14. Assignment topics

Unit 1:

1. What are the dominant and degenerate modes
Ans: Dominant mode:
» The mode with the lowest cut-off frequency is called the dominant mode.
» Since TM modes for rectangular waveguides start from TM_{11} mode, the dominant frequency is

$$ (f_c)_{11} = \frac{1}{2a} \sqrt{\frac{1}{\mu} + \frac{1}{\varepsilon}} \ (Hz) $$

» TE_{10} mode is the minimum possible mode that gives nonzero field expressions for rectangular waveguides, it is the dominant mode of a rectangular waveguide with a>b and so the dominant frequency is

$$ (f_c)_{10} = \frac{1}{2a} \sqrt{\varepsilon} \ (Hz) $$

Degenerate modes:
» In a waveguide when two or more modes have the same cut off frequency then they are said to be degenerate modes.
» In a rectangular waveguide the TE_{mn} and TM_{mn} with m \neq 0 and n \neq 0 are degenerate modes.

2. An air-filled rectangular waveguide of inside dimensions 7 x 3.5 cm operates in the dominant TE10 mode as shown in Fig find frequency, wavelength, group velocity

Solution:

a. \( f_c = \frac{c}{2a} = \frac{3 \times 10^8}{2 \times 7 \times 10^{-2}} = 2.14 \ GHz \)

b. \( v_g = \frac{c}{\sqrt{1 - (f_c/f)^2}} = \frac{3 \times 10^8}{\sqrt{1 - (2.14/3.5)^2}} = 3.78 \times 10^8 \ m/s \)

c. \( \lambda_g = \frac{\lambda_0}{\sqrt{1 - (f_c/f)^2}} = \frac{3 \times 10^8/(3.5 \times 10^9)}{\sqrt{1 - (2.14/3.5)^2}} = 10.8 \ cm \)

3. An air-filled a\times b \ (b<a<2b) \ rectangular waveguide is to be constructed to operate at 3GHz in the dominant mode. We desire the operating frequency to be at least 20% higher than the cutoff frequency of the dominant mode and also at least 20% below

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the cutoff frequency of the next higher-order mode. (a) Give a typical design for the dimensions \(a\) and \(b\). (b) Calculate for your design \(\beta\)\(, \nu_p\)\(, \lambda_g\) and the wave impedance at the operating frequency. [台大電研]

(Sol.) (a) \(f_c = \frac{1}{2\sqrt{\mu \varepsilon}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}\). \(b < a < 2b\), the dominant mode: \(TE_{10}\), the next mode: \(TE_{01}\)

\[
\left(f_c\right)_{TE_{10}} = \frac{1}{2a\sqrt{\mu \varepsilon}}, \quad \left(f_c\right)_{TE_{01}} = \frac{1}{2b\sqrt{\mu \varepsilon}}, \quad \frac{3 \times 10^9 - (1/2a\sqrt{\mu \varepsilon})}{(1/2a\sqrt{\mu \varepsilon})} > 20\%
\]

\[
\frac{(1/2b\sqrt{\mu \varepsilon}) - 3 \times 10^9}{(1/2b\sqrt{\mu \varepsilon})} > 20\% \Rightarrow a \geq 0.06 m, \quad b \leq 0.04 m, \quad \text{and} \quad a < 2b
\]

(b) Choose \(a = 0.065 m, b = 0.035 m\), \(\left(f_c\right)_{TE_{10}} = 2.3 \times 10^9 (Hz), \quad \sqrt{1 - \left(\frac{f}{f_c}\right)^2} = 0.679, \quad \beta = \omega \sqrt{\mu \varepsilon} \sqrt{1 - \left(\frac{f}{f_c}\right)^2} = 40.15 rad/m, \quad \nu_p = \frac{1}{\sqrt{\mu \varepsilon \sqrt{1 - \left(\frac{f}{f_c}\right)^2}}} = 4.7 \times 10^8 m/s,
\]

\[\lambda_g = \frac{\nu_p}{f} = 0.157 m, \quad Z_{TE_{10}} = \frac{\eta_0}{\sqrt{1 - \left(\frac{f}{f_c}\right)^2}} = 120\pi / 0.639 = 590 \Omega\]

4. **Explain the power transmission in RWG**

Ans: The power transmitted through a waveguide and the power loss in the guide walls can be calculated by means of the complex Poynting theorem. It is assumed that the guide is terminated in such a way that there is no reflection from the receiving end or that the guide is infinitely long compared with the wavelength. From the Poynting theorem the power transmitted through a guide is given by

\[
P_u = \oint p \cdot ds = \oint \frac{1}{2} (E \times H^*) \cdot ds
\]

For a lossless dielectric, the time-average power flow through a rectangular guide is given by

\[
P_u = \frac{1}{2Z_e} \int_a \left| E \right|^2 da = \frac{Z_g}{2} \int_a \left| H \right|^2 da
\]

where \(Z_e = \frac{E_x}{H_x} = -\frac{E_y}{H_y}\)

\[
\left| E \right|^2 = \left| E_x \right|^2 + \left| E_y \right|^2
\]

\[
\left| H \right|^2 = \left| H_x \right|^2 + \left| H_y \right|^2
\]

For TE_{mn} modes, the average power transmitted through a rectangular waveguide is

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given by

\[ P_{av} = \frac{\sqrt{1 - (\frac{f_c}{f})^2}}{2\eta} \int_0^a \int_0^b (|E_x|^2 + |E_y|^2) \, dx \, dy \]

For \( TM_{mnm} \) modes, the average power transmitted through a rectangular waveguide is given by

\[ P_{av} = \frac{1}{2\eta \sqrt{1 - (\frac{f_c}{f})^2}} \int_0^b \int_0^a (|E_x|^2 + |E_y|^2) \, dx \, dy \]

where \( \eta = \sqrt{\frac{\mu}{\epsilon}} \)

5. **Explain the losses in microstrip lines**

**Ans:** Losses in microstrip lines:
  1. Dielectric losses
  2. Ohmic losses
  3. Radiation losses

**Dielectric losses:**
when the conductivity of a dielectric cannot be neglected, the electric and magnetic fields in the dielectric are no longer in time phase.

\[ \alpha_d = \frac{\sigma}{2} \sqrt{\frac{\mu}{\epsilon}} \quad \text{Np/cm} \]

The dielectric constant is

\[ \alpha_d = \frac{\omega}{2} \sqrt{\mu \epsilon \tan \theta} \quad \text{Np/cm} \]

\[ \tan \theta = \frac{\sigma}{\omega \epsilon} \]

where loss tangent

**Ohmic losses:**
In a microstrip line over a low-loss dielectric substrate, the predominant sources of losses at microwave frequencies are the no perfect conductors. The current density in the conductors of a microstrip line is concentrated in a sheet that is approximately a skin depth thick inside the conductor surface and exposed to the electric field. Both the strip conductor thickness and the ground plane thickness are assumed to be at least three or four skin depths thick. The current density in the strip conductor and the ground conductor is not uniform in the transverse plane. The microstrip conductor contributes the major part of the ohmic loss. The attenuation constant for ohmic loss is:

\[ \alpha_c = 8.686 R_s \frac{dB}{cm} \quad \text{for} \quad \frac{w}{h} > 1 \]

**Radiation losses:**
In addition to the conductor and dielectric losses, microstrip line also has radiation losses. The radiation loss depends on the substrate's thickness and dielectric constant, as well as its geometry. Lewin has calculated the radiation loss for several discontinuities using the following approximations:
  1. TEM transmission
  2. Uniform dielectric in the neighborhood of the strip, equal in magnitude to an effective value
3. Neglect of radiation from the transverse electric (TE) field component parallel to the strip
4. Substrate thickness much less than the free-space wavelength
5. Lewin’s results show that the ratio of radiated power to total dissipated power for an
   a. open-circuited microstrip line is

\[
\frac{P_{\text{rad}}}{P_t} = 240\pi^2 \left(\frac{h}{\lambda_0}\right)^2 \frac{F(\varepsilon_r)}{Z_0}
\]

where \( F(\varepsilon_r) \) is a radiation factor given by

\[
F(\varepsilon_r) = \frac{\varepsilon_r + 1}{\varepsilon_r} - \frac{\varepsilon_r - 1}{2\varepsilon_r \sqrt{\varepsilon_r - 1}} \ln \frac{\sqrt{\varepsilon_r} + 1}{\sqrt{\varepsilon_r} - 1}
\]

where

\[
\frac{P_{\text{rad}}}{P_t} = \frac{R_r}{Z_0}
\]

Where radiation resistance is

\[
R_r = 240\pi^2 \left(\frac{h}{\lambda_0}\right)^2 F(\varepsilon_r)
\]

Unit 2:

1. An air-filled rectangular cavity with brass walls \( \varepsilon = 1.57 \times 10^7 \text{S/m} \) has the following dimensions: \( a = 4 \text{cm}, b = 3 \text{cm}, \) and \( d = 5 \text{cm} \). (a) Determine the dominant mode and its resonant frequency for this cavity. (b) Find the \( Q \) and the time-average stored electric and magnetic energies at the resonant frequency, assuming \( H_0 \) to be 0.1A/m.

Ans: (Sol.) (a) \( f_r = \frac{c}{2\sqrt{\left(\frac{m}{0.04}\right)^2 + \left(\frac{n}{0.03}\right)^2 + \left(\frac{p}{0.05}\right)^2}} \),

dominant mode: \( TE_{101} \),

\( (f_r)_{TE_{101}} = 4.8 \text{GHz} \)

(b) \( Q_{TE_{101}} = \frac{\pi(f_r)_{TE_{101}} \mu_0 \alpha bd(a^2 + d^2)}{R_s[2b(a^3 + b^3) + \alpha d(a^2 + d^2)]} = 6869 \),

\( R_s = \frac{\pi(f_r)_{TE_{101}} \mu_0}{\sigma_c} \)

At the resonant frequency,

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\[ W' = W = \frac{\varepsilon_0}{2} \mu a^2 b d f^2 \]

2. What should be the size of a hollow cubic cavity made of copper in order for it to have a dominant resonant frequency of 10 GHz? (b) Find the \( Q \) at that frequency.

(Sol.) (a) For a cubic cavity, \( a=b=d, \ TM_{110}, \ TE_{011}, \) and \( \ TE_{101} \) are degenerate dominant modes. \( f_{101} = \frac{3 \times 10^8}{2a} = 10^{10} \text{Hz} \), \( a = \frac{3 \times 10^8}{\sqrt{2} \times 10^{10}} = 2.12 \times 10^{-2} \text{m} \).

(b) \( Q_{101} = \frac{\pi f_{101} \mu \sigma}{3 R_i} = \frac{a}{3 \sqrt{\pi f_{101} \mu}} \)

a. For copper, \( \sigma = 5.80 \times 10^7 \text{S/m} \),

\[ Q_{101} = \frac{2.12}{3} \times 10^{-2} \sqrt{\pi 10^{10} (4 \pi 10^{-7}) (5.80 \times 10^7)} = 10700. \]

3. Describe the coupling coefficients of cavity resonator

Ans: There are three types of coupling coefficients:

1. **Critical coupling**: If the resonator is matched to the generator, then 

   \( K=1 \) then

   The loaded \( Q \) is given by 

   \[ Q' = \frac{1}{2} Q = \frac{1}{2} Q_0 \]

2. **Overcoupling**: If \( K > 1 \), the cavity terminals are at a voltage maximum in the input line at resonance. The normalized impedance at the voltage maximum is the standing-wave ratio \( \rho \). That is 

   \[ K = \rho \]

   The loaded \( Q' \) is given by 

   \[ Q' = \frac{Q_0}{1 + \rho} \]

3. **Undercoupling**: If \( K < 1 \), the cavity terminals are at a voltage minimum and the input terminal impedance is equal to the reciprocal of the standing-wave ratio. That is,

   \[ K = \frac{1}{\rho} \]

   The loaded \( Q' \) is given by 

   \[ Q' = \frac{\rho}{\rho + 1} Q_0 \]

4. What are various waveguide discontinuities

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5. **Explain about the phase shifters**

**Ans:** Microwave Phase Shifter is a device designed to alter the phase of electromagnetic oscillations at the output of a microwave transmission line with respect to the phase of the oscillations at the input of the line. The phase shift is achieved by changing the electrical length of the line.

Phase Shifters are devices, in which the phase of an electromagnetic wave of a given frequency can be shifted when propagating through a transmission line without any attenuation.

**Dielectric Phase Shifter**

A simplest waveguide phase shifter consists of a rectangular waveguide loaded with a dielectric slab of thickness \( t \), height \( h \), and dielectric constant \( e \) in such a way that dimension \( h \) is parallel to the dominant TE10 mode. Dielectric reduces the velocity of
propagation of microwaves which results in an increased electrical path and, hence, a phase delay.

A precision rotary phase shifter:
The instrument consists of two rectangular to circular waveguide tapered transitions, together with two quarter wave sections on both sides of the free rotatable central half wave section.

