Birla Institute of Technology & Science, Pilani
First Semester 2023-2024 (Comprehensive Examination)
ECE F314: Electromagnetic Field & Microwave Engineering
Part-A (Closed Book)

Duration: 90 minutes **Total Marks: 50**

Note to Students:
Please write the answers in the answer sheet provided with proper units and signs. Marks will be deducted for improper signs and units.

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1. On the **Smith chart**, the distance between **normalized input impedance** and its **inverted impedance** is ……………………… **[1]**
2. If the **spacing for the antenna array** element **increases**, the **directivity** will …………… (increase/decrease/no effect). **[1]**
3. The numerical values for **S_{24} and S_{31}** elements **of Directional-coupler's** S-matrix are …………………… and ………………………., respectively. **[2]**
4. In an **8-cavity** cylindrical magnetron, the number of spokes generated for **π mode and π/2** modes are ……………… and …………………………., respectively. **[2]**
5. A transmission line has a characteristic impedance of **60 Ω.** It is terminated in a purely resistive load. The minimum and maximum voltage upon it is **6 and 9 μV**, respectively. Calculate the value of load impedance. **[2]**
6. Can the **reflected and transmitted E field** be greater than the incident E field on the media interface? Give your answer with a valid explanation. **[2]**
7. Write **Maxwell's equation derived from Ampere's Circuital Law** (differential and integral form) **in a lossless/non-conducing medium** for time-varying fields. **[2]**
8. A **10 GHz** aircraft uses a narrow beam scanning antenna mounted behind a dielectric radome. Assuming that the random shape is planar over the narrow extent of the radar beam, find its thickness such that the **radome appears to be transparent** to the radar beam. Given that the radome is made of **a lossless dielectric material with μ_r =1 and ϵ_r =4.** The mechanical integrity requires the radome thickness to be **greater than 1 inch.** **[2]**
9. One night, **a red LED** is dropped into a freshwater lake containing water with a refractive index of **1.33.** A cameraman from a boat directly above the LED wants to take a few photographs from the air. If the light coming out of the **LED is TM polarized**, is there any angle **θ** for which almost all light from the LED emitted at that angle reaches the camera? **[2]**
10. Describe **completely the nature of the polarization** of the waves. **[2]**
    a) $\vec{E} = \widehat{a_x} E_0 \cos(kz - \omega t) - \widehat{a_y} E_0 \cos(kz - \omega t)$
    b) $\vec{E} = \widehat{a_x} E_0 \cos(kz - \omega t) + \widehat{a_y} E_0 \cos\left(kz - \omega t + \frac{\pi}{2}\right)$
11. In a **parallel plate waveguide**, the electromagnetic energy travels through the multiple reflections of the plane wave. One such waveguide with a width of **50 cm** supports the EM waves at **1GHz**. At what angles does the plane wave have sustained propagations? **[2]**

12. A tunnel is modeled as **an air-filled metallic rectangular waveguide** with dimensions **a = 8m and b =16 m.** Determine whether the tunnel will pass (a) **a 1.5MHz AM broadcast signal** and (b) a **120 MHz FM broadcast signal.** **[2]**
13. A GaAs Gunn diode has an active **region of 5 µm**. If the electron drift velocity is **0.5 X 10^5 m/s**, calculate **the natural frequency and threshold voltage** if the critical electric field is **3kV/cm**.**[2]**
14. The **effective area of** a parabolic dish antenna is approximately **equal to its physical aperture**. If the directivity of a dish antenna is **30 dB at 3 GHz**, its **effective area** is .... **[2]**
15. The power radiated by a lossless antenna is **10 watts**. The directional characteristics of the antenna are represented by the radiation intensity of;

$$P(\theta,\Phi) = B_0 cos^2\theta \; where \; 0 \le \theta \le \frac{\pi}{2} \; and \; 0 \le \Phi \le 2\pi$$

