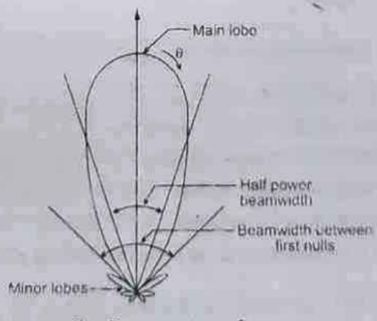
Total No. of Questions: 4] [Total No. of Pages : 11

P9139

Oct-22/BE/Insem-S-90
B.E. (E & TC)
RADIATION AND MICROWAVE THEORY
(2019 Pattern) (Semester - VII) (404181)
Solution and Scheme of Marking

Que. No.			Marks
Q1.	a)	Calculate the power density reaching the moon's surface from 1MW pulse transmitter located on the earth. The antenna gain is 55 db. The distance between the moon and earth 4,00,000km.	[04]
		Given $P_T = 1MW = 1\times10^6 W$, $G_T = 55db$. $G_T(db) = 10\log_{10} G_T$ $55 = 10\log_{10} G_T$. $G_T = \text{Anti}\log 5.5 = 0.3162\times10^6$. $r = 4,00,000km = 400\times10^6 m$. $W_D = P_T G_T / 4\pi r^2$ $= 1\times10^6 \times 0.3162\times10^6 / 4\pi(400\times10^6)^2$. $\boxed{W_D = 0.15734 \mu Watt}$	2m 2m
	b)	Explain the following characteristics of antenna in detail: i. Radiation Pattern, ii. Efficiency	[05]
		The radiation pattern of the antenna consists of three dimensional quantities involving variation of power which is proportional to the square of field as a function of spherical co-ordinates θ and ϕ as shown in below Fig. The pattern parameters are half power beamwidth and beamwidth between first nulls.  Fig.: Power pattern of antenna • Power pattern can be expressed in terms of the power per unit area [or Poynting vector P(θ, ϕ)]. The normalized power pattern is obtained by normalizing this power with respect to its maximum value, which is a function of angle and dimensionless number with a maximum value of unity. Normalized power pattern = $P_n(\theta, \phi)$	1m 1m 0.5m

P.T.O.

$$= \frac{P(\theta,\phi)}{P(\theta,\phi)_{max}} \text{ (dimensionless)} \quad \ldots (1)$$

where, $P(\theta,\phi) = \frac{E_\theta^2(\theta,\phi) + E_\phi^2(\theta,\phi)}{\eta} \cdot r^2$

$P(\theta,\phi)$ = Radiation intensity, W/m^2

$E_\theta(\theta,\phi)$ = θ component of E, V_{rms}/m

$E_\phi(\theta,\phi)$ = ϕ component of E, V_{rms}/m

η = Characteristic impedance of space, $377\ \Omega$

r = Distance from antenna to point of measurement, m

From equation (1.7), decibel level is given by,

$$dB = 10 \log_{10} P_n(\theta,\phi)$$

Efficiency:

for perfectly matched antenna

2.5m

$e_0 = e_c e_c e_d = e_{cd}\, e_r = (1-|\Gamma|^2) \cdot e_{cd} \cdot$ $\boxed{e_0 = e_{cd}}$

$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$.

c) Explain in details the radiation mechanism of antenna with suitable diagram. [06]

Antenna is a device which converts electromagnetic wave into RF current or vice-versa. Thus, antenna is called as a transducer. Antenna is a structure associated with the region of transition between a guided wave and a free space wave, or vice-versa.

- The basic principle of the antenna that radiation is produced by the accelerated (or decelerated) charge. The basic equation of the radiation can be expressed as,

$$L\frac{dI}{dt} = Q\frac{dv}{dt} \quad \ldots (1.23)$$

where, L = Length of the current element, m

$\frac{dI}{dt}$ = Time changing current, A/s

Q = Charge, C

$\frac{dv}{dt}$ = Time change of velocity, m/s^2

- The time change of velocity which equals the acceleration of the charge Therefore, from the equation which states that time changing current radiates and accelerated charge radiates. In steady-state harmonic variation, we generally consider current and in transient or pulse we generally consider charge.
- Therefore, we can say that radiation is perpendicular to the acceleration and the radiated power is proportional to the square of $L\frac{dI}{dt}$ or $Q\frac{dv}{dt}$.
- Let us consider a two-wire transmission line connected with a transmitter as shown in Fig. 1.12. The energy is guided as a plane transverse electromagnetic mode wave with little loss along the uniform part of the

line. The spacing between the wires is assumed to be a small fraction of wavelength and the transmission line further opens out in a tappered transition.

