THE PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL & COMMUNICATIONS ENGINEERING

FINAL EXAMINATION (2021)

FIRST SEMESTER

EE481 ANTENNNAS AND PROPAGATION

TIME ALLOWED: 2 HOURS & 30 MINUTES

INFORMATION FOR STUDENTS:

1. You have **TEN (10) MINUTES to** read this paper. Do not write during this allocated time
2. There are **Four (4) Questions** in this Exam Booklet. **Answer all Questions**
3. All answers must be written in the **Answer Booklet**
4. **COMPLETE STUDENT DETAILS ARE TO BE FILLED ON THE ANSWER BOOKLET-DO THIS NOW**
5. Only drawing instruments and calculators are allowed on your desk. Textbooks and notebooks are **NOT** allowed
6. If you are found **Cheating** in this Exam, penalties specified by the **University** shall be applied.
7. **TURN OFF** all your mobile phones and place them on the floor under your seat before you start the examination.

QUESTION ONE [TOTAL 10 Marks]

(a) The real instantaneous electric field radiated by an antenna is given by

$$E(z,t) = (E_0/r).\ (\mathrm{Sin}\theta)\ \mathrm{Cos}(\omega t - kr)\ \mathrm{V/m}.$$

Determine the following

(i) the directions of the maximum radiated signals, [2 Marks]
(ii) the half wave beamwidth of the antenna, and [1.5 Marks]
(iii) the directivity of the antenna [1.5 Marks]

(b) The radiation resistance of a thin, lossless linear electric dipole of length $l = 0.6\lambda$ is 120 ohms. What is the input resistance? [3 Marks]

(c) With the aid of the linear (rectangular) power plot, describe the radiation pattern of a half-wave dipole. [2 Marks]

QUESTION 2 [TOTAL 10 Marks]

(a) Rectangular aperture, also known as horn antenna, are widely used as microwave antennas. With the aid of an appropriate diagram describe:
   (i) the E-plane, H-plane and Pyramidal configuration and [1.5 Marks]
   (ii) a use for each type. [1.5 Marks]

(b) For the rectangular aperture in Figure 2.1 below with a = b = 3λ, compute the directivity using a fitting formula from Table 12.1 attached. [2 Marks]

