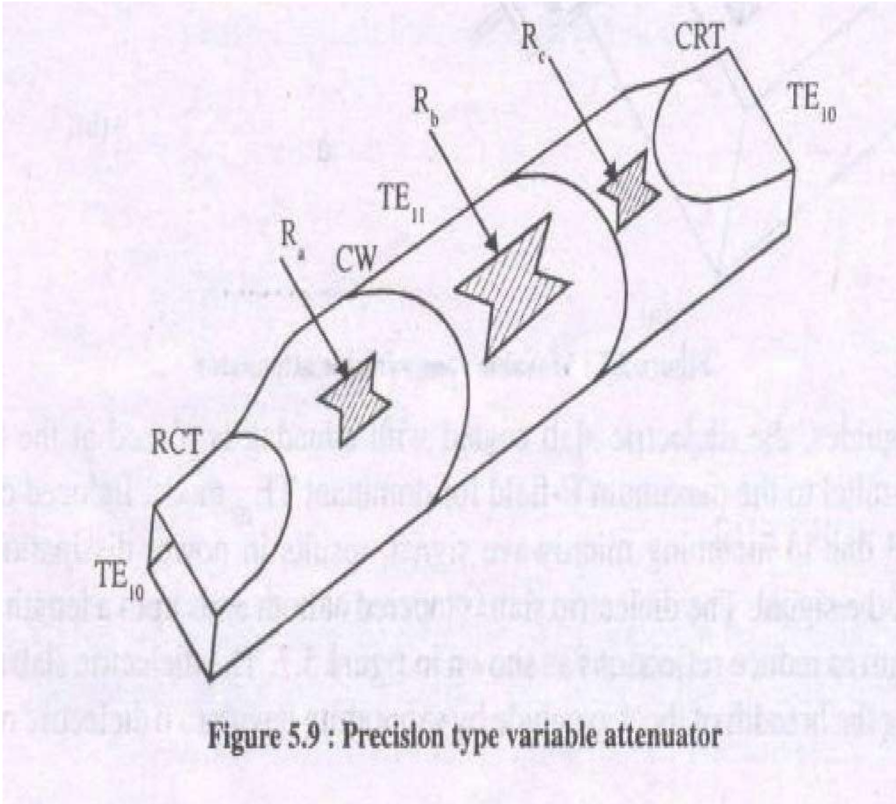
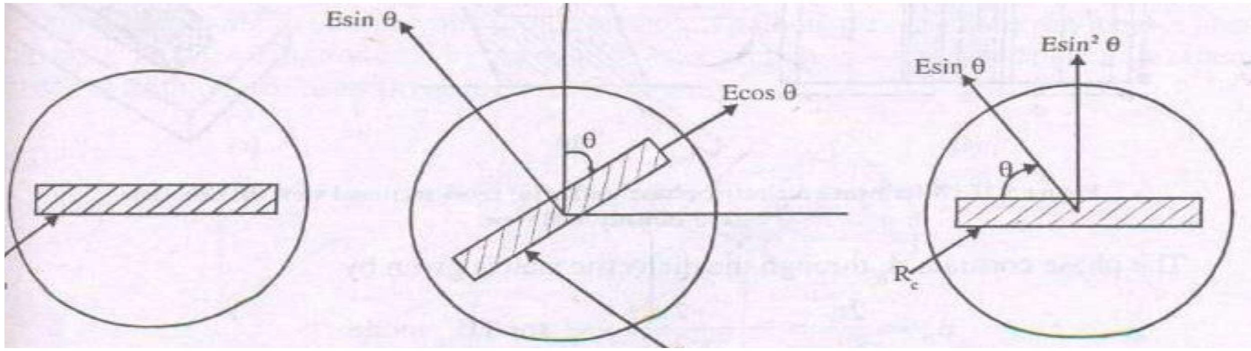


Figure 5.9 : Precision type variable attenuator

- A precision type variable attenuator consists of a rectangular to circular transition (ReT), a piece of circular waveguide (CW) and a circular-to-rectangular transition (CRT) as shown in figure. Resistive cards Ra, Rb and Re are placed inside these sections as shown. The centre circular section containing the resistive card Rb can be precisely rotated by 360 degree with respect to the two fixed resistive cards.
- The induced current on the resistive card R due to the incident signal is dissipated as heat producing attenuation of the transmitted signal
- If the resistive card in the centre section is kept at an angle θ relative to the E-field direction of the TE11 mode, the component E cos θ parallel to the card get absorbed while the component E sin θ is transmitted without attenuation. This component finally comes out as E $\sin^2\theta$ as shown in figure

- 

- later component finally appears as electric field component $E\sin^2\theta$ in rectangular output guide. Therefore, the attenuation of the incident wave is

$$\alpha = \frac{E}{E\sin^2\theta} = \frac{1}{\sin^2\theta} = \frac{1}{|S_{21}|}$$

or,

$$\alpha\,(\text{dB}) = -40\log(\sin\theta) = -20\log|S_{21}| \qquad (6.79)$$

Therefore, the precision rotary attenuator produces attenuation which depends only on the angle of rotation θ of the resistive card with respect to the incident wave polarisation. Attenuators are normally matched reciprocal devices, so that

$$|S_{21}| = |S_{12}| \qquad (6.80)$$

$$|S_{21}| = |S_{12}| \tag{6.80}$$

and

$$|S_{11}| \quad \text{or} \quad |S_{22}| = \frac{\text{VSWR} - 1}{\text{VSWR} + 1} << 0.1 \tag{6.81}$$

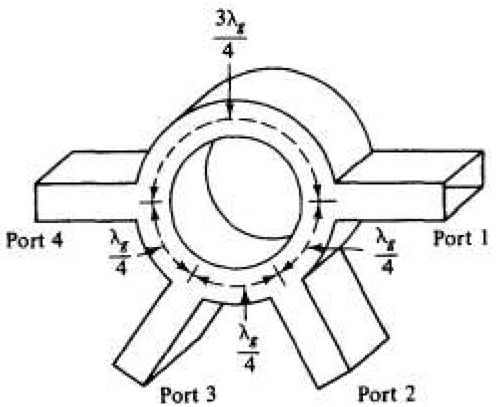
where the VSWR is measured at the port concerned. The S-matrix of an ideal precision rotary attenuator is

$$[S] = \begin{bmatrix} 0 & \sin^2\theta \\ \sin^2\theta & 0 \end{bmatrix} \tag{6.82}$$

•

15(ii)Draw the hybrid ring and write its S-matrix 4M

A hybrid ring consists of an annular line of proper electrical length to sustain standing waves, to which four arms are connected at proper intervals by means of series or parallel junctions



The **S** matrix for an ideal hybrid ring can be expressed as

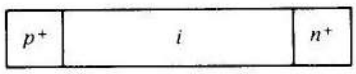
$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

16ECT72-RF and Microwave Engineering-Question Bank

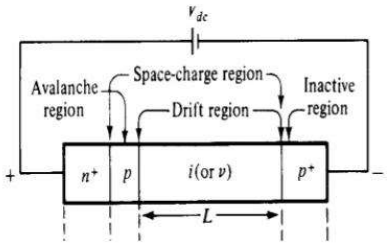
Unit III

2 marks Questions:

S.No	Questions
1.	Recognize the advantages of parametric amplifiers **Ans:** Advantages of parametric amplifiers: (Any 2) 1. A positive input impedance 2. Unconditionally stable and unilateral 3.Power gain independent of changes in its source impedance 4. No circulator required 5. A typical bandwidth on the order of 5%
2.	List the various types of strip lines used in MMIC **Ans:** Strip lines used in MMIC: • Micro strip lines and • Coplanar strip lines
3.	Draw the structure of IMPATT diode:

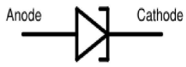


(Or)

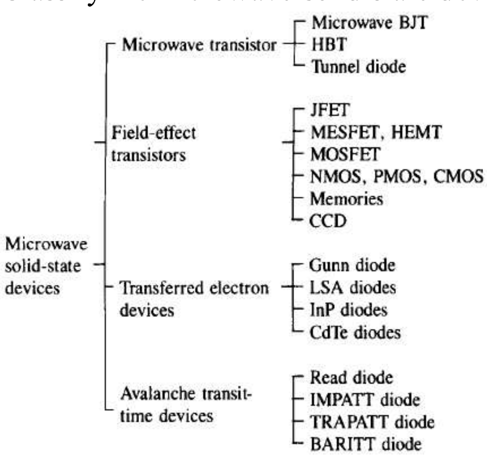


4. Define Tunnel Diode.

- Tunnel Diode is the P-N junction device that exhibits negative resistance.
- When the voltage is increased than the current flowing through it decreases. It works on the principle of the Tunneling effect.



5. Classify the microwave solid state devices



6. List the applications of Gunn Diode

Gunn diode can be used as an amplifier and as an oscillator. The applications of Gunn diode are

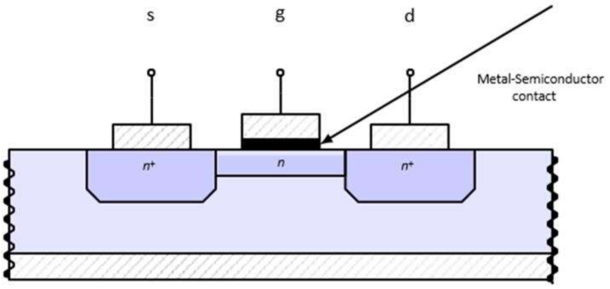
- ➢ In broadband linear amplifier
- ➢ In radar transmitters.
- ➢ Used in transponders for air traffic control.
- ➢ In fast combinational and sequential logic circuit.
- ➢ In low and medium power oscillators in microwave receivers

7. Define HEMT
   - ➢ The High Electron Mobility Transistors (HEMT) is hetero junction approach applied to the MESFET topology
   - ➢ This means that the channel region of the FET is constructed of two materials with different band gaps instead of a doped region of single material in the case for the simple MESFET, an approach known as modulation doping
   - ➢ The hetero junction approach results in higher electron mobility in the channel, allowing the device to respond to rapid changes in the gate voltage

8. List the advantages of Tunnel Diode
   1. Tunnel diodes have less weight, high speed, low noise and low cost.
   2. Require very simple DC power supply.
   3. Low-noise figure less than (5 dB at 10 GHz) due to low current levels.
   4. Broadband operation is possible.
   5. Immune to the natural radiation in the solar system and suitable for space communication.
   6. Wide range of tuning either mechanical or electrical is possible.
   7. For low power applications, tunnel diode replace the reflex klystron.

9. Define negative resistance effect
   1. The impact ionization avalanche effect, which causes the carrier current $I_0(t)$ and the ac voltage to be out of phase by 90^0
   2. The transit-time effect, which further delays the external current $I_e(t)$ relative to the ac voltage by 90^0

10. State MESFET
   - The device consists of a channel of semiconducting material positioned between source and drain regions. The carrier flow from source to drain is controlled by the voltage applied to the gate electrode.
   - The controlled current flows only through the thin n-type channel between the two highly doped n+ regions, meaning that MESFETs are unipolar devices



16 marks Questions and Answers

1. **Examine the fabrication process of MMICs with neat diagrams**

   1. Diffusion and ion implantation:
   - ➢ Diffusion and ion implantation are the two processes used in controlling amounts of dopants in semiconductor device fabrications.
   - ➢ The process of diffusion consists of diffusing impurities into a pure material in order to alter the

basic electronic characteristics of the pure material. Ion implantation is used to dope the substrate crystal with high-energy ion impurities.

- Both processes are used to dope selectively the semiconductor substrate to produce either an n- or p-type layer.
- In this process the dopant ions are implanted into the semiconductor by using a high-energy ion beam. The advantages of the ion implantation method are precise control of the total amount of dopants, the improvement of reproducibility, and reduced processing temperature.
- Both diffusion and ion implantation can be used for fabricating discrete and integrated devices because these processes are generally complementary to one another.

2. Oxidation and film deposition:

To fabricate discrete and integrated devices or circuits many different types of thin films are used:

1. Thermal oxides   2. Dielectric layers
3. Polycrystalline silicon   4. Metal films

3. Epitaxial growth:

In epitaxy technology, single-crystal semiconductor layers grow on a single-crystal semiconductor substrate. The word epitaxy comes from the Greek epi (on) and taxis (arrangement). The epitaxial process offers an important means of controlling the doping profiles so that device and circuit performances can be optimized. Three types of epitaxy:

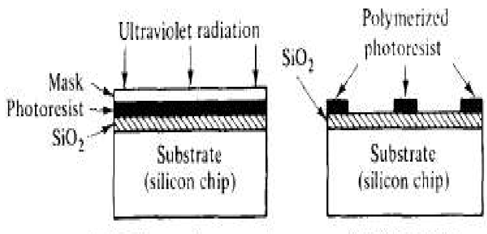
1. Vapor-phase epitaxy,
2. Molecular-beam epitaxy and
3. Liquid-phase epitaxy.

4. Lithography:

Lithography is the process of transferring patterns of geometric shapes on a mask to a thin layer of radiation-sensitive material, which is known as resist, for covering the surface of a semiconductor wafer. The resist patterns defined by the lithographic process are not permanent elements of the final device but only replicas of circuit features. There are four types of lithography technology:

1. Electron-beam lithography
2. Ion-beam lithography
3. Optical lithography
4. X-ray lithography

5. Etching and Photoresist:



(a) Masking and exposure to ultraviolet radiation   (b) Photoresist

- In the processes of making MICs, a selective removal of Si02 is required in order to form openings through which impurities can be diffused.
- During the photolithographic process the substrate is coated with a uniform film of Kodak photoresist (KPR), which is a photosensitive emulsion. A mask for the desired openings is placed over the photoresist, and ultraviolet light exposes the photoresist through the mask.
- A polymerized photoresist is developed, and the unpolymerized portions are dissolved by using trichloroethylene after the mask is removed; The Si02, which is not covered by the photoresist, can be removed by hydrofluoric acid.
- The thick-film process usually involves the printing and silk-screening of silver or gold through a metal mask in a glass frit, which is applied on the ceramic and fired at 850° C. After firing, the initial layer may be covered with gold.

6. Deposition: Three methods-vacuum evaporation, electron-beam evaporation and de sputtering.

(i) Vacuum Evaporation:

- Here the impurity material to be evaporated is placed in a metallic boat through which a high current is passed. The substrate with a mask on it and the heated boat are located in a glass tube in which a high vacuum at a pressure of 10-6 to 10-s torr is maintained.
- The substrate is heated slightly while the heat is evaporating the impurities, and the impurity vapor deposits itself on the substrate, forming a polycrystalline layer on it.

(ii) Electron-Beam Evaporation:

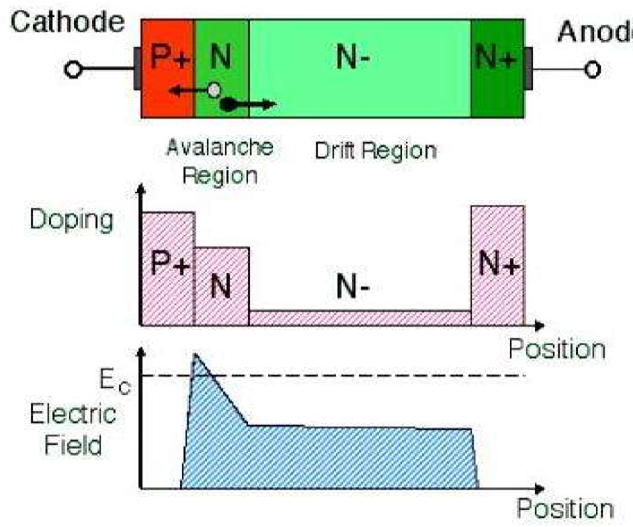
- In another method of evaporating the impurity a narrow beam of electrons is generated to scan the substrate in the boat in order to vaporize the impurity.