Unit 3:
1. Classify microwave tubes:
   
   **Ans:** O-typetubes:
   1. These are linear beam tubes, i.e. the magnetic field is in parallel with the d.c. electric field.
   2. In these tubes, electrons receive potential energy from the d.c. beam voltage before
they arrive in the microwave interaction region this energy is converted into their kinetic energy. e.g. Klyston, Helix TWT and BWA, BWO etc.

**M-typetubes**
1. These are cross field devices i.e. the d.c. magnetic field and the d.c. electric field are perpendicular to each other.
2. In these tubes, the electrons emitted by the cathode are accelerated by the electric field and gain velocity but the greater their velocity, the more their path is bent by the magnetic field. e.g. magnetron, FWCFA, Dematron. Gyrotrons etc.

**Define reflex klystrons, some characteristics and applications**
**Ans.** The reflex klystron is an oscillator with a built in feedback mechanism. It uses the cavity for bunching and for the output cavity.

**Characteristics:** Frequency range: 1 to 25GHz  Power output: It is a low-power generator of 10 to 500mW  Efficiency: About 20 to 30%

**Applications:**
1. This type is widely used in the laboratory for microwave measurements.
2. In microwave receivers as local oscillators in commercial and military applications.
3. In airborne Doppler radars as well as missiles.

3. **Derive the expression for velocity modulation**
   **Ans:** Velocity modulation:

   When electrons are first accelerated by the high de voltage $V_0$ before entering the
buncher grids, their velocity is uniform: 

\[ v_0 = \sqrt{\frac{2eV_0}{m}} = 0.593 \times 10^6 \sqrt{V_0} \text{ m/s} \]

it is assumed that electrons leave the cathode with zero velocity. When a microwave signal is applied to the input terminal, the gap voltage between the buncher grids appears as

\[ V_s = V_1 \sin (\omega t) \]

where \( V_1 \) is the amplitude of the signal and \( V_1 \ll V_0 \) is assumed. In order to find the modulated velocity in the buncher cavity in terms of either the entering time \( t_0 \) or the exiting time \( t_1 \) and the gap transit angle \( \theta_g \) as shown in it is necessary to determine the average microwave voltage in the buncher gap. Since \( V_1 \ll V_0 \), the average transit time through the buncher gap distance \( d \) is

\[ \tau = \frac{d}{v_0} = t_1 - t_0 \]

The average gap transit angle can be expressed as

\[ \theta_g = \omega \tau = \omega (t_1 - t_0) = \frac{\omega d}{v_0} \]

The average microwave voltage in the buncher gap can be found in the following way:

\[
\langle V_s \rangle = \frac{1}{\tau} \int_{t_0}^{t_1} V_1 \sin(\omega t) dt = -\frac{V_1}{\omega \tau} \left[ \cos(\omega t_1) - \cos(\omega t_0) \right]
\]

\[
= \frac{V_1}{\omega \tau} \left[ \cos(\omega t_0) - \cos\left(\omega_0 + \frac{\omega d}{v_0}\right) \right]
\]

Then using the trigonometric identity that \( \cos(A - B) - \cos(A + B) = 2 \sin A \sin B \), Eq. becomes

\[
\langle V_s \rangle = V_1 \frac{\sin[\omega d/(2v_0)]}{\omega d/(2v_0)} \sin \left( \frac{\omega t_0 + \omega d}{2v_0} \right) = V_1 \frac{\sin(\theta_g/2)}{\theta_g/2} \sin \left( \frac{\omega t_0 + \theta_g}{2} \right)
\]

\[
\beta_i = \frac{\sin[\omega d/(2v_0)]}{\omega d/(2v_0)} = \frac{\sin(\theta_g/2)}{\theta_g/2}
\]

where.

It can be seen that increasing the gap transit angle \( \theta_g \) decreases the coupling between the electron beam and the buncher cavity; that is, the velocity modulation of the beam for a given microwave signal is decreased. Immediately after velocity

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modulation, the exit velocity from the buncher gap is given by
\[ v(t_1) = \sqrt{\frac{2e}{m}} \left[ V_0 + \beta_i V_1 \sin \left( \omega t_0 + \frac{\theta_i}{2} \right) \right] \]
\[ = \sqrt{\frac{2e}{m}} V_0 \left[ 1 + \frac{\beta_i V_1}{V_0} \sin \left( \omega t_0 + \frac{\theta_i}{2} \right) \right] \]

where the factor \( \frac{Vi}{Vo} \) is called the depth of velocity modulation.

Using binomial expansion under the assumption of
\[ \beta_i V_1 \ll V_0 \]
\[ v(t_1) = v_0 \left[ 1 + \frac{\beta_i V_1}{2V_0} \sin \left( \omega t_0 + \frac{\theta_i}{2} \right) \right] \]

Equation is the equation of velocity modulation. Alternatively, the equation of velocity modulation can be given by
\[ v(t_1) = v_0 \left[ 1 + \frac{\beta_i V_1}{2V_0} \sin \left( \omega t_1 - \frac{\theta_i}{2} \right) \right] \]

4. Explain about the bunching process
Ans: Bunching process:
- Once the electrons leave the buncher cavity, they drift with a velocity given by velocity modulation equation along in the field-free space between the two cavities.
- The effect of velocity modulation produces bunching of the electron beam or current modulation.
- The electrons that pass the buncher at \( V_s = 0 \) travel through with unchanged velocity \( V_0 \) and become the bunching center.
- Those electrons that pass the buncher cavity during the positive half cycles of the microwave input voltage \( V_s \) travel faster than the electrons that passed the gap when \( V_s = 0 \).
- Those electrons that pass the buncher cavity during the negative half cycles of the voltage \( V_s \) travel slower than the electrons that passed the gap when \( V_s = 0 \).
- At a distance of \( \Delta L \) along the beam from the buncher cavity, the beam electrons have drifted into dense clusters.
- Figure shows the trajectories of minimum, zero, and maximum electron acceleration.
The distance from the buncher grid to the location of dense electron bunching for the electron at $t_b$ is

$$\Delta L = v_0(t_d - t_b)$$

Similarly, the distances for the electrons at $t_a$ and $t_c$ are

$$\Delta L = v_{\text{min}}(t_d - t_a) = v_{\text{min}}(t_d - t_b + \frac{\pi}{2\omega})$$

$$\Delta L = v_{\text{max}}(t_d - t_c) = v_{\text{max}}(t_d - t_b - \frac{\pi}{2\omega})$$

the minimum and maximum velocities are

$$v_{\text{min}} = v_0 \left(1 - \frac{\beta_i V_1}{2V_0}\right) \quad v_{\text{max}} = v_0 \left(1 + \frac{\beta_i V_1}{2V_0}\right)$$

Hence the substitution yields

$$\Delta L = v_0(t_d - t_b) + \left[v_0 \frac{\pi}{2\omega} - v_0 \frac{\beta_i V_1}{2V_0} (t_d - t_b) - v_0 \frac{\beta_i V_1}{2V_0} \frac{\pi}{2\omega}\right]$$

$$\Delta L = v_0(t_d - t_b) + \left[-v_0 \frac{\pi}{2\omega} + v_0 \frac{\beta_i V_1}{2V_0} (t_d - t_b) + v_0 \frac{\beta_i V_1}{2V_0} \frac{\pi}{2\omega}\right]$$

The necessary condition for those electrons at $t_a$, $t_b$, and $t_c$ to meet at the same distance $\Delta L$ is
It should be noted that the mutual repulsion of the space charge is neglected, but the qualitative results are similar to the preceding representation when the effects of repulsion are included.

\[
T = t_2 - t_1 = \frac{L}{v(t_1)} = T_0 \left[ 1 - \frac{\beta_i V_1}{2V_0} \sin \left( \omega t_1 - \frac{\theta_x}{2} \right) \right]
\]

Where

\[
\theta_0 = \frac{\omega L}{v_0} = 2\pi N
\]

is the dc transit angle between cavities, \( N \) is the number of electron transit cycles in the drift space, and

\[
X \equiv \frac{\beta_i V_1}{2V_0} \theta_0
\]

is defined as the bunching parameter of a klystron.

5. A reflex klystron operates under the following conditions:

- \( V_0 = 600 \text{ V} \)
- \( R_{sh} = 15 \Omega \)
- \( f_r = 9 \text{ GHz} \)
- \( L = 1 \text{ mm} \)
- \( e/m = 1.759 \times 10^{11} \) (MKS system)

The tube is oscillating at \( f_r \) at the peak of the \( n = 2 \) mode or \( 1(3/4) \) mode. Assume that the transit time through the gap and beam loading can be neglected.

a. Find the value of the repeller voltage \( V_r \).

b. Find the direct current necessary to give a microwave gap voltage of 200 V.

c. What is the electronic efficiency under this condition?

Sol: wkt.,

\[
\frac{V_0}{(V_r + V_0)^2} = \left( \frac{e}{m} \right) \frac{(2\pi n - \pi/2)^2}{8\omega^2 L^2}
\]

\[
= (1.759 \times 10^{11}) \frac{(2\pi 2 - \pi/2)^2}{8(2\pi \times 9 \times 10^9)^2(10^{-3})^2} = 0.832 \times 10^{-3}
\]
Unit 4:

1. Write about pi mode operation of magnetron, its efficiency and applications
   Ans. In the p-mode of operation, the successive cavities in anode have opposite phase, excitation is maximum in the cavities.
   - A magnetron can deliver a peak power output of up to 40MW with the dc voltage of 50KV at 10GHz.
   - The average power output is 800KW.
   - The magnetron possesses a very high efficiency ranging from 40 to 70%.
   - Magnetrons are commercially available for peak power output from 3KW and higher.
   The magnetron are widely used on
   - Radar transmitters
   - Industrial heating
   - Microwave ovens.

2. Derive Hartree condition
   Ans: Hartree condition. The Hull cutoff condition determines the anode voltage or magnetic field necessary to obtain nonzero anode current as a function of the magnetic field or anode voltage in the absence of an electromagnetic field. The Hartree condition can be derived as follows
   - The electron beam lies within a region extending a distance h from the cathode, where h is known as the hub thickness. The spacing between the cathode
and anode is d. The electron motion is assumed to be in the positive y direction with a velocity

$$v_y = -\frac{E_x}{B_0} = \frac{1}{B_0} \frac{dV}{dx}$$

**Figure**    Linear model of a magnetron.

Combining Eqs. yields

$$\left(\frac{dV}{dx}\right)^2 = \frac{2eV}{mB_0^2}$$

This differential equation may be rearranged as

$$\left(\frac{m}{2eB_0}\right)^{1/2} \frac{dV}{\sqrt{V}} = dx$$

Integration of Eq. yields the potential within the electron beam as

$$V = \frac{eB_0^2}{2m} x^2$$

where the constant of integration has been eliminated for $V = 0$ at $x = 0$. The potential and electric field at the hub surface are given by

$$V(h) = \frac{e}{2m} B_0^2 h^2$$

and

$$E_x = -\frac{dV}{dx} = -\frac{e}{m} B_0^2 h$$

The potential at the anode is thus obtained as

$$V_0 = -\int_0^d E_x \, dx$$

$$= -\int_0^d E_x \, dx - \int_a^d E_x \, dx$$

$$= V(h) + \frac{e}{m} B_0^2 h (d - h)$$

$$= \frac{e}{m} B_0^2 h (d - h/2)$$

The electron velocity at the hub surface is obtained as

$$v_y(h) = \frac{e}{m} B_0 h$$
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For synchronism, this electron velocity is equal to the phase velocity of the slowwave structure. That is,

\[ \frac{\omega}{\beta} = \frac{e}{m} B_0 h \]

For the \( \Pi \)-mode operation, the anode potential is finally given by

\[ V_{ao} = \frac{m}{2e} \frac{\omega^2 \phi n}{\beta} \]

This is the Hartree anode voltage equation that is a function of the magnetic flux density and the spacing between the cathode and anode.

3. Explain about the modes of resonance in magnetron
   Ans: modes of resonance:
   An N-cavity magnetron has N modes of operations. These operations depend upon the frequency and the phase of oscillations. The total phase shift around the ring of this cavity resonators should be \( 2\pi n \) where \( n \) is an integer.

\[ \phi n = 2\pi n/N \]

Where \( n=0,\pm 1,\pm 2,\pm (N/2 - 1),\pm N/2 \)

Which means that \( N/2 \) mode of resonance can exist if \( N \) is an even number. If, \( n=N/2 \) then \( \phi n = \pi \)

This mode of resonance is called as \( \pi \)-mode

If \( n=0 \) then \( \phi n = 0 \)

This is called as the Zero mode, because there will be no RF electric field between the anode and the cathode. This is also called as Fringing Field and this mode is not used in magnetrons. Figure shows the lines of force in the \( \Pi \) mode of an eight-cavity magnetron. It is evident that in the \( \Pi \) mode the excitation is largely in the cavities, having opposite phase in successive cavities. The successive rise and fall of adjacent anode cavity fields may be regarded as a traveling wave along the surface of the slow-wave structure. For the energy to be transferred from the moving electrons to the traveling field, the electrons must be decelerated by a retarding field when they pass through each anode cavity.