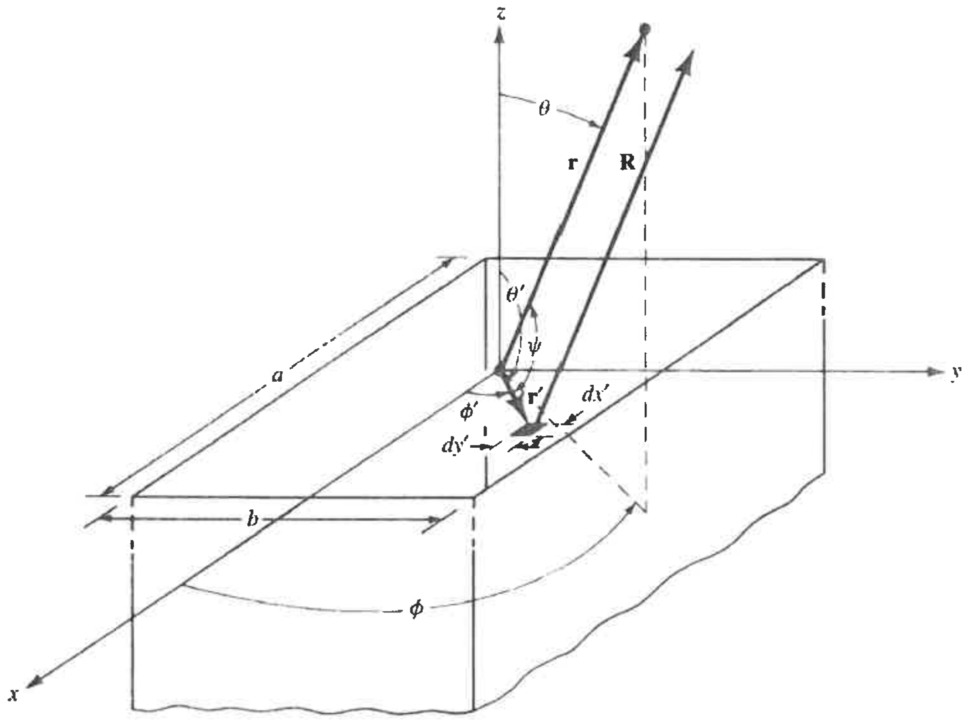


Figure 2.1 Rectangular aperture on an infinite electric ground plate.

(c) Assume that a satellite link is needed to connect remote schools in the country. You are tasked to design the antenna system for the earth stations. Describe three main antenna design considerations when designing an earth station in the rural area. [3 Marks]

QUESTION THREE [TOTAL 10 Marks]

(a) Using the Figure 3.1 below as a guide, derive the Friis equation for the wireless communication system and explain the importance of each term in the design of a communication system.

[4 Marks]

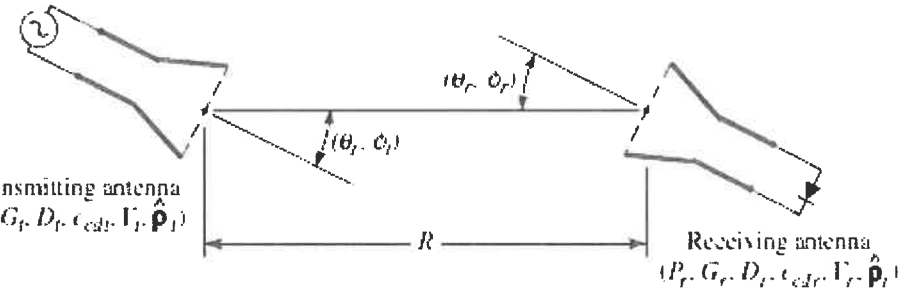


Figure 3.1 Geometrical Orientation of Transmitting and Receiving Antenna

(b) Transmitting and receiving antennas operating at 1 GHz with gains of 20 and 15 dB respectively with matched polarization. If the input power is 150W, find the power delivered to the load at

- i. 1 km [1.5 Marks]
- ii. 3 km [1.5 Marks]

(c) If the input power in (b) is halved and the receiving antenna gain remains the same, what should be the gain of the transmitting antenna to achieve the same power delivered at

- i. 1 km. [1.5 Marks]
- ii. 3 km. [1.5 Marks]

QUESTION FOUR [TOTAL 10 Marks]

(a) A series of microwave repeater links operating at 10 GHz are used to relay television signals into Goroka town that is surrounded by mountain ranges. Each repeater consists of a receiver, transmitter, antennas and associated equipment. The transmitting and receiving antennas are identical horns, each having gain over 15 dBi. The repeaters are separated in distance by 10 km. For acceptable signal-to-noise ratio, the power received at each repeater must be greater than 10 nW. Loss due to polarization mismatch is not expected to exceed 3 dB. Assume matched loads and free space propagation conditions. Determine the minimum transmit power that should be used.

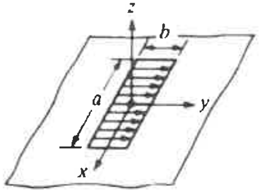
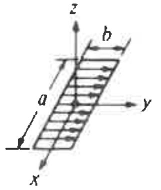
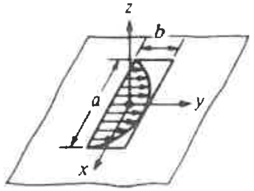
[6 Marks]

(b) Assume that you are designing the antenna system to track miners in an underground mine passage.

i. Describe the main propagation mechanism that will dominate in this propagation environment and it's effect on the performance of the communications system. [2 Marks]

ii. Select an antenna type for this application and describe the two influencing parameters for your antenna of choice. [2 Marks]