(iii) dc Sputtering:

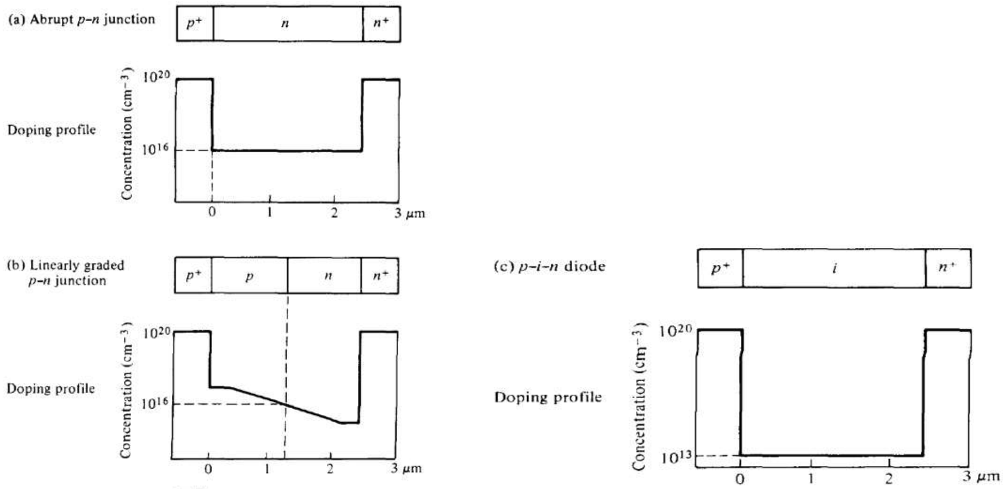
- The third method of vacuum deposition is known as de sputtering or cathode sputtering. In a vacuum, the crucible containing the impurity is used as the cathode and the substrate as the anode of a diode.
- A slight trace of argon gas is introduced into the vacuum. When the applied voltage between cathode and anode is high enough, a glow discharge of argon gas is formed.
- The positive argon ions are accelerated toward the cathode, where they dislodge atoms of the impurity. The impurity atoms have enough energy to reach the substrate and adhere to it.

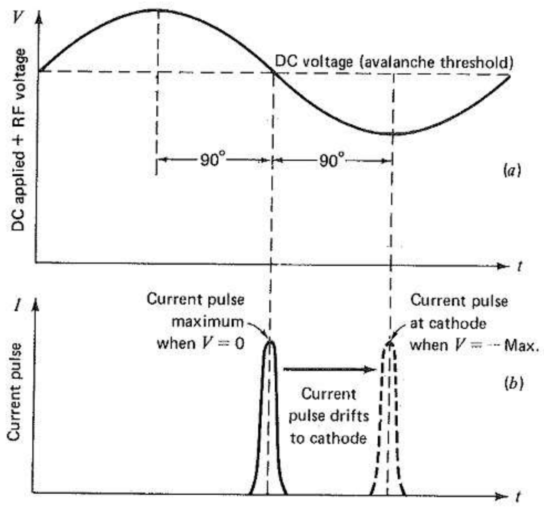
2. **Describe the operation and construction of IMPATT diode**

- Diode is operated in reverse bias near breakdown, and both the N and N- regions are completely depleted
- Electric field is highly peaked in the avalanche region and nearly flat in drift region



- Avalanche breakdown occurs at the point of highest electric field, and this generates a large number of hole-electron pairs by impact ionization
- Holes swept into the cathode – electrons travel across drift region toward anode
- As they drift, they induce image charges on the anode, giving rise to a displacement current in the external circuit that is 180 degree out of phase with the nearly sinusoidal voltage waveform





IMPATT Diode – Negative Resistance

$$R = R_s + \frac{2L^2}{v_d \epsilon_s A} \frac{1}{1 - \omega^2/\omega_r^2} \frac{1 - \cos\theta}{\theta}$$

Where, R_s = passive resistance of the inactive region

v_d = carrier drift velocity

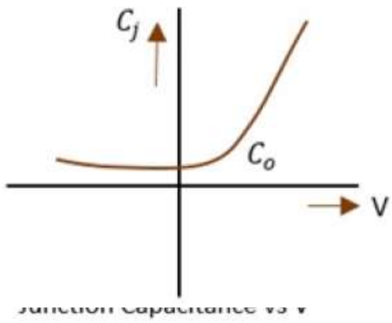
L = length of the drift space-charge region

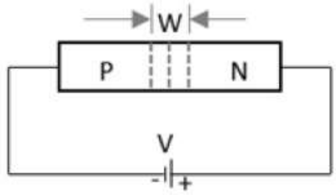
A = diode cross section

e_s = semiconductor dielectric permittivity

3. **(a) Describe the operation of Varactor diode**

- VARiable reactor
- Also referred as "Varicap (Variable Capacitor) diode"





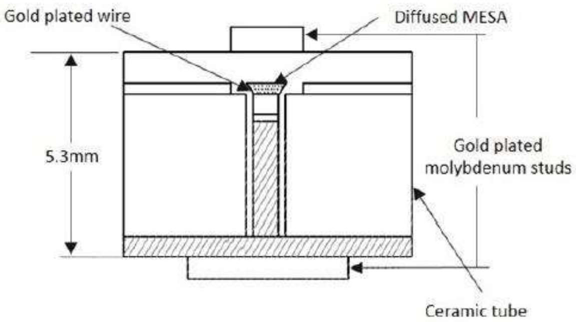
$$C_j \, \alpha \, V_r^{-n}$$

Where,

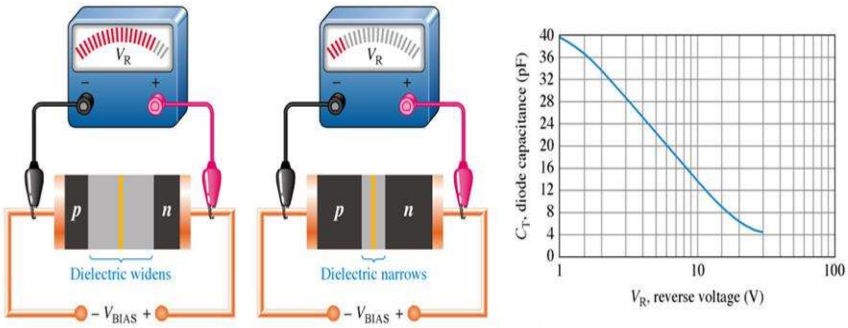
C_j = Junction capacitance

V_r = Reverse bias voltage

n = A parameter that decides the type of junction



- A **varactor diode** is a special purpose diode operated in reverse-bias to form a voltage-controlled capacitor. The width of the depletion region increases with reverse-bias.
- Varactor diodes are used in tuning applications. The applied voltage controls the capacitance and hence the resonant frequency
- The diode is operated under reverse biased condition and this gives rise to three regions.
- P region, N region & Depletion region: P and N regions are the regions where current can be conducted
- Depletion region is the region where no current carriers are available P and N behave as conducting plates of a capacitor and depletion region acts as an Insulator (dielectric in a capacitor)



(a) Greater reverse bias, less capacitance (b) Less reverse bias, greater capacitance (c) Graph of diode capacitance versus reverse voltage

Applications of Varactor Diode:

- Tuning stage of radio receiver to replace bulky variable plate capacitor
- Microwave frequency multiplication
- Active filters
- Voltage Controlled Oscillators
- RF Filters
- Up conversion
- Parametric amplifier
- Pulse generation
- Pulse shaping
- Switching circuits
- Modulation of microwave signals

(b) Describe the principle and operation of Tunnel diode

- Heavily-doped p-n junction
- Impurity concentration is 1 part in 10^3 as compared to 1 part in 10^8 in p-n junction diode
- Width of the depletion layer is very small (about 100 A).

- ➢ It is generally made up of Ge and GaAs Tunneling is a quantum mechanical phenomenon with no analog in classical physics
- ➢ Occurs when an electron passes through a potential barrier without having enough energy to do so. Classically, carrier must have energy at least equal to potential-barrier height to cross the junction
- ➢ But according to Quantum mechanics there is finite probability that it can penetrate through the barrier for a thin width. This phenomenon is called tunnelling and hence the Esaki Diode is known as Tunnel Diode

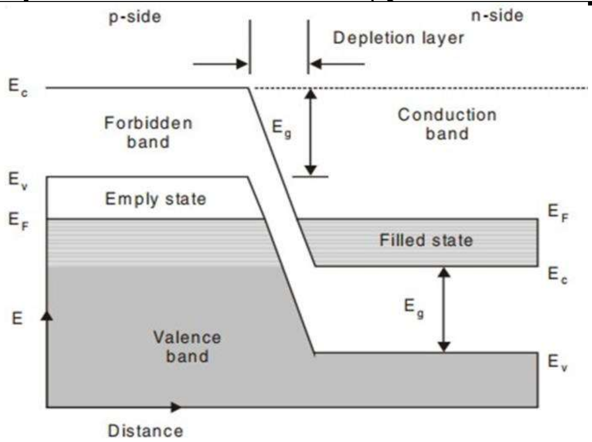
Tunnelling device:

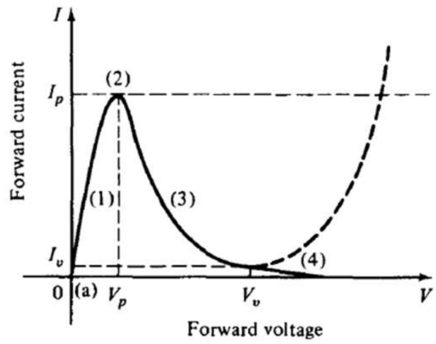
- Lower sub-threshold swing can allow for lower operating voltages to be used
- Negative differential resistance (NDR) properties can be exploited to create simpler designs for bi-stable circuits, differential comparators, oscillators, etc
- Leads to chips that consume less power

(Esaki) Tunnel Diode (TD):

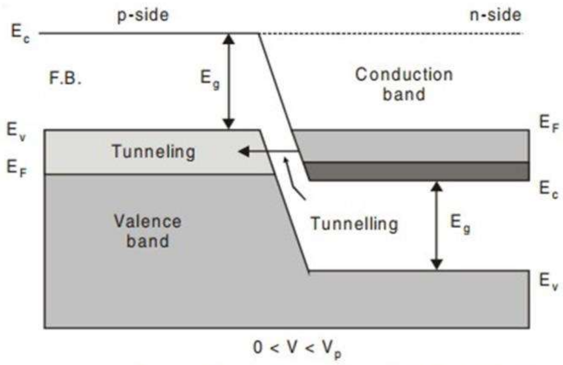
- ➢ Simplest tunneling device
- ➢ Heavily-doped pn junction
  - ➢ Leads to overlap of conduction and valence bands
- Carriers are able to tunnel inter-band
- Tunneling goes exponentially with tunneling distance
  - ➢ Requires junction to be abrupt

<u>Operation of Tunnel Diode (Quantum Mechanical Tunnelling):</u>

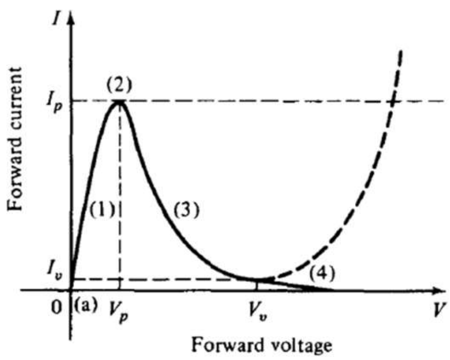




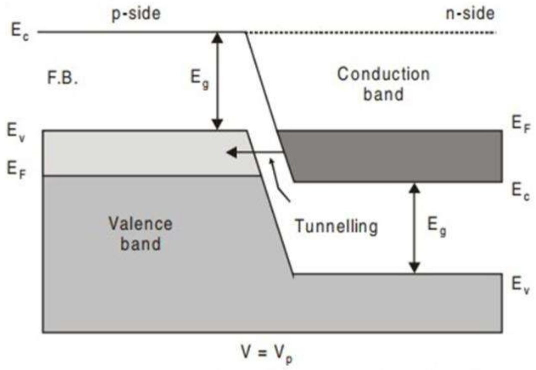
When 0 < V < Vp



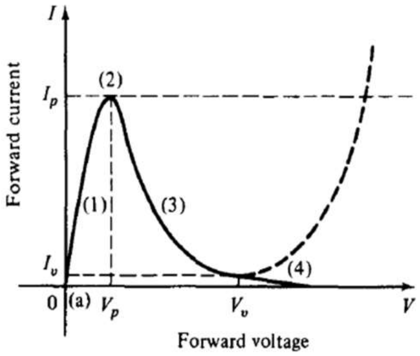
Energy band diagram when $0 < V < V_p$.



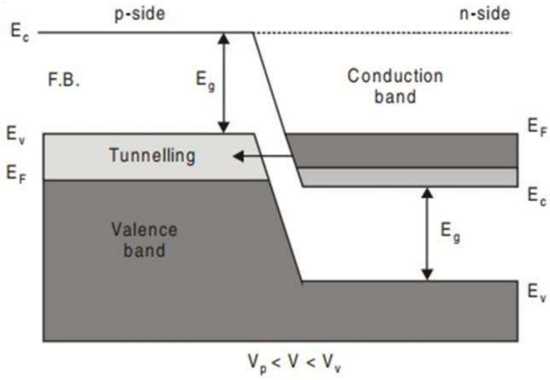
When V = Vp



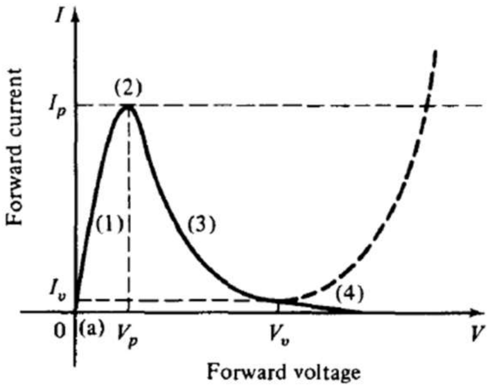
Energy band diagram when $V = V_p$.