4. An X-band pulsed cylindrical magnetron has the following operating parameters:
   Anode voltage: \( V_0 = 26 \) kV, Beam current: \( I_0 = 27 \) A, Magnetic flux density: \( B_0 = 0.336 \) Wb/m2, Radius of cathode cylinder: \( a = 5 \) cm, Radius of vane edge to center: \( b = 10 \) cm
   Compute:
   a. The cyclotron angular frequency
   b. The cutoff voltage for a fixed \( B_0 \)
   c. The cutoff magnetic flux density for a fixed \( V_0 \)
5. Explain RWH theory

Ans: The fundamental concept of the Ridley-Watkins-Hilsum (RWH) theory is the differential negative resistance developed in a bulk solid-state III-V compound when either a voltage (or electric field) or a current is applied to the terminals of the sample.

There are two modes of negative-resistance devices:

i) voltage-controlled

ii) current controlled mode

In the voltage-controlled mode the current density can be multivalued, whereas in the current-controlled mode the voltage can be multivalued.

Two valley theory:

- Electron densities in the lower and upper valleys remain the same under an equilibrium condition.
- When the applied electric field is lower than the electric field of the lower valley ($E < E_e$), no electrons will transfer to the upper valley.
- When the applied electric field is higher than that of the lower valley and lower than that of the upper valley ($E_e < E < E_u$), electrons will begin to transfer to the upper valley.
- When the upper valley field is higher than that of the upper valley ($E_u < E$), all electrons will transfer to the upper valley.

\[
\omega_c = \frac{q}{m} B_0 = 1.759 \times 10^{11} \times 0.336 = 5.91 \times 10^{10} \text{ rad}
\]

\[
V_{th} = \frac{1}{8} \times 1.759 \times 10^{11} (0.336)^2 (10 \times 10^{-7})^2 \left(1 - \frac{5^2}{10^2}\right)
\]

\[
= 139.50 \text{ kV}
\]

\[
B_{th} = \left(8 \times 26 \times 10^3 \times \frac{1}{1.759 \times 10^{11}}\right)^{1/2} \left[10 \times 10^{-2} \left(1 - \frac{5^2}{10^2}\right)\right]^{-1}
\]

\[
= 14.495 \text{ mWb/m}^2
\]
Unit 5:

1. **In circuits carrying high power, why matching the impedances are important?**
   
   Ans. In circuits carrying high power, matching the impedances is important for at least two reasons: 1. The maximum power at maximum efficiency will be transferred when the impedances are complex conjugate matched throughout the power chain, from the transmitter output, through the transmission line (a balanced pair, a coaxial cable, or a waveguide), to the antenna system, which consists of an impedance matching device and the radiating element(s). For maximum power, \( Z_{\text{load}} = Z_{\text{source}}^* \) (where \( ^* \) indicates the complex conjugate). 2. Failure to match impedances will create standing waves on the transmission line due to reflections. These will be periodic regions of higher than normal voltage. If this voltage exceeds the dielectric breakdown strength of the insulating material of the line then an arc will occur. This in turn can cause a reactive pulse of high voltage that can destroy the transmitter’s final output stage. For reflection less matching \( Z_{\text{load}} = Z_{\text{source}} \) (no complex conjugate).

2. **Derive the S matrix for Magic TEE**
   
   Ans: **Magic tee:**
   
   ![Diagram](image)

   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 \( H \) arm), 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, \( S_{43} = S_{34} = 0 \).
   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 \( H \) arm causes a phase advance. That is, \( S_{12} = S_{21} = 0 \).

   Hence the matrix is
3. Draw the diagram of circulator and give its S matrix

**Ans: Circulator:**

A perfectly matched lossless nonreciprocal four port circulator has an S matrix of the form.

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

Using the parameters of S parameters the above matrix is simplifies as

\[
S = \begin{bmatrix}
0 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix}
\]
4. Explain different blocks of microwave bench

Ans: A general block diagram of the test bench comprising its different units and ancillaries are shown below.

1. **Klystron Power Supply:**
Klystron Power Supply generates voltages required for driving the reflex Klystron tube like 2k25.

2. **Gunn Power Supply:**
Gunn Power Supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn oscillator and PIN Modulator. The Supply Voltage ranges from 0 to 12V with a maximum current, 1A.

3. **Reflex Klystron Oscillator:**
At high frequencies, the performance of a conventional vacuum tube is impaired due to transit time effects, lead inductance and inter-electrode capacitance. Klystron is a microwave vacuum tube employing velocity modulation and transit time in achieving its normal operation. It has been the most used source of microwave power.

4. **Gunn oscillator:**
Gunn oscillator utilizes Gunn diode which works on the principle that when a DC voltage is applied across a sample of n-type Gallium Arsenide; the current oscillates at microwave frequencies. This does not need high voltage as it is necessary for Klystrons and therefore solid state oscillators are now finding wide applications. Normally, they are capable of delivering 0.5 watt at 10GHz.

5. **Isolator:**
This un attenuated device permits un attenuated transmission in one direction (forward direction) but provides very high attenuation in the reverse direction (backward direction).

6. **Variable Attenuator:**
The device that attenuates the signal is termed as attenuator.

7. **Frequency Meter:**
It is basically a cavity resonator. The method of measuring frequency is to use a cavity where the size can be varied and it will resonate at a particular frequency for given size.

8. **Slotted Section:**
To sample the field within a wave guide, a narrow longitudinal slot with ends tapered to provide smoother impedance transformation and thereby providing minimum mismatch, is milled on the top of broader dimension of wave guide.

9. **Matched Load:**
The microwave components which absorb all power falling on them are matched loads.

10. **Short Circuit Termination:**
Wave guide short circuit terminations provide standard reflection at any desired, precisely measurable positions.

10. **VSWR meter:**
Direct-reading VSWR meter is a low-noise tuned amplifier voltmeter calibrated in db and VSWR for use with square law detectors.

11. **Crystal Detector:**
The simplest and the most sensitive detecting element is a microwave crystal. It is a nonlinear, non reciprocal device which rectifies the received signal and produces a current proportional to the power input.

5. Explain about the power measurement

Ans: **Bolometer: power measurement:**
A bolometer is a device for measuring the power of incident electromagnetic radiation via the heating of a material with a temperature-dependent electrical resistance. A bolometer consists of an absorptive element, such as a thin layer of metal, connected to a thermal reservoir (a body of constant temperature) through a thermal link. The result is that any radiation impinging on the absorptive element raises its temperature above that of the reservoir – the greater the absorbed power, the higher the temperature. The intrinsic thermal time constant, which sets the speed of the detector, is equal to the ratio of the heat capacity of the absorptive element to the thermal conductance between the absorptive element and the reservoir. The temperature change can be measured directly with an attached resistive thermometer, or the resistance of the absorptive element itself can be used as a thermometer. Metal bolometers usually work without cooling. They are produced from thin foils or metal films. Today, most bolometers use semiconductor or superconductor absorptive elements rather than metals. These devices can be operated at cryogenic temperatures, enabling significantly greater sensitivity.
15. Tutorial Topics and questions

(Not Applicable)
16. Unit wise question bank

UNIT 1:

Group A: Two marks question with answers

1. What is Microwave Engineering?
   Ans. Microwave engineering is the study and design of microwave circuits, components, and systems. Fundamental principles are applied to analysis, design and measurement techniques in this field. The short wavelengths involved distinguish this discipline from electronic engineering. This is because there are different interactions with circuits, transmissions and propagation characteristics at microwave frequencies.

2. Write the applications of microwave engineering?
   Ans. Following are the applications of microwave engineering:
   1. Antenna gain is proportional to the electrical size of the antenna. At higher frequencies, more antenna gain is therefore possible for a given physical antenna size, which has important consequences for implementing miniaturized microwave systems.
   2. More bandwidth can be realized at higher frequencies. Bandwidth is critically important because available frequency bands in the electromagnetic spectrum are being rapidly depleted.
   3. Microwave signals travel by line of sight are not bent by the ionosphere as are lower frequency signals and thus satellite and terrestrial communication links with very high capacities are possible.

3. What are the major bands available in microwave frequencies?
   Ans. The microwave frequencies span the following three major bands at the highest end of RF spectrum.
   I. Ultra High Frequency (UHF) 0.3 to 3 GHz.
   II. Super High Frequency (SHF) 3 to 30 GHz.
   III. Extra High Frequency (EHF) 30 to 300 GHz

4. State definition of guide wavelength?
   Ans. Guide wavelength is defined as the distance between two equal phase planes along the waveguide. The guide wavelength is a function of operating wavelength (or frequency) and the lower cutoff wavelength, and is always longer than the wavelength would be in freespace.

5. State definition of guide wavelength?
   Ans. Guide wavelength is defined as the distance between two equal phase planes along the waveguide. The guide wavelength is a function of operating wavelength (or frequency) and the lower cutoff wavelength, and is always longer than the wavelength would be in freespace.

Group B: Three marks question with answers

1. State definition of cutoff wavelength

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Microwave Engineering

Ans. the maximum wavelength that will propagate in an optical fiber or waveguide. The cutoff frequency is found with the characteristic equation of the Helmholtz equation for electromagnetic waves, which is derived from the electromagnetic wave equation by setting the longitudinal wave number equal to zero and solving for the frequency. Thus, any exciting frequency lowers than the cutoff frequency will attenuate, rather than propagate.

2. Name the Waveguide components
   Ans. waveguide components are many, some of them are including  
   1) circulators 2) isolators 3) attenuators 4) loads 5) mixers 6) amplifiers

3. Enumerate the basic advantage of microwaves.
   Ans. 1. Fewer repeaters are necessary for amplification.  
   2. Minimal cross talk exists between voice channels.  
   3. Increased reliability and less maintenance are important factors.  
   4. Increased bandwidth availability.  
   5. Provides high antenna gain  
   6. Provides antenna minimization  
   7. As microwave signals travels in line of sight & not reflected by ionosphere, so the comm. Link between satellite & terrestrial (satellite) stations with high capability is possible

4. What are the solutions to wave equations
   Ans: Consider a rectangular waveguide with $0 < x < a$, $0 < y < b$ and $a > b$. There are two types of waves in a hollow waveguide with only one conductor; _ Transverse electric waves (TE-waves). $E = (E_x; E_y; 0)$ and $H = (H_x; H_y; H_z)$.  
   _ Transverse magnetic waves (TM-waves). $E = (E_x; E_y; E_z)$ and $H = (H_x; H_y; 0)$.

Solutions to wave equations:

\[
\begin{align*}
E_x &= \frac{j\omega \mu}{\hbar^2} \frac{\partial H_z}{\partial y} - \frac{j\beta}{\hbar^2} \frac{\partial E_y}{\partial x} \\
E_y &= \frac{j\omega \mu}{\hbar^2} \frac{\partial H_z}{\partial x} - \frac{j\beta}{\hbar^2} \frac{\partial E_x}{\partial y} \\
H_x &= \frac{j\omega \epsilon}{\hbar^2} \frac{\partial E_z}{\partial y} - \frac{j\beta}{\hbar^2} \frac{\partial H_y}{\partial x} \\
H_y &= \frac{j\omega \epsilon}{\hbar^2} \frac{\partial E_z}{\partial x} - \frac{j\beta}{\hbar^2} \frac{\partial H_x}{\partial y}
\end{align*}
\]

5. Give the expressions for dielectric constant and characteristics impedance
   Ans: Effective dielectric constant: 
   \[
   \epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/d_w}}.
   \]
   Characteristic impedance:

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\[ Z_0 = \begin{cases} 
\frac{60}{\sqrt{\varepsilon_r}} \ln \left( \frac{8d}{W} + \frac{W}{4d} \right) & \text{for } W/d \leq 1 \\
\frac{120\pi}{\sqrt{\varepsilon_r} [W/d + 1.393 + 0.667 \ln (W/d + 1.444)]} & \text{for } W/d \geq 1.
\end{cases} \]

\[ \frac{W}{d} = \begin{cases} 
\frac{8d^4}{e^{2d} - 2} & \text{for } W/d < 2 \\
\frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left\{ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right\} \right] & \text{for } W/d > 2,
\end{cases} \]

Attenuation due to dielectric:

\[ \alpha_d = \frac{k_0 \varepsilon_r (\varepsilon_r - 1) \tan \delta}{2\sqrt{\varepsilon_r (\varepsilon_r - 1)}} \text{ Np/m}, \]