TABLE 12.1 Equivalents, Fields, Beamwidths, Side Lobe Levels, and Directivities of Rectangular Apertures

	Uniform Distribution Aperture on Ground Plane	Uniform Distribution Aperture in Free-Space	TE_{10}-Mode Distribution Aperture on Ground Plane
Aperture distribution of tangential components (analytical)	$\mathbf{E}_a = \hat{\mathbf{a}}_y E_0 \left.\begin{matrix} \\ \end{matrix}\right\} \begin{matrix} -a/2 \le x' \le a/2 \\ -b/2 \le y' \le b/2 \end{matrix}$	$\left.\begin{matrix} \mathbf{E}_a = \hat{\mathbf{a}}_y E_0 \\ \mathbf{H}_a = -\hat{\mathbf{a}}_x \dfrac{E_0}{\eta} \end{matrix}\right\} \begin{matrix} -a/2 \le x' \le a/2 \\ -b/2 \le y' \le b/2 \end{matrix}$	$\mathbf{E}_a = \hat{\mathbf{a}}_y E_0 \cos\left(\frac{\pi}{a}x'\right) \left.\begin{matrix} \\ \end{matrix}\right\} \begin{matrix} -a/2 \le x' \le a/2 \\ -b/2 \le y' \le b/2 \end{matrix}$
Aperture distribution of tangential components (graphical)			
Equivalent	$\mathbf{M}_s = \begin{cases} -2\hat{\mathbf{n}} \times \mathbf{E}_a & -a/2 \le x' \le a/2,\ -b/2 \le y' \le b/2 \\ 0 & \text{elsewhere} \end{cases}$ $\mathbf{J}_s = 0 \quad \text{everywhere}$	$\left.\begin{matrix} \mathbf{M}_s = -\hat{\mathbf{n}} \times \mathbf{E}_a \\ \mathbf{J}_s = \hat{\mathbf{n}} \times \mathbf{H}_a \end{matrix}\right\} \begin{matrix} -a/2 \le x' \le a/2 \\ -b/2 \le y' \le b/2 \end{matrix}$ $\mathbf{M}_s \simeq \mathbf{J}_s \simeq 0 \quad \text{elsewhere}$	$\mathbf{M}_s = \begin{cases} -2\hat{\mathbf{n}} \times \mathbf{E}_a & -a/2 \le x' \le a/2,\ -b/2 \le y' \le b/2 \\ 0 & \text{elsewhere} \end{cases}$ $\mathbf{J}_s = 0 \quad \text{everywhere}$
Far-zone fields $X = \dfrac{ka}{2}\sin\theta\cos\phi$ $Y = \dfrac{kb}{2}\sin\theta\sin\phi$ $C = j\dfrac{abkE_0 e^{-jkr}}{2\pi r}$	$E_r = H_r = 0$ $E_\theta = C\sin\phi\dfrac{\sin X}{X}\dfrac{\sin Y}{Y}$ $E_\phi = C\cos\theta\cos\phi\dfrac{\sin X}{X}\dfrac{\sin Y}{Y}$ $H_\theta = -E_\phi/\eta$ $H_\phi = E_\theta/\eta$	$E_r = H_r = 0$ $E_\theta = \dfrac{C}{2}\sin\phi(1+\cos\theta)\dfrac{\sin X}{X}\dfrac{\sin Y}{Y}$ $E_\phi = \dfrac{C}{2}\cos\phi(1+\cos\theta)\dfrac{\sin X}{X}\dfrac{\sin Y}{Y}$ $H_\theta = -E_\phi/\eta$ $H_\phi = E_\theta/\eta$	$E_r = H_r = 0$ $E_\theta = -\dfrac{\pi}{2}C\sin\phi\dfrac{\cos X}{(X)^2 - \left(\frac{\pi}{2}\right)^2}\dfrac{\sin Y}{Y}$ $E_\phi = -\dfrac{\pi}{2}C\cos\theta\cos\phi\dfrac{\cos X}{(X)^2 - \left(\frac{\pi}{2}\right)^2}\dfrac{\sin Y}{Y}$ $H_\theta = -E_\phi/\eta$ $H_\phi = E_\theta/\eta$