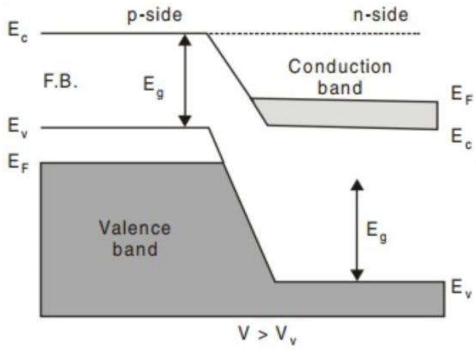
When Vp < V < Vv



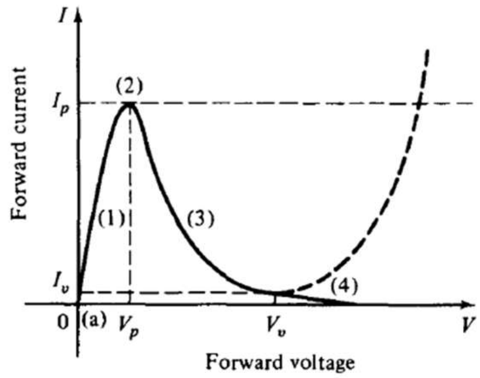
Energy band diagram when $V_p < V < V_v$.



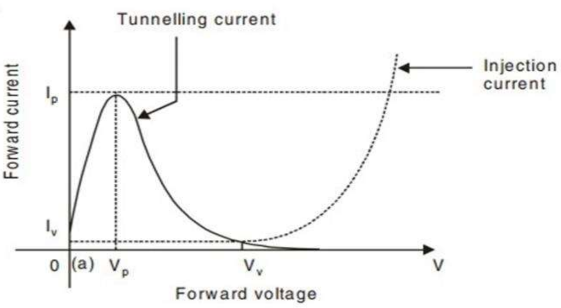
When V > Vv



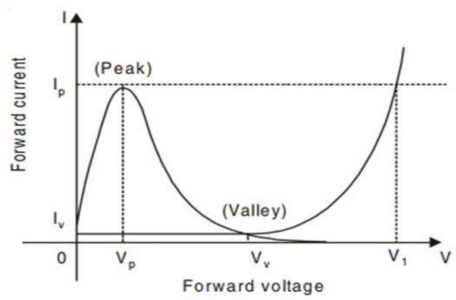
Energy band diagram when $V > V_v$.



VI characteristic of tunnel diode



(a) Tunnelling current and injection current



(b) VI Characteristic

Equivalent Circuit of Tunnel Diode

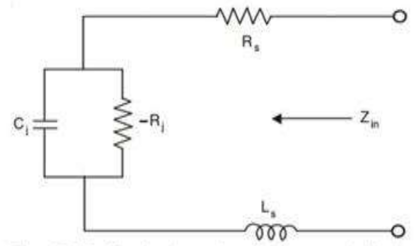


Fig. 7.30. *Equivalent circuit of tunnel diode.*

where, C_j = Junction capacitance.
$-R_j$ = Negative junction resistance.
R_s = Ohmic series resistance due to lead wire.
L_s = Series inductance of the bonding wire.

At the higher frequencies, the series resistance and inductance can be ignored. The resulting diode equivalent circuit is thus reduced to the parallel combination of the junction capacitance C_j and negative resistance $-R_j$. The junction capacitance of tunnel diode is highly dependent on the bias voltage and temperature.

4. **Apply two valley theory to explain the negative resistance property of a Gunn diode**

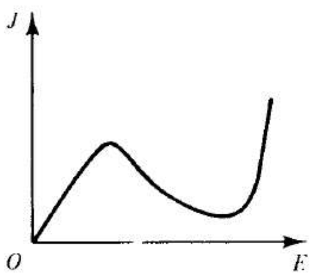
Gunn Diode:

- The device is simply an n-type bar with n+ contacts. It is necessary to use n-type material because the transferred electron effect is only applicable to electrons and not to holes
- The most common method of manufacturing a Gunn diode is to grow and epitaxial layer on a degenerate n+ substrate. The active region is very thin and its thickness is between a few microns and a few hundred microns.
- The thickness of the active region determines the frequency of oscillation. The base also acts as a heat sink which is critical for the removal of heat.

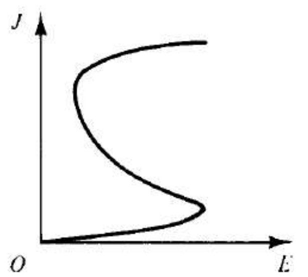
<u>Negative mobility:</u>

- In bulk semi conductors by transferring electrons from high mobility energy band to low mobility energy bands –[Ridley and Watkinson]
- The careful calculation of transferred electron effect in several III-V compounds; TEOs & TEAs- [Hilsum]
- Gunn effect from thin disks of n type GaAs and n type InP specimens [J.B.Gunn]
- The field domain is continuously moving through the crystal, disappearing at the anode and then reappearing at a favored nucleating centre, and starting the whole cycle one more [Ridley]
- Kromer stated that the origin of negtaive differential mobiltiy is Ridley-watkinson-Hilsum's mechanism of electron transfer into the satellite valleys that occur in the conduction bands of both the n type GaAs and the n type Inp

<u>RWH Theory:</u>

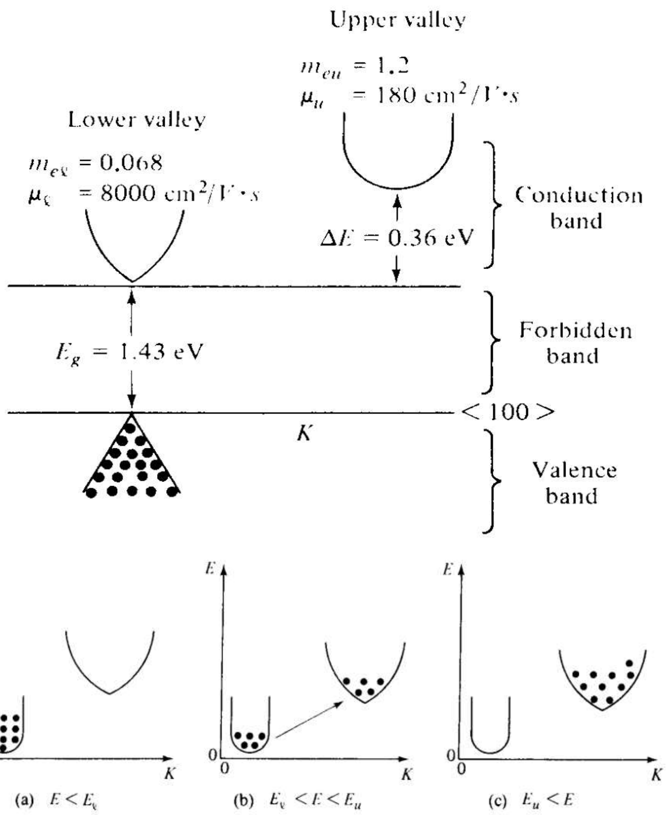


(a) Voltage-controlled mode



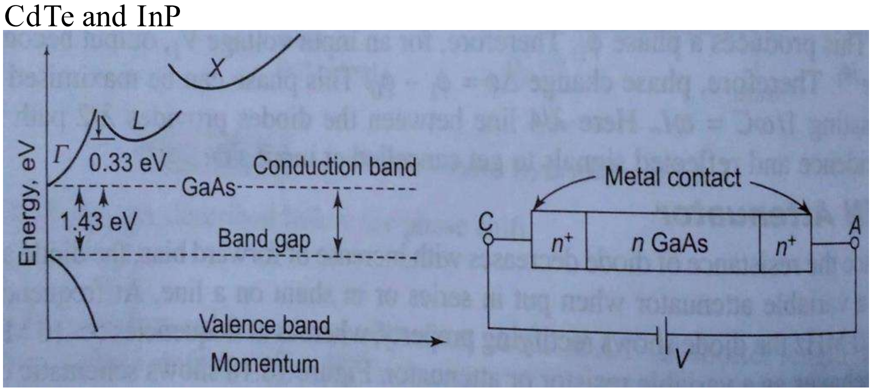
(b) Current-controlled mode

Two Valley Model Theory



Multiple energy Valley:

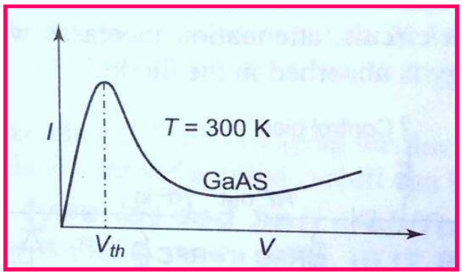
- Some semiconductors have closely spaced multiple energy valleys in the conduction band
- GaAS, CdTe and InP

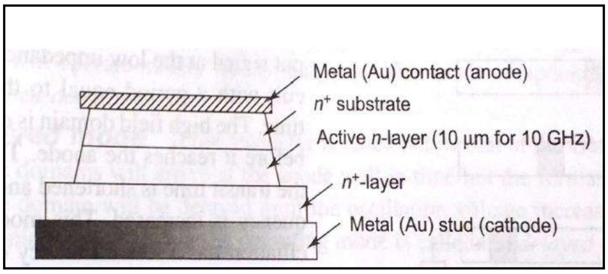


- When dc bias applied across the material, an electric field established across it.
- At low E filed, electrons remains in the lower energy center valley Γ
- At higher E field, most of the electrons will be transferred to the higher energy satellite L and X valleys
- In higher valleys Effective electron mass is larger. So that the electron mobility is lower.
- Conductivity is proportional to Mobility
- Current Decreases

5. **Interpret various modes of operation of gunn diode and its IV characteristics with necessary diagram.**

- Transferred Electron effect-TED
- Threshold
- Negative resistance





Construction of Gunn Diode

- No junction, but cathode and Anode –hence Diode
- At threshold Voltage is E field is 3.2KV/cm for GaAS
- Well bonded to heat sink (Cu-stud)

Modes of Operation:

Two principal modes are of microwave oscillation

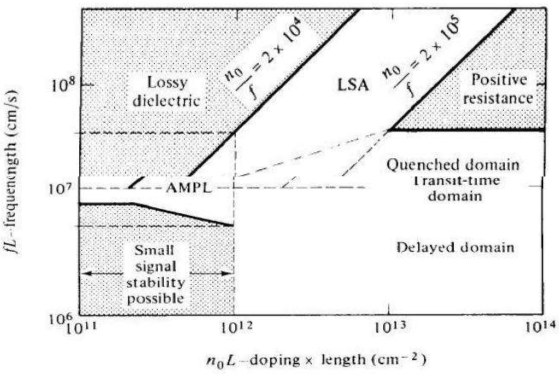
- Transit Time mode
- Limited Space Charge mode

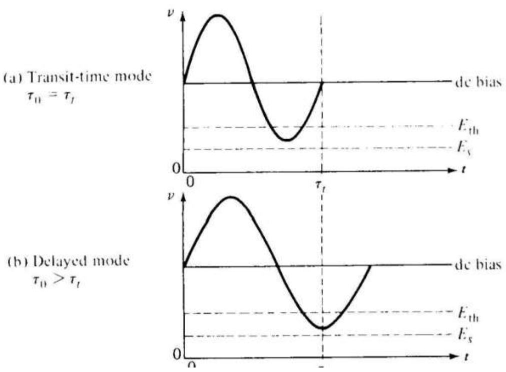
Two special modes are,

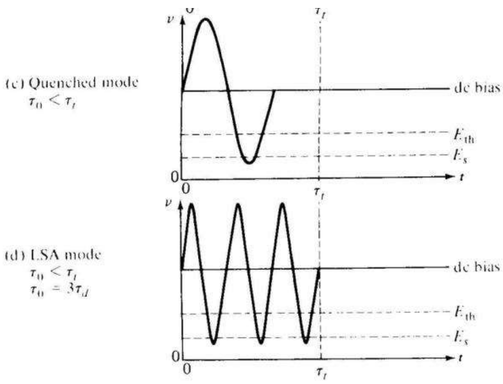
- Quenched domain mode
- Delayed mode

A gunn diode can operate in four modes:

1. Gunn oscillation mode
2. Stable amplification mode
3. LSA oscillation mode
4. Bias circuit oscillation mode(It occurs either in Gunn oscillation or LSA Oscillation mode)







1. Gunn oscillation mode

- This mode is defined in the region where the product of frequency multiplied by length is about 10^7 cm/s and the product of doping multiplied by length is greater than 10^{12}/cm2.
- In this region the device is unstable because of the cyclic formation of either the

accumulation layer or the high field domain.

- When the device is operated is a relatively high Q cavity and coupled properly to the load, the domain I quenched or delayed before nucleating.

2. Stable amplification mode

- This mode is defined in the region where the product of frequency times length is about 10^7 cmls and the product of doping times length is between 10^{11} and $10^{12}/cm^2$

3. LSA oscillation mode

- This mode is defined in the region where the product of frequency times length is above 10^7 cm ls and the quotient of doping divided by frequency is between 2 x 10^4 and 2 x 10^5

4. Bias-circuit oscillation mode

- This mode occurs only when there is either Gunn or LSA oscillation. and it is usually at the region where the product of frequency times length is too small to appear in the figure. When a bulk diode is biased to threshold. the average current suddenly drops as Gunn oscillation begins

<u>Delayed domain mode (106 cm/s < fL < 10^7 cm/s).</u>

- When the transit time is Chosen so that the domain is collected while E < Eth, a new domain cannot form until the field rises above threshold again.
- In this case, the oscillation period is greater than the transit time-that is, To > T,. This delayed mode is also called inhibited mode. The efficiency of this mode is about 20%.

Quenched domain mode (fL > 2 X 10^7 cm/s).

- If the bias field drops below the sustaining field Es during the negative half-cycle as shown ,the domain collapses before it reaches the anode. When the bias field swings back above threshold ,a new domain is nucleated and the process repeats.
- Therefore the oscillations occur at the frequency of the resonant circuit rather than at the transit-time frequency.
- It has been found that the resonant frequency of the circuit is several times the transit-time frequency, since one dipole does not have enough time to readjust and absorb the voltage of the other dipoles. Theoretically, the efficiency of quenched domain oscillators can reach 13%

16ECT72-RF and Microwave Engineering-Question Bank

Unit IV

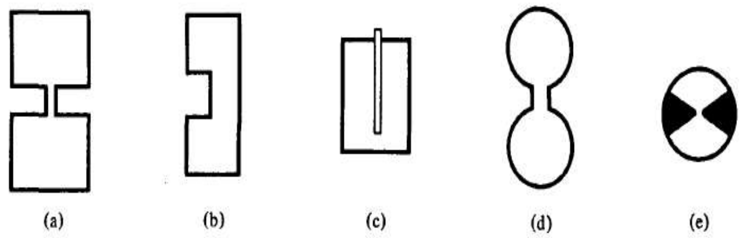
2 mark Questions & Answers:

1. Define velocity modulation of electrons and draw some reentrant cavities.

   Velocity Modulation:

   The variation in electron velocity in the drift space is known as velocity modulation. Velocity modulation is defined as that variation in the velocity of a beam of electrons caused by the alternate speeding up and slowing down of the electrons in the beam. This variation is usually caused by a voltage signal applied between the grids through which the beam must pass.

   Reentrant cavities:



   (a) Coaxial cavity
   (b) Radial cavity
   (c) Tunable cavity
   (d) Toroidal cavity
   (e) Butterfly cavity

2. List the drawbacks and applications of klystron amplifiers.

   Drawbacks:

   - As the oscillator frequency changes then resonator frequency also changes and the feedback path phase shift must be readjusted for a positive feedback.
   - The multi cavity klystron amplifiers suffer from the noise caused because bunching is never complete and electrons arrive at random at catcher cavity. Hence it is not used in receivers.