- At the tappered end, the wave tends to be radiated therefore the opened outline act as an antenna which launches a free space wave. The current on the transmission line flow out on the antenna and the field associated with them keep on going.
- The transmitting antenna which is a region of transition from a guided wave on a transmission line to a free space wave and the receiving antenna is a region of transition from a space wave to a guided wave on a transmission line as shown in below Fig.
- It is seen that a resistance coupled from space to the antenna terminals is called as radiation resistance (R_r). In the transmitting case, the radiated power is absorbed by objects at a distance trees, buildings, the ground, the sky and the other antenna.
- However, in receiving case, passive radiation from distant objects or active radiation from other antennas raises the apparent temperature of R. Both the radiation resistance R_r and its temperature T_A are simple scalar quantities.

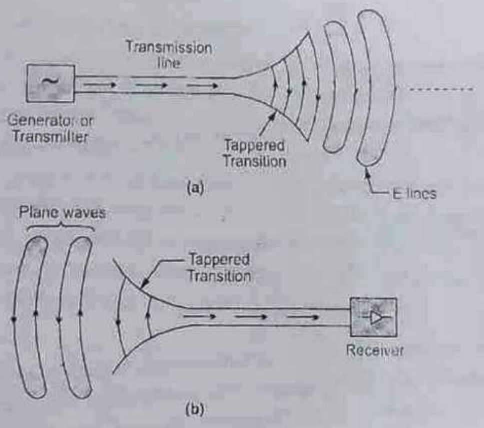


Fig.: (a) Transmitting Antenna, (b) Receiving Antenna

OR

Q2.	a)	Derive the fundamental equation for free space propagation.	[04]

For fundamental equation for free space propagation or transmission, first of all assume average power (W_T) radiated equally in all directions (Isotropically). Then assume that the isotropic radiator is kept in a free space (homogeneous, non-absorbing medium of unity dielectric constant). When this radiations spread spherically then at a distance (r) from the source the power density (power per unit area) is given by

$$P_r = \frac{W_T}{4\pi d^2} \text{ (W/m}^2\text{)} \quad \dots (1)$$

where, $4\pi d^4$ represents surface area of sphere of radius (d) centered at the source.

- As all antennas have directional properties i.e. they radiate more power in one direction and less in the other direction, the directivity gain is defined as "the ratio of actual power density along the main axis of the radiation of antenna to that which would be produced by isotropic antenna at same distance fed with the same input power".

Thus, $$G_T = \frac{P_{D(test\ antenna)}}{P_{(isotropic\ antenna)}} \quad ...(2)$$

Hence $$\boxed{P_D = G_T \ P_i = \frac{G_T W_T}{4\pi d^2}} \quad ...(3)$$

- Now, assume that the receiving antenna is positioned so as to collect the maximum power. The effective aperture area (A_e) of receiving antenna receives a power (W_R) so that

$$\boxed{W_R = P_D \ Ae = \frac{G_T W_T A_e}{4\pi d^2}} \quad (4)$$

This is known as friis transmission equation.

- But for any antenna maximum directivity gain (G) and effective aperture area (Ae) is related by

$$G = \frac{4\pi}{\lambda^2} \cdot A_e$$

or $$\frac{A_e}{G} = \frac{\lambda^2}{4\pi} \quad ...(5)$$

If G_R is the maximum directivity gain of receiving antenna then

$$\boxed{A_e = G_R \frac{\lambda^2}{4\pi}} \quad ...(6)$$

From equation (1.12) and (1.14) we have

$$\boxed{\frac{W_R}{W_T} = \frac{G_T G_R}{4\pi d^2}\left(\frac{\lambda^2}{4\pi}\right)} \text{ (Watts)} \quad ...(7)$$

- Above equation (1.15) is the fundamental equation for the free space propagation (or transmission). This equation is also called FRITS FREE SPACE equation in S.I. unit for antenna in a loss free medium.

In alternative form it is also given by :

$$\boxed{\frac{W_R}{W_T} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2}$$

or $$\boxed{W_R = W_T \frac{G_T G_R}{\left(\frac{4\pi d}{\lambda}\right)^2}} \quad ...(8)$$

where, W_T : Radiated power (Watts)

W_R : Received power (Watts).

G_T : Maximum directivity gain of transmitting antenna

G_R : Maximum directivity gain of receiving antenna.

