CINEC CAMPUS
Beyond A Graduate

Faculty of Engineering & Technology	
Department of Electrical and Electronics Engineering	
BSc. Hons. (Eng.) in Electronic and Telecommunication Engineering	
Semester 08 First Sit - Final Examination 2026	
Batch: 05	
Module Code: EE4322	**Module Title: Microwave Engineering**
Date: 10th August 2026	**Duration: 03 Hours**
Examiner:	**Ms. Dushani Munasinghe**

Instructions to Candidates:

- *This is a closed book examination. No reference materials are allowed unless specified.*
- *This paper consists of four (04) questions and 06 pages. Answer all questions.*
- *The marks allocated to each question are listed in the column on the far right. Final mark of the question paper will be calculated out of 100.*
- *Use only the provided answer booklet, additional sheets, and graph papers for your answers.*
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- *Write your student number on all sheets.*
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Q1 i) Modern satellite communication and radar systems almost exclusively operate in the microwave frequency range rather than the lower radio frequency bands. Using four (04) well-structured points, justify why microwaves are preferred for these applications. [04]

ii) A two-port microwave network is represented by the following scattering matrix:

$$S = \begin{bmatrix} 0.30\angle 0^0 & X \\ 0.80\angle 45^0 & 0.60\angle 0^0 \end{bmatrix}$$

The manufacturer claims that the network is reciprocal.

a) Determine the value of the unknown scattering parameter X. [03]

b) The manufacturer further claims that the network is lossless. [04]

Verify whether this claim is correct by applying the lossless condition for a two-port network. Clearly justify your answer.

c) A Vector Network Analyzer (VNA) is connected to Port 1 while Port 2 is terminated with a matched load. Determine the expected value of S_{11} (in dB) and comment on the quality of the impedance matching at Port 1. [04]

iii) The two port network shown in Figure 1 consists of a series impedance followed by a lossless transmission line whose $\beta l = 90^0$. Using ABCD parameter matrices provided, determine the voltage across the load, V_L. [06]

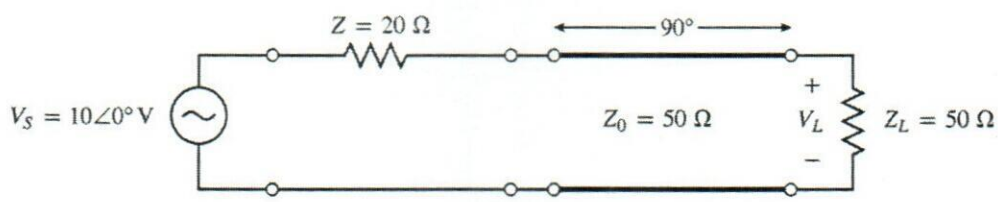

Figure 1

iv) State the rule of Signal Flow Graph (SFG) for the simplification of a self-loop in a microwave network. Use required illustrations as necessary. [04]

Total [25]

Q2. i) Increasing the thickness of a copper conductor is an effective way to reduce resistance in DC circuits. However, this approach becomes much less effective at microwave frequencies. Justify this claim with reasons. [05]

ii) Striplines and microstrip lines are widely used as planar transmission lines in microwave circuits.

a) Clearly differentiate between a stripline and a microstrip line with respect to their physical structure, field distribution, propagation mode, shielding, and radiation loss. Support your answer using suitably labelled cross-sectional illustrations. [06]

b) A symmetric stripline is fabricated using a dielectric material with a relative permittivity of $\varepsilon_r = 3.8$. The width of the centre conductor is $w = 1.5\,mm$ and the separation between the two ground planes is $b = 4.0\,mm$. Assume that the conductor thickness is negligible. Using the standard stripline approximation provided in the Reference Equations, calculate the characteristic impedance Z_0 of the stripline. [09]

iii) Figure 2 shows a 50 Ω transmission line connected to a 100 Ω load through a quarter-wave impedance transformer having a characteristic impedance of 70.7 Ω. The main transmission line has a physical length of $0.25\,m$, and the operating wavelength is $1.0\,m$.