   Applications:

   - Signal source in MW generator
   - Local oscillators in receivers
   - It is used in FM oscillator in low power MW links.
   - In parametric amplifier as pump source.

3. Define transit time in reflex klystron and illustrate the effect of transit time.

   The time taken by the electron to travel into the repeller space and back to the gap is called transit time. T =n + ¾. There are two effects:

   1) At low frequencies, the grid and anode signals are no longer 180O out of phase, thus causing design problems with feedback in oscillators.

   2) The grid begins to take power from the driving source and the power is absorbed even when the grid is negatively biased

4. State the purpose of slow wave structures used in TWT amplifiers and draw some slow wave structures

   Slow wave structures are special circuits that are used in microwave tubes to reduce wave velocity in a certain direction so that the electron beam and the signal wave can interact. In TWT, since the beam can be accelerated only to velocities that are about a fraction of the velocity of light, slow wave structures are used.

   (a) Helical Line
   (b) Folded-back line

5. Give the performance specification of Reflex klystron and list the applications of klystron amplifier.

   Performance specification:
   - Frequency range: 2- 200 GHz
   - Band width: + 30 MHz for _ VR = + 10
   - V Power output: 10 mw – 2.5W
   - Efficiency: 20 to 30%

   Applications:
   - UHF TV Transmitters
   - Long ranger radar
   - Linear particle accelerator
   - Troposcatter links
   - Earth station transmitter.

6. Define phase focusing effect.

   The bunching of electrons in known as "Phase focusing effect" This effect is important because without it, favored electrons will fall behind the phase change of electric field across the gaps. Such electrons are retarded at each interaction with the R.F field in magnetron.

7. Define O-type tubes and list some O-type tubes.

   In O – type tube a magnetic field whose axis coincides with that electron beam is used to hold the beam together as it travels the length of the tube. It is also called as linear beam tube.

   i) Helix Traveling wave tube
   ii) Coupled cavity TWT
   iii) Forward wave amplifier
   iv) Backward wave amplifier
   v) Backward wave oscillator

8. Differentiate between Klystron amplifier and Travelling Wave Tube amplifier and list the advantages and applications of TWT

S.no	Klystron amplifier	TWTA
1	Linear beam or „O" type device	Linear beam or „O" type device
2	Uses cavities for input and Output circuits.	Use non resonant wave circuit
3	Narrow band device due to resonant cavities	Wide band device because use of Non-resonant wave circuit

<u>Advantages of TWT:</u>

1. Bandwidth is large.
2. High reliability
3. High gain
4. Constant Performance in space

5. Higher duty cycle

Applications of TWT

1) Low power, low noise TWT"s used in radar and microwave receivers
2) Laboratory instruments
3) Drivers for more powerful tubes
4) Medium and high power CWTWT"S are used for communication and radar.

9. State the applications of magnetrons. Why magnetron is called as cross filed device?

   1) Pulse work in radar
   2) Linear particle accelerators.

   In cavity magnetron, there exists a radial electric field and an axial magnetic field perpendicular to each other and hence magnetron is called as a cross filed device.

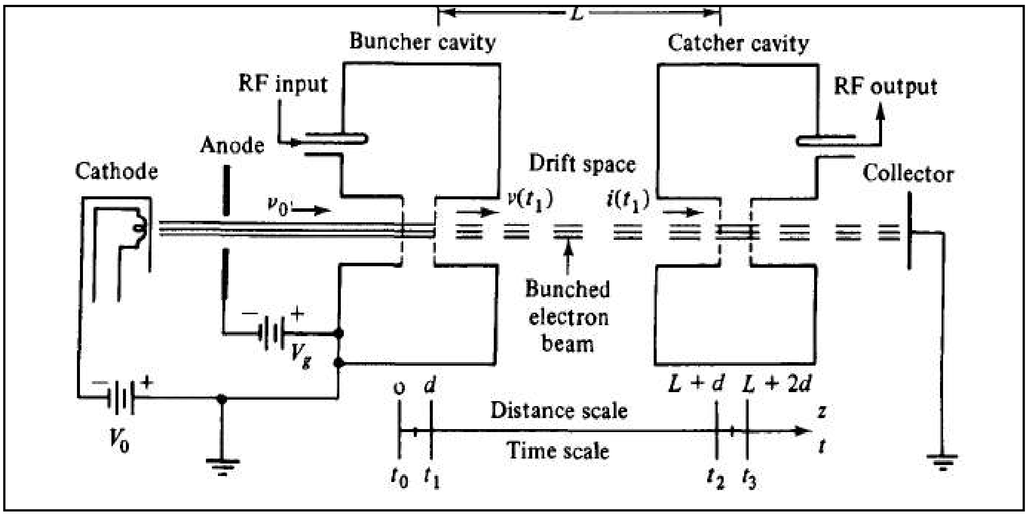
10. List the different types of Impedance measurement methods and frequency measurement techniques.

   Impedance measurement methods:
   1. Slotted line method
   2. Reflecto-meter method
   3. Reactor dis-constructer method

   Frequency measurement methods:
   1. Wave meter method
   2. Slotted line method
   3. down conversion method

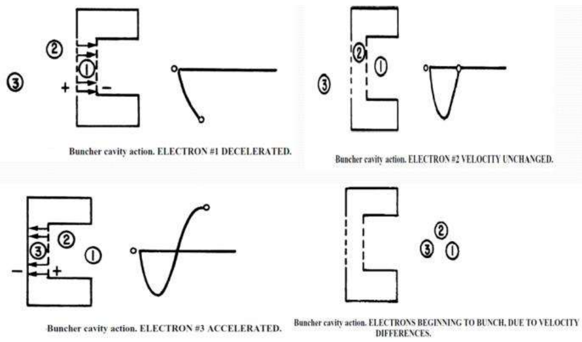
16 mark Questions:

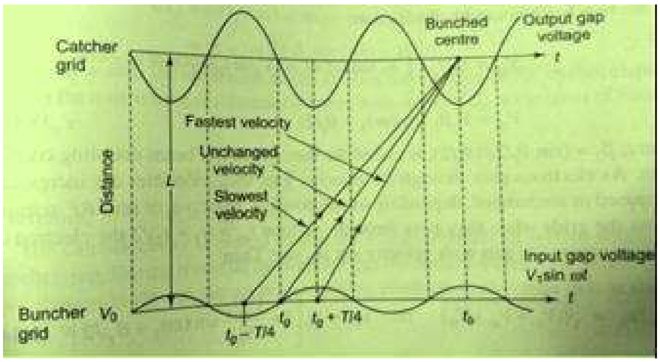
1. **Explain in detail about two cavity klystron amplifier which is used as a low power microwave amplifier**



Circuit diagram of a two cavity klystron amplifier

Electron beam via Buncher Cavity: **Velocity Modulation-Applegate Diagram**





The two-cavity klystron is a widely used microwave amplifier operated by the principles of velocity and current modulation. All electrons injected from the cathode arrive at the first cavity with uniform velocity. Those electrons passing the first cavity gap at zeros of the gap voltage (or signal voltage) pass through with unchanged velocity; those passing through the positive half cycles of the gap voltage undergo an increase in velocity; those passing through the negative swings of the gap voltage undergo a decrease in velocity. As a result of these actions, the electrons gradually bunch together as they travel down the drift space. The variation in electron velocity in the drift space is known as *velocity modulation*. The density of the electrons in the second cavity gap varies cyclically with time. The electron beam contains an ac component and is said to be current-modulated. The maximum bunching should occur approximately midway between the second cavity grids during its retarding phase; thus the kinetic energy is transferred from the electrons to the field of the second cavity. The electrons then emerge from the second cavity with reduced velocity and finally terminate at the collector. The charateristics of a two-cavity klystron amplifier are as follows:

- Pulsed Power: 30 MW @ 5GHz
- Efficiency : 40%
- Power Gain 30dB

Important parameters are,

- Velocity Modulation
- Klystron amplification
- Power output
- Efficiency

Buncher cavity: The direction of the field changes with the frequency of the “buncher” cavity. These changes alternately accelerate and decelerate the electrons of the beam passing through the grids of the buncher cavity

Catcher Cavity: The function of the “catcher” cavity is to absorb energy from the electron beam. The “catcher” grids are placed along the beam at a point where the bunches are fully formed. The location is determined by the transit time of the bunches at the natural resonant frequency of the cavities

Drift Space: The area beyond the cavities is called the "drift space". The electrons form bunches in this area when the accelerated electrons overtake the decelerated electrons.

- The resonant frequency of the catcher cavity is the same as the buncher cavity
- The air-cooled collector collect the energy of the electron beam and change it into heat and X radiation

2. Explain in detail about reflex klystron amplifier

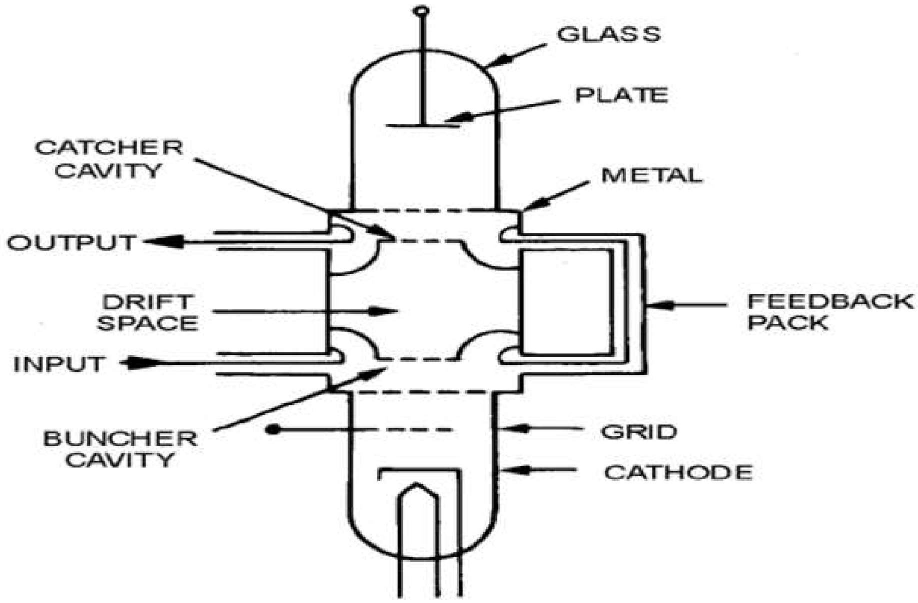
The reflex klystron has been the most used source of microwave power in laboratory applications

Construction:

- A reflex klystron consists of an electron gun, a cavity with a pair of grids and a repeller plate as shown in the above diagram.
- In this klystron, a single pair of grids does the functions of both the buncher and the catcher grids.
- The main difference between two cavity reflex klystron amplifier and reflex klystron is that the output cavity is omitted in reflex klystron and the repeller or reflector electrode, placed a very short distance from the single cavity, replaces the collector electrode.

Working:

- The cathode emits electrons which are accelerated forward by an accelerating grid with a positive voltage on it and focused into a narrow beam. The electrons pass through the cavity and undergo velocity modulation, which produces electron bunching and the beam is repelled back by a repeller plate kept at a negative potential with respect to the cathode.
- On return, the electron beam once again enters the same grids which act as a buncher, thereby the same pair of grids acts simultaneously as a buncher for the forward moving electron and as a catcher for the returning beam. The feedback necessary for electrical oscillations is developed by reflecting the electron beam, the velocity modulated electron beam does not actually reach the repeller plate, but is repelled back by the negative voltage.
- The point at which the electron beam is turned back can be varied by adjusting the repeller voltage. Thus the repeller voltage is so adjusted that complete bunching of the electrons takes place at the catcher grids, the distance between the repeller and the cavity is chosen such that the repeller electron bunches will reach the cavity at proper time to be in synchronization. Due to this, they deliver energy to the cavity, the result is the oscillation at the cavity producing RF frequency.

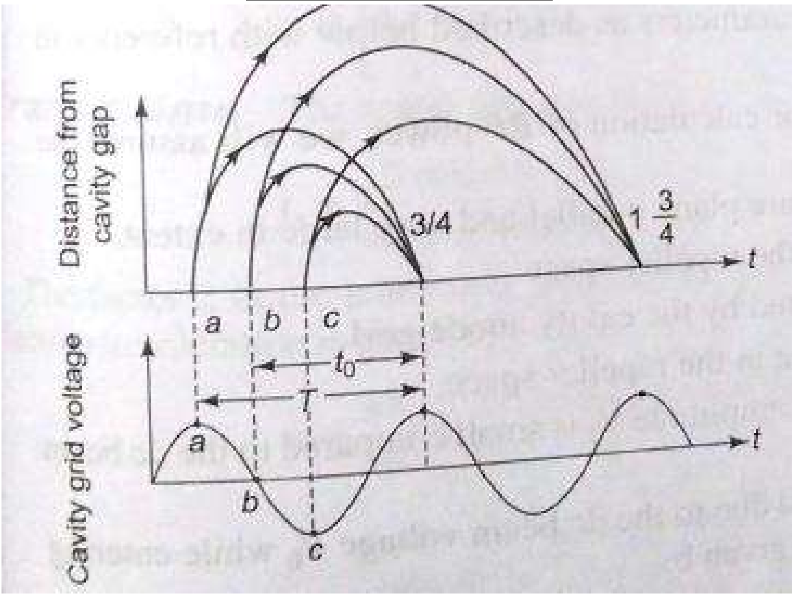


Mode of Oscillation

- The electrons should return after 1¾, 2 ¾ or 3 ¾ cycles – most optimum departure time.
- If T is the time period at the resonant frequency, t_o is the time taken by the reference electron to travel in the repeller space between entering the repeller space and returning to the cavity at positive peak voltage on formation of the bunch,

Then, $t_o = (n + ¾)T = NT$, where $N = n + ¾$, n = 0,1,2,3……. and N – mode of oscillation

Reflex Klystron Modes



Performance Characteristics:

- Frequency: 4 – 200 GHz
- Power: 1 mW – 2.5 W
- Theoretical efficiency : 22.78 %
- Practical efficiency : 10 % - 20 %
- Tuning range : 5 GHz at 2 W – 30 GHz at 10 mW

Applications:

The reflex klystrons are used in

- Radar receivers

- Local oscillator in microwave receivers
- Signal source in microwave generator of variable frequency
- Portable microwave links
- Pump oscillator in parametric amplifier

3. With neat diagrams describe the function of helix traveling wave tube.

Traveling Wave Tube (TWT) is the most versatile microwave RF power amplifiers. The main virtue of the TWT is its extremely wide band width of operation.

