



Beijing-Dublin International College



SPRING SEMESTER EXAMINATION – 2022/2023

UCD School of Electrical and Electronic Engineering

EEEN3006J Wireless Systems

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Time Allowed: 120 minutes

Instructions for Candidates

Answer any **THREE** questions. All questions carry equal marks.

BJUT Student ID: _____

UCD Student ID: _____

I have read and clearly understand the Examination Rules of both Beijing University of Technology and University College Dublin. I am aware of the Punishment for Violating the Rules of Beijing University of Technology and/or University College Dublin. I hereby promise to abide by the relevant rules and regulations by not giving or receiving any help during the exam. If caught violating the rules, I accept the punishment thereof.

Honesty Pledge : _____ **(Signature)**

Instructions for Invigilators

Non-programmable calculators are permitted.
No rough-work paper is to be provided for candidates.

Formulas

Vector calculus

Cartesian coordinates:

$$\text{Div: } \vec{\nabla} \circ \vec{A} = \left(\frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} \right)$$

$$\text{Grad: } \vec{\nabla} \psi = \hat{i} \frac{\partial \psi}{\partial x} + \hat{j} \frac{\partial \psi}{\partial y} + \hat{k} \frac{\partial \psi}{\partial z}$$

$$\text{Curl: } \vec{\nabla} \times \vec{A} = \left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right) \hat{i} + \left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right) \hat{j} + \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right) \hat{k}$$

Spherical coordinates:

$$\text{Div: } \vec{\nabla} \circ \vec{A} = \left(\frac{1}{r^2} \frac{\partial}{\partial r} (r^2 A_r) + \frac{1}{r \sin \theta} \frac{\partial}{\partial \theta} (A_\theta \sin \theta) + \frac{1}{r \sin \theta} \frac{\partial A_\phi}{\partial \phi} \right)$$

$$\text{Grad: } \vec{\nabla} \psi = \hat{r} \frac{\partial \psi}{\partial r} + \hat{\theta} \frac{1}{r} \frac{\partial \psi}{\partial \theta} + \hat{\phi} \frac{1}{r \sin \theta} \frac{\partial \psi}{\partial \phi}$$

$$\text{Curl: } \vec{\nabla} \times \vec{A} = \frac{1}{r \sin \theta} \left(\frac{\partial (A_\phi \sin \theta)}{\partial \theta} - \frac{\partial A_\theta}{\partial \phi} \right) \hat{r} + \frac{1}{r} \left(\frac{1}{\sin \theta} \frac{\partial A_r}{\partial \phi} - \frac{\partial (r A_\phi)}{\partial r} \right) \hat{\theta} + \frac{1}{r} \left(\frac{\partial (r A_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta} \right) \hat{\phi}$$

Cylindrical coordinates:

$$\text{Div: } \vec{\nabla} \circ \vec{A} = \left(\frac{1}{r} \frac{\partial}{\partial r} (r A_r) + \frac{1}{r} \frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z} \right)$$

$$\text{Grad: } \vec{\nabla} \psi = \hat{r} \frac{\partial \psi}{\partial r} + \hat{\theta} \frac{1}{r} \frac{\partial \psi}{\partial \theta} + \hat{z} \frac{\partial \psi}{\partial z}$$

$$\text{Curl: } \vec{\nabla} \times \vec{A} = \left(\frac{1}{r} \frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z} \right) \hat{r} + \left(\frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r} \right) \hat{\phi} + \frac{1}{r} \left(\frac{\partial (r A_\phi)}{\partial r} - \frac{\partial A_r}{\partial \phi} \right) \hat{z}$$

Useful constants

Vacuum permeability: $\mu_0 = 4\pi \times 10^{-7} \text{ H}$

Vacuum permittivity: $\epsilon_0 = 8.85 \times 10^{-12} \text{ F}$

Boltzmann's constant: $k = 1.38064852 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$

Charge on Electron: $q = 1.6 \times 10^{-19}$

Integral forms of Maxwell's Equations

$$\text{Gauss's Law for electric fields: } \oint_S \vec{E} \circ \hat{n} da = \frac{q_{\text{enc}}}{\epsilon_0}$$

$$\text{Gauss's Law for magnetic fields: } \oint_S \vec{B} \circ \hat{n} da = 0$$

$$\text{Faraday's Law: } \oint_C \vec{E} \circ d\vec{l} = -\frac{d}{dt} \int_S \vec{B} \circ \hat{n} da \text{ or } \oint_C \vec{E} \circ d\vec{l} = -\int_S \frac{\partial \vec{B}}{\partial t} \circ \hat{n} da$$

$$\text{Ampere-Maxwell Law: } \oint_C \vec{B} \circ d\vec{l} = \mu_0 \left(I_{\text{enc}} + \epsilon_0 \frac{d}{dt} \int_S \vec{E} \circ \hat{n} da \right)$$