The value of **B_0** is **..................................** **[2]**

16. Find the **angular frequency** of the cylindrical magnetron, which has a magnetic flux density of **0.34 Wb/m^2** and **inner and outer radius of 0.15m and 0.45m**, respectively. **[2]**
17. A resonator needs to be designed for the resonance frequency of **20 GHz** for **TE_{101}** mode. The resonator is formed by the segment of a rectangular waveguide with dimensions **20 mm** and **b =10mm**. The resonator is filled with a medium of **dielectric constant =4.** **[3]**
18. Write down the **S matrix for magic Tee**, assuming **Port 1 and Port 2** represent the **E** and **H** arms, respectively. **[3]**
19. Write an expression in Cartesian coordinates for a harmonic plane wave of **amplitude A** and **angular frequency ω** propagating in free space in the direction of vector **k**, which in turn lies on a **line drawn from the origin to a point (4,2,1).** **[3]**
20. The **magnetic field** associated with a uniform EM wave in free space is given by

$$\vec{H} = \widehat{a_y} H_0 \cos(6\pi * 10^7 t - 0.2\pi z)$$

Find the **time-average power** flow across a surface of **area 1m^2 in the z = 0 plane**. **[3]**

21. Below is the **S** matrix for an **ideal 2 port Isolator** and a **lossy transmission line**, respectively. What are the values of **p, q, r, s and t, u, v and w**? **[4]**

$S_{isolator} = \begin{bmatrix} p & q \\ r & s \end{bmatrix}$ $\qquad$ $S_{trans\text{-}line} = \begin{bmatrix} t & u \\ v & w \end{bmatrix}$

22. A **two-cavity Klystron amplifier** has the following parameters:
DC voltage for acceleration of electron = **1000 V, f = 3GHz, gap spacing in either cavity= 1mm,** and **spacing between the two cavities = 4cm**. Calculate the **transit angle in the gap** and between the **cavities.** **[4]**

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1. A uniform plane wave of frequency **50 MHz** is propagating in a material medium, and it is found that the waves get attenuated by a factor of **1/e** after propagating through a distance of **28.65 m** in the medium. It is also found that the field undergoes a phase change of **2π** after propagating through a distance of **111.2** m. The ratio of the amplitudes of electric to magnetic field at a point in the medium is **59.4**. Find the **complex propagation constant**, **complex intrinsic impedance**, **conductivity**, **permittivity**, and **permeability** of the medium. **[5]**

2. A uniform plane wave having an electric field

$$\overrightarrow{E_{inc}} = E_0(a_x - a_z)\cos[6\pi * 10^8 t - \sqrt{2}\pi(x + z)]$$

Is incident on the interface between free space and a dielectric medium at an angle of incidence of **45°** with **ε=1.5 ε_0** and **μ= μ_0.** Find the magnitude and complete expression for the transmitted wave. **[6]**

3. An air-filled **a x b (a=2.5b)** rectangular waveguide to be constructed to operate at **3 GHz** in the dominant mode. We desire the frequency to be at least **20%** higher than the operating frequency of the dominant mode and also at least **20%** lower than the next higher-order mode. **[6]**
   a) Give the typical design for dimensions **a and b.**
   b) Calculate **phase constant**, **phase velocity,** and **guide wavelength** at the operating frequency.

4. A rectangular waveguide with dimensions **a = 4 cm and b =2 cm** is filled with air and operates at **18GHz.** The electric field inside the waveguide is characterized by

$$\overrightarrow{E_z} = 20\sin(50\pi x)\sin(100\pi y)e^{-j\beta z}$$

What **mode** is propagating inside the waveguide? Find **its cut-off frequency and phase velocity**. Draw the **field pattern** for the propagating mode in the waveguide. **[7]**

5. Consider a transmission line of characteristic impedance **Zo = 50Ω** terminated by a load impedance **Z_L = 30-j40 Ω.** It is desired to solve the double stub (short-circuited) matching problem using the Smith chart, assuming the **Zo** for both stubs to be **50 Ω.** The first stub is to be located at the load, and the distance between both stubs is equal to **3λ/8.** **[8]**

6. The maximum radar cross-section of a resonant linear **λ/2 dipole** is approximately **$0.85\lambda^2$**. For a monostatic system (i.e., transmitter and receiver at the same location), find the **received power (in W)** if the transmitted power is **100 W**, the distance of the dipole from the transmitting and receiving antennas is **100 m**, the gain of the transmitting and receiving antennas is **15 dB** each, and the frequency of operation is **3 GHz**. Assume a polarization loss factor of **−1 dB.** **[8]**