Basic structure:

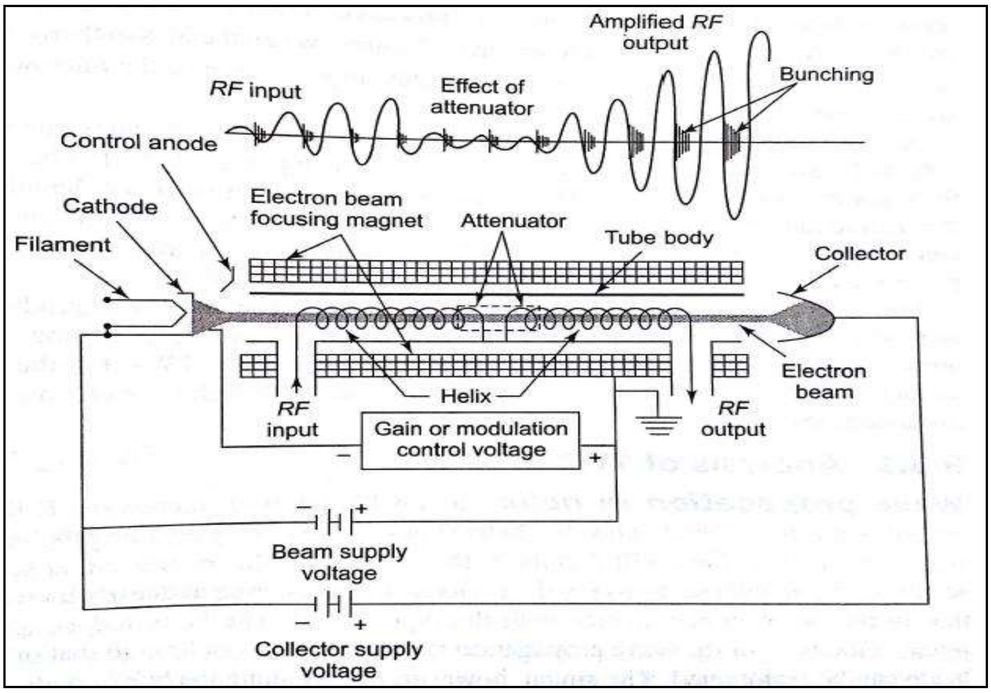
- The basic structure of a TWT consists of a cathode and filament heater plus an anode that is biased positively to accelerate the electron beam forward and to focus it into a narrow beam. The electrons are attracted by a positive plate called the collector, which has given a high dc voltage.
- The length of the tube is usually many wavelengths at the operating frequency. Surrounding the tube are either permanent magnets or electromagnets that keep the electrons tightly focused into a narrow beam.

Features:

- The unique feature of the TWT is a helix or coil that surrounds the length of the tube and the electron beam passes through the center or axis of the helix. The microwave signal to be amplified is applied to the end of the helix near the cathode and the output is taken from the end of the helix near the collector.
- The purpose of the helix is to provide path for RF signal. The propagation of the RF signal along the helix is made approximately equal to the velocity of the electron beam from the cathode to the collector

Functioning:

- The passage of the microwave signal down the helix produces electric and magnetic fields that will interact with the electron beam. The electromagnetic field produced by the helix causes the electrons to be speeded up and slowed down, this produces velocity modulation of the beam which produces density modulation.



- Density modulation causes bunches of electrons to group together one wavelength apart and these bunch of electrons travel down the length of the tube toward the collector.

- The electron bunches induce voltages into the helix which reinforce the voltage already present there. Due to that the strength of the electromagnetic field on the helix increases as the wave travels down the tube towards the collector. At the end of the helix, the signal is considerably amplified. Coaxial cable or waveguide structures are used to extract the energy from the helix.

Advantages:

- TWT has extremely wide bandwidth. Hence, it can be made to amplify signals from UHF to hundreds of gigahertz.
- Most of the TWT's have a frequency range of approximately 2:1 in the desired segment of the microwave region to be amplified.
- The TWT's can be used in both continuous and pulsed modes of operation with power levels up to several thousand watts.

Performance characteristics:

- Frequency of operation : 0.5 GHz – 95 GHz
- Power outputs:
    - 5 mW (10 – 40 GHz – low power TWT)
    - 250 kW (CW) at 3 GHz (high power TWT)
    - 10 MW (pulsed) at 3 GHz
- Efficiency : 5 – 20 % (30 % with depressed collector)

4. Illustrate the operating principles of cylindrical magnetron with neat sketch.

Magnetron Oscillators:

- Magnetrons provide microwave oscillations of very high frequency. All magnetrons consist of some form of anode & cathode operated in dc Magnetic field between cathode & anode. Because of cross field between cathode & anode, the electrons emitted from cathode are influenced by the cross field to move in a curved path.
- If the dc magnetic field is strong enough the electrons will not arrive at in the anode but return to the cathode, consequently anode current is cutoff.
- Magnetrons can be classified in to three types as follows,

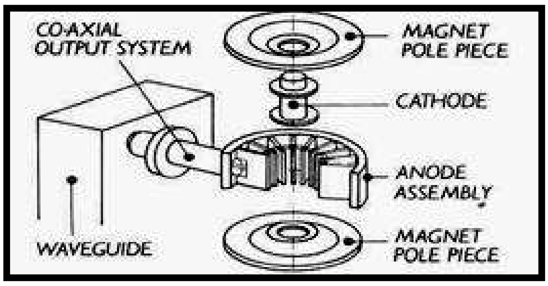
  1. *Negative resistance Magnetrons or Split-Anode Magnetron:*
  - Make use of static negative resistance between two anode segments. Low efficiency and are useful only at low frequencies (< 500 MHz).

  2. *Cyclotron-frequency Magnetrons:*
  - Operates under the influence of synchronism between an alternating component of electric field and periodic oscillation of electrons in a direction parallel to this field.
  - Useful only for frequencies greater than 100 MHz

  3. *Cavity or Traveling-wave Magnetrons*:
  - Depends upon the interaction of electrons with a traveling electromagnetic field of linear velocity.
  - These are customarily referred as *Magnetrons*
  - Provide oscillations of very high peak power and hence are useful in radar applications

Cylindrical Magnetron:

- Cylindrical magnetron Oscillator is also called as conventional Magnetron. In a cylindrical magnetron, several reentrant cavities are connected to the gaps and hence sometimes called as Cavity Magnetron.
- Schematic diagram illustrating the major elements of the magnetron oscillator is shown below



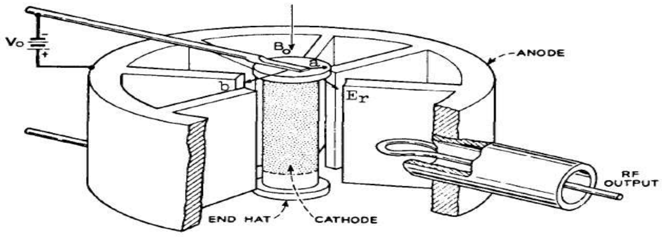


Figure 10-1-1 Schematic diagram of a cylindrical magnetron.

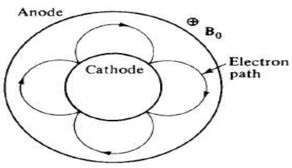
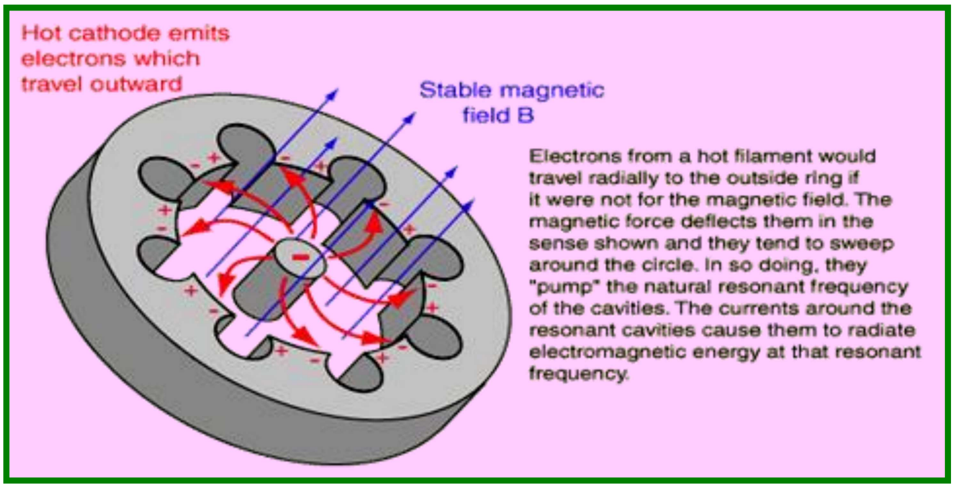


Figure 10-1-2 Electron path in a cylindrical magnetron.

Construction:

- Each cavity in the anode acts as an inductor having only one turn and the slot connecting the cavity and the interaction space acts as a capacitor. These two form a parallel resonant circuit and its resonant frequency depends on the value of L of the cavity and the C of the slot.
- The frequency of the microwaves generated by the magnetron oscillator depends on the frequency of the RF oscillations existing in the resonant cavities. Cross sectional view of anode assembly can be viewed as,

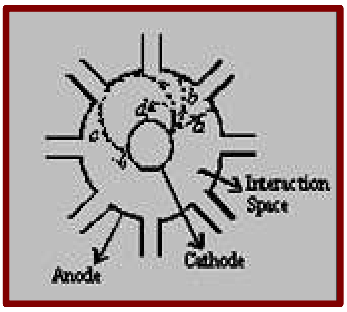


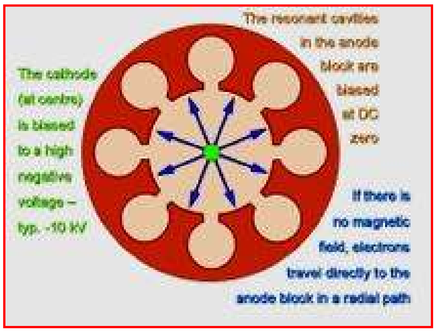
Working principle:

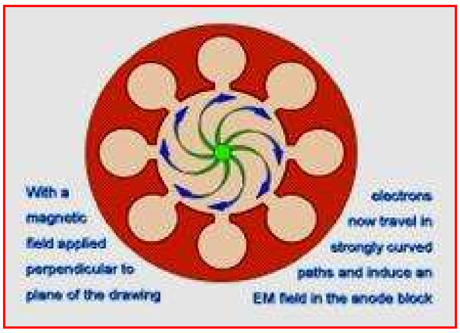
- Magnetron is a cross field device as the electric field between the anode and the cathode is radial whereas the magnetic field produced by a permanent magnet is axial. A high dc potential can be applied between the cathode and anode which produces the radial electric field.
- Depending on the relative strengths of the electric and magnetic fields, the electrons emitted from the cathode and moving towards the anode will traverse through the interaction space. In the absence of magnetic field (B = 0), the electron travel straight from the cathode to the anode due to the radial electric field force acting on it as given by the path ‘a’ in the following figure. If the

magnetic field strength is increased slightly, the lateral force bending the path of the electron as given by the path '*b*' in the following figure.

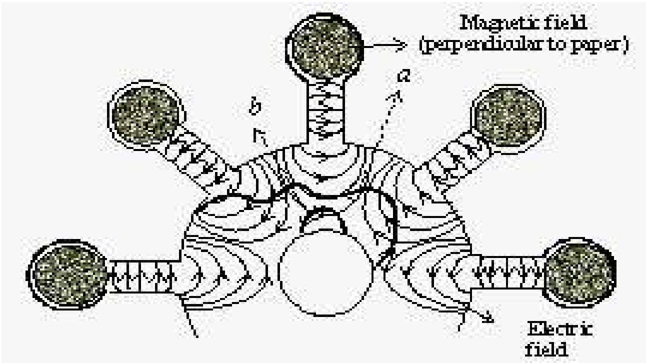
- The radius of the path is given by, if the strength of the magnetic field is made sufficiently high , then the electrons can be prevented from reaching the anode as indicated path '*c*' in figure shown below. The magnetic field required to return electrons back to the cathode just grazing the surface of the anode is called the *critical magnetic field* (B_c) *or the cut-off magnetic field.*
- If the magnetic field is larger than the critical field ($B > B_c$), the electron experiences a greater rotational force and may return back to the cathode quite faster. The various motion of electrons in the presence of different magnitudes of magnetic field can be viewed in the following figures,



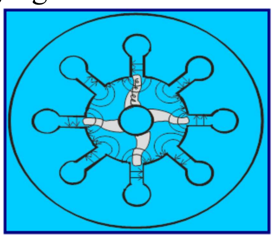




- The RF oscillations of transient nature produced when the HT is switched on, are sufficient to produce the oscillations in the cavities, these oscillations are maintained in the cavities reentrant feedback which results in the production of microwaves.
- Reentrant feedback takes place as a result of interaction of the electrons with the electric field of the RF oscillations existing in the cavities. The cavity oscillations produce electric fields which fringe out into the interaction space from the slots in the anode structure, as shown in figure , which illustrates possible trajectory of electrons from cathode to anode in an eight cavity magnetron operating in π mode .
- Energy is transferred from the radial dc field to the RF field by the interaction of the electrons with the fringing RF field. Due to the oscillations in the cavities, the either sides of the slots (which acts as a capacitor) becomes alternatively positive and negative and hence the directions of the electric field across the slot also reverse its sign alternatively.
- The following figure illustrates possible trajectory of electrons from cathode to anode in an eight cavity magnetron operating in π mode,



- At any instant the anode close to the spiraling electron goes positive, the electrons gets retarded and this is because; the electron has to move in the RF field, existing close to the slot, from positive side to the negative side of the slot. In this process, the electron loses energy and transfer an equal amount of energy to the RF field which retard the spiraling electron. On return to the previous orbit the electron may reach the adjacent section or a section farther away and transfer energy to the RF field if that part of the anode goes positive at that instant.
- This electron travels in a longest path from cathode to the anode as indicated by *'a'* in above Figure, transferring the energy to the RF field are called as *favored electrons* and are responsible for bunching effect and give up most of its energy before it finally terminates on the anode surface. An electron '*b*' is accelerated by the RF field and instead of imparting energy to the oscillations, takes energy from oscillations resulting in increased velocity, such electrons are called *unfavored electrons* which do not participate in the bunching process and cause back heating.
- Every time an electron approaches the anode "in phase" with the RF signal, it completes a cycle. This corresponds to a phase shift 2π. For a dominant mode, the adjacent poles have a phase difference of π radians, this called the π - mode. At any particular instant, one set of alternate poles goes positive and the remaining set of alternate poles goes negative due to the RF oscillations in the cavities.
- As the electron approaches the anode, one set of alternate poles accelerates the electrons and turns back the electrons quickly to the cathode and the other set alternate poles retard the electrons, thereby transferring the energy from electrons to the RF signal. This process results in the bunching of electrons, the mechanism by which electron bunches are formed and by which electrons are kept in synchronism with the RF field is called ***phase focusing effect.***
- 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 as shown in following figure.



- 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.

