INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 1 – September 2023
AV411 – Navigation Systems and Sensors
Time: One hour Date: 11/09/2023 Max. Marks: 15

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to carry one A4 sheet written in their own handwriting containing formulas. However, no block diagrams and derivations are allowed. The sheet shall carry the student's name and SC code and should be submitted along with the answer script.

1. Navigation Systems and Sensors
   (a) Explain strapdown navigation system with a neat diagram. (2)
   (b) Explain the working principle of a mechanical gyroscope and what is it used for? (2)
2. What are the key features required to define a cartesian co-ordinate system? Define synodic coordinate system using the above features. (3)
3. Consider the following DCM matrix

$$Q = \begin{bmatrix} C\psi C\theta & s\psi C\theta & -S\theta \\ C\psi S\theta S\phi - S\psi C\phi & S\psi S\theta S\phi + C\psi C\phi & C\theta S\phi \\ C\psi S\theta C\phi + S\psi S\phi & S\psi S\theta C\phi - C\psi S\phi & C\theta C\phi \end{bmatrix}$$

   (a) Determine the sequence and angle of elementry rotations for the above matrix. (1)
   (b) Explain gimbal lock in a coordinate transformation sequence using the above matrix and determine the gimbal lock angle. (2)
4. Consider the following matrix

$$\begin{bmatrix} 0 & 0 & -1 \\ \sin(\psi) & \cos(\psi) & 0 \\ \cos(\psi) & -\sin(\psi) & 0 \end{bmatrix}.$$

   (a) Determine weather the above matrix is a rotation matrix and justify. If the above matrix is not a rotation matrix modify it to a rotation matrix. (2)
   (b) Determine the axis and angle of rotation for the above/converted matrix. (3)

$$\begin{bmatrix} -1 & 0 & -1 \\ \sin\psi & C\psi-1 & 0 \\ C\psi+1 & -S\psi & 0 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 0 & -1 \\ \sin\psi & C\psi-1 & 0 \\ C\psi & -S\psi & -1 \end{bmatrix}$$

$y = x$

$x = \frac{(S\psi)x}{(C\psi+1)}$

$\frac{(S\psi)^2 x}{(C\psi+1)} + (C\psi-1)x$

$$\begin{bmatrix} 0 & 0 & -1 \\ S\psi & C\psi-1 & 0 \\ C\psi+1 & -S\psi & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad z=0$$

$S\psi x \; (C\psi-1)y = 0$

$(C\psi+1)x) - (S\psi)y$

$$x \begin{bmatrix} \frac{S\psi^2}{(C\psi+1)} \\ (C\psi-1) \\ 0 \end{bmatrix}$$

axis of rotation : $\frac{(S\psi)x}{C\psi+1} + (C\psi^2-1)y + 0z$ | axis of rotation : $(x \pm y) \to (x-y)$

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 2 – October 2023
AV411 – Navigation Systems and Sensors
Time: One hour Date: 19/10/2023 Max. Marks: 15

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to bring one A4 sized cheat sheet with formulas (no derivations and no drawings) written in their own handwriting. This sheet must be submitted with the answer scripts.

1. Define angular momentum and torque and show that torque is the rate of change of angular momentum. (3)

2. State the assumptions made in deriving the solution of Focault's pendulum. Describe the behaviour of the solution. An experiment is conducted at the equator of the Planet Mars to determine its rotation using Focault's pendulum. Will the experiment succeed. Justify your answer. (3)

3. The first stage empty fuel tank of a launch vehicle weighing 14 tons is dropped from a height of 75km above a certain location in northern hemisphere. Assuming free fall and negligible wind velocity, would it fall directly below the positon from where it was dropped? Justify. Compute the position of the fuel tank on the ground in relation to the position from where it was dropped. Assume that the latitude and longitude of the point above the earth from where the fuel tank was dropped is 60° and 30°, respectively. (3)