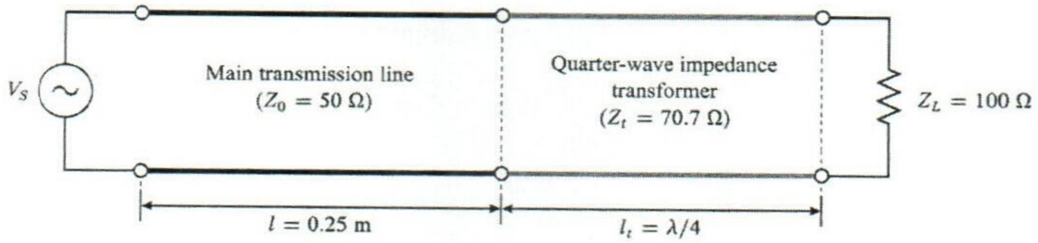

Figure 2

a) Determine the equivalent impedance seen at the input of the quarter-wave transformer. [05]

b) Calculate the input impedance, Z_{in} at the source end of the 50 Ω transmission line. [05]

Total [30]

Q3. i) A $\lambda/2$ coaxial resonator is constructed using a copper coaxial transmission line with the following dimensions: [07]

- Inner conductor radius: a = 0.8 mm
- Outer conductor radius: b = 3.5 mm
- Resonant frequency: f = 6 GHz

The resonator is fabricated using two different dielectric materials:

- Air ($\varepsilon_r = 1, \tan\delta \approx 0$)
- PTFE (Teflon) ($\varepsilon_r = 2.1, \tan\delta = 0.0002$)

Using the expressions provided in the Reference Equations, determine the unloaded quality factor Q of each resonator. Hence, comment on which resonator is more suitable for high-Q microwave applications.

ii) A high-power microwave amplifier is connected directly to an antenna. During operation, impedance mismatches at the antenna cause a portion of the transmitted power to be reflected back towards the amplifier. [03]

Explain how a microwave isolator protects the amplifier under these conditions. In your answer, describe the operating principle of the isolator and its effect on forward and reverse travelling waves.

iii) A microwave transmitter delivers an input power of 15 dBm to a directional coupler that has the following specifications: [09]

- Coupling factor = 15 dB
- Directivity = 30 dB
- Insertion loss = 0.8 dB

Assuming all ports are perfectly matched, determine the output powers (in dBm) at the:

a) Through port
b) Coupled port
c) Isolated port

iv) Describe the bunching process in a two-cavity klystron amplifier. In your answer, explain how velocity modulation produced in the buncher cavity leads to electron bunch formation and efficient energy transfer in the catcher cavity. [06]

Total [25]

Q4. i) Explain the working principle of a varactor diode. In your answer, describe how the reverse-bias voltage affects the depletion region and junction capacitance, and state one practical microwave application of a varactor diode. [05]

iii) a) Explain how the transferred electron effect (Gunn effect) gives rise to negative differential resistance in GaAs. [05]

b) Describe how the formation and movement of an electron domain (Ridley domain) produce microwave oscillations in a Gunn diode. [05]

c) A GaAs Gunn diode has an active region length of $15\ \mu m$. Assuming the electron domain travels with a saturation velocity of $1x10^7 \mathrm{cm/s}$, determine: [05]

- the transit time of the electron domain, and
- the corresponding oscillation frequency of the Gunn diode.

Total [20]

End of the Examination Paper

Reference Equations

Series Impedance Z:	$M_1 = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$	*Conductor Attenuation:*	$\alpha_c = \frac{R_s}{4\pi Z_0}\left(\frac{1}{a} + \frac{1}{b}\right)$
Ideal Transmission Line:	$\begin{bmatrix} \cos(\beta l) & jZ_0\sin(\beta l) \\ j\frac{1}{Z_0}\sin(\beta l) & \cos(\beta l) \end{bmatrix}$	*Phase Constant for Copper:*	$\beta = \frac{2\pi f\sqrt{\varepsilon_r}}{c}$
Phase Constant:	$\beta = \frac{2\pi}{\lambda}$	*Dielectric Attenuation:*	$\alpha_d = \frac{\beta\tan(\delta)}{2}$
Transmission Line Input Impedance:	$Z_{in} = Z_o\frac{Z_L + jZ_0\tan(\beta l)}{Z_0 + jZ_L\tan(\beta l)}$	*Total Attenuation:*	$\alpha = \alpha_c + \alpha_d$
Symmetric Stripline Approximation:	$Z_0 = \frac{30\pi}{\sqrt{\varepsilon_r}(\frac{W}{b} + 0.441)}$	*Unloaded Quality Factor:*	$Q_0 = \frac{\beta}{2\alpha}$
Quarter-wave Transformer Input Impedance:	$Z_{in} = \frac{Z_t^2}{Z_L}$	*Directional Couplers: (in dB)*	$C = 10log_{10}\left(\frac{P_{in}}{P_{coupled}}\right)$ $D = 10log_{10}\left(\frac{P_{coupled}}{P_{isolated}}\right)$ $I = 10log_{10}\left(\frac{P_{in}}{P_{isolated}}\right)$
Surface Resistance of Copper:	$R_s = \sqrt{\frac{\pi f\mu_0}{\sigma}}$	*Transit Time:*	$T_t = \frac{L}{V_s}$
Characteristic Impedance of the Coaxial Line:	$Z_0 = \frac{60}{\sqrt{\varepsilon_r}}\ln(\frac{b}{a})$	*Oscillation Frequency:*	$f = \frac{1}{T_t}$

