Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2022/2023

COURSE NAME	:	ELECTROMAGNETIC WAVES PROPAGATION
COURSE CODE	:	BEJ31103
PROGRAMME CODE	:	BEJ
EXAMINATION DATE	:	FEBRUARY 2023
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS. 2. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.** 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

Q1 (a) Name **FOUR (4)** transmission line parameters.

(4 marks)

(b) A transmission line with the characteristic impedance of 50 Ω operating at 250 MHz is terminated by (120 + j40) Ω load impedance.

(i) Show by calculation that the line is not matched.

(6 marks)

(ii) Short-circuited stub matching technique is used to match the line. Using the Smith chart, find the distance of the stub from the load, and the length of the stub.

(11 marks)

(iii) Sketch the transmission line after the short-circuited stub has been added. Label all relevant parameters.

(4 marks)

Q2 (a) Describe the differences between waveguide and the cavity.

(6 marks)

(b) An air-filled waveguide with dimensions 5 cm × 4 cm operating at 10 GHz has:

$$H_z = 20\cos(60\pi x)\cos(25\pi y)e^{-j\beta z}\ A/m$$

Determine:

(i) the propagation constant for the propagation case, and

(7 marks)

(ii) the wave impedance.

(4 marks)

(c) An air-filled rectangular cavity with the width, *a*, height, *b*, and depth, *d* has the resonant frequency of 6 GHz for the TM's lowest mode. Find *a*, *b*, and *d* by taking into consideration that $a = 4b = 2d$. Note that $a > b < d$.

(8 marks)

Q3 A transmission line with the characteristic impedance of 75 Ω is connected to a half-wave dipole antenna at the transmitting station. The length of the transmission line is 2 m. The system is operating at 100 MHz. The distance between the transmitter and receiver is 14 km. The half-wave dipole is made of copper and has a diameter of 4 mm. A magnetic field strength of 15 μA/m is measured at a point of $\theta = \pi/2$ at the receiver site. There is a building with a height of 10 m located 7 km away from the transmitter. Transmit and receive antennas are reciprocal.
Copper: $\mu_c = \mu_0$ and $\sigma_c = 5.8 \times 10^7$ S/m.

(a) Sketch the scenario for the communication system described above.
(2 marks)

(b) Calculate the length of the half-wave dipole in meters.
(2 marks)

(c) Calculate the antenna's efficiency (in %).
(4 marks)

(d) Calculate the antenna's radiated power (in dBm).
(5 marks)

(e) Calculate the antenna's transmit power (in dBm).
(2 marks)

(f) Calculate the antenna's Effective Isotropic Radiated Power (EIRP) (in dBm).
(4 marks)

(g) Calculate the power density at the receiver site.
(4 marks)

(h) Calculate the antenna's received power (in dBm) at the receiver site.
(4 marks)

(i) Calculate the first Fresnel clearance zone.
(4 marks)

(j) With an aid of a suitable diagram, illustrate your answer in part **Q3 (i)**.
(3 marks)

(k) Based on your understanding of the Fresnel zone, explain the effect of the building present between the transmitter and the receiver on the quality of the system, and suggest ways to improve the system quality.

(6 marks)

(l) Calculate the free space path loss (in dB) for the system.

(2 marks)

(m) Identify the suitable radio wave propagation mode for the system.

(4 marks)

(n) Conclude what you have learned from your answers in **Q3 (a) – (m)**.

(4 marks)

- END OF QUESTIONS -

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Table 1: Transmission line parameters

Parameter	Coaxial	Two-Wire	Parallel-Plate
R' (Ω/m)	$\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$	$\frac{2R_s}{\pi d}$	$\frac{2R_s}{w}$
L' (H/m)	$\frac{\mu}{2\pi}\ln\left(\frac{b}{a}\right)$	$\frac{\mu}{\pi}\ln\left[\left(\frac{D}{d}\right)+\sqrt{\left(\frac{D}{d}\right)^2-1}\right]$	$\frac{\mu h}{w}$
G' (S/m)	$\frac{2\pi\sigma}{\ln\left(\frac{b}{a}\right)}$	$\frac{\pi\sigma}{\ln\left[\left(\frac{D}{d}\right)+\sqrt{\left(\frac{D}{d}\right)^2-1}\right]}$	$\frac{\sigma w}{h}$
C' (F/m)	$\frac{2\pi\varepsilon}{\ln\left(\frac{b}{a}\right)}$	$\frac{\pi\varepsilon}{\ln\left[\left(\frac{D}{d}\right)+\sqrt{\left(\frac{D}{d}\right)^2-1}\right]}$	$\frac{\varepsilon w}{h}$
where $R_s=\sqrt{\frac{\pi f\mu_c}{\sigma_c}}$			