**Group C : 5 MARKS QUESTIONS WITH ANSWERS**

**Ans:** Electromagnetic frequency bands:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Band Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3Hz—30 Hz</td>
<td>Ultra low frequency (ULF)</td>
</tr>
<tr>
<td>30 to 300 Hz</td>
<td>Extra low frequency (ELF)</td>
</tr>
<tr>
<td>300 to 3000 Hz (3 KHz)</td>
<td>Voice frequency, base band / telephony</td>
</tr>
<tr>
<td>3 KHz to 30 KHz</td>
<td>VLF</td>
</tr>
<tr>
<td>30 to 300 KHz</td>
<td>LF</td>
</tr>
<tr>
<td>300 to 3000 KHz (3 MHz)</td>
<td>MF</td>
</tr>
<tr>
<td>3 MHz to 30 MHz</td>
<td>HF</td>
</tr>
<tr>
<td>30 to 300 MHz</td>
<td>VHF</td>
</tr>
<tr>
<td>300 to 3000 MHz (3 GHz)</td>
<td>Ultra high frequency (UHF)</td>
</tr>
<tr>
<td>3 GHz to 30 GHz</td>
<td>SHF</td>
</tr>
<tr>
<td>30 to 300 GHz</td>
<td>EHF</td>
</tr>
<tr>
<td>300 to 3000 GHz (3 THz)</td>
<td>Infra red frequencies</td>
</tr>
<tr>
<td>(3-30 THz, 30 to 3000 T)</td>
<td></td>
</tr>
</tbody>
</table>

Microwave bands
6. What are the TE and TM wave equations

Ans: Solutions to wave equations: TE mode

For TE wave

\[ E_z = 0 \quad \text{and} \quad H_z \neq 0 \]

Hence

\[ H_z = D \cos \left( \frac{2\pi x}{a} \right) \cos \left( \frac{\pi y}{b} \right) e^{-j\beta z} \]

Sub \( H_z \) in \( E_x, E_y, H_x, H_y \), we get,

\[ E_x = \frac{-iu}{\beta} D \frac{2\pi x}{a} \sin \left( \frac{\pi y}{b} \right) e^{-j\beta z} \]

\[ E_y = \frac{-iu}{\beta} D \frac{2\pi x}{a} \cos \left( \frac{\pi y}{b} \right) e^{-j\beta z} \]

\[ H_x = \frac{u}{\beta} D \frac{2\pi x}{a} \sin \left( \frac{\pi y}{b} \right) e^{-j\beta z} \]

\[ H_y = \frac{u}{\beta} D \frac{2\pi x}{a} \cos \left( \frac{\pi y}{b} \right) e^{-j\beta z} \]

Where

\[ k^2 = \frac{1}{\varepsilon} \left( \frac{2\pi x}{a} \right)^2 + \left( \frac{\pi y}{b} \right)^2 \]

Solutions for wave equations: TM mode:

For TM mode we have:

\[ H_z = 0 \quad \text{and} \quad E_z \neq 0 \]

Hence

\[ E_z = C \sin \left( \frac{\pi x}{a} \right) \sin \left( \frac{\pi y}{b} \right) e^{-j\beta z}\]
7. What are the dominant and degenerate modes

Ans: Dominant mode:

- The mode with the lowest cut-off frequency is called the dominant mode.
- Since TM modes for rectangular waveguides start from TM$_{11}$ mode, the dominant frequency is

$$f_{10} = \frac{1}{2\sqrt{\mu_0\varepsilon_0}} \left( \frac{1}{a} \right)^2 + \left( \frac{1}{b} \right)^2$$

- TE$_{10}$ mode is the minimum possible mode that gives nonzero field expressions for rectangular waveguides, it is the dominant mode of a rectangular waveguide with a > b and so the dominant frequency is

$$f_{10} = \frac{1}{2\pi\sqrt{\mu_0\varepsilon_0}}$$

Degenerate modes:

- In a waveguide when two or more modes have the same cut off frequency then they are said to be degenerate modes.
- In a rectangular waveguide the TE$_{mn}$ and TM$_{mn}$ with m ≠ 0 and n ≠ 0 are degenerate modes.

8. An air-filled $a \times b \ (b < a < 2b)$ rectangular waveguide is to be constructed to operate at 3GHz in the dominant mode. We desire the operating frequency to be at least 20% higher than the cutoff frequency of the dominant mode and also at least 20% below the cutoff frequency of the next higher-order mode. (a) Give a typical design for the dimensions $a$ and $b$. (b) Calculate for your design $\beta$, $\nu_p$, $\lambda_g$ and the wave impedance at the operating frequency. [台大電研]

(Sol.) (a) $f_c = \frac{1}{2\sqrt{\mu_0\varepsilon_0}} \sqrt{\left( \frac{m}{a} \right)^2 + \left( \frac{n}{b} \right)^2}$, $b < a < 2b$, the dominant mode: TE$_{10}$, the next mode: TE$_{01}$
\( (f_c)_{\text{TE}_0} = \frac{1}{2\pi \sqrt{\mu \varepsilon}}, \quad (f_c)_{\text{TE}_1} = \frac{1}{2b \sqrt{\mu \varepsilon}}, \quad \frac{3 \times 10^9}{(1/2a \sqrt{\mu \varepsilon})} > 20\%, \)

\( \frac{(1/2b \sqrt{\mu \varepsilon}) - 3 \times 10^9}{(1/2h \sqrt{\mu \varepsilon})} > 20\% \Rightarrow a \geq 0.06m, \quad b \leq 0.04m, \quad \text{and} \quad a < 2b \)

(b) Choose \( a = 0.065m, \quad b = 0.035m, \quad (f_c)_{\text{TE}_0} = 2.3 \times 10^9 (\text{Hz}), \quad \sqrt{1 - (\frac{f_c}{f})^2} = 0.679, \)

\[ \beta = \sqrt{\mu \varepsilon} \cdot \sqrt{1 - (\frac{f}{f_c})^2} = 40.15 \text{rad} / \text{m}, \quad v_p = \frac{1}{\sqrt{\mu \varepsilon}} \cdot \frac{1}{\sqrt{1 - (\frac{f_c}{f})^2}} = 4.7 \times 10^8 \text{m/s}, \]

\[ \lambda_s = \frac{v_p}{f} = 0.157 \text{m}, \quad Z_{\text{TE}_0} = \eta_0 / \sqrt{1 - (\frac{f_c}{f})^2} = 120\pi 0.639 = 590\Omega \]

9. Explain the power transmission in RWG

**Ans:** The power transmitted through a waveguide and the power loss in the guide walls can be calculated by means of the complex Poynting theorem. It is assumed that the guide is terminated in such a way that there is no reflection from the receiving end or that the guide is infinitely long compared with the wavelength. From the Poynting theorem, the power transmitted through a guide is given by

\[ P_u = \oint \mathbf{p} \cdot d\mathbf{s} = \oint \frac{1}{2} (\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s} \]

For a lossless dielectric, the time-average power flow through a rectangular guide is given by

\[ P_a = \frac{1}{2Z_\varepsilon} \int_a |E|^2 \; da = \frac{Z_\varepsilon}{2} \int_a |H|^2 \; da \]

where \( Z_\varepsilon = \frac{E_x}{H_x} = -\frac{E_y}{H_y} \)

\[ |E|^2 = |E_x|^2 + |E_y|^2 \]

\[ |H|^2 = |H_x|^2 + |H_y|^2 \]

For TEMmn modes, the average power transmitted through a rectangular waveguide is given by

\[ P_{\text{TEM}} = \frac{\sqrt{1 - (f_c/f)^2}}{2\eta} \int_0^b \int_0^a (|E_x|^2 + |E_y|^2) \; dx \; dy \]

For TMmn modes, the average power transmitted through a rectangular waveguide is given by
Group D: Multiple Choice Questions

1. The main advantage of microwave is that
   b. Moves at the speed of light.
   c. S/N ratio grater.
   d. High penetration power.

   **Explanation:** High frequency waves are more directive

2. The frequency correspond to Microwave frequency range is
   a. 10 to 100GHz
   b. 1 to 1000 GHz
   c. 0.1 to 1 Ghz
   d. 100 to 1000GHz

   **Explanation:** microwave frequency: 1 to 1000 GHz

3. Which TM mode in rectangular waveguide has lowest cutoff frequency?
   a. TM_{11}
   b. TM_{01}
   c. TM_{10}
   d. TM_{21}

   **Explanation:** The field components for other lower modes of propagation in TM mode disappear for other lower modes of propagation. Hence, the lowest mode of propagation is TM_{11} mode.

4. **Assertion:** Microstrip is very commonly used in microwave integrated circuits.

   **Explanation (R):** Microstrip has an easy access to the top-surface so that active and passive discrete components can be easily mounted.

   a. Both A and R are correct and R is correct explanation of A
   b. Both A and R are correct but R is not correct explanation of A
   c. A is correct but R is wrong
   d. A is wrong but R is correct

5. Which of the following modes of transmission will not be supported by a rectangular waveguide?
6. **Assertion (A):** In TE\(_{10}\) mode the cutoff frequency of rectangular waveguide is \(\frac{c}{2a}\) where \(a\) is the broad dimension and \(c\) is velocity of light.

**Explanation (R):** TE\(_{10}\) mode is the dominant mode in rectangular waveguide.

- a. Both A and R are correct and R is correct explanation of A
- b. Both A and R are correct but R is not correct explanation of A
- c. A is correct but R is wrong
- d. A is wrong but R is correct

7. In which mode of rectangular waveguide are all field components zero?
   - a. TM\(_{00}\)
   - b. TM\(_{11}\)
   - c. TM\(_{01}\)
   - d. TM\(_{10}\)

**Explanation:** In TM\(_{00}\) mode of rectangular waveguide are all field components zero

8. Which of the following statements is not correct regarding modes of electromagnetic energy transmission?
   - a. In TE mode the direction of electric field is always and everywhere transverse to the direction of propagation
   - b. In TM mode the magnetic field pattern is always and everywhere transverse to the direction of propagation
   - c. The subscripts in TE and TM designations denote the number of half sine wave variations of the field components in x and y directions respectively.
   - d. TM\(_{12}\) is called the dominant mode.

**Explanation:** TM\(_{11}\) is dominant mode.

9. A rectangular waveguide has a discontinuity in the form of reduced narrow dimension. In the equivalent circuit this discontinuity can be represented by
   - a. a shunt capacitance at the discontinuity
   - b. a shunt inductance at the discontinuity
   - c. a shunt resistance at the discontinuity
   - d. none of the above

**Explanation:** A rectangular waveguide has a discontinuity in the form of reduced narrow dimension. In the equivalent circuit this discontinuity can be represented by a shunt capacitance at the discontinuity

T Gayatri, Assistant. Professor
10. Microwaves
   a. get reflected by ionosphere
   b. are absorbed by ionosphere
   c. are neither reflected nor absorbed by ionosphere
   d. are both reflected and absorbed by ionosphere

Explanation: Microwaves are neither reflected nor absorbed by ionosphere

<table>
<thead>
<tr>
<th>Q. NO</th>
<th>ANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a</td>
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<tr>
<td>2</td>
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<tr>
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<td>d</td>
</tr>
<tr>
<td>9</td>
<td>a</td>
</tr>
<tr>
<td>10</td>
<td>c</td>
</tr>
</tbody>
</table>

Group E: Fill in the blanks

1. Microwave energies propagate the length of the waveguide by __________ its side walls.
2. A frequency at which microwave ovens operate is ________
3. ________ & ________ materials are generally preferred for waveguides?
4. ________ the main advantage of microwaves
5. ________ elements are taken in Microwave
6. In Microwave circuit, Wave guide section will act as a _______
7. ________ noise becomes important at microwave frequencies
8. Attenuation constant of microstrip line is ____________
9. The Q factor of microstrip line is ______________
10. The effective dielectric constant of microstrip line is___________

<table>
<thead>
<tr>
<th>S.no</th>
<th>Ans</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Reflection of</td>
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<tr>
<td>2</td>
<td>2.45 GHz</td>
</tr>
<tr>
<td>3</td>
<td>Brass and aluminium</td>
</tr>
<tr>
<td>4</td>
<td>Directivity</td>
</tr>
<tr>
<td>5</td>
<td>Distributed circuit</td>
</tr>
<tr>
<td>6</td>
<td>High pass filter</td>
</tr>
<tr>
<td>7</td>
<td>Transit time</td>
</tr>
<tr>
<td>8</td>
<td>$\alpha_c = \frac{8.686R_s}{Z_0w}$</td>
</tr>
<tr>
<td>9</td>
<td>$Q_c = 0.63h \sqrt{\sigma f_{GHz}}$</td>
</tr>
<tr>
<td>10</td>
<td>$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}$</td>
</tr>
</tbody>
</table>
Microwave Engineering

**Group A: Two marks question with answers**

1. What are junctions? Give some example
   
   Ans. A microwave circuit consists of several microwave devices connected in some way to achieve the desired transmission of MW signal. The interconnection of two or more microwave may be regarded as MW junction.
   
   E.g.: TEE, HYBRID RING

2. What are non-reciprocal devices? Give two examples?
   
   Ans. The devices which are having the properties that the forward characteristics are not equal to the reverse characteristics are called non-reciprocal devices.

3. Give two examples for two port junctions.
   
   Ans. Following are the two examples of two port junctions:
   
   1. The junction of two rectangular guides of unequal height
   2. A symmetrical junction consisting of two similar rectangular guides joined by an Intermediate guide of greater width.

4. What is Faraday’s rotation law?
   
   Ans. If a circularly polarized wave is made to pass through a ferrite rod which has been influenced by an axial magnetic field B, then the axis of polarization gets tilted in clockwise direction and amount of tilt depends upon the strength of magnetic field and geometry of the ferrite.