4. Let OXYZ be an inertial frame. Let Oxyz be initially coincident with OXYZ and rotate with constant angular velocity $|\Omega|$ about Oz. Consider a fixed point 'A' in space at a radius r from Oz. Compute the absolute acceleration of 'A', a_A. (3)

5. Quaternion

   (a) Let p and q be two quaternions. Show that $(pq)^{-1} = q^{-1}p^{-1}$ (1)

   (b) Consider the two quaternions (1)

$$p = \frac{\sqrt{3}}{2} + i\frac{1}{2}$$
$$q = -\frac{\sqrt{3}}{2} - i\frac{1}{2}$$

   What are the angle and axis of rotation of p and q when interpreted as rotation representation? What do you conclude from this?

   (c) What are the rotation angle and axis represented by the quaternions (1)

      1. i, j and k
      2. ijk

End of exam.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – End Semester – November 2023
AV411 – Navigation Systems and Sensors
Time: Three hours   Date: 29/11/2023   Max. Marks: 50

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to carry two A4 sheets written in their own handwriting containing formulas. However, no block diagrams and derivations are allowed. The sheet shall carry the student's name and SC code and should be submitted along with the answer script.

Tensor of Inertia

1. State the properties of Tensor of Inertia matrix. (2)

2. Let Θ be tensor of inertia with respect to unit vectors in the directions $e^1 = (2, 1, 1)$, $e^2 = (1, -1, -1)$, $e^3 = (0, 1, -1)$ where (5)

$$\Theta = \begin{bmatrix} 5 & -2 & -1 \\ -2 & 6 & -2 \\ -1 & -2 & 4 \end{bmatrix}$$

Compute the moment of inertia about the axis $n = (2, -1, 3)$ which is expressed in the axes $(1, 0, 0)$, $(0, 1, 0)$, $(0, 0, 1)$.

3. The tensor of inertia matrix for a certain rigid body with respect to the standard basis is given to be (2)

$$\Theta = \begin{bmatrix} 4 & -2 & -1 \\ -2 & 5 & -2 \\ -1 & -2 & 6 \end{bmatrix}$$

It is given that moment of inertia about a particular axis $\hat{n}$ is 12.

Is $\hat{n}$ unique? If so justify and compute $\hat{n}$. Otherwise, state/derive the equations which lead to computing the vector $\hat{n}$.

4. Determine the candidate shape of the object of mass M and the co-ordinate axes for which the TOI takes the form $\Theta = \begin{bmatrix} 3M & 0 & 0 \\ 0 & 3M & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (5)

5. A gyroscope consists of two identical uniform disks with mass M and radius R mounted on a rigid axle with length $2D$ as shown in Figure 5. The axle is fixed to the outer disk, while the inner disk is allowed to spin freely but is constrained to remain at a distance D from the pivot (at left) by a collar. The axle spins about the pivot freely on a frictionless mount. The outer disk and axle are initially spun up to an angular frequency ω_0 . Assume that the mass of the axle and pivot mount are negligible. Gravity points downward. Ignore nutation. Calculate the precession rate $\vec{\Omega}$ of the gyroscope assuming that the inner disk is not spinning. (5)

6. Let Θ be the tensor of inertia matrix in some orthogonal co-ordinate frame. Determine the new tensor of inertia matrix when the co-ordinate system is translated by a constant vector r_0. (5)

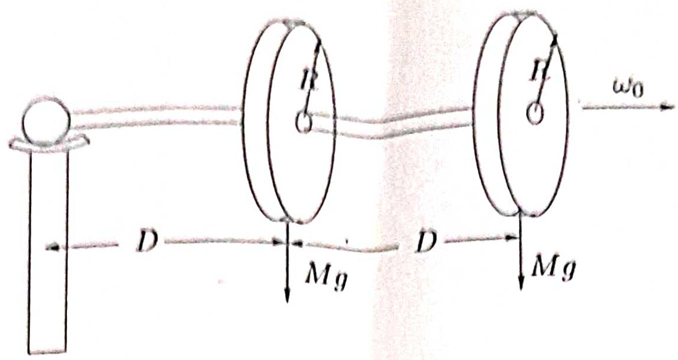


Figure 1: Double Wheel

Coordinate-systems

7. Show that rotation matrices are orthogonal matrices with determinant 1. (2)

8. Show that for any $t \in \mathbb{R}$ the matrix Q_t defined below is a rotation matrix. Find its axis of rotation and cosine of the angle of rotation. (3)