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Table 2: Wave properties for TE and TM modes

TE mode	**TM mode**
$\tilde{E}_x = \frac{j\omega\mu}{k_c^2}\left(\frac{n\pi}{b}\right) H_0 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$	$\tilde{E}_x = \frac{-j\beta}{k_c^2}\left(\frac{m\pi}{a}\right) E_0 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$
$\tilde{E}_y = \frac{-j\omega\mu}{k_c^2}\left(\frac{m\pi}{a}\right) H_0 \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$	$\tilde{E}_y = \frac{-j\beta}{k_c^2}\left(\frac{n\pi}{b}\right) E_0 \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$
$\tilde{E}_z = 0$	$\tilde{E}_z = E_0 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$
$\tilde{H}_x = \frac{j\beta}{k_c^2}\left(\frac{m\pi}{a}\right) H_0 \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$	$\tilde{H}_x = \frac{j\omega\varepsilon}{k_c^2}\left(\frac{n\pi}{b}\right) E_0 \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$
$\tilde{H}_y = \frac{j\beta}{k_c^2}\left(\frac{n\pi}{b}\right) H_0 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$	$\tilde{H}_y = \frac{-j\omega\varepsilon}{k_c^2}\left(\frac{m\pi}{a}\right) E_0 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$
$\tilde{H}_z = H_0 \cos\left(\frac{m\pi x}{a}\right) \cos\left(\frac{n\pi y}{b}\right) e^{-j\beta z}$	$\tilde{H}_z = 0$
$Z_{TE} = \frac{\tilde{E}_x}{\tilde{H}_y} = -\frac{\tilde{E}_y}{\tilde{H}_x} = \frac{\eta}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$	$Z_{TM} = \frac{\tilde{E}_x}{\tilde{H}_y} = -\frac{\tilde{E}_y}{\tilde{H}_x} = \eta\sqrt{1-\left(\frac{f_c}{f}\right)^2}$
Properties common to TE and TM modes	

$$f_c = \frac{u_{p0}}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}, \text{ where } u_{p0} = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$\beta = \frac{\omega}{u_{p0}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

$$u_p = \frac{\omega}{\beta} = \frac{u_{p0}}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

$$u_g = \frac{1}{d\beta/d\omega} = u_{p0}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

$$k_c^2 = k^2 - \beta^2 = \omega^2\mu\varepsilon - \beta^2$$

$$\eta = \sqrt{\frac{\mu}{\varepsilon}}$$

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Table 3 (i): List of equations

$Z_0 = \sqrt{\frac{(R' + j\omega L')}{(G' + j\omega C')}}$	$\beta = \frac{2\pi}{\lambda} = \omega\sqrt{\mu\varepsilon}$
$\gamma = \sqrt{(R' + j\omega L')(G' + j\omega C')}$	$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$
$\text{SWR} = \frac{1 + \lvert\Gamma\rvert}{1 - \lvert\Gamma\rvert}$	$L'C' = \mu\varepsilon$
$u_p = \frac{1}{\sqrt{L'C'}} = \frac{\omega}{\beta}$	$u_p = \frac{G'}{C'} = \frac{\sigma}{\varepsilon}$
$v_f = \frac{1}{\sqrt{\varepsilon_r}}$	$Z_0' = \sqrt{Z_0 Z_L}$
$Z_{in} = Z_0 \left[\frac{Z_L + jZ_0 \tan\beta l}{Z_0 + jZ_L \tan\beta l}\right]$	$Z_{in}^{SC} = Z_{in}\rvert_{Z_L=0} = jZ_0 \tan\beta\, l$
$Z_{in}^{OC} = \frac{Z_0}{j\tan\beta\, l}$	$P_{ave} = \frac{\lvert V_o^+\rvert^2}{2Z_0}(1 - \lvert\Gamma\rvert^2)$
$d_{max} = \frac{\theta_\Gamma \lambda}{4\pi} + \frac{n\lambda}{2}, \begin{cases} n = 1, 2, \ldots & \text{if } \theta_\Gamma < 0 \\ n = 0, 1, 2, \ldots & \text{if } \theta_\Gamma \geq 0 \end{cases}$ $d_{min} = \begin{cases} d_{max} + \frac{\lambda}{4}, & \text{if } d_{max} < \frac{\lambda}{4} \\ d_{max} - \frac{\lambda}{4}, & \text{if } d_{max} \geq \frac{\lambda}{4} \end{cases}$	$P_{ave} = \frac{1}{2}\text{Re}(E_{xs}H_{ys}^* - E_{ys}H_{xs}^*)\mathrm{a}_z$ $= \frac{\lvert E_{xs}\rvert^2 + \lvert E_{ys}\rvert^2}{2\eta}\mathrm{a}_z$ $= \int P_{ave} \cdot dS$ $= \int_{x=0}^{a}\int_{y=0}^{b} \frac{\lvert E_{xs}\rvert^2 + \lvert E_{ys}\rvert^2}{2\eta} dydx$
$Q_{TE101} = \frac{abd(a^2 + d^2)}{\delta[a^3(d + 2b) + d^3(a + 2b)]}$ where $\delta = \frac{1}{\sqrt{\pi f_{101}\mu_o\sigma_c}}$	$f_{mnp} = \frac{u_{p0}}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$