Half-power beamwidth (degrees)	*E*-plane $b \gg \lambda$	$\frac{50.8}{b/\lambda}$	$\frac{50.8}{b/\lambda}$	$\frac{50.8}{b/\lambda}$
	H-plane $a \gg \lambda$	$\frac{50.8}{a/\lambda}$	$\frac{50.8}{a/\lambda}$	$\frac{68.8}{a/\lambda}$
First null beamwidth (degrees)	*E*-plane $b \gg \lambda$	$\frac{114.6}{b/\lambda}$	$\frac{114.6}{b/\lambda}$	$\frac{114.6}{b/\lambda}$
	H-plane $a \gg \lambda$	$\frac{114.6}{a/\lambda}$	$\frac{114.6}{a/\lambda}$	$\frac{171.9}{a/\lambda}$
First side lobe max. (to main max.) (dB)	*E*-plane	-13.26	-13.26	-13.26
	H-plane	-13.26 $a \gg \lambda$	-13.26 $a \gg \lambda$	-23 $a \gg \lambda$
Directivity D_0 (dimensionless)		$\frac{4\pi}{\lambda^2}(\text{area}) = 4\pi\left(\frac{ab}{\lambda^2}\right)$	$\frac{4\pi}{\lambda^2}(\text{area}) = 4\pi\left(\frac{ab}{\lambda^2}\right)$	$\frac{8}{\pi^2}\left[4\pi\left(\frac{ab}{\lambda^2}\right)\right] = 0.81\left[4\pi\left(\frac{ab}{\lambda^2}\right)\right]$

TABLE 4.3 Summary of Important Parameters and Associated Formulas and Equation Numbers for a Dipole in the Far Field

Parameter	Formula	Equation Number
	Infinitesimal Dipole $(l \le \lambda/50)$	
Normalized power pattern	$U = (E_{\theta n})^2 = C_0 \sin^2\theta$	(4-29)
Radiation resistance R_r	$R_r = \eta\left(\frac{2\pi}{3}\right)\left(\frac{l}{\lambda}\right)^2 = 80\pi^2\left(\frac{l}{\lambda}\right)^2$	(4-19)
Input resistance R_{in}	$R_{in} = R_r = \eta\left(\frac{2\pi}{3}\right)\left(\frac{l}{\lambda}\right)^2 = 80\pi^2\left(\frac{l}{\lambda}\right)^2$	(4-19)
Wave impedance Z_w	$Z_w = \frac{E_\theta}{H_\phi} \simeq \eta = 377$ ohms	
Directivity D_0	$D_0 = \frac{3}{2} = 1.761$ dB	(4-31)
Maximum effective area A_{em}	$A_{em} = \frac{3\lambda^2}{8\pi}$	(4-32)
Vector effective length ℓ_e	$\boldsymbol{\ell}_e = -\hat{\mathbf{a}}_\theta l \sin\theta$ $\lvert\boldsymbol{\ell}_e\rvert_{\max} = \lambda$	(2-92) Example 4.2
Half-power beamwidth	HPBW = 90°	(4-65)
Loss resistance R_L	$R_L = \frac{l}{P}\sqrt{\frac{\omega\mu_0}{2\sigma}} = \frac{l}{2\pi b}\sqrt{\frac{\omega\mu_0}{2\sigma}}$	(2-90b)
	Small Dipole $(\lambda/50 < l \le \lambda/10)$	
Normalized power pattern	$U = (E_{\theta n})^2 = C_1 \sin^2\theta$	(4-36a)
Radiation resistance R_r	$R_r = 20\pi^2\left(\frac{l}{\lambda}\right)^2$	(4-37)
Input resistance R_{in}	$R_{in} = R_r = 20\pi^2\left(\frac{l}{\lambda}\right)^2$	(4-37)
Wave impedance Z_w	$Z_w = \frac{E_\theta}{H_\phi} \simeq \eta = 377$ ohms	(4-36a), (4-36c)
Directivity D_0	$D_0 = \frac{3}{2} = 1.761$ dB	
Maximum effective area A_{em}	$A_{em} = \frac{3\lambda^2}{8\pi}$	
Vector effective length ℓ_e	$\boldsymbol{\ell}_e = -\hat{\mathbf{a}}_\theta \frac{l}{2} \sin\theta$	(2-92)
	$\lvert\boldsymbol{\ell}_e\rvert_{\max} = \frac{l}{2}$	(4-36a)
Half-power beamwidth	HPBW = 90°	(4-65)
	Half Wavelength Dipole $(l = \lambda/2)$	
Normalized power pattern	$U = (E_{\theta n})^2 = C_2\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]^2 \simeq C_2 \sin^3\theta$	(4-87)
Radiation resistance R_r	$R_r = \frac{\eta}{4\pi} C_{in}(2\pi) \simeq 73$ ohms	(4-93)