$$Q_t = \frac{1}{1+t+t^2}\begin{bmatrix} -t & t+t^2 & 1+t \\ 1+t & -t & t+t^2 \\ t+t^2 & 1+t & -t \end{bmatrix}$$

9. The IRNSS 1A satellite was launched into geosynchronous orbit with an inclination of 27.47 degrees with equator, Perigee 35,704Km and Apogee 35,866 Km. On 31st Dec., 2020 at 12:35 IST IRNSS makes an observation of Sun and the Star Sirius. The co-ordinates as measured by IRNSS of the Sun are $(2, 1, 3)$ and $(1, -1, 1)$ in the body and ECI frame respectively and that of the Sirius are $(1, 0, 1)$ and $(-1, 1, 0)$ in the body and ECI frame respectively.

   (a) Is it possible to determine the orientation of IRNSS body frame with respect to the ECI frame with the above given measurements? Justify (1)

   (b) If the answer to the above question is yes then justify by determining the transformation matrix between the IRNSS body frame and ECI frame. If the answer to the previous question is no then how many additional vector measurements are required to obtain the transformation matrix between IRNSS body frame and ECI frame? Give an example of additional measurement vectors and the corresponding transformation matrix. (2)

10. An inertial measuring unit consisting of three rate gyroscopes and three servo accelerometers are placed in a rocket at the launchpad located in Sydney, 33.8600° S, 151.2094° E Australia. The input axes of the inertial measuring unit are aligned with North, East and Zenith axis. Determine the measurements obtained by all the gyroscopes and accelerometers. (1)

11. Find the quaternion corresponding to the DCM matrix (1)

$$\begin{bmatrix} -\frac{5}{8} & \frac{\sqrt{3}}{4} & \frac{3^{3/2}}{8} \\ \frac{\sqrt{3}}{4} & -\frac{1}{2} & \frac{3}{4} \\ \frac{3^{3/2}}{8} & \frac{3}{4} & \frac{1}{8} \end{bmatrix}$$

Kalman filter

12. Given the following scalar Kalman filter state space model,

$$x_k = ax_{k-1} + w_k, \quad w_k \sim \mathcal{N}(0, \sigma_w^2)$$
$$y_k = x_k + v_k, \quad w_k \sim \mathcal{N}(0, \sigma_w^2)$$

and the Kalman equations

$$\begin{aligned} \widehat{x}_{k|k-1} &= a\widehat{x}_{k-1|k-1} \\ P_{k|k-1} &= a^2 P_{k|k-1} + \sigma_w^2 \\ K_k &= \frac{P_{k|k-1}}{P_{k|k-1} + \sigma_v^2} \\ \widehat{x}_{k|k} &= a\widehat{x}_{k|k-1} + K_k(y_k - \widehat{x}_{k|k-1}) \\ P_{k|k} &= (1 - K_k)P_{k|k-1} \end{aligned}$$

Using the above equations, prove the following

(a) Show $0 \leq K_k \leq 1$. (1)

(b) Therefore, show that $P_{k|k} \leq P_{k|k-1}$. (2)

(c) Compute the following (2)

$$\lim_{\sigma_w^2 \to \infty} K_k = ? \quad \lim_{\sigma_v^2 \to \infty} K_k = ?$$

Inertial Sensors

13. (a) What are the major gasses of contamination inside the active medium of ISROs Laser Gyro (ILG)? A. O2 and Ne B. O2 and H2 C. N2 and H2 D. O2 and N2 (2)

(b) A closed loop null balanced analog accelerometer has a torquer coil to counter balance the pendulum deflection and the amount of current required to rebalance the pendulum is a measure of acceleration. It is a fact that the permanent magnet used in the sensor will naturally losses its properties gradually over a period of time. Assuming all other parameters are time invariant, what would happen to the sensor scale factor?