Derivative forms of Maxwell's Equations

$$\text{Gauss's Law for electric fields: } \vec{\nabla} \circ \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\text{Gauss's Law for magnetic fields: } \vec{\nabla} \circ \vec{B} = 0$$

$$\text{Faraday's Law: } \vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\text{Ampere-Maxwell Law: } \vec{\nabla} \times \vec{B} = \mu_0 \left(\vec{J} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

Some useful relationships

Gauss's theorem: $\oint_S \vec{A} \cdot \hat{n} da = \oint_V (\nabla \cdot \vec{A}) dV$

Stokes' Theorem: $\oint_C \vec{A} \cdot d\vec{l} = \int_S (\vec{\nabla} \times \vec{A}) \cdot \hat{n} da$

Curl of grad is always zero: $\vec{\nabla} \times \vec{\nabla} \psi = 0$

Laplacian: $\vec{\nabla} \cdot \vec{\nabla} \psi = \nabla^2 \psi = \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2}$

Grad of div less Laplacian is curl of curl: $\vec{\nabla}(\vec{\nabla} \cdot \psi) - \nabla^2 \psi = \vec{\nabla} \times (\vec{\nabla} \times \psi)$

Link Design

Friis' Transmission Equation: $P_{rx} = \frac{P_{tx} G_{tx} G_{rx} \lambda^2}{(4\pi)^2 r^2}$

Useful trigonometric identities

$\cos(a) \cos(b) = 0.5(\cos(a+b) + \cos(a-b))$

Circuit Noise Formulas

Thermal Noise: $E[v_t^2] = 4kTRB$ V^2

Shot Noise: $E[i_D^2] = 2qI_{DC}B$ A^2

Question 1:

- (a) A line with charge density 9×10^{-11} C/m passes through the centre of a sphere. If the flux through the surface of the sphere is 3.26×10^{-9} Vm, find the radius of the sphere?

(7 marks)

- (b) Find the divergence of the field given by $\vec{A} = r\hat{r}$ in spherical coordinates.

(10 marks)

- (c) i - Find Given an expression for the magnetic field as a function of time, find the emf induced in a loop of specified size.

$$\vec{B}(y, t) = 0.1 \sin(10^3 t) \hat{z}$$

Circular loop of radius of 0.2 m lying perpendicular to the z plane.

[Hint: integration over the area of a circle ($rdrd\phi$)

- ii - If the loop has a resistance of 12 ohms, what is the current in the loop?

(10marks)

- (d) What density of current would produce a magnetic field given by:

$$\vec{B} = \left(\frac{a}{r} + \frac{b}{r} e^{-r} + c e^{-r} \right) \hat{\phi}$$

in cylindrical coordinates?

(6 marks)

(33 marks)**Question 2:**

- (a) Explain what is meant by the Fresnel zone of a radio link. How might this effect the design of ground to ground directional communication links?

(5 marks)

- (b) A satellite communication link spans a 30,000 km distance, has a transmitter power of 50 W and transmitter gain of 55 dB. If the receiver noise level is measured as 0.4

pW, what is the required receiver antenna effective aperture to achieve a signal to noise ratio of 130?

(8 marks)

- (c) A wifi access point operates at a frequency of 2.2 GHz and has a maximum allowed transmit power of 30 dBm and its antenna has a gain of 7 dB. A receiver antenna has a gain of 3 dB and a measured noise floor in the area of 70 pW. What is the furthest distance the signal can be received by the receiver if the required SNR to successfully receive signals is 120?

(10 marks)

- (d) GSM 450 operates in the frequency range between 450.6 MHz – 457.6 MHz (with first channel centred on 450.6 MHz, and last used channel centred on 457.6 MHz), with each channel having a BW of 200 kHz. Use a Fractional-N frequency synthesis design such that all required channel centre frequencies **can be produced** by the design. What are the values of f_{ref} , N , k , R for the channel with centre frequency at 452.2 MHz.