λ : Wavelength (in meters) = $\frac{f}{c}$.

d : Distance (meters)

b) The radiation resistance of an antenna is 72Ω and loss resistance is 8Ω. Calculate directivity in db if power gain is 16 [05]

$R_r = 72\Omega,\ R_1 = 8\Omega,\ G_p = 16,\ D = ?$

$\eta = \frac{R_r}{R_r + R_L} = \frac{72}{72+8} = 0.9 = 90\%$ — 1m

$D = G/\eta = 17.77$ — 2m

$D(db) = 10\log_{10} D$, $\boxed{D(db) = 12.497 dB}$ — 2m

c) Enlist the different types of antennas. Explain any two types in detail [06]

Antenna can be divided into four basic types from their operating frequency. From this performance parameter i.e. frequency, we can determine type of antenna

1. Electrically small antenna
2. Resonant antenna
3. Broadband antennas
4. Aperture antennas

1. Electrically Small Antenna

- It has small wavelength. Its size is smaller than the wavelength. Its structure is simple as shown in below Fig. Its properties are not sensitive to construction details. These small antennas are operating well at a single or selected narrow frequency bands.
- Radiation pattern of small antennas is nearly omni-directional in horizontal plane. Gain of small antenna is low to moderate. It operates at narrow bandwidth. Disadvantages of this small antennas are low input resistance and high input reactance. These antennas are inefficient because of ohmic losses on the structure.

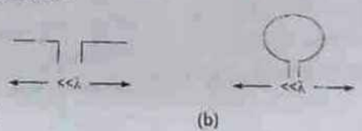


Fig.: Electrically Small Antenna

2. Resonant Antenna :

- These types of antenna has simple structure with good input impedance. Resonant antennas are popular at narrowband of frequencies applications. Its radiation pattern has a broad main beam and low or moderate gain.
- Resonant antennas are operate at a single or selected narrow frequency bands. The half wavelength dipole, microstrip patch, yagi are examples of resonant antennas as shown in below Fig

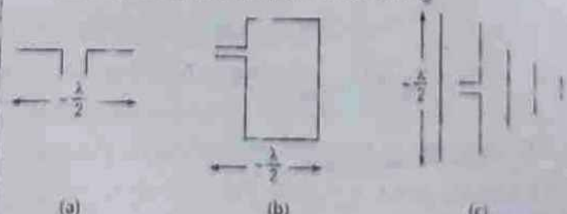


Fig.: Resonant antennas

3. Broadband Antennas :

- These antennas are operated over a wide range of frequencies. A broadband antenna performance can be measured with parameters like pattern, gain and impedance. These antennas are characterized by an active region, where most of the power is radiated. The broadband antenna which has circular geometry as an active region produces circular polarization.
- A broadband antenna made-up of linear elements has an active regions where these elements are about a half wavelength produces linearly polarized radiation. A broadband antenna has low to moderate gain due to their radiation pattern particular at direction. It has wide bandwidth. Example of broadband antennas are spiral and log periodic dipole array as shown in below Fig.

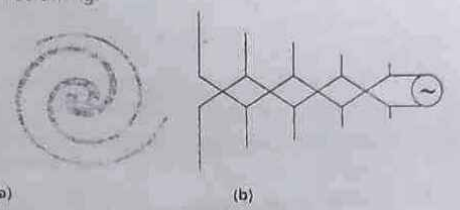


Fig.: Broadband antenna

4. Aperture Antennas :

- Aperture antennas have opening called aperture due to this structure its propagate electromagnetic wave in space. The sizes of the aperture is several wavelength long in one or more direction.
- Example of aperture antenna is horn antenna, its structure is looks like funnel, directing the waves into the connecting transmission line such as waveguide.
- The radiation pattern of aperture antenna has narrow main beam which result in high gain. The pattern will be narrow with increasing frequency for a fixed aperture size. Examples of aperture antennas are Horn antenna and reflector as shown in below Fig. These antennas has moderate bandwidth.

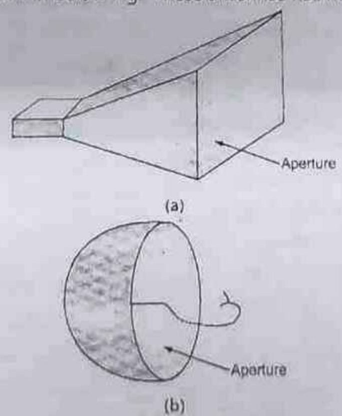


Fig.: Aperture antenna

Q3.	a)	Give the comparison between co-axial cable and waveguide	[04]