5. What is Gyrator?
   
   Ans. Gyrator is a two port device which provides a relative phase shift of 180 degree for transmission from port 1 to port 2 as compared to the phase for transmission from Port 2 to port 1.

**Group B: Three marks question with answers**

1. What is hybrid ring?
   
   Ans. 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.

2. Explain Structure of magic tee
   
   Ans. The magic tee is a combination of E and H plane tees. Arm 3 forms an H-plane tee with arms 1 and 2. Arm 4 forms an E-plane tee with arms 1 and 2. Arms 1 and 2 are sometimes called the side or collinear arms. Port 3 is called the H-plane port, and is also called the \( \Sigma \) port, sum port or the P-port (for Parallel). Port 4 is the E-plane port, and is also called the \( \Delta \) port, difference port, or S-port (for Series). There is no one single established convention regarding the numbering of the ports.

3. What is E-plane Tee
   
   Ans. An E-plane tee is a waveguide tee in which the axis of its side arm is parallel to the E-field of the main guide.

4. What is H-plane Tee
   
   Ans. An H-plane tee is a waveguide tee in which the axis of its side arm is shunting the E yield or parallel to the H-field of the main guide.

5. What are the high frequency effects in conventional tubes?

T Gayatri, Assistant. Professor
Ans. The high frequency effects in conventional tubes are
i) Circuit reactance
   a) Inter electrode capacitance
   b) Lead inductance
ii) Transit time effect
iii) Cathode emission
iv) Plate heat dissipation area
v) Power loss due to skin effect, radiation and dielectric loss.

6. Explain about some microwave devices
   Ans. a magic tee (or magic T or hybrid tee) is a hybrid or 3dB coupler used in microwave systems. It is an alternative to the rat-race coupler. In contrast to the rat-race, the three-dimensional structure of the magic-tee makes is less readily constructed in planar technologies such as microstrip or stripline.
   - An H-plane tee is a waveguide tee in which the axis of its side arm is shunting the E yield or parallel to the H-field of the main guide.
   - An E-plane tee is a waveguide tee in which the axis of its side arm is parallel to the E-field of the main guide.
In microwave circuits a waveguide or co-axial line with three independent ports is commonly referred to as a tee junction.
   - Directional couplers are transmission line devices that couple together two circuits in one direction, while providing a great degree of isolation in the opposite direction.
   - An isolator or uniline is a two-port non reciprocal device which produces a minimum attenuation to wave in one direction and very high attenuation in the opposite direction.
   - A circulator is a multiport junction in which the wave can travel from one port to next immediate port in one direction only. They are useful in parametric amplifiers, tunnel diode, amplifiers and duplexer in radar.
   - Slotted line is a fundamental tool for microwave measurements. Slotted line consists of a section of waveguide or coaxial line with a longitudinal slot. The slot is roughly 1mm wide and allows an electric field probe to enter the waveguide for measurement of the relative magnitude of field at location of the probe.

7. Explain about the rectangular cavity resonators
   Ans: RECTANGULAR CAVITY RESONATOR:
   The electromagnetic field inside the cavity should satisfy Maxwell's equations, subject
to the boundary conditions that the electric field tangential to and the magnetic field normal to the metal walls must vanish.

The wave equations in the rectangular resonator should satisfy the boundary condition of the zero tangential E at four of the walls. It is merely necessary to choose the harmonic functions in z to satisfy this condition at the remaining two end walls. These functions can be found if

\[ H_z = H_{0z} \cos \left( \frac{m\pi x}{a} \right) \cos \left( \frac{n\pi y}{b} \right) \sin \left( \frac{p\pi z}{d} \right) \quad (\text{TE}_{mnp}) \]

\[ E_z = E_{0z} \sin \left( \frac{m\pi x}{a} \right) \sin \left( \frac{n\pi y}{b} \right) \cos \left( \frac{p\pi z}{d} \right) \quad (\text{TM}_{mnp}) \]

The separation equation for both TE and TM modes is given by

\[ k^2 = \left( \frac{m\pi}{a} \right)^2 + \left( \frac{n\pi}{b} \right)^2 + \left( \frac{p\pi}{d} \right)^2 \]

For a lossless dielectric, \( k^2 = \omega^2 \mu \epsilon \); therefore, the resonant frequency is by

\[ f_r = \frac{1}{2 \sqrt{\mu \epsilon}} \sqrt{\left( \frac{m}{a} \right)^2 + \left( \frac{n}{b} \right)^2 + \left( \frac{p}{d} \right)^2} \quad (\text{TE}_{mnp}, \text{TM}_{mnp}) \]

The maximum amplitude of the standing wave occurs when the frequency of the impressed signal is equal to the resonant frequency.

In general, a straight-wire probe inserted at the position of maximum electric intensity is used to excite a desired mode, and the loop coupling placed at the position of maximum magnetic intensity is utilized to launch a specific mode.

**8. Explain about the Q factor**
Ans: Quality Factor of Rectangular Cavity Resonators: \( Q = \frac{\omega W}{P_L} \), \( W = W_c + W_m \)

\[
Q = 2\pi \frac{\text{maximum energy stored}}{\text{energy dissipated per cycle}} = \frac{\omega W}{P}
\]

\[
W_c = \int \frac{\varepsilon}{2} |E|^2 \, dv = W_m = \int \frac{\mu}{2} |H|^2 \, dv = W
\]

Where

\[
P = \frac{R_s}{2} \int |H_r|^2 \, da
\]

\[
Q = \frac{\omega \mu \int |H|^2 \, dv}{R_s \int |H_r|^2 \, da} \quad \text{but} \quad |H|^2 = |H_r|^2 + |H_n|^2
\]

Hence the \( Q \) factor is

The resonant frequency and the unloaded \( Q_0 \) of a cavity resonator are

\[
f_0 = \frac{1}{2\pi \sqrt{LC}}
\]

\[
Q_0 = \frac{\omega_0 L}{R}
\]

The loaded \( Q_e \) of the system is given by

\[
Q_e = \frac{\omega_0 L}{R + N^2 Z_g} \quad \text{for} \quad |N^2 L_s| \ll |R + N^2 Z_g|
\]

Coupling coefficient is

\[
K = \frac{N^2 Z_g}{R}
\]

and the loaded \( Q_e \) would become

\[
Q_e = \frac{\omega_0 L}{R(1 + K)} = \frac{Q_0}{1 + K}
\]

Where,

\[
\frac{1}{Q_e} = \frac{1}{Q_0} + \frac{1}{Q_{\text{ext}}}
\]

T Gayatri, Assistant Professor
9. An air-filled rectangular cavity with brass walls \( \sigma = 1.57 \times 10^{7} \text{S/m} \) has the following dimensions: \( a = 4 \text{cm} \), \( b = 3 \text{cm} \), and \( d = 5 \text{cm} \). (a) Determine the dominant mode and its resonant frequency for this cavity. (b) Find the \( Q \) and the time-average stored electric and magnetic energies at the resonant frequency, assuming \( H_0 \) to be 0.1 A/m.

\[
\frac{1}{Q_e} = \frac{1}{Q_0} + \frac{1}{Q_{\text{ext}}}
\]

Where \( Q_{\text{ext}} \) is given by

\[
where Q_{\text{ext}} is given by \frac{1}{Q_e} = \frac{1}{Q_0} + \frac{1}{Q_{\text{ext}}}
\]

\[
9. \text{ An air-filled rectangular cavity with brass walls } \sigma = 1.57 \times 10^{7} \text{S/m} \text{ has the following dimensions: } a = 4 \text{cm}, b = 3 \text{cm}, \text{ and } d = 5 \text{cm}. (a) Determine the dominant mode and its resonant frequency for this cavity. (b) Find the } Q \text{ and the time-average stored electric and magnetic energies at the resonant frequency, assuming } H_0 \text{ to be 0.1 A/m.}
\]

\[
\text{Ans: (Sol.) (a) } \frac{c}{2} \sqrt{\left( \frac{m}{0.04} \right)^2 + \left( \frac{n}{0.03} \right)^2 + \left( \frac{p}{0.05} \right)^2},
\]

dominant mode: \( TE_{101} \),

\[
(f_r)_{TE_{101}} = 4.8 \text{GHz}
\]

\[
(b) (Q)_{TE_{101}} = \frac{\pi (f_r)_{TE_{101}} \mu_0 \alpha \beta d (a^2 + d^2)}{R \left[ 2b(a^3 - b^3) + a \alpha d (a^2 + d^2) \right]} = 6869,
\]

\[
R_s = \sqrt{\frac{\pi (f_r)_{TE_{101}} \mu_0}{\sigma}}
\]

At the resonant frequency,

\[
W_e = W_m = \frac{E_0}{4} \alpha \beta \gamma d (f_r)_{TE_{101}}^2 \mu_0^2 = 7.73 \times 10^{-14} \text{J}
\]

10. Explain about the coupling mechanisms

**Ans: Coupling mechanisms:**

Special devices must be used to put energy into a waveguide at one end and remove it from the other end. The three devices used to inject or remove energy from waveguides are PROBES, LOOPS, and SLOTS. Slots may also be called APERTURES or WINDOWS.

i) **Probe coupling:**

a small probe is inserted into a waveguide and supplied with microwave energy, it acts as a quarter-wave antenna. Current flows in the probe and sets up an E field.

The E lines detach themselves from the probe. When the probe is located at the point of highest efficiency, the E lines set up an E field of considerable intensity.
The most efficient place to locate the probe is in the center of the "a" wall, parallel to the "b" wall, and one quarter-wavelength from the shorted end of the waveguide.

ii) **Loop coupling:**
Another way of injecting energy into a waveguide is by setting up an H field in the waveguide. This can be accomplished by inserting a small loop which carries a high current into the waveguide.

Fig (A). A magnetic field builds up around the loop and expands to fit the waveguide Fig. (B). If the frequency of the current in the loop is within the bandwidth of the waveguide, energy will be transferred to the waveguide. For the most efficient coupling to the waveguide, the loop is inserted at one of several points where the magnetic field will be of greatest strength.

When less efficient coupling is desired, you can rotate or move the loop until it encircles a smaller number of H lines.

When the diameter of the loop is increased, its power-handling capability also increases. The bandwidth can be increased by increasing the size of the wire used to make the loop.

iii) **Slots & apertures**
Slots or apertures are sometimes used when very loose (inefficient) coupling is desired.

In this method energy enters through a small slot in the waveguide and the E field expands into the waveguide.

The E lines expand first across the slot and then across the interior of the waveguide.
Minimum reflections occur when energy is injected or removed if the size of the slot is properly proportioned to the frequency of the energy.

**Group D: Objective question with answers**

1. Microwave resonators are used in
   a. microwave oscillators
   b. microwave narrow band amplifier
   c. microwave frequency meters
   d. all of the above

   **Explanation:** Microwave resonators are used to generate microwave signal in oscillator, amplifiers, frequency meters

2. A cavity resonator is
   a. a hollow metallic enclosure
   b. a hollow enclosure having magnetic material as its walls
   c. a hollow enclosure having dielectric material as its walls
   d. either (b) or (c)
   e. **Explanation:** A cavity resonator is a hollow metallic enclosure

3. The two terms used to describe performance of a directional coupler are
   a. coupling and directivity
   b. gain and coupling
   c. gain and directivity
   d. gain and isolation

   **Explanation:** The two terms coupling and directivity used to describe performance of a directional coupler are
4. A directional coupler is used to determine
   a. $\beta$
   b. $\beta$ and VSWR
   c. L and C
   d. wave velocity

**Explanation:** A directional coupler is used to determine $\beta$ and VSWR

5. Which one of the following is also called ‘rat race’?
   a. E plane tee
   b. H plane tee
   c. Magic tee
   d. Hybrid ring

**Explanation:** Hybrid ring circuit is called Rat race

6. A magic tee is to be used as CW duplexer. Then port 1, port 2, port 3 (E arm), port 4 (H arm) respectively should be connected to
   a. matched load, antenna, receiver and CW transmitter
   b. CW transmitter, antenna, receiver and matched load
   c. CW transmitter, receiver, antenna and matched load
   d. CW transmitter, matched load, receiver and antenna

**Explanation:** A magic tee is to be used as CW duplexer. Then port 1, port 2, port 3 (E arm), port 4 (H arm) respectively should be connected to matched load, antenna, receiver and CW transmitter

7. A directional coupler is used
   a. to transmit microwave signals
   b. to generate microwave signals
   c. to measure amplitude and phase of a travelling wave
   d. both (a) and (b)

**Explanation:** A directional coupler is used to measure amplitude and phase of a travelling wave

8. Consider the following statements about a magic tee
   1. The collinear arms are isolated from each other.
   2. One of the collinear arms is isolated from E arm.
   3. One of the collinear arms is isolated from H arm.
   4. E and H arms are isolated from each other.