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Department of Electrical and Electronic Engineering	
BSc. Hons. (Eng.) in Electronic and Telecommunication Engineering	
BSc. Hons. (Eng.) in Mechatronics Engineering	
Semester 8 First Sit - Final Examination 2026	
Batch : 5	
Module Code: EE4326	**Module Title: Advanced Control Systems**
Date: 03 08 2026	**Duration: 3 hours**
Examiner 1:	**Dr K. Gunawickrama**
Examiner 2:	**Dr D. Suraweera**

Instructions to Candidates:

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Q1 **i)** Given the state space model of a plant in the general form

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t)$$

derive and show that the transfer function of the plant is given by

$$G(s) = \frac{Y(s)}{U(s)} = C[sI - A]^{-1}B + D$$

if initial conditions are zero.
Note: Laplace Transform $\mathcal{L}\left\{\frac{dx}{dt}\right\} = sX(s) - x(0)$ [5 Marks]

ii) Find the transfer function for the following state space model

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix}-3 & 1\\ -2 & 0\end{bmatrix} x(t) + \begin{bmatrix}0\\ 1\end{bmatrix} u(t)\\ y(t) &= \begin{bmatrix}1 & 0\end{bmatrix} x(t)\end{aligned}$$

Note: If $M = \begin{bmatrix}a & b\\ c & d\end{bmatrix}$ then

$$M^{-1} = \frac{adj(M)}{det(M)} = \frac{1}{ad - bc}\begin{bmatrix}d & -b\\ -c & a\end{bmatrix}$$

[5 Marks]

iii) Derive the state space models in controllable cannonical form for the systems, given by the following transfer functions.

a)

$$G(s) = \frac{1}{s^3 + 6s^2 + 11s + 6}$$

b)

$$G(s) = \frac{2s + 1}{s^2 + 7s + 1}$$

[10 Marks]

Total [20 Marks]

Q2 If a plant is modeled in state space as

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix}0 & 1\\ 0 & 0\end{bmatrix} x(t) + \begin{bmatrix}0\\ 1\end{bmatrix} u(t)\\ y(t) &= \begin{bmatrix}1 & 0\end{bmatrix} x(t)\end{aligned}$$

i) Calculate the controllability matrix Q_C and verify that the system is controllable.
Note: For $x(t) \in \mathbb{R}^{n\times 1}$, the controlability matrix is given by

$$Q_C = \begin{bmatrix}B & AB & A^2B & \dots & A^{n-1}B\end{bmatrix}$$

[5 Marks]

ii) It is required to design a full state feedback gain controller to position closed loop poles at $-1 \pm 0.1j$.

a) Determine the actual closed loop characteristic equation of the system given by $det(sI - [A - BK]) = 0$, where $K = [k_1 \quad k_2]$ is the state feedback gain matrix that satisfies the control law $u(t) = -Kx(t)$.

b) Determine the desired characteristic equation of the desired closed loop system.

c) Compare charcteristic equations (system and desired) and determine $K = [k_1 \quad k_2]$. Express the control law in the form of $u(t) = -Kx(t)$

[15 Marks]

Total [20 Marks]

Q3 A certain linear mechanical translational system shown in Figure Q3 is governed by the following state space model.

$$\begin{aligned} \begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} &= \begin{bmatrix} 0 & 1 \\ -\frac{k}{M} & -\frac{b}{M} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{M} \end{bmatrix} u(t) \\ y(t) &= \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} \end{aligned}$$

A force $u(t)$ applide to mass M is the input and resulting displacement $y(t)$ of $M$is the output. Damper and the spring coefficients are b and k respectively. State variables $x_1(t)$ and $x_2(t)$ are the velocity and accelaration of M, respectively.