Waveguide	Coaxial Cable

1.Waveguide transmits frequency above cut off frequency so acts as a high pass filter	1.Coaxial Cable transmits all frequencies hence acts as a all pass filter
2.It is one conductor transmission line.	2. It is a two-conductor transmission line.
3.Electric and magnetic field lines are confined through waveguide hence there is no power loss.	3. Electric and magnetic field lines are confined to outer cable through inner conductor hence there is power loss.
4.Waveguide does not support TEM wave	4.TEM wave exist in the Coaxial Cable
5. EM energy propagate through waveguide in the form of TE and TM mode	5. EM energy propagate through coaxial cable in the form of TEM mode
6. Power handling capability of waveguide is better	6. Coaxial Cable is suitable for low power transmission.

b) What are micro waves. Enlighten on advantages and applications of microwave. [05]

Advantages of Microwave :

The important characteristic of microwaves frequencies are shorter wavelength and higher frequencies which prompts the various advantages as follows.

- **Wide Bandwidth :** In electromagnetic spectrum the microwave operates at higher frequency. Due to high frequency operation, wider bandwidth is realize that provides more information carrying capacity. Therefore more channels with more data bits can be sent which result in low cost operation.
- **Improved Gain / Directive Properties :** The radiated power and the gain/ directivity of an antenna are inversely proportional to wavelength. Hence at high frequency, the resultant wavelength is very small which gives antenna gain/ directivity very large. The high gain antenna produces narrow beam radiation pattern which results in narrow beam width.
- **Low Power Requirement :** Small wavelength provides narrow beam width and high gain/directivity which allows microwave energy to be concentrated in small area that make low power requirement for transmitter or receiver.
- **Small Antenna Size :** The size of an antenna is proportional to the operating wavelength. At microwave frequency the wavelength is small which reduces the size of antenna.

c) What is cavity resonator. Explain re-entrant type of cavity resonator. [06]

When one end of the waveguide is terminated in a shorting plate there will be reflections and hence standing waves as shown in Fig. 2.9. When another shorting plate is kept at a distance of **"Multiple of $\lambda_g/2$"** then the hollow space so formed can support a signal which bounces back and forth between the two shorting plates. This results in a resonance and hence hollow space is called cavity and hence resonator as **"Cavity Resonator"**

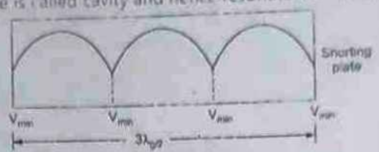


Fig.: Standing waves

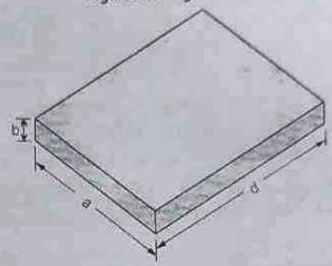


Fig. 2.10 : Rectangular cavity resonator

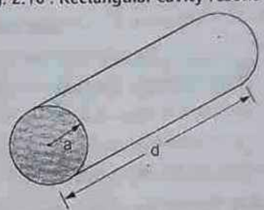


Fig. 2.11 : Circular cavity resonator

- In microwave applications, the commonly used cavity resonators are :
  - Rectangular cavity resonator.
  - Circular cavity resonator
  - Re-entrant cavity resonator.
- Rectangular and circular cavity waveguides are shown in Fig. 2.10 and Fig. 2.11 respectively. Just like a parallel resonator circuit, cavity resonator can resonate at only one particular frequency.
- In Fig. 2.11, $d = \frac{3\lambda_g}{2}$ for a given resonator and mode a, b, m and n are constants. Therefore, λ_c (cut-off wavelength) is also fixed and λ_o (free space wavelength) will also have a fixed value. But, $\lambda_o = \frac{c}{f_o}$ and f will also have a constant value equal to f_o, which is a resonant frequency of cavity resonator.
- In rectangular cavity resonator, resonant frequency is same for both TE and TM mode and given as,

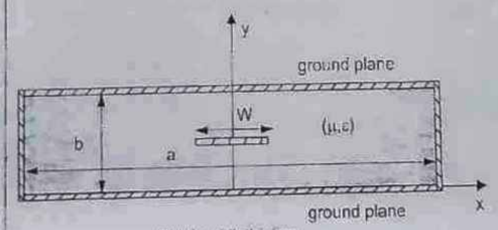
$$f_o = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2\right]^{1/2}$$

		$$f_c = \frac{c}{2}\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2\right]^{1/2}$$ where, m = Number of half wave variation in X direction; n = Number of half wave variation in Y direction; P= Number of half wave variation in Z direction	
		OR	
Q4.	a)	Give the comparison between TE Mode and TM Mode.	[04]