5. **(i) Explain in detail the VSWR measurement using microwave devices.**

VSWR (VOLTAGE STANDING WAVE RATIO) MEASUREMENT

- Used to determine the degree of mismatch between the source and load when the value VSWR $\neq$ 1. It can be measured by using a slotted line. **Direct Method Measurement** is used for VSWR values upto about 10. Its value can be read directly using a standing wave detector .
- The measurement consists simply of adjusting attenuator to give an adequate reading, making sure that the frequency is correct and then using the dc voltmeter to measure the detector output at a maximum on the slotted section and then at the nearest minimum.
- The ratio of the voltage maximum to the minimum gives the VSWR i.e

$$VSWR = V_{max} / V_{min}$$

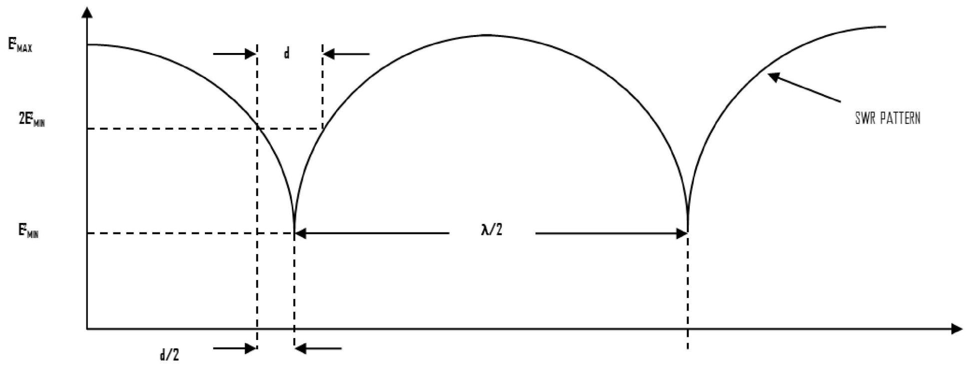
$$ISWR = I_{max} / I_{min} = k\,(V_{max})^2 / k\,(V_{min})^2 = (V_{max} / V_{min})^2 = VSWR^2$$

$$VSWR = \sqrt{(I_{max} / I_{min})} = \sqrt{ISWR}$$

- Methods used depends on the value of VSWR whether it is high or low. If the load is not exactly matched to the line, standing wave pattern is produced. Reflections can be measured in terms of voltage, current or power. Measurement using voltage is preffered because it is simplicity.
- When reflection occured, the incident and the reflected waves will reinforce each other in some places, and in others they will tend to cancel each other out.

DOUBLE MINIMUM METHOD MEASUREMENT (VSWR > 10)

- 'Double Minimum' method is usually employed for VSWR values greater than about 10.



- The detector output (proportional to field strength squared) is plotted against position. The probe is moved aling the line to find the minimum value of signal.
- It is then moved either side to determine 2 positions at which twice as much detector signal is obtained. The distance d between these two positions then gives the VSWR according to the formula:

$$S = \sqrt{1 + 1/\sin^2(\pi d/\lambda)}$$

(ii) Discuss in detail the power measurement using microwave devices.

- Power is defined as the quantity of energy dissipated or stored per unit time. Methods of measurement of power depend on the frequency of operation, levels of power and whether the power is continuous or pulsed.
- The range of microwave power is divided into three categories :-
    - Low power (< 10mW @ 0dBm)
    - Medium power (from 10 mW - 10 W @ 0 – 40 dBm)
    - High power (> 10 W @ 40 dBm)

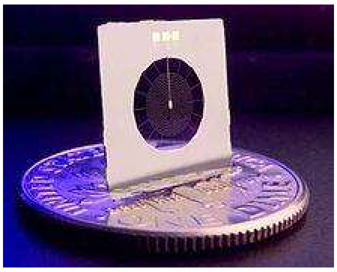
- The microwave power meter consists of a power sensor, which converts the microwave power to heat energy. The sensors used for power measurements are the Schottky barrier diode, bolometer and the thermocouple.

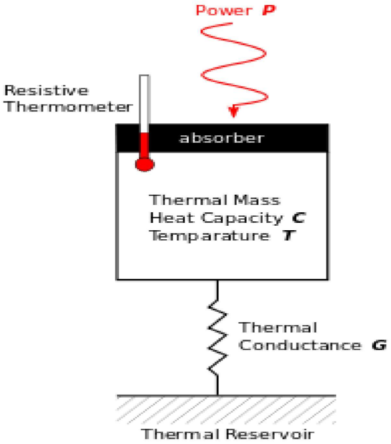
SCHOTTKY BARRIER DIODE

- A zero-biased Schottky Barrier Diode is used as a square-law detector whose output is proportional to the input power.
- The diode detectors can be used to measure power levels as low as 70dBm.

BOLOMETER

- A Bolometer is a power sensor whose resistance changes with temperature as it absorbs microwave power. Are power detectors that operate on thermal principles. Since the temperature of the resistance is dependent on the signal power absorbed, the resistance must also be in proportion to the signal power.
- The two most common types of bolometer are, the barretter and the thermistor. Both are sensitive power detectors and is used to indicate microwatts of power. They are used with bridge circuits to convert resistance to power using a meter or other indicating devices.



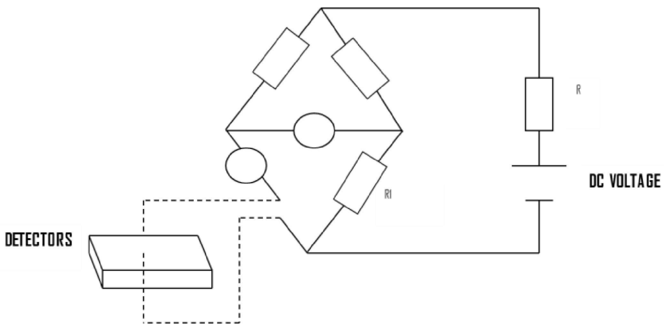


BARETTERS

- Are usually thin pieces of wire such as platinum. They are mounted as terminating devices in a section of transmission line. The section of transmission line with the mounting structure is called a detector mount. The increase of temperature of the baretter due to the power absorbed from the signal in the line causes the temperature of the device to increase.
- The temperature coefficient of the device causes the resistance to change in value in proportion to the change in temperature of the device (positive temperature coefficient i.e the resistance increases with increasing temperature; $R \alpha t$).

THERMISTOR

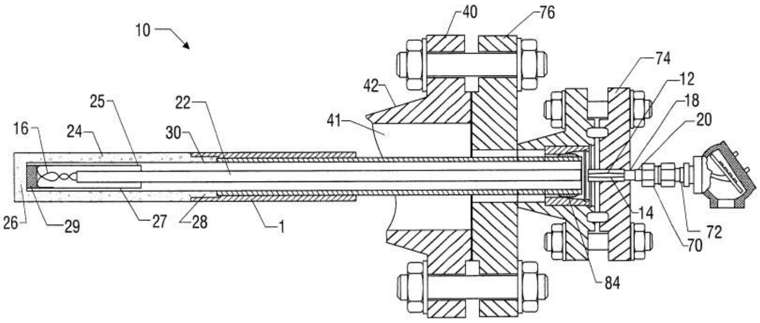
- Are beads of semiconductor material that are mounted across the line._They have a negative temperature coefficient i.e the resistance decreases with increasing temperature; R α 1/ t.
- The impedance of baretters and thermistors must match that of the transmission so that all power is absorbed by the device.
- Variations in resistance due to thermal-sensing devices must be converted to a reading on an indicating device such as a meter. This can be done accurately using a balanced bridge arrangement as shown below:-



- With no power to the detector that contains the sensor element, the sensor-line R1 is adjusted to zero reading through the meter M1 and the bridge circuit is balanced. When signal is applied to the sensor element, causing its temperature to change, the sensor resistance changes, causing the bridge to become unbalanced. Resistor R1 is adjusted to balance meter M1. The change in the reading of meter M2 in the sensor element leg is a direct measure of the microwave power.

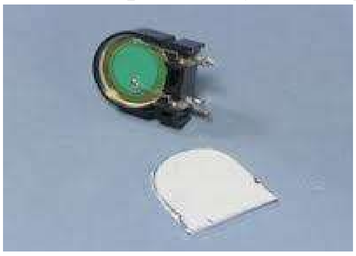
THERMOCOUPLES

- Are used as power monitors in the low-to-medium power regions and are very sensitve. Is a thin wire made of two disimilar metals. Hence there will be two junctions (hot & cold).
- When the temperature at two junctions are different, a voltage is developed across the thermocouple (i.e across both junctions). This developed voltage is proportional to the difference between the two junction temperatures. When the temperature at both junctions are the same, the difference in voltage = 0.



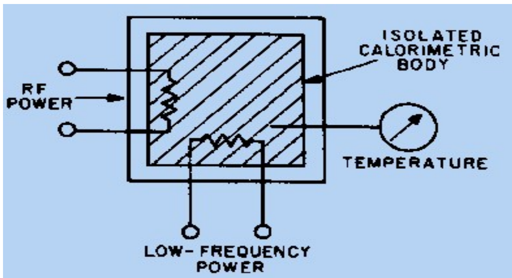
MICROWAVE CRYSTALS

- Are non-linear detectors that provide current in proportion to the power. It is limited to making low-power measurements.
- The current is proportional to the power due to the square-law characteristic of the crystal. This square-law characteristic only occurs for small signal levels.
- At larger signal levels the relationship is linear, as with any diode. Therefore the proportional relationship between power and current output is only true at power levels below 10mW.



CALORIMETERS

- The calorimeters are the most accurate of all instruments for measuring high power. Calorimeters depend on the complete conversion of the input electromagnetic energy into heat. Direct heating requires the measurement of the heating effect on the medium, or load, terminating the line. Indirect heating requires the measurement of the heating effect on a medium or body other than the original power-absorbing material.
- Power measurement with true calorimeter methods is based solely on temperature, mass, and time. *Substitution* methods use a known, low-frequency power to produce the same physical effect as an unknown of power being measured. Calorimeters are classified as STATIC (non flow) types and CIRCULATING (flow) types.



16ECT72-RF and Microwave Engineering-Question Bank

Unit V

Part A - 2 marks Questions & Answers

1. List the key parameters used to evaluate the performance of an amplifier?
   Key parameters of amplifier, to evaluate its performance are
   - Gain and gain flatness
   - Operating frequency and bandwidth
   - Output power
   - Power supply requirements
   - Input and output reflection coefficients
   - Noise figure
2. Define transducer power gain and unilateral power gain
   - ➢ Transducer power gain is nothing but the gain of the amplifier when placed between source and load. G_T= Power delivered to the load / Available power from the source = P_L/P_A
   - ➢ Unilateral power gain is the amplifier power gain, When feedback effect of amplifier is neglected i.e. S12 = 0.
3. What is the function of input and output matching networks?
   - ➢ Matching networks can help stabilize the amplifier by keeping the source and load impedance in the appropriate range.
   - ➢ Input and output matching networks are needed to reduce undesired reflections and improve the power flow capabilities.
4. Write short notes on feedback of RF circuits.
   (i) If $|\Gamma|>1$, then the magnitude of the return voltage wave increases called positive feedback, which causes instability (Oscillator).
   (ii) If $|\Gamma|<1$, the return voltage wave is totally avoided (amplifier). It's called as negative feedback.
5. Define unconditional stability and noise figure
   - ➢ Unconditional stability refers to the situation where the amplifier remains stable for any passive source and load at the selected frequency and bias conditions.
   - ➢ Noise figure F is defined as "the ratio of the input SNR to the output SNR".
     F= Input SNR / Output SNR
6. State the need of a matching network and Illustrate the importance of a matching network
   <u>Need for a matching network:</u>
   Matching networks can help stabilize the amplifier by keeping the source and load impedances in the appropriate range. The need for matching network is,
   - To stabilize the amplifier by keeping the source and load impedances in the appropriate range
   - To reduce undesired reflections
   - To improve the power flow capabilities

   <u>Importance of a matching network:</u>
   1. Minimum power loss in the feed line
   2. Maximum power delivers (or) Transfer
   3. Improving the S/N ratio of the system for sensitive receiver components
   4. Reducing amplitude & phase errors in a power distribution network
   5. Minimum reflection in transmission line
   6. Optimal efficiency

7. Define loaded quality factor and nodal quality factor

- The loaded quality factor is equal to the ratio of the resonance frequency to the 3 dB bandwidth.

$$Ql=f_0/BW$$

- Nodal quality factor is defined as the ratio of the absolute value of the reactance to the corresponding resistance.

$$Qn=Xs/Rs$$

8. List the advantage of T and Pi matching network and state the purpose of double stub matching networks.

<u>Advantage of T and Pi matching network:</u>
The addition of the third element into the two element matching network introduces an addition degree of freedom in the circuit and allows us to control the value of ql by choosing appropriate intermediate impedance for wider bandwidth.

<u>Purpose of double stub matching networks:</u>
One of the main drawbacks of single stub matching network is that they require a variable length transmission line between the stub and the input port, or between the stub and the load impedance. Usually, this does not a problem for fixed networks, but may create difficulties for variable tuners.

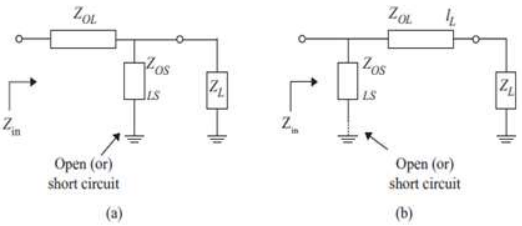
9. Name the factor which is used for selecting a matching network and mention the advantage of Smith chart.

<u>Factors which is used for selecting a matching network:</u>
1. Complexity
2. Bandwidth Requirement
3. Adjustability
4. Implementation

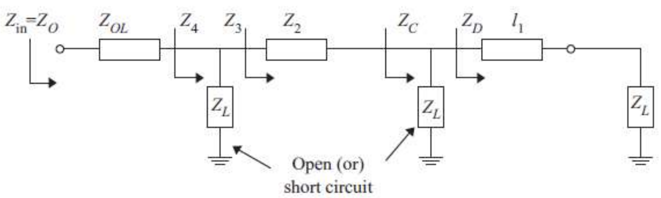
<u>Advantage of Smith chart:</u>
The smith chart allows immediately observing whether or not a particular impedance transformation is capable of achieving the desired matching. Moreover, the total number of possible network configurations can be readily be seen.