Of the above statements

T Gayatri, Assistant Professor
a. 1 and 2 are correct  
b. 1 and 3 are correct  
c. 1 and 4 are correct  
d. 2 and 3 are correct  

**Explanation:** The collinear arms & E and H arms are isolated from each other in magic tee

9. Microwave resonators can be constructed from open sections of waveguide.  
   a) True  
   b) False  

**Explanation:** Microwave resonators cannot be constructed from open sections of waveguide

10. In order to obtain the resonant frequency of a rectangular waveguide, the closed cavity has to satisfy:  
    a) Gaussian equation  
    b) Helmholtz equation  
    c) Ampere’s law  
    d) None of the mentioned  

**Explanation:** To obtain the resonant frequency of a rectangular waveguide, the closed cavity has to satisfy Helmholtz equation

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</table>

**Group E: Fill in the blanks question with answers**

1. Two entities that are combined to form a Magic Tee are _______ & _________

T Gayatri, Assistant. Professor
2. **To couple two waveguides a choke flange may be used** To compensate for _________ at the joint.

3. **The waveguide tuning component, which is not easily adjustable, is** _________

4. _________ is unlikely to be used as a pulsed device

5. ______ is a nonreciprocal transmission device that is used to isolate one component from reflections of other components in the transmission line.

6. the isolator is usually called _____________

7. Ferrite is a family of _________

8. **a magic tee** (or magic T or hybrid tee) is a _____ hybrid used in microwave systems.

9. As there is no reflection, diagonal S parameters of scattering matrix will be zero. ______________

10. A microwave circulator is a multiport waveguide junction in which the wave can flow only from the ____ port to the _______ port in one direction.

<table>
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<td>Uni line.</td>
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<td>MeO, Fez 03</td>
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<tr>
<td>8</td>
<td>or 3dB coupler</td>
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<tr>
<td>9</td>
<td>S11, S22 and S33</td>
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<td>Nth, ((n + 1))th</td>
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**UNIT 3:**

**Group A: Two marks question with answers**

1. What are the applications of reflex klystron?
   Ans. The main applications of a reflex klystron are as follows-
   1. Signal source in MW generator
   2. Local oscillators in receivers
   3. It is used in FM oscillator in low power MW links.
   4. In parametric amplifier as pump source.

2. What is the purpose of slow wave structures used in TWT amplifiers?
   Ans. 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.

3. How to increase the band width in klystron amplifier

T Gayatri, Assistant Professor
Ans. Klystron amplifiers use one or more intermediate cavities in addition to buncher and catcher cavity. When one or more intermediate cavities are used the bandwidth can be increased.

4. Write about the features of multi cavity klystron
Ans. The features of a multicavity klystron are:
   1. Frequency range - 0.25 GHz to 100 GHz
   2. Power output - 10 kW to several hundred kW
   3. Power gain - 60 dB (nominal value)
   4. Efficiency - about 40%.

A multicavity klystron is used in UHF TV transmitters, Radar transmitter and satellite communication.

5. What is bunching effect
Ans. Bunching effect converts velocity modulation into current modulation of beam in the klystron.

**Group B: Three marks question with answers**

1. What do you mean by O-type tubes? Name some O-type tubes.
Ans. 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.
   a. Helix Traveling wave tube
   b. Coupled cavity TWT
   c. Forward wave amplifier
   d. Backward wave amplifier
   e. Backward wave oscillator

2. What are the assumptions for calculation of RF power in Reflex Klystron?
Ans. i) Cavity grids and repeller are plane parallel and very large in extent.
   
   ii) No RF field is excited in repeller space

   iii) Electrons are not intercepted by the cavity anode grid.

   iv) No debunching takes place in repeller space.

   v) The cavity RF gap voltage amplitude $V_c$ is small compared to the dc beam voltage $V_o$.
3. **Draw various reentrant cavities**

Ans:

![Reentrant Cavities](image)

Figure: Reentrant cavities. (a) Conical cavity. (b) Radial cavity. (c) Tunable cavity. (d) Toroidal cavity. (e) Butterfly cavity.

4. **Give the eqn of velocity modulation**

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

Ans:

5. **Give the expression for output power and efficiency of klystron**

\[ P_{\text{out}} = \frac{(\beta_0 I_2)^2}{2} R_{\text{sh}} = \frac{\beta_0 I_2 V_2}{2} \]

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

Group C: Five marks question with answers

1. **Explain the performance and working of Klystron**

Ans. A klystron is a specialized linear-beam vacuum tube (evacuated electron tube). Klystrons are used as amplifiers at microwave and radio frequencies to produce both low-power reference signals for super heterodyne radar receivers and to produce highpower carrier waves for communications and the driving force for modern particle accelerators.

- Klystrons amplify RF signals by converting the kinetic energy in a DC electron beam into radio frequency power.
- A beam of electrons is produced by a thermionic cathode (a heated pellet of low work function material), and accelerated by high-voltage electrodes (typically in the tens of kilovolts).
- This beam is then passed through an input cavity. RF energy is fed into the input cavity at, or nears, its natural frequency to produce a voltage which acts on the electron beam.
- The electric field causes the electrons to bunch: electrons that pass through during an opposing electric field are accelerated and later electrons are slowed, causing the previously continuous electron beam to form bunches at the input frequency.
- To reinforce the bunching, a klystron may contain additional "buncher" cavities. The RF current carried by the beam will produce an RF magnetic field, and this will in turn excite a voltage across the gap of subsequent resonant cavities.
In the output cavity, the developed RF energy is coupled out. The spent electron beam, with reduced energy, is captured in a collector.

2. Explain the principle of operation, modes and applications of Reflex klystron

Ans. - It works on the principle of velocity modulation and current modulation.

- Variation in velocities of the electrons in the electron beam is called velocity modulation; variation in the current density of the electron beam is referred to as current modulation.
- A reference electron passing the gap when the gap voltage is zero travels with no change in velocity. An electron leaving the gap earlier during slightly positive voltage would travel further into repeller space and hence would take longer time then the reference electron to return to the gap.
- An electron leaving the gap later will face slightly negative voltage and gets retarded. So it returns back after a shorter travel in the repeller space.
- Thus all the electrons would arrive back to the gap in bunches. Bunching around reference electron takes place once per cycle of RF oscillations.
- There are several combinations of repeller voltage and anode voltage that provide favorable conditions for bunching.
- Accordingly there are several modes of operation, expressed by N + \( \frac{3}{4} \) where N is an integer.
- They are used as
  1) signal source in microwave generators.
  2) Local oscillators in receivers.
  3) Pump oscillators in parametric amplifiers.

3. Explain about slow wave structure of TWT & methods to suppress spurious oscillations in TWT, applications of TWT

Ans. 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.

- In a TWT, adjacent turns of the helix are so close to each other and hence oscillations are likely to occur. To prevent these spurious signals some form of attenuator is placed near the input end of the tube which absorb the oscillations.
- Applications:
  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 CW TWT’S are used for communication and radar.

4. Classify microwave tubes:

T Gayatri, Assistant Professor
Ans: O-typetubes:
1. These are linear beam tubes, i.e. the magnetic field is in parallel with the d.c. electric field.
2. In these tubes, electrons receive potential energy from the d.c. beam voltage before they arrive in the microwave interaction region this energy is converted into their kinetic energy. e.g. Klyston, Helix TWT and BWA, BWO etc.

M-typetubes
1. These are cross field devices i.e. the d.c. magnetic field and the d.c. electric field are perpendicular to each other.
2. In these tubes, the electrons emitted by the cathode are accelerated by the electric field and gain velocity but the greater their velocity, the more their path is bent by the magnetic field. e.g. magnetron, FWCFA, Dematron, Gyrotrons etc.

5. Define reflex klystrons, some characteristics and applications
Ans. The reflex klystron is an oscillator with a built in feedback mechanism. It uses the cavity for bunching and for the output cavity.

Characteristics: Frequency range: 1 to 25GHz Power output: It is a low-power generator of 10 to 500mW Efficiency: About 20 to 30%

Applications:
1. This type is widely used in the laboratory for microwave measurements.
2. In microwave receivers as local oscillators in commercial and military applications.
3. In airborne Doppler radars as well as missiles.
Group D: Objective question with answers

1. TWT is
   a. Oscillator
   b. Tuned Amplifier
   c. Wide band Amplifier.
   d. Both amplifier and Oscillator
   **Explanation:** TWT is amplifier and Oscillator

2. A space between two cavities in two cavity klystron is
   a. Drift space
   b. Free space
   c. Running space
   d. Normal space
   **Explanation:** A space between two cavities in two cavity klystron is called Drift space

3. A reflex Klystron function as
   a. Microwave Oscillator.
   b. Amplifier
   c. Phase shifter
   d. Both amplifier and phase shifter
   **Explanation:** A reflex Klystron function as a Microwave Oscillator

4. The modes in the reflex Klystron
   a. give same frequency but different transit time.
   b. are caused by spurious frequency modulation.
   c. are just for theoretical consideration.
   d. result from excessive transit time across resonator gap
   **Explanation:** The modes in the reflex Klystron give same frequency but different transit time.

5. In multicavity Klystron additional cavities are inserted between buncher and catcher cavities to achieve-
   a. Higher Gain
   b. Higher Efficiency
   c. Higher Frequency
   d. Higher Bandwidth
   **Explanation:** In multicavity Klystron additional cavities are inserted between buncher and catcher cavities to increase Gain

6. Klystron operates on the principle of-
   a. Amplitude Modulation.
   b. Frequency Modulation.
Microwave Engineering

T Gayatri, Assistant Professor

c. Pulse Modulation.
d. Velocity modulation.

**Explanation:** Klystron operates on the principle of velocity Modulation.

7. Reflex Klystron is a
   a. Amplifier.
   b. Oscillator.
   c. Attenuator.
   d. Amplifier & Oscillator.

**Explanation:** Reflex Klystron is a Amplifier & Oscillator

8. In a klystron amplifier the input cavity is called
   a. Buncher
   b. Catcher
   c. Pierce gun
   d. Collector

**Explanation:** In a klystron amplifier the input cavity is called Buncher

9. In a TWT the amplitude of resultant wave travelling down the helix
   a. increases exponentially
   b. increases linearly
   c. decreases exponentially
   d. is almost constant
   e. **Explanation:** In a TWT the amplitude of resultant wave travelling down the helix increases exponentially

10. Which of the following devices uses a helix?
    a. Klystron amplifier
    b. Klystron oscillator
    c. TWT
    d. Both (a) and (b)

**Explanation:** TWT uses Helix

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**Group E: Fill in the blanks question with answers**

1. **Operating frequency of the reflex klystron is as high as__________**
2. **The microwave tube that uses buncher and catcher cavities is ____________**
3. **To reduce _________ is the primary purpose of the helix in a travelling wave tube**
4. **Klystron operates on the principle of___________**
5. **Reflex klystron is a _______**
6. **A space between two cavities in two cavity klystron is ________**

T Gayatri, Assistant Professor
7. Traveling Wave Tube is __________
8. TWT operates for frequency of_____
9. Reflex klystron has ______number of cavities
10. _______is the equation for velocity modulation

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<td>6</td>
<td>Drift space</td>
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<td>7</td>
<td>Wide band amplifier</td>
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<td>8</td>
<td>3 GHz and higher</td>
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<td>10</td>
<td>$v(t) = v_0 \left[ 1 + \frac{\beta V_1}{2v_0} \sin \left( \omega t - \frac{\theta}{2} \right) \right]$</td>
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UNIT 4:

Group A: Two marks question with answers

1. State the characteristics of magnetron and of 2-cavity klystron amplifier.
   Ans. Magnetron:
   a. Operating frequencies _ 70 GHz
   b. Output power _ 40 MW
   c. Efficiency _ 40 to 70%

   2-cavity klystron:
   a) Efficiency _ 40%
   b) Power output _ average power _> 500 KW
   c) Pulsed power _> 30 MW
   d) Power gain _ about 30 db.

2. What are the advantages of TWT?

T Gayatri, Assistant. Professor
Ans. 1. Bandwidth is large.
2. High reliability
3. High gain
4. Constant Performance in space
5. Higher duty cycle.

3. What are the elements that exhibit Gunn effect?
   Ans. The elements are:
   a. Gallium arsenide
   b. Indium phosphide
   c. Cadmium telluride
   d. Indium arsenide.

4. State the applications of magnetrons. why magnetron is called as cross filed device?
   Ans. 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.

5. Define GUNN EFFECT.
   Ans. Gunn effect was first observed by GUNN in n_type GaAs bulk diode. According to GUNN, above some critical voltage corresponding to an electric field of 2000-4000v/cm, the current in every specimen became a fluctuating function of time. The frequency of oscillation was determined mainly by the specimen and not by the external circuit.

**Group B: Three marks question with answers**

1. What is Transferred electron effect?
   Ans. Some materials like GaAs exhibit negative differential mobility, when biased above a threshold value of the electric field. This behavior is called transferred electron effect.

2. What are the crossed fields
   Ans. Crossed-field tubes derive their name from the fact that the dc electric field and the dc magnetic field are perpendicular to each other. They are also called M – type tubes after the French TPOM. In a crossed-field tube, because of the crossed-field interactions, only those electrons that have given up sufficient energy to the RF field can travel all the way to the anode.

