Antennas, Radar and Metamaterials

23WSD523

Semester 1 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL THREE** questions.

Use of a calculator is permitted - It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are not allowed).

State any assumptions you make.

ALL working out for calculated questions must be shown to gain FULL marks.

A range of formulae and tables likely to be of benefit in the solution of these questions is provided at the rear of the paper.

1.

a) What happens to the frequency, the bandwidth, fractional bandwidth, and gain as we increase the length of a dipole antenna? [2 marks]

b) Sketch typical radiation patterns of a monopole with i) a small ground plane and ii) a large ground plane. [2 marks]

c) What does it mean in words if the S11 is above 0 dB? Explain what you would do if you saw this in simulations or measurements. [2 marks]

d) Describe how you can measure the boresight gain and the radiation patterns if you are given two unknown but identical antennas. [2 marks]

e) If an antenna transmits 0.2 mW, calculate this value in dBW and dBm. [2 marks]

f) What is the function of an artificial magnetic conductor (AMC)? What is the ideal phase reflection of an AMC, and how do you define its bandwidth? [2 marks]

g) A 10 GHz radar signal is incident on a car moving at 50 km/hour towards the radar. Calculate the Doppler frequency shift of the received signal and state whether the received frequency increases or decreases. [2 marks]

h) Explain how you would check the connector had been properly soldered onto a microstrip patch antenna using a multimeter. [2 marks]

i) What happens to the behaviour of an antenna if it is placed close to a lossy dielectric? [2 marks]

j) Calculate the far field distance of a 5.8 GHz dipole antenna. [2 marks]

2. This question relates to microstrip patch antennas.

a) What is the bandwidth of a typical microstrip patch antenna? How could you redesign the antenna to increase the bandwidth? [1 mark]

b) Sketch the electric field and the magnetic field distribution across the patch antenna. What is the impedance at the edge, and at the centre of a patch antenna? [2 marks]

c) Calculate the width and length of a 1 GHz patch antenna etched on a 2 mm thick substrate with a relative permittivity of 4.4. Include the fringing fields and the effective permittivity in your calculations. State any assumptions you make. [8 marks]

d) Calculate the inset distance to obtain a 50 ohm input impedance. [3 marks]

e) Find the S11, total efficiency (in dB and %) and gain (in dB units and linear scale) if the impedance of the antenna is 35 ohms, the radiation efficiency is 27% and the directivity is 5 dBi. [4 marks]

f) Sketch the current distributions for the TM_{10}, TM_{01}, TM_{11} and TM_{20} modes. [2 marks]

3. A 5G communication system is setup to send data 100m. It consists of two identical arrays of wideband dipole antennas. An individual dipole element has a return loss of -15 dB, a radiation efficiency of 68% and a directivity of 2 dBi. The overall antenna array has a return loss of 7 dB. The feedlines in the array contribute to a further 1 dB of absorption losses.

a) The available space for each array is 50 cm and the separation between the centre of the individual elements is half a wavelength. (You can assume that the dipoles are miniaturised and will not physically overlap). By considering two different frequencies, calculate the required transmitted power if the receiver sensitivity is -35 dBm. State any assumptions you make. Explain your result in terms of effective area of the antenna. Analyse the strengths and weaknesses of the higher frequency and lower frequency systems. [10 marks]

b) A different array compared to part (a) has 25 elements is designed to steer the main beam at 60 degrees. The centre to centre spacing of each element is a third of a wavelength. Calculate the required phase difference; the half power beamwidth; the angles of the first null, first sidelobe, 2nd null and the 2nd sidelobe in degrees and radians. Calculate the magnitude of the gain of the 1st and 2nd sidelobes relative to the main beam. State your assumptions, show your working and sketch the pattern. Explain the challenges of feeding this array. [10 marks]

W. Whittow

ANTENNAS TOOLKIT

CONSTANTS

Velocity of light in vacuum	$c = 2.998 \times 10^{8}\ \frac{m}{s}$
Permeability of vacuum	$\mu_o = 4\pi \times 10^{-7}\ \frac{H}{m}$
Permittivity of vacuum	$\varepsilon_o = 8.854 \times 10^{-12}\ \frac{Farad}{m}$

POWER

$$P_v = \frac{1}{2}\mathrm{Re}\left(\underline{E} \times \underline{H}^*\right) \cdot \hat{r} \quad \left(= \frac{\left|E_\theta\right|^2}{2\eta} \right)$$

RADIO LINK AND RCS

$$P_R = P_T G_R G_T \left[\frac{\lambda}{4\pi r}\right]^2 \qquad P_R = P_T G_R G_T \left[\frac{\lambda}{4\pi r}\right]^2 \frac{\sigma_o}{4\pi r^2}$$

ARRAYS

$$AF = \frac{1}{N}\left|\frac{\sin(\frac{N\psi}{2})}{\sin(\frac{\psi}{2})}\right| \approx \left|\frac{\sin\left(\frac{N}{2}\psi\right)}{\frac{N}{2}\psi}\right|$$

Half power: $\frac{N\psi}{2} = \pm 1.391$

Sidelobes: $\frac{N\psi}{2} = \frac{(2s+1)\pi}{2}$ where s = 1, 2, 3

$$D_B = 2N\frac{d}{\lambda} \qquad D_E = 4N\frac{d}{\lambda}$$

PATCH ANTENNAS

$$W = \frac{v_0}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

$$R_{edge} \approx 45\left(\frac{\lambda_0}{W}\right)^2$$

$$50\Omega \approx R_{edge}\cos^2\left(\frac{\pi}{L}y_0\right)$$

GUIDED ATTENUATION

$$A_g = 10\log_{10}\left(e^{-2\alpha_g d}\right) \approx -8.69\alpha_g d$$

DOPPLER SHIFT

$$\boldsymbol{f_r = f_t\left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}\right)}$$

ARTIFICIAL DIELECTRICS

$$p = \frac{4a^3}{3s^3}\pi$$

$$\varepsilon_{reff} = \varepsilon_1\left(1 + \frac{3p}{1 - p}\right)$$

$$\mu_{reff} = \mu_1\left(1 - \frac{3p}{2 + p}\right)$$