(continued overleaf)

TABLE 4.3 *(continued)*

Parameter	Formula	Equation Number
Input resistance R_{in}	$R_{in} = R_r = \frac{\eta}{4\pi} C_{in}(2\pi) \simeq 73$ ohms	(4-79), (4-93)
Input impedance Z_{in}	$Z_{in} = 73 + j42.5$	(4-93a)
Wave impedance Z_w	$Z_w = \frac{E_\theta}{H_\phi} \simeq \eta = 377$ ohms	
Directivity D_0	$D_0 = \frac{4}{C_{in}(2\pi)} \simeq 1.643 = 2.156$ dB	(4-91)
Vector effective length $\boldsymbol{\ell}_e$	$\boldsymbol{\ell}_e = -\hat{\mathbf{a}}_\theta \frac{\lambda}{\pi} \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$	(2-91)
	$\lvert\boldsymbol{\ell}_e\rvert_{\max} = \frac{\lambda}{\pi} = 0.3183\lambda$	(4-84)
Half-power beamwidth	HPBW = 78°	(4-65)
Loss resistance R_L	$R_L = \frac{l}{2P}\sqrt{\frac{\omega\mu_0}{2\sigma}} = \frac{l}{4\pi b}\sqrt{\frac{\omega\mu_0}{2\sigma}}$	Example (2-13)
	Quarter-Wavelength Monopole $(l = \lambda/4)$	
Normalized power pattern	$U = (E_{\theta n})^2 = C_2 \left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]^2 \simeq C_2 \sin^3\theta$	(4-87)
Radiation resistance R_r	$R_r = \frac{\eta}{8\pi} C_{in}(2\pi) \simeq 36.5$ ohms	(4-106)
Input resistance R_{in}	$R_{in} = R_r = \frac{\eta}{8\pi} C_{in}(2\pi) \simeq 36.5$ ohms	(4-106)
Input impedance Z_{in}	$Z_{in} = 36.5 + j21.25$	(4-106)
Wave impedance Z_w	$Z_w = \frac{E_\theta}{H_\phi} \simeq \eta = 377$ ohms	
Directivity D_0	$D_0 = 3.286 = 5.167$ dB	
Vector effective length $\boldsymbol{\ell}_e$	$\boldsymbol{\ell}_e = -\hat{\mathbf{a}}_\theta \frac{\lambda}{\pi} \cos\left(\frac{\pi}{2}\cos\theta\right)$	(2-91)
	$\lvert\boldsymbol{\ell}_e\rvert_{\max} = \frac{\lambda}{\pi} = 0.3183\lambda$	(4-84)

REFERENCES

1. W. A. Wheeler, "The Spherical Coil as an Inductor, Shield, or Antenna," *Proc. IRE*, Vol. 46, pp. 1595–1602, September 1958 (correction, Vol. 48, p. 328, March 1960).
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