3. Classify crossed field tubes
4. Give the expression for Hull Cutoff Voltage

\[ V_{0k} = \frac{e}{8m} B_0 b^2 \left( 1 - \frac{a^2}{b^2} \right) \]

Ans:

5. Give the hartree condition

\[ V_{0h} = \frac{\omega B_0 d}{\beta} - \frac{m \omega^2}{2e \beta^2} \]

Ans:

**Group C: Five marks question with answers**

6. What is Gunn Diode

Ans. • The Gunn diode is named for the physicist J.B. Gunn who, in 1963, produced the first device based upon the theoretical calculations of Cyril Hilsum.
• A Gunn diode, also known as a transferred electron device (TED), is a form of diode used in high-frequency electronics.
• It is somewhat unusual in that it consists only of N-doped semiconductor material, whereas most diodes consist of both P and N-doped regions.
• In the Gunn diode, three regions exist: two of them are heavily N-doped on each terminal, with a thin layer of lightly doped material in between.
• Negative resistance behavior can be used to amplify 2 Common use is a high frequency and high power signal source

7. Explain Operation of the Gunn diode

Ans. The operation of the Gunn diode can be explained in basic terms. When a voltage is placed across the device, most of the voltage appears across the inner active region. As this is particularly thin this means that the voltage gradient that exists in this region is exceedingly high. It is found that when the voltage across the active region reaches a
certain point a current is initiated and travels across the active region. During the time when the current pulse is moving across the active region the potential gradient falls preventing any further pulses from forming. Only when the pulse has reached the far sides of the active region will the potential gradient rise, allowing the next pulse to be created. It can be seen that the time taken for the current pulse to traverse the active region largely determines the rate at which current pulses are generated, and hence it determines the frequency of operation.

8. Briefly explain about Magnetron

Ans. In a magnetron, the dc magnetic field and dc electric field are perpendicular to each other and hence magnetron is called as a cross field device.

- There are three types of magnetrons:
  i. Split anode magnetron
  ii. Cyclotron – frequency magnetrons
  iii. Traveling wave magnetrons.

Negative – resistance magnetrons ordinarily operate at frequencies below the microwave region. This type of magnetron uses a static negative resistance between two anode segments but has low efficiency and is useful only at low frequencies.

Coaxial magnetron- The coaxial magnetron is composed of an anode resonator structure surrounded by an inner – single, high-Q cavity operating in the TE011.

Voltage – tunable magnetron- The voltage tunable magnetron is a broadband oscillator with frequency changed by varying the applied voltage between the anode and sole.

Characteristics of coaxial magnetron:
- Minimum peak power of 400kW at a frequency range from 8.9 to 9.6GHz.
- Its duty cycle is 0.0013.
- Nominal anode voltage is 32kV.
- Peak anode current is 32A.

9. Write about pi mode operation of magnetron, its efficiency and applications

Ans. In the p - mode of operation, the successive cavities in anode have opposite phase, excitation is maximum in the cavities.

- A magnetron can deliver a peak power output of up to 40MW with the dc voltage of 50KV at 10GHz.
- The average power output is 800KW.
- The magnetron possesses a very high efficiency ranging from 40 to 70%.
- Magnetrons are commercially available for peak power output from 3KW and higher.

The magnetron are widely used on
- Radar transmitters
- Industrial heating
- Microwave ovens.

10. Define cavity magnetron, Explain working of cavity magnetrons

Ans. The cavity magnetron is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field.

- All cavity magnetrons consist of a hot cathode with a high (continuous or pulsed) negative potential by a high-voltage, direct-current power supply.
• The cathode is built into the center of an evacuated, lobed, circular chamber. A magnetic field parallel to the filament is imposed by a permanent magnet.

• The magnetic field causes the electrons, attracted to the (relatively) positive outer part of the chamber, to spiral outward in a circular path rather than moving directly to this anode. Spaced around the rim of the chamber are cylindrical cavities.

• The cavities are open along their length and connect the common cavity space. As electrons sweep past these openings, they induce a resonant, high-frequency radio field in the cavity, which in turn causes the electrons to bunch into groups.

• A portion of this field is extracted with a short antenna that is connected to a waveguide (a metal tube usually of rectangular cross section).

• The waveguide directs the extracted RF energy to the load, which may be a cooking chamber in a microwave oven.

Group D: Objective question with answers

1. Magnetron is an
   a. Amplifier
   b. Oscillator
   c. Phase shifter
   d. Both phase shifter and amplifier

Explanation: Magnetron is an oscillator

2. A magnetron has a cylindrical cathode surrounded by an anode structure having cavities opening into interaction space by means of slots
   a. True
   b. False

Explanation: A magnetron has a cylindrical cathode surrounded by an anode structure having cavities opening into interaction space by means of slots

3. Assertion (A): Gunn diode is a transferred electron device.
   Explanation (R): A Gunn oscillator uses the phenomenon of transferred electron effect.
   a. Both A and R are correct and R is correct explanation of A
   b. Both A and R are correct but R is not correct explanation of A
   c. A is correct but R is wrong
   d. A is wrong but R is correct

4. The external magnetic field in a magnetron is such that lines are
   a. parallel to the axis of cathode
   b. perpendicular to the axis of cathode
   c. inclined to the axis of cathode
   d. either (b) or (c)

5. Explanation: The external magnetic field in a magnetron is such that lines are parallel to the axis of cathode

T Gayatri, Assistant Professor
6. In 8 cavity magnetron the Π mode corresponds to a total phase shift equal to 
   a. ± 8 Π radians around the periphery 
   b. ± 4 Π radians around the periphery 
   c. ± 2 Π radians around the periphery 
   d. ± 16 Π radians around the periphery 
7. **Explanation:** In 8 cavity magnetron the Π mode corresponds to a total phase shift equal to ± 8 Π radians around the periphery 

8. In a magnetron the magnetic flux density is of the order of 
   a. 1 mWb/s 
   b. 1 Wb/m² 
   c. 10⁶ m/s 
   d. 10¹² m/s 
   e. **Explanation:** In a magnetron the magnetic flux density is of the order of 1 Wb/m² 

9. The Π mode of operation of magnetron signifies that 
   a. the phase difference between adjacent anode poles is Π radians 
   b. the phase difference between adjacent anode poles is a multiple of Π radians 
   c. the total phase shift around the periphery is Π radians 
   d. none of the above 
**Explanation:** This mode of operation is called the PI MODE, since adjacent segments of the anode have a phase difference of 180 degrees, or one-pi radian. Several other modes of oscillation are possible, but a magnetron operating in the pi mode has greater power and output and is the most commonly used. 

10. In Π mode of operation of magnetron the spikes due to phase focusing effect rotate at an angular velocity corresponding to 
    a. one pole/cycle 
    b. 2 pole/cycle 
    c. 4 pole/cycle 
    d. 6 pole/cycle 
**Explanation:** In Π mode of operation of magnetron the spikes due to phase focusing effect rotate at an angular velocity corresponding to 2 pole/cycle 

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**Group E:** Fill in the blanks question with answers 

1. ________ device behavior is governed by bulk effect. 
2. In a magnetron the electrons travel in a cycloidal path because of strong field supplied by _________ 
3. Magnetron is an ________ 
4. _________ amplifier uses an axial magnetic field & radial electric field

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5. In $\pi$ mode operation of magnetron, the spokes due to phase focusing effect rotate at an angular velocity corresponding to ________

6. beyond the threshold value of ________ for the n-type GaAs, the drift velocity is decreased and the diode exhibits negative resistance.

7. ________ is the Hartree condition

8. ________ is the Hull cutoff voltage equation

9. In Crossed-field tubes the dc electric field and the dc magnetic field are ________ to each other.

10. the Zero mode, is also called as ________

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<td>2</td>
<td>permanent magnet</td>
</tr>
<tr>
<td>3</td>
<td>Oscillator</td>
</tr>
<tr>
<td>4</td>
<td>Crossed field</td>
</tr>
<tr>
<td>5</td>
<td>Two poles / cycle</td>
</tr>
<tr>
<td>6</td>
<td>3000 V/cm</td>
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<td>7</td>
<td>$v_0 = \frac{\omega B_d a}{\beta} - \frac{m \omega^2}{2e \beta^2}$</td>
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<tr>
<td>8</td>
<td>$V_0 = \frac{e}{8m} B_0 b^2 \left(1 - \frac{a^2}{b^2}\right)^2$</td>
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UNIT 5:

Group A: Two marks question with answers

1. Define s-matrix and its properties?
   Ans. In a microwave junction there is an interaction of three or more components. There will be an output port, in addition there may be reflection from the junction of other ports. Totally there may be many combination, these are represented easily using a matrix called S matrix.

2. What are the properties of S- matrix
   Ans. Properties of s- matrix
   1. it possess symmetric properties $S_{ij}=S_{ji}$
   2. it possess unitary property
   3. $[s][s]^*=[i]$

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3. Why is s-matrix used in MW analysis?
   Ans. Matrix is used in MW analysis to overcome the problem which occurs when H, Y & Z parameter are used in high frequencies.
   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.

4. What are the properties of scattering matrix for a lossless junction?
   Ans. 1. The product of any column of the S-matrix with conjugate of this column equals unity.
   2. The product of any column of the scattering matrix with the complex conjugate of any other column is zero.

5. Define VSWR
   Ans. Voltage standing wave ratio is defined as the ratio of maximum voltage to the minimum voltage $\text{VSWR} = \frac{V_{\text{max}}}{V_{\text{min}}}$

**Group B: Three marks question with answers**

1. What are tunable detector?
   Ans. The tunable detectors are used to demodulate the signal and couple the required output to high frequency scope analyzer. The low frequency demodulated output is detected using non reciprocal detector diode mounted in the microwave transmission line.

2. What is slotted section with line carriage?
   Ans. It is a microwave sectioned coaxial line connecting a coaxial E-field probe which penetrates inside a rectangular waveguide slotted section. The longitudinal slot is cut along the center of the waveguide broad walls. The probe is made to move along the slotted wall which samples the electric field proportional to probe voltage.

3. What is the main purpose of slotted section with line carriage?
   Ans. 1. For determination of location of voltage standing wave maxima and minima along the line.
   2. Measure the VSWR and standing wave pattern.
   3. Wavelength.
   4. Impedance.
   5. Reflection coefficient.
   6. Return loss measurement.

4. What is Bolometer?
   Ans. It is a power sensor whose resistance change with changed temperature as it absorb the
microwave power. It is a short thin metallic wire sensor with positive temperature coefficient of resistance.

5. What is a VSWR meter?
Ans. VSWR meter is a highly sensitive, high gain, high theta, low noise voltage amplifier tuned normally at fixed frequency of 1 KHZ of which microwave signals modulated. This meter indicates calibrated VSWR reading for any loads.

Group C: Five marks question with answers

17. How to measure power in microwaves
Ans. Bolometer: It is used to measure low power. It is a power sensor whose resistance changes with changed temperature as it absorbs the microwave power. It is a short thin metallic wire sensor with positive temperature coefficient of resistance.

- Calorimeter: It is a convenient device setup for measuring the high power at microwave which involves conversion of microwave energy into heat, absorbing the heat in a fluid and determine the temp.

18. Explain about some measuring devices on microwave bench
Ans. Wave meter: It is a device used for frequency measurement in microwave. It has cylindrical cavity with a variable short circuit termination. It changes the resonant frequency of cavity by changing cavity length.

Slotted line: A coupling probe moving along the waveguide can be used to detect the standing wave pattern present inside the waveguide. It is basically used for measuring the standing wave ratio.

Tuner: The tuner is the device which provides some magnetrons with the ability to vary from the basic frequency determined by the anode. Tuners fall into three basic categories: _ Capacitive _ Inductive _ Combination of both

Power dividers and directional couplers are passive devices used in the field of radio technology. They couple part of the transmission power in a transmission by a known amount out through another port, often by using two transmission lines set close enough together such that energy passing through one is coupled to the other.

Bolometer: It is a power sensor whose resistance changes with changed temperature as it absorbs the microwave power.

Calorimeter: It is a convenient device setup for measuring the high power at microwave which involves conversion of microwave energy into heat, absorbing the heat in a fluid and determine the temperature.

19. Define S parameters, properties, its importance in microwave theory
Ans. Scattering matrix is a square matrix which gives all the combinations of power relationships between the various input and output port of a microwave junction.

- The elements of scattering matrix are called scattering coefficients or scattering parameters.
- The H, Y, Z and ABCD parameters are difficult at microwave frequencies due to following explanations. · Equipment is not readily available to measure total voltage and total current at the ports of the networks. · Short circuit and open...
Microwave Engineering

circuit are difficult to achieve over a wide range of frequencies. Presence of active devices makes the circuit unstable for short (or) open circuit. Therefore, microwave circuits are analyses using scattering (or) S parameters which linearly relate the reflected wave’s amplitude with those of incident waves.