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Table 3 (ii): List of equations

Hertzian dipole

$$\tilde{E}_\theta = \frac{jI_0 lk\eta_0}{4\pi}\left(\frac{e^{-jkR}}{R}\right)\sin\theta$$

$$\tilde{H}_\phi = \frac{\tilde{E}_\theta}{\eta_0}$$

$$G_d(\theta,\phi) = 1.5\sin^2\theta$$

$$R_{rad} = 80\pi^2\left(\frac{l}{\lambda}\right)^2$$

$$P_{rad} = 40\pi^2 {I_0}^2\left(\frac{l}{\lambda}\right)^2$$

$$P_d = \frac{15\pi {I_0}^2}{R^2}\left(\frac{l}{\lambda}\right)^2$$

Half-wave dipole

$$\tilde{E}_\theta = j60I_0\left\{\frac{\cos\left[\left(\frac{\pi}{2}\right)\cos\theta\right]}{\sin\theta}\right\}\left(\frac{e^{-jkR}}{R}\right)$$

$$\tilde{H}_\phi = \frac{\tilde{E}_\theta}{\eta_0}$$

$$G_d(\theta,\phi) = 1.64\frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin^2\theta}$$

$$R_{rad} = 73\,\Omega$$

$$P_{rad} = 36.6{I_0}^2$$

$$P_d = \frac{15{I_0}^2}{\pi R^2}$$

General equations

$$\eta_r = \frac{G_p}{G_d} = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{rad}+R_{loss}}$$

where $R_{loss} = \frac{l}{2\pi a}\sqrt{\frac{\pi f\mu_c}{\sigma_c}}$

$$P_d = \frac{P_{rad}G_d}{4\pi R^2} = \frac{P_{in}G_p}{4\pi R^2} = \frac{|E_s|^2}{2\eta} = \frac{P_T\eta_T A_T}{R^2\lambda^2}$$

$$R_{rad} = \frac{2P_{rad}}{{I_o}^2}$$

$$P_R = \frac{P_T\eta_T A_T\eta_R A_R}{R^2\lambda^2}$$

$$\frac{P_R}{P_T} = G_T G_R\left(\frac{\lambda}{4\pi R}\right)^2$$

$$k = \sqrt{1-\frac{81N}{f^2}}$$

$$f_{crit} = 9\sqrt{N_{max}}$$

$$MUF = \frac{f_{crit}}{\cos\theta_i}$$

$A_e = \frac{3\lambda^2}{8\pi}$ (for short dipole)

$A_e = \frac{\lambda^2}{4\pi}D$ (for any antenna)

$$EIRP = P_{in}G_p = P_{rad}G_d$$

$$L_F = 32.4 + 20\log R_{km} + 20\log f_{MHz}$$

$$d_{km} = \sqrt{2h_{t(m)}} + \sqrt{2h_{r(m)}}$$

$$d_{\max\,(km)} = \sqrt{17h_{t(m)}} + \sqrt{17h_{r(m)}}$$

$$L_{KE}(v) \approx -20\log\frac{1}{\pi v\sqrt{2}} \approx -20\log\frac{0.225}{v}$$

$$v \approx h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2d_1 d_2}{\lambda(d_1+d_2)}}$$

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1+d_2}}$$