TE Mode	TM Mode
1. In TE mode, TE_{10} is dominant mode.	1. In TM mode, TM_{11} is dominant mode.
2. Wave impedance for TE mode. $Z_{TE} = \frac{\eta}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$	2. Wave impedance TM mode. $Z_{TM} = \eta\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$
3. Attenuation in waveguide for TE_{mn} is $\alpha_g = \frac{\alpha}{\sqrt{1-(\lambda_0/\lambda_c)^2}}$	3. Attenuation in waveguide for TM_{mn} is $\alpha_g = \alpha\sqrt{1-(\lambda_0/\lambda_c)^2}$

	b)	Explain the Structural details, types and applications of Striplines.	[05]

To analyse the stripline, consider a shielded stripline configuration as shown in Fig. In stripline configuration, assume that a is large in comparison to W. The shielded stripline configuration can support the pure TEM mode if it is totally enclosed. The characteristic impedance of this structure can be obtained by an analytical expression for the per-unit length capacitance can be found.



Shielded llstlripline

In general, the characteristic impedance of the transmission line is given by

$$Z_0 = \sqrt{\frac{L}{C}}$$

The phase velocity within the shielded stripline is obtained using

$$v_p = \frac{1}{\sqrt{\mu_0\epsilon_0\epsilon_r}} = \frac{c}{\sqrt{\epsilon_r}} = \frac{1}{\sqrt{LC}}$$

Therefore, characteristic impedance can be written as

$$Z_0 = \sqrt{\frac{L}{C}} = \frac{\sqrt{LC}}{C} = \frac{1}{v_pC}$$

		To determine shielded stripline capacitance, consider that the dielectric within the stripline is lossless and the thickness of the center conductor is zero. The characteristic impedance can be written as $$Z0 = \frac{30p}{\sqrt{er}} \frac{K(k)}{K(k')}$$ Where, K is the elliptic integral $k = \text{sech}\left(\frac{pW}{2b}\right) \quad k' = \tanh\left(\frac{pW}{2b}\right)$ Apply curve fit, we get $$Z0 = \frac{30p}{\sqrt{er}} \frac{1}{\left(\frac{We}{b}\right) + 0.441}$$ where, We is the effective width of the center conductor $$\frac{We}{b} = \begin{cases} \frac{W}{b} & \frac{W}{b} > 0.35 \\ \frac{W}{b} - \left(0.35 - \frac{W}{b}\right)^2 & \frac{W}{b} < 0.35 \end{cases}$$ In stripline design, characteristic impedance is We/b. Therefore, We can be written as $$\frac{W}{b} = \begin{cases} \frac{30p}{\sqrt{er}Zo} - 0.441 & \sqrt{er}Z0 < 120 \\ 0.85 - \sqrt{1.041 - \frac{30p}{\sqrt{er}Zo}} & \sqrt{er}Z0 > 120 \end{cases}$$ The attenuation constant in a stripline (with a center conductor of thickness t) occur due to conductor losses. It can be written as $$\alpha c = \begin{cases} \frac{90RserZoA}{p(b-t)} & \sqrt{er}Zo < 120 \\ \frac{0.16RsB}{Z0b} & \sqrt{er}Z0 > 120 \end{cases}$$ where $$A = 1 + \frac{2W}{b-t} + \frac{1}{p}\frac{b+t}{b-t}\ln\left(\frac{2b-t}{t}\right)$$ $$B = 1 + \frac{b}{0.5W + 0.7t}\left(0.5 + \frac{0.414t}{W} + \frac{1}{2p}\ln\frac{4pW}{t}\right)$$	
	c)	An air-filled rectangular waveguide of dimension 8x4 cm operates in the dominant TE10 mode Find: 1) The cut off frequency 2)Phase velocity at operating frequency of 3.5GHz and 3)Guide Wavelength	[06]
		$a = 8cm = 0.08m$, $b = 4cm = 0.04m$ $m=1, n=0$. i) <u>cut off</u> <u>frequency</u>: for dominant mode $f_c = C/2a = \frac{3\times10^8}{2\times8\times10^{-2}} = 1.8GHz$	(2m)

2) Phase velocity at 3.5 GHz.

$V_p = c / \sqrt{1-(f_c/f)^2} = \frac{3\times10^8}{\sqrt{1-\left(\frac{1.8}{3.5}\right)^2}} = 2.09\times10^8$ m/sec. - 2m

3) Guide Wavelength

$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$ $\lambda_0 = c/f_0 = \frac{3\times10^8}{3.5\times10^9} = 0.089$. - 2m

$\lambda_g = 12.31$ m

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