10. Draw the two topologies of single stub matching networks and double stub matching network arrangement.

Single stub matching network



Double stub matching network



<u>Part B – 16 mark questions & answers</u>

1. Derive the expressions for following parameters using S-parameters in amplifier design:

(i) Available power (ii) Transducer power gain

(iii) Unilateral power gain (iv) Available power gain and (v) Operating power gain

$$P_{\text{in}} = \frac{1}{2}\frac{|b_s|^2}{|1-\Gamma_{\text{in}}\Gamma_s|^2}(1-|\Gamma_{\text{in}}|^2) \qquad \text{------ (1)}$$

(i) Available power:

Under the maximum power transfer condition, the available power P_A is defined as,

$$P_A = P_{\text{in}}\Big|_{\Gamma_{\text{in}}=\Gamma_s^*} \qquad \text{-----(2)}$$

Substitute (1) in (2)

$$P_A = \frac{1}{2}\frac{|b_s|^2(1-|\Gamma_{\text{in}}|^2)}{|1-\Gamma_{\text{in}}\Gamma_s|^2}\Bigg|_{\Gamma_{\text{in}}=\Gamma_s^*}$$

$$P_A = \frac{1}{2}\frac{|b_s|^2(1-|\Gamma_{\text{in}}|^2)}{|1-\Gamma_s^*\Gamma_s|^2}$$

$$P_A = \frac{1}{2}\frac{|b_s|^2(1-|\Gamma_{\text{in}}|^2)}{|1-|\Gamma_s|^2|^2}$$

$$= \frac{1}{2}\frac{|b_s|^2(1-|\Gamma_{\text{in}}|^2)}{(1-|\Gamma_s|^2)(1-|\Gamma_s^*|^2)} \quad [\because\ |Z|^2 = Z\cdot Z^*]$$

$$= \frac{1}{2}\frac{|b_s|^2(1-|\Gamma_{\text{in}}|^2)}{(1-|\Gamma_s|^2)(1-|\Gamma_{\text{in}}|^2)} \quad [\because\ \Gamma_s^* = \Gamma_{\text{in}}] \qquad P_A = \frac{1}{2}\frac{|b_s|^2}{(1-|\Gamma_s|^2)}$$

(ii) Transducer power gain: Transducer power gain (GT) is nothing but the gain of the amplifier placed between source and load.

$$G_T = \frac{\text{Power delivered to the load}}{\text{Available power from the source}}$$

$$G_T = \frac{P_L}{P_A}$$

$$P_L = \frac{1}{2}|b_2|^2(1-|\Gamma_L|^2)$$

substitute P_L, P_A value in G_T,

$$\therefore G_T = \frac{P_L}{P_A}$$

$$= \frac{\frac{1}{2}|b_2|^2(1-|\Gamma_L|^2)}{\frac{1}{2}\frac{|b_s|^2}{1-|\Gamma_s|^2}}$$

$$G_T = \frac{|b_2|^2}{|b_s|^2}(1-|\Gamma_L|^2)(1-|\Gamma_s|^2)$$

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_L|^2)(1-|\Gamma_s|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L)-S_{12}S_{21}\Gamma_L\Gamma_S|^2}$$

Let us define the input and output reflection coefficients as,

$$\Gamma_{\text{in}} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$

$$\Gamma_{\text{out}} = S_{22} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{11}\Gamma_S}$$

`

(iii) Unilateral power gain

In the transducer power gain, the feedback effect of the amplifier is neglected i.e., $S_{12} = 0$, then it is called unilateral power gain (G_{TU}).

$$G_{TU} = \frac{(1-|\Gamma_L|^2)|S_{21}|^2(1-|\Gamma_S|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L)|^2}$$

$$G_{TU} = \frac{(1-|\Gamma_L|^2)|S_{21}|^2(1-|\Gamma_S|^2)}{|1-\Gamma_S S_{11}||1-S_{22}\Gamma_L|^2}$$

(iv) Available power gain:

$$G_A = G_T\Big|_{\Gamma_L=\Gamma^*_{\text{out}}}$$

$$= \frac{\text{Power available from the amplifier}}{\text{Power available from the source}}$$

$$
\begin{aligned}
G_A &= \frac{|S_{21}|^2(1-|\Gamma_s|^2)(1-|\Gamma_{\text{out}}^*|^2)}{(1-\Gamma_{\text{out}}\Gamma_{\text{out}}^*)^2|1-S_{11}\Gamma_s|^2} \\
&= \frac{|S_{21}|^2(1-|\Gamma_s|^2)(1-\Gamma_{\text{out}}^*\Gamma_{\text{out}})}{(1-\Gamma_{\text{out}}\Gamma_{\text{out}}^*)^2|1-S_{11}\Gamma_s|^2} \\
&= \frac{|S_{21}|^2(1-|\Gamma_s|^2)}{(1-\Gamma_{\text{out}}\Gamma_{\text{out}}^*)^2|1-S_{11}\Gamma_s|^2} \\
G_A &= \frac{|S_{21}|^2(1-|\Gamma_s|^2)}{(1-|\Gamma_{\text{out}}|^2)|1-S_{11}\Gamma_s|^2} \quad [|Z|^2 = Z \cdot Z^*]
\end{aligned}
$$

(v) Operating power gain

$$
\begin{aligned}
G &= \frac{\text{Power delivered to the load}}{\text{Power supplied to the amplifier}} \\
&= \frac{P_L}{P_{\text{in}}}
\end{aligned}
$$

$$
G = \frac{(1-|\Gamma_L|^2)|S_{21}|^2}{(1-|\Gamma_{\text{in}}|^2)|1-S_{22}\Gamma_L|^2}
$$

2. Apply stabilization methods to illustrate stability considerations for RF amplifier design

Stability Circles: Stability occurs when the magnitudes of the reflection coefficients are less than unity.

$$
|\Gamma_L| < 1, \quad |\Gamma_S| > 1
$$

$$
\begin{aligned}
\Gamma_{\text{in}} &= S_{11} + \frac{S_{21}S_{12}\Gamma_L}{1-S_{22}\Gamma_L} \\
&= \frac{S_{11} - S_{11}S_{22}\Gamma_L + S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \\
\Gamma_{\text{in}} &= \frac{S_{11} - (S_{11}S_{22} - S_{12}S_{21})\Gamma_L}{1-S_{22}\Gamma_L} \\
\Gamma_{\text{in}} &= \frac{S_{11} - \Gamma_L\Delta}{1-S_{22}\Gamma_L} \quad [\because\ S_{11}S_{12} - S_{12}S_{21} = \Delta] \\
\because \Gamma_{\text{in}} &= \left|\frac{S_{11} - \Gamma_L\Delta}{1-S_{22}\Gamma_L}\right| < 1
\end{aligned}
$$

$$
\Gamma_{\text{out}} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}
$$

$$\begin{aligned}
\Gamma_{\text{out}} &= \frac{S_{22} - S_{11}S_{22}\Gamma_S + S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \\
&= \frac{S_{22} - (S_{11}S_{22} - S_{12}S_{21})\Gamma_S}{1 - S_{11}\Gamma_S} \\
&= \frac{S_{22} - \Delta\Gamma_S}{1 - S_{11}\Gamma_S} \quad [\because\ S_{11}S_{12} - S_{12}S_{21} = \Delta] \\
|\Gamma_{\text{out}}| &= \left|\frac{S_{22} - \Gamma_S\Delta}{1 - \Gamma_S S_{11}}\right| < 1
\end{aligned}$$

Since for a particular frequency S-parameters are fixed Let us consider the complex quantities as

$$\begin{aligned}
S_{11} &= S_{11}^R + jS_{11}^I \\
S_{22} &= S_{22}^R + jS_{22}^I \\
\Delta &= \Delta^R + j\Delta^I \\
\Gamma_L &= \Gamma_L^R + j\Gamma_L^I
\end{aligned}$$

$$|\Gamma_{\text{in}}| = \left|\frac{S_{11}^R + jS_{11}^I - (\Gamma_L^R + j\Gamma_L^I)(\Delta^R + j\Delta^I)}{1 - (S_{22}^R + jS_{22}^I)(\Gamma_L^R + j\Gamma_L^I)}\right|$$

After simplification, the output stability circle equation is,

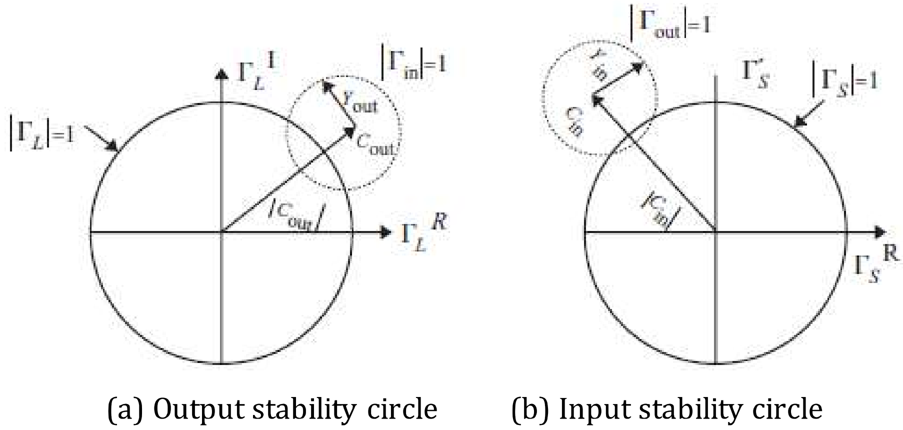
$$(\Gamma_L^R - C_{\text{out}}^R)^2 + (\Gamma_L^I - C_{\text{out}}^I)^2 = \gamma_{\text{out}}^2$$

where the circle radius is given by,

$$\gamma_{\text{out}} = \frac{|S_{12}S_{21}|}{||S_{22}|^2 - |\Delta|^2|}$$

and the centre of the circle is located at,

$$\begin{aligned}
C_{\text{out}} &= C_{\text{out}}^R + jC_{\text{out}}^I \\
&= \frac{(S_{22} - S_{11}^*\Delta)^*}{|S_{22}|^2 - |\Delta|^2}
\end{aligned}$$



(a) Output stability circle (b) Input stability circle where radius of the circle,

$$\gamma_{\text{in}} = \frac{|S_{12}S_{21}|}{||S_{11}|^2| - |\Delta|^2}$$

Centre of the circle located at,

$$C_{\text{in}} = C_{\text{in}}^R + C_{\text{in}}^I$$
$$= \frac{(S_{11} - S_{22}^*\Delta)^*}{|S_{11}|^2 - |\Delta|^2}$$

For Output Stability Circle

If $\Gamma_L = 0$, then $|\Gamma_{\text{in}}| = |S_{11}|$, there are two cases possible depends on $|S_{11}| < 1$ or $|S_{11}| > 1$.

Case (i): For $|S_{11}| < 1$, the origin ($|\Gamma_L = 0$) is part of the stable region shown in Figure (a).

Case (ii): For $|S_{11}| > 1$, the matching condition $\Gamma_L = 0$ results in $\Gamma_{\text{in}} = |S_{11}| > 1$, *i.e.*, the origin is part of the unstable region. In this case only stable region is shaded which is shown in Figure (b).

For Input Stability Circle

Figure shows the two stability domains for the input stability circle. From the thumb rule, if $|S_{22}| < 1$, which leads to the conclusion that the center ($\Gamma_S = 0$) must be stable; otherwise the center becomes unstable for $|S_{22}| > 1$.

Unconditional Stability

Unconditional stability is nothing but the situation where the amplifier remains stable throughout the entire domain of the Smith chart at the selected frequency and bias conditions. This applies to both the input and output ports. For $|S_{11}| < 1$, $|S_{22}| < 1$, it is stated as,

$$||C_{\text{in}}| - \gamma_{\text{in}}| > 1$$
$$||C_{\text{out}}| - \gamma_{\text{out}}| > 1$$

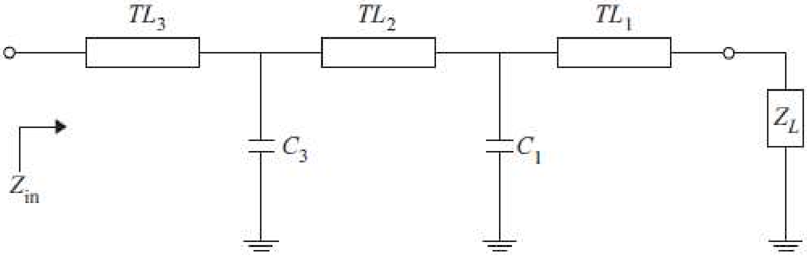
The stability factor k applies for both input and output ports.

$$\boxed{K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta^2|}{2|S_{12}||S_{21}|} > 1}$$

3. Describe in detail about microstrip line matching networks

From Discrete Components to Micro Strip Lines:

In the mid GHz range, design engineers often employ a mixed approach by combining lumped and distributed elements. These types of matching networks usually contain a number of transmission lines connected in series and capacitors spaced in a parallel configuration as illustrated in following figure.



Mixed design of matching network involving transmission line section T_L and discrete capacitive elements.

Inductors are usually avoided in such designs because they tend to have higher resistive loses than capacitors. In general only one shunt capacitor with two transmission lines are connected in series on both sides as sufficient to transform any given load impedance to any input impedance.

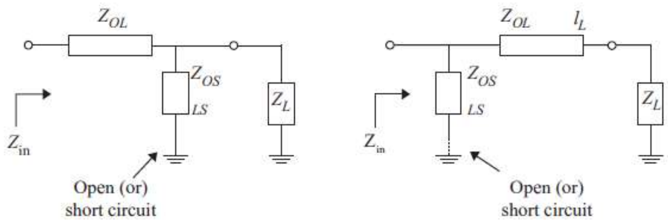
The arrangement of components in above figure is very attractive in practice. Since it permits tuning the circuit after it has been manufactured changing the values of the capacitors as well as placing them at different locations along transmission lines offers wide range of flexibility. The tuning capability makes these types of matching networks a very popular for prototyping.

Single Stub Matching Network

This is one of the step for the transition from the lumped to distributed element networks in the complete elimination of all lumped components. This is accomplished by employing open/short circuit in stub lines. In this a series transmission line is connected to a parallel open circuit (or) short-circuit stub. It has two topologies.

- First one involves a series transmission line connected to a parallel combination of load and stub
- Second one involves a parallel stub connected to the series combination of load and transmission line

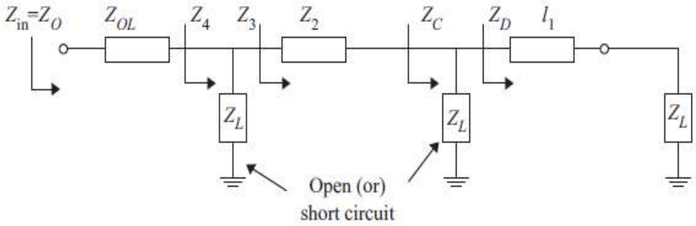
The matching networks possess four adjustable parameters, length l_s, and characteristic impedance Z_{os} of the stub and the length l_L and characteristic impedance Z_{OL} of the transmission line.



Two topologies of single stub matching networks

Double Stub Matching Networks

The single stub matching networks are quite versatile and allow matching between any input and load impedances, so long as they have a non-zero real part. One of the main drawbacks of such matching networks is that they require a variable-length transmission to between stub and input part (or) between the stub and load impedance. And this drawback can be avoided by double stub matching networks.



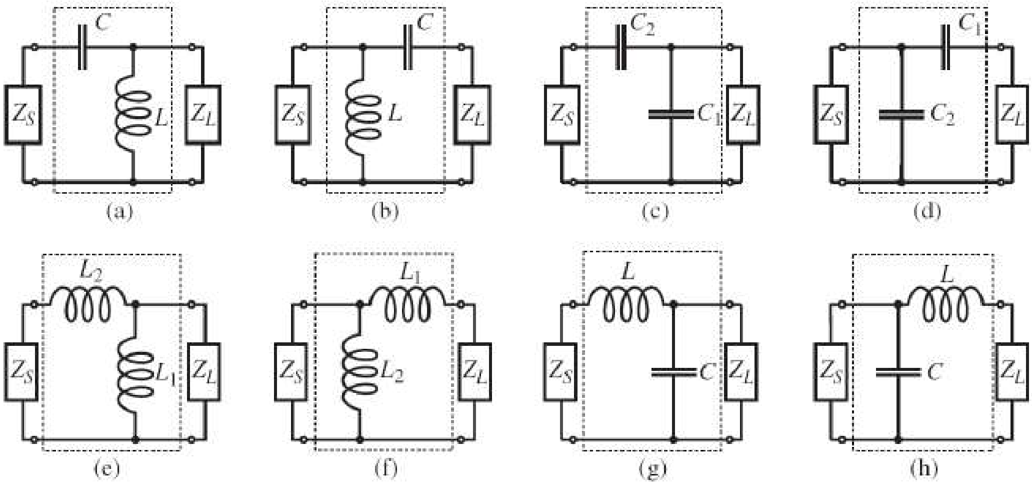
In this double stub matching networks, two short (or) open circuit stubs are connected in parallel with a fixed length transmission line placed in between. The length $l2$ of this line is usually chosen to be one eight three-eight and five eights of wavelengths. The $3/8^{th}$ and $5/8^{th}$ are mostly used in the high frequency applications. The length of the line segment between two stubs is $l2 = (3/8)\lambda$.