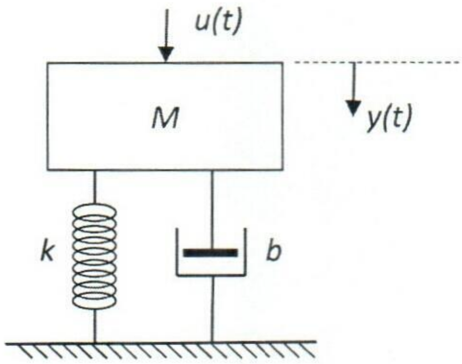

Figure Q3: Mechanical System

Consider that the $m = 2$ kg, $k = 0.2$ N/m and $b = 0.4$ Ns/m, sampling period of $\Delta t = 0.1$ s, applied force $u(t) = 1$ N, for $t \geq 0$ s. Initially at $t = 0$, the system is at rest. Hence all initial condditions are zero.

a) Calculate $x(t)$, $\dot{x}(t)$, and $y(t)$ for the simulation steps $t = 0$, $t = 0.1$ and $t = 0.2$. [15 Marks]

b) There by, show that the velocity, accelaration and displacement of M at $t = 0.2$ are 0.099 m/s, 0.4797 m/s^2 and 0.005 m, respectively. [5 Marks]

Note: Use Euler integration method to numerically calculate x from $\dot{x}$ as
$x(t) = x(t-\Delta t) + \dot{x}(t-\Delta t)\Delta t$

Total [20 Marks]

Q4 If a plant is modeled in state space as

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix}0 & 1\\ 0 & 0\end{bmatrix} x(t) + \begin{bmatrix}0\\ 1\end{bmatrix} u(t)\\ y(t) &= \begin{bmatrix}1 & 0\end{bmatrix} x(t)\end{aligned}$$

a) Determine the observability matrix Q_{Obs} and verify that all system states are observable.
Note: For $x(t) \in \mathbb{R}^{n\times 1}$ the observability matrix is given by

$$Q_{Obs} = \begin{bmatrix} C\\ CA\\ \vdots\\ CA^{n-1}\end{bmatrix}$$

[5 Marks]

b) Suppose, a critically damped ($\zeta = 1$) full state observer with time constant $\tau = 0.1$s is to be designed. What is the desired characteristic equation $\alpha_{Des}(s)$of the 2nd order observer.
Note: Characteristic equation of a 2nd oder system is given by
$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$, where $\omega_n = 1/(\zeta\tau)$ [5 Marks]

c) Calculate the observer gain matrix G, found in the observer equation

$$\dot{\hat{x}}(t) = (A - GC)\hat{x(t)} + Bu(t) + Gy(t)$$

Note: For $x(t) \in \mathbb{R}^{n\times 1}$, the observer gain matrix is calculated by

$$G = \alpha_{Des}(A)\begin{bmatrix} C\\ CA\\ \vdots\\ CA^{n-1}\end{bmatrix}^{-1}\begin{bmatrix}0\\ 0\\ \vdots\\ 1\end{bmatrix}$$

[10 Marks]

Total [20 Marks]

Q5 a) Suppose it is necessary to design an optimal controller for a robot arm based on the cost function

$$J = \int_0^\infty \left(x^T Q x + u^T R u\right) dt$$

where, $x(t) \in \mathbb{R}^{2\times1}$, $Q \in \mathbb{R}^{2\times2}$ and $R \in \mathbb{R}^{1\times1}$, and
$x_1(t)$ - position error (m)
$x_2(t)$ - velocity (m/s)
$u(t)$ - motor force input (N)

Choose the Q and R matrices based on the Bryson's Rule, in order to satisfy the following engineering constraints.

- Robotic arm should reach its target accurately. Maximum acceptable position error $x_1(t)$ is 0.1m
- Intermidiate velocity is not very important as long as it gets to the destination. Maximum acceptable velocity ($x_2(t)$) is 2 m/s.
- Excessive force should be avoided as the motor gets overheated. Maximum acceptable force dilivered by the motor is 10 N.

[5 Marks]

b) Describe the purpose of robust controllers. Give two sample areas of applications in which optimal control is essential. [5 Marks]

c) What is understood by stability in time-domain for a linear time-invarient 2-nd order system? [5 Marks]

d) What is understood by stability in Lyapunov sense? What type of systems are tested using Lyapunov stability testing method. [5 Marks]

Total [20 Marks]