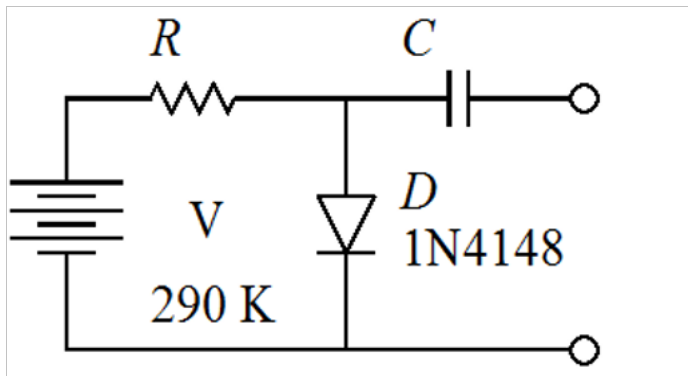
Hint: The frequency synthesis design is allowed to produce frequencies outside the needed range!

(10 marks)

(33 marks)

Question 3:

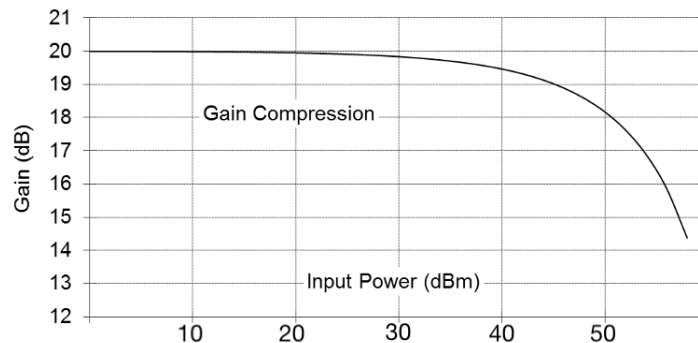
- (a) The given 1 port network produces both *thermal noise* from the real resistances in the circuit and *shot noise* from the diode in the circuit. Given the values of $R = 500 \text{ ohms}$, $C = 50 \text{ nF}$, $V = 8 \text{ V}$, and diode D with forward bias threshold voltage of 0.7 V.



Model the noise produced in the network using R_{th} and T_{eq} .

(8 marks)

- (b) The graph below shows the function of the gain with respect to input power for an amplifier:



What is the output power if the input signal to the amplifier is 32 mW ? Give your answer in Watts (W).

(5 marks)

- (c) An antenna has a noise temperature of 177 K collects a signal of power 5 nW and feeds this into an amplifier with a gain of 120 and an equivalent noise temperature of 222 K. The signal is then filtered. The filter has a gain of 0.7 and an equivalent noise temperature of 237 K and a effective bandwidth of 2.5 MHz. The rest of the receiver architecture has a gain of 20, an equivalent noise temperature of 530 K. What is the signal to noise ratio when it is passed in for demodulation after the receiver architecture?

Give your answer in dB.

(10 marks)

- (d) The power amplifier of a radio has a small-signal gain of 18 dB and its third-order intercept point is at an input power of 4 dBW. The amplifier is followed by a low-pass filter with corner frequency 800 MHz, passband loss 0.5 dB and attenuation of at least 60 dB at frequencies above 900 MHz. The transmitter output should be the sum of two sinusoidal signals with equal power, at frequencies of 830 MHz and 850 MHz. Any other signal at the filter output must not exceed 5 mW?

What is the maximum power in each of the intended signals at the filter output?

(10 marks)

(33 marks)

Question 4:

- (a) Explain the term up-conversion and down-conversion in radio systems. Why are these necessary in radio transmission.

(7 marks)

- (b) For the following radio system designs - Tuned Radio Frequency, Direct Conversion, Super-Hetrodyne:

- i Draw the receiver architecture
- ii Discuss the strengths and weaknesses of the design

(10 marks)

- (c) A hetrodyne receiver architecture uses a frequency band between 430 MHz and 540 MHz. The channel BW for the signal is 22 MHz.

The decision has been made to use the band select filter to remove image frequencies. The band select filter has a shape factor of 1.5 at 3/30.

As the designer you have been asked to choose the IF frequency f_c .

What frequency will minimise the fractional bandwidth requirements for the channel select filter while guaranteeing 30 dB reduction in the image frequency?

(10 marks)

- (d) A transceiver architecture uses FDD to share the antenna. What considerations should be taken when designing the LNA and band select filter for the receiver side?

Hint: Consider the effects of *desensitisation* and *gain blocking*.

(6 marks)

(33 marks)

(100 marks)