For a perfect match it is required that $Zin = ZO$ and $YA = 1$. Since the lines are assumed to be lossless, the normalized admittance $YB = YA - jbs2$ is located in the constant circle $J = 1$. For $l2 = (3/8)\lambda$ line the $g = 1$ circle is rotated by $\alpha/3l2 = 3\pi/2$ radians (or) 270^0 towards the load. The admittance y_e needs to reside on this rotated $g = 1$ circle called yc circle in order to tp ensure matching.

By varying the length of ls stub we can transform point $Y0$ such a way that the resulting Y_c is indeed located on the rotated $g = 1$ circle. This procedure can be done for any load impedance except Y_d as it is located in $g = 2$ circle. This represents the forbidden region. To overcome this problem in practical applications, commercial double stub tunnel are usually have input and output transmission lines whose lengths are related according to $l1 = l3 \pm \lambda4$. In this case if particular load impedance cannot be matched, one simply connects the load to the opposite end of the tuner which moves Y_D,out of forbidden region.

4. Describe L – Type Matching Network with suitable example

Various configurations



Their usefulness is regulated by the specified source and load impedances and the associated matching requirements

Design procedure for two element L – Type matching Network:

1. Find the normalized source and load impedances.
2. In the Smith chart, plot circles of constant resistance and conductance that pass through the point denoting the source impedance.
3. Plot circles of constant resistance and conductance that pass through the point of the complex conjugate of the load impedance ($z_M = z_L^*$).
4. Identify the intersection points between the circles in steps 2 and 3. The numbers of intersection points determine the number of possible L-type matching networks.

5. Find the values of normalized reactances and susceptances of the inductors and capacitors by tracing a path along the circles from the source impedance to the intersection point and then to the complex conjugate of the load impedance.
6. Determine the actual values of inductors and capacitors for a given frequency.

Example: Using the Smith chart, design all possible configurations of discrete two element matching networks that match the source impedance $Z_S = (50+j25)\Omega$ to the load $Z_L = (25-j50)\Omega$. Assume a characteristic impedance of $Z_0 = 50\Omega$ and an operating frequency of f = 2 GHz

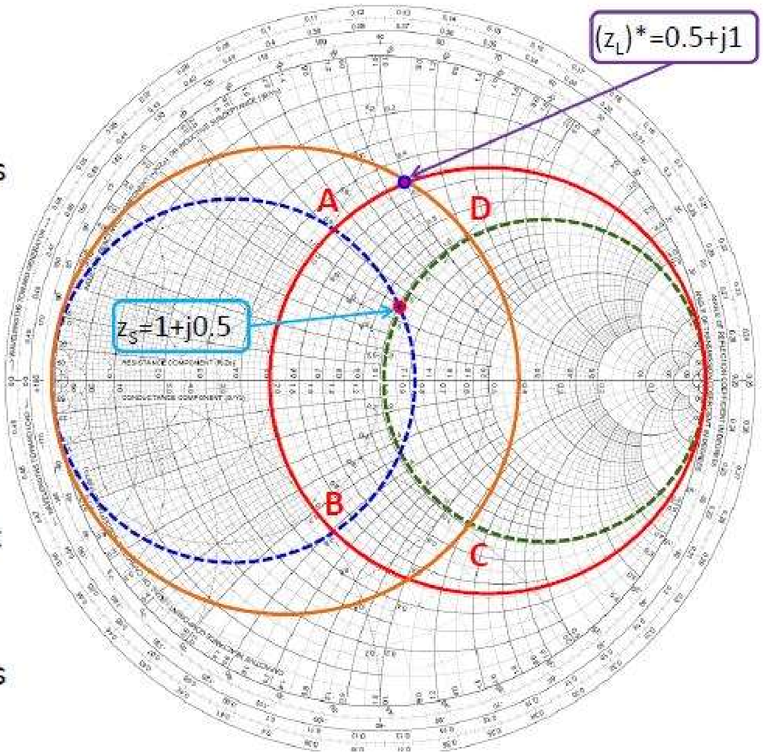
Solution:

1. The normalized source and load impedances are:

$$\boxed{z_S = Z_S / Z_0 = 1 + j0.5 \qquad y_S = 0.8 - j0.4}$$

$$\boxed{z_S = Z_L / Z_0 = 0.5 - j1 \qquad y_S = 3 + j0.8}$$

2. Mark z_S and then plot circles of constant resistance and conductance that passes through z_S.



3. Mark $(z_L)^*$ and then plot circles of constant resistance and conductance that passes through $(z_L)^*$.

4. The intersection points of these circles are A, B, C and D with the normalized impedances and inductances as:

$z_A = 0.5 + j0.6 \qquad y_A = 0.8 - j1$

$z_B = 0.5 - j0.6 \qquad y_B = 0.8 + j1$

$z_C = 1 - j1.2 \qquad y_C = 3 + j0.5$

$z_D = 1 + j1.2 \qquad y_D = 3 - j0.5$

5. There are four intersection points and therefore four L-type matching circuit configurations are possible.

$z_S \rightarrow z_A \rightarrow (z_L)^*$ ⇨ Shunt L, Series L

$z_S \rightarrow z_B \rightarrow (z_L)^*$ ⇨ Shunt C, Series L

$z_S \rightarrow z_C \rightarrow (z_L)^*$ ⇨ Series C, Shunt L

$z_S \rightarrow z_D \rightarrow (z_L)^*$ ⇨ Series L, Shunt L

6. Find the actual values of the components

In the first case:

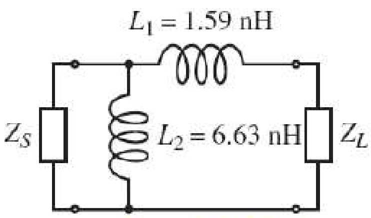
$z_S \rightarrow z_A$: the normalized admittance is changed by

$$jb_{L_2} = y_A - y_S = -j0.6 \qquad \Rightarrow L_2 = -\frac{Z_0}{b_{L_2}\omega} = 6.63nH$$

$z_A \rightarrow z_L$: the normalized impedance is changed by

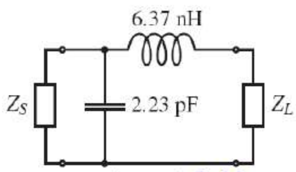
$$jx_{L_1} = (z_L)^* - z_A = j0.4 \qquad \Rightarrow L_1 = \frac{x_{L_1} Z_0}{\omega} = 1.59nH$$

Therefore the circuit is:

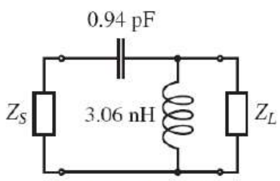


$z_S \rightarrow z_A \rightarrow (z_L)^*$

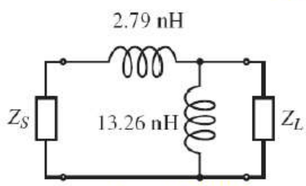
Similarly:



$z_S \rightarrow z_B \rightarrow (z_L)^*$



$z_S \rightarrow z_C \rightarrow (z_L)^*$



$z_S \rightarrow z_D \rightarrow (z_L)^*$

5. Explain in detail about pi and T matching networks

T and Pi Matching Networks:

• The knowledge of nodal quality factor (Qn) of a network enables estimation of loaded quality factor → hence the Band Width (BW).

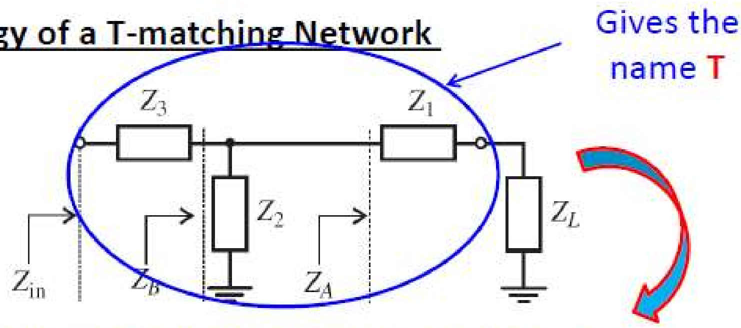
• The addition of third element into the matching network allows control of QL by choosing appropriate intermediate impedance.

Example-1:

Design a T-type matching network that transforms a load impedance $Z_L = (60 - j30)\Omega$ into a $Z_{in} = (10 + j20)\Omega$ input impedance and that has a maximum Q_n of 3. Compute the values for the matching network components, assuming that matching is required at f = 1GHz.

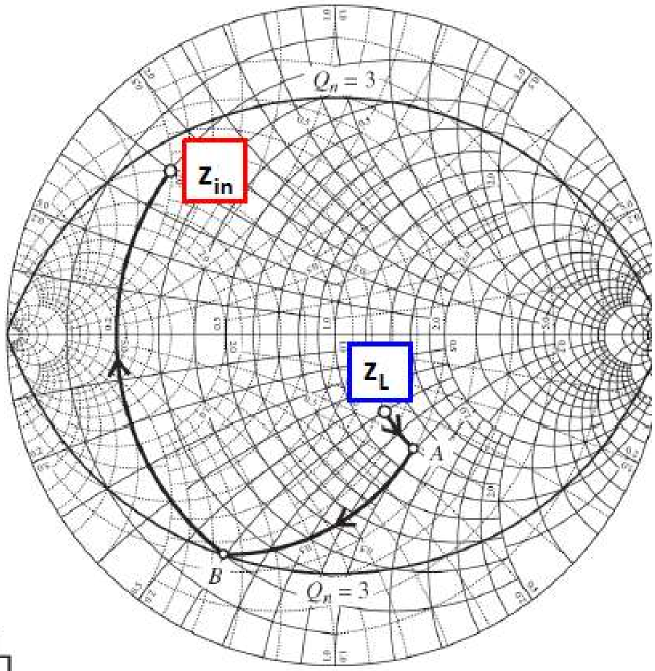
Solution:

General Topology of a T-matching Network

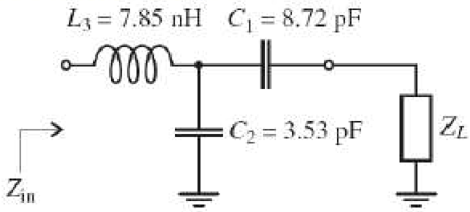


- First element in series (Z_1) is purely reactive, therefore the **combined impedance of (Z_L and Z_1)** will reside on the constant resistance circle of **$r = r_L$**
- Similarly, Z_3 (that is purely reactive!) **is connected in series** with the input, therefore **the combined impedance Z_B** (consisting of Z_L, Z_1, and Z_2) lies on the constant resistance circle **$r = r_{in}$**
- Network needs to have a Q_n of 3 → we should choose impedance in such a way that Z_B is located on the **intersection** of constant resistance circle **$r = r_{in}$** and Q_n = 3 circle → helps in the determination of Z_3

- The constant resistance circle of z_{in} intersects the $Q_n = 3$ circle at point **B**. This gives value of Z_3.
- The constant resistance circle $r = r_L$ and a constant conductance circle that passes through B helps in the determination of and allows determination Z_2 and Z_1.



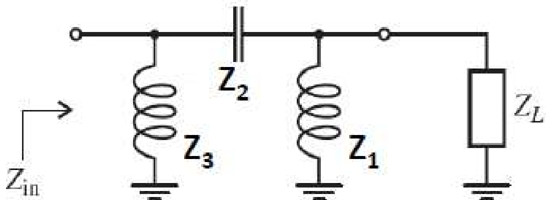
Final solution at 1 GHz



Example 2:

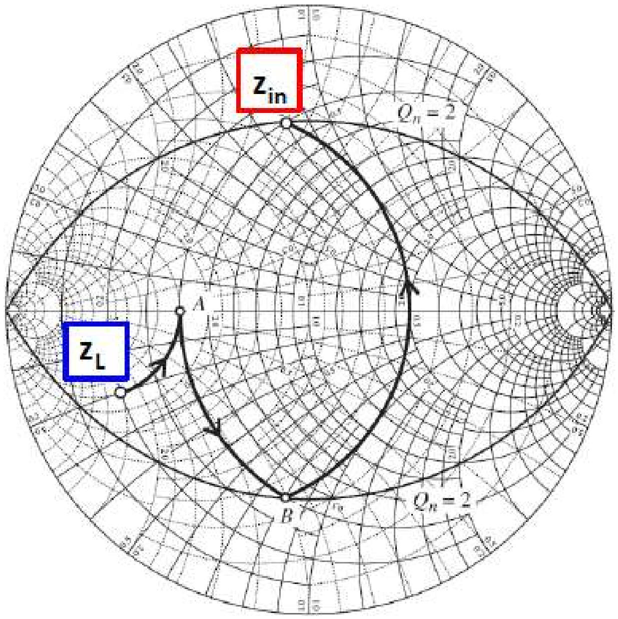
For a broadband amplifier, it is required to develop a Pi-type matching network that transforms a load impedance $Z_L = (10 - j10)\Omega$ into an input impedance of $Z_{in} = (20 + j40)\Omega$. The design should involve the lowest possible Q_n. Compute the values for the matching network components, assuming that matching is required at f = 2.4GHz.

Solution:

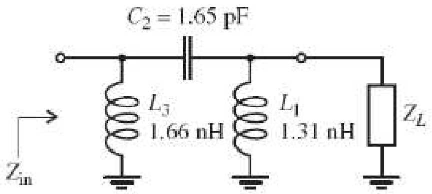


- Since the load and source impedances are fixed, we can't develop a matching network that has Q_n lower than the values at locations Z_L and Z_{in}
- Therefore in this example, the minimum value of Q_n is determined at the input impedance location as $Q_n = |X_{in}|/R_{in} = 40/20 = 2$

- In the design, we first plot constant conductance circle $g = g_{in}$ and find its intersection with $Q_n=2$ circle (point B) → determines the value of Z_3
- Next find the intersection point (labeled as A) of the $g=g_L$ circle and constant-resistance circle that passes through B → determines value of Z_2 and Z_1



Final solution at 2.4 GHz



- It is important to note that the relative positions of Z_{in} and Z_L **allows only one** optimal Pi-type network for a given specification.
- All other realizations will result in higher Q_n → **essentially smaller BW!**
- Furthermore, **for smaller Z_L** the Pi-matching isn't possible!

It is thus apparent that BW can't be enhanced arbitrarily by reducing the Q_n. The limits are set by the desired complex Z_{in} and Z_L.

With increasing frequency and correspondingly reduced wavelength the influence of parasitics in the discrete elements are noticeable → distributed matching networks overcome most of the limitations (of discrete components) at high frequency