- Properties:
  - 1. $[s]$ is always a square matrix of order $(nxn)$
  - 2. $[s]$ is a symmetric matrix i.e. $S_{ij}=S_{ji}$
  - 3. $[s]$ is a unitary matrix i.e. $[S][S^*]=[I]$
  - 4. Under perfect matched conditions, the diagonal elements of $[s]$ are zero.

20. Explain different blocks of microwave bench

Ans: A general block diagram of the test bench comprising its different units and ancillaries are shown below.

11. Klystron Power Supply:
Klystron Power Supply generates voltages required for driving the reflex Klystron tube like 2k25.

12. Gunn Power Supply:
Gunn Power Supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn oscillator and PIN Modulator. The Supply Voltage ranges from 0 to 12V with a maximum current, 1A.

13. Reflex Klystron Oscillator:
At high frequencies, the performance of a conventional vacuum tube is impaired due to transit time effects, lead inductance and inter-electrode capacitance. Klystron is a microwave vacuum tube employing velocity modulation and transit time in achieving its normal operation. It has been the most used source of microwave power.

14. Gunn Oscillator:
Gunn oscillator utilizes Gunn diode which works on the principle that when a DC voltage is applied across a sample of n-type Gallium Arsenide; the current oscillates at microwave frequencies. This does not need high voltage as it is necessary for Klystrons and therefore solid state oscillators are now finding wide applications. Normally, they are capable of delivering 0.5 watt at 10GHz

Isolator:
This un attenuated device permits un attenuated transmission in one direction (forward direction) but provides very high attenuation in the reverse direction (backward direction).

15. Variable Attenuator:
The device that attenuates the signal is termed as attenuator.

16. Frequency Meter:
It is basically a cavity resonator. The method of measuring frequency is to use a

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cavity where the size can be varied and it will resonate at a particular frequency for given size.

17. Slotted Section:
To sample the field within a wave guide, a narrow longitudinal slot with ends tapered to provide smoother impedance transformation and thereby providing minimum mismatch, is milled on the top of broader dimension of wave guide.

18. Matched Load:
The microwave components which absorb all power falling on them are matched loads.

19. Short Circuit Termination:
Wave guide short circuit terminations provide standard reflection at any desired, precisely measurable positions.

20. VSWR meter:
Direct-reading VSWR meter is a low-noise tuned amplifier voltmeter calibrated in db and VSWR for use with square law detectors.

11. Crystal Detector:
The simplest and the most sensitive detecting element is a microwave crystal. It is a nonlinear, non reciprocal device which rectifies the received signal and produces a current proportional to the power input.

21. Explain about the power measurement
Ans: Bolometer: power measurement:
A bolometer is a device for measuring the power of incident electromagnetic radiation via the heating of a material with a temperature-dependent electrical resistance. A bolometer consists of an absorptive element, such as a thin layer of metal, connected to a thermal reservoir (a body of constant temperature) through a thermal link. The result is that any radiation impinging on the absorptive element raises its temperature above that of the reservoir – the greater the absorbed power, the higher the temperature. The intrinsic thermal time constant, which sets the speed of the detector, is equal to the ratio of the heat capacity of the absorptive element to the thermal conductance between the absorptive element and the reservoir. The temperature change can be measured directly with an attached resistive thermometer, or the resistance of the absorptive element itself can be used as a thermometer. Metal bolometers usually work without cooling. They are produced from thin foils or metal films. Today, most bolometers use semiconductor or superconductor absorptive elements rather than metals. These devices can be operated at cryogenic temperatures, enabling significantly greater sensitivity.

Group D: Objective question with answers

1. A loss less line of characteristic impedance $Z_0$ is terminated in pure reactance of $-jZ_0$ value. VSWR is
   a. 10
   b. 2
   c. 1

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2. The reflection coefficient on a line is 0.2 \(\angle 45^\circ\). The SWR is
   a. 0.8
   b. 1.1
   c. 1.2
   d. 1.5

\[
\text{SWR} = \frac{1 + |\rho_v|}{1 - |\rho_v|} = \frac{1.2}{0.8} = 1.5.
\]

**Explanation:**

3. **Assertion (A):** Bolometer is frequently used in microwave power measurement.
   **Explanation (R):** In a bolometer the input microwave power causes a change in resistance.
   a. Both A and R are correct and R is correct explanation of A
   b. Both A and R are correct and R is not correct explanation of A
   c. A is correct but R is wrong
   d. R is correct but A is wrong

4. A microwave junction is matched at all ports if the S matrix
   a. has all diagonal elements zero
   b. has all diagonal elements equal but not zero
   c. has all diagonal elements complex
   d. is Hermitian

**Explanation:** A microwave junction is matched at all ports if the S matrix has all diagonal elements zero

5. **Assertion (A):** Slotted line is frequently used for microwave measurements.
   **Explanation (R):** The unknown impedance is mounted at the end of slotted line.
   a. Both A and R are correct and R is correct explanation of A
   b. Both A and R are correct and R is not correct explanation of A
   c. A is correct but R is wrong
   d. R is correct but A is wrong

6. **Assertion (A):** For a reciprocal microwave junction the S matrix is symmetrical.
   **Explanation (R):** In a symmetrical matrix \( S_{ij} = S_{ji} \).
   a. Both A and R are correct and R is correct explanation of A
   b. Both A and R are correct and R is not correct explanation of A
   c. A is correct but R is wrong
   d. R is correct but A is wrong

7. The scattering matrix of magic tee is
**Explanation:** The scattering matrix of magic tee is

8. \( VSWR = \frac{E_{\text{max}}}{E_{\text{min}}} \).
   a. True
   b. False

**Explanation:** \( VSWR = \frac{E_{\text{max}}}{E_{\text{min}}} \).

9. The relation between incident voltage matrix, reflected voltage matrix and S matrix for a microwave network:
   a) \([v-] = [s] [v+]\).
   b) \([v+] = [s] [v-]\).
   c) \([v-] [v] = [s] \).
   d) \([s] = [v] [v-]\).

**Explanation:** The relation between incident voltage matrix, reflected voltage matrix and S matrix for a microwave network \([v-] = [s] [v+]\).

10. Scattering matrix for a lossless matrix is:
    a) Unitary
    b) Symmetric

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c) Identity matrix
d) Null matrix

Explanation: Scattering matrix for a lossless matrix is Unitary

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Group E: Fill in the blanks question with answers

1. Standard mismatching in microwave circuits have SWR from ________ to ________
2. Microwave devices measure ________ power
3. PIN diode is suitable for use as a ______
4. In Microwave power measurements using bolometer, the principle of working is the variation of ______
5. Relation between λ₀, λₑ, and λ₁ in rectangular waveguide
6. ________ is the expression for Q factor
7. ________ is the expression for impedance in RWG
8. ________ is the relation between SWR and impedance in RWG
9. Expression for SWR is ________
10. Expression for reflection coefficient is ________

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<td>Microwave switch</td>
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<td>4</td>
<td>Resistance with absorption of power</td>
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<td>5</td>
<td>( \frac{1}{\lambda_o^2} = \frac{1}{\lambda_e^2} + \frac{1}{\lambda_c^2} )</td>
</tr>
<tr>
<td>6</td>
<td>( Q = \frac{\text{Maximum Energy stored}}{\text{Power Loss}} )</td>
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<tr>
<td>7</td>
<td>( R = \frac{Z - Z_0}{Z + Z_0} ),</td>
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T Gayatri, Assistant Professor
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<td>[ \rho = \frac{E_r}{E_I} = \frac{Z-Z_0}{Z+Z_0}, \quad</td>
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17. Topic beyond Syllabus with material:

**Microwave antennas:**

The antennas which are operated between the frequency ranges 30 to 300 MHz and 300 to 3000 MHz are known as VHF antennas and UHF antennas respectively. Typically, antennas operating over 3000 MHz are called microwave antennas.

- Short Dipole Antenna
- Dipole Antenna
- Half-Wave Dipole
- Broadband Dipoles
- Monopole Antenna
- Folded Dipole Antenna
- Small Loop Antenna
- Microstrip antennas
- Rectangular Microstrip (Patch) Antennas
- Planar Inverted-F Antennas (PIFA)
- Reflector Antennas
- Corner Reflector
- Parabolic Reflector (Dish Antenna)
- Travelling Wave Antennas
- Helical Antennas
- Yagi-Uda Antennas
- Spiral Antennas
- Aperture Antennas
- Slot Antenna
- Cavity-Backed Slot Antenna
- Inverted-F Antenna
- Slotted Waveguide Antenna
- Horn Antenna
- Vivaldi Antenna

The most popular microwave antennas:

**Microstrip antenna:**

The Microstrip Patch Antenna is a single-layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part). In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.
Having a relative dielectric constant in the range of 1.0–2.0. This type of material can be air, polystyrene foam, or dielectric honeycomb.

Having $\varepsilon_r$ in the range of 2.0–4.0 with material consisting mostly of fiberglass reinforced Teflon. With a between 4 and 10. The material can consist of ceramic, quartz, or alumina.

Types of microstrip antennas

![Diagram of microstrip antennas]

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

**Advantages:** are given below

Light weight and low volume.
Low profile planar configuration which can be easily made conformal to host surface.
Low fabrication cost, hence can be manufactured in large quantities.
Supports both, linear as well as circular polarization.
Can be easily integrated with microwave integrated circuits (MICs).
Capable of dual and triple frequency operations.

**Disadvantages:** are given below
- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

**Paraboloid or microwave dish:**

**Principle of Operation**

The standard definition of a parabola is - Locus of a point, which moves in such a way that its distance from the fixed point (called **focus**) plus its distance from a straight line (called **directrix**) is constant.

The following figure shows the geometry of parabolic reflector. The point **F** is the focus (feed is given) and **V** is the vertex. The line joining **F** and **V** is the axis of symmetry. **PQ** are the reflected rays where **L** represents the line directrix on which the reflected points lie (to say that they are being collinear). Hence, as per the above definition, the distance between **F** and **L** lie constant with respect to the waves being focussed.

The reflected wave forms a collimated wave front, out of the parabolic shape. The ratio of focal length to aperture size (i.e. \( f/D \)) known as “**f over D ratio**” is an important parameter of parabolic reflector. Its value varies from **0.25 to 0.50**.
The law of reflection states that the angle of incidence and the angle of reflection are equal. This law when used along with a parabola, helps the beam focus. The shape of the parabola when used for the purpose of reflection of waves, exhibits some properties of the parabola, which are helpful for building an antenna, using the waves reflected

**Properties of Parabola**
- All the waves originating from focus, reflects back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.
- As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.
- Following these points, the parabolic reflectors help in producing high directivity with narrower beam width.

The gain of the paraboloid is a function of aperture ratio ($\frac{D}{\lambda}$). The Effective Radiated Power (ERP) of an antenna is the multiplication of the input power fed to the antenna and its power gain.

**Lens antenna:**

The frequency range of usage of lens antenna starts at **1000 MHz** but its use is greater at **3000 MHz and above**. To have a better understanding of the lens antenna, the working principle of a lens has to be known. A normal glass lens works on the principle of refraction.

**Construction & Working of Lens Antenna**

If a light source is assumed to be present at a focal point of a lens, which is at a focal distance from the lens, then the rays get through the lens as collimated or parallel rays on the plane wavefront.

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The rays that pass through the center of the lens are less refracted than the rays that pass through the edges of the lens. All of the rays are sent in parallel to the plane wave front. This phenomenon of lens is called as **divergence**.

The same procedure gets reversed if a light beam is sent from right side to left of the same lens. Then the beam gets refracted and meets at a point called focal point, at a focal distance from the lens. This phenomenon is called **convergence**.

The same can be better understood by observing the following diagram-

![Diagram of diverging and converging lens](image)

The ray diagram represents the focal point and focal length from the source to the lens.

The parallel rays obtained are also called as collimated rays. In the above figure, the source at the focal point, at a focal distance from the lens, gets collimated in the plane wave front. This phenomenon can be reversed which means the light if sent from the left side, gets converged at the right side of the lens.

It is because of this reciprocity, the lens can be used as an antenna, as the same phenomenon helps in utilizing the same antenna for both transmission and reception.

To achieve the focusing properties at higher frequencies, the refractive index should be less than unity. Whatever may be the refractive index, the purpose of lens is to straighten the waveform. Based on this, the E-plane and H-plane lens are developed, which also delay or speed up the wave front.

**Types of Lens Antennas**

The following types of Lens Antennas are available-

- Di-electric lens or H-plane metal plate lens or Delay lens (Travelling waves are delayed by lens media)
- E-plane metal plate lens
- Non-metallic di-electric type lens
- Metallic or artificial dielectric type of lens

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Advantages
The following are the advantages of Lens antenna-

- In lens antennas, feed and feed support, do not obstruct the aperture.
- It has greater design tolerance.
- Larger amount of wave, than a parabolic reflector, can be handled.
- Beam can be moved angularly with respect to the axis.

Disadvantages
The following are the disadvantages of Lens antenna-

- Lenses are heavy and bulky, especially at lower frequencies
- Complexity in design
- Costlier compared to reflectors, for the same specifications

Applications

The following are the applications of Lens antenna

- Used as wide band antenna

Especially used for Microwave frequency applications