A. The requirement of rebalancing force current will decrease and hence scale factor will increase.

B. The requirement of rebalancing force current will decrease and hence scale factor will decrease.

C. The requirement of rebalancing force current will increase and hence scale factor will increase.

D. The requirement of rebalancing force current will increase and hence scale factor will decrease

(c) A single axis accelerometer is used as an INS to navigate a 1-D world. A person living there wants to travel 1000m with an uncertainty of 1m in a vehicle that produces 1mg constant thrust. What should be the maximum unmodelled residual bias that the accelerometer is allowed to have?

A. 1μ g B. 10μ g C. 100μ g D. 0.1μ g

(d) A 1000Kg satellite equipped with a 440N thruster is injected in to an elliptical transfer orbit and it is planned to circularize the orbit by adding a ΔV of 100m/s. How much duration thruster should be fired and where should this maneuver be executed?

A. 227.273 s at Apogee point B. 227.273 s at Perigee point C. 44 s at Apogee point D. 44 s at Perigee point

14. With neat diagrams explain the working principles of any two of the following sensors: (4)

(a) Momentum wheel gyros

(b) Laser Gyros

(c) Accelerometer

15. Write your own question and answer with diagrams if necessary in the area of Navigation Systems and Sensors and not covered in the above questions. (5)

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
DEPARTMENT OF AVIONICS

Satellite and Optical Communication (AV412)

B.Tech ECE (Avionics), **Quiz 2**

Total marks=15

Date: 20/10/23

Part-A Satellite Communication [5 marks]

1. Draw the convolutional encoder circuit for rate 1/3 code for the given generator polynomial and draw the state diagram [5 marks]
   G1(D)= D+D²
   G2(D)= 1+D
   G3(D)= 1+D+D²

Part-B Optical Communication [10 marks]

2. In which optical fiber do you have the intermodal dispersion absent? How can you design such a waveguide/optical fiber? Explain. [3 marks]
3. A student was asked to plot the modes of a planar waveguide whose core index is n_g and cladding index is n. While doing so, the student calculated the value of κ [kappa] and β [beta], and both of them were imaginary. Explain whether the propagation constant which the student obtained will result in a guided mode in the given waveguide. [Rather than a mere YES or NO, explain your argument clearly.] [3 marks]
4. An optical source has a spectral linewidth of $\Delta\lambda_0$ and a free space wavelength of λ_0. The output of this source is made to propagate through a dispersive medium of length L leading to temporal broadening of the pulse. Obtain an expression for this broadening. How can you minimize this broadening? [4 marks]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 19 Sept., 2023 Time: 1 Hour Total Marks: 30 No. of Students: 35

Quiz-1 Dept. of Avionics

Sub. Name: **Advanced Sensors & Interface Electronics** (B. Tech VII Semester Elective)

Answer All Questions

Question 1 **(7 Marks)**

(a) A sine wave of 1 V amplitude is given as the input to a bipolar 12- bit ADC whose reference voltage ($\pm V_R$) is $\pm$ 10 V. Find the SNR of the ADC at the given input level.

(b) Derive the relation between INL and DNL of an ADC. Briefly discuss an application in which INL should be considered as an important specification.

Question 2 **(6 Marks)**

A 3-bit sigma-delta ADC (with reference voltages: -1 V, 1 V) is given an input of 1/3 V. Find the voltages at different nodes of the circuit (at different clock cycles) and the digital-output of the ADC for this input.

Question 3 **(8 Marks)**

Draw the circuit diagram of a LOW-pass-filter based on universal active filter topology. Design this circuit for a natural frequency = 1 kHz, damping ratio = 1, pass-band gain = 1.5.

Question 4 **(5 Marks)**

Derive the expression for output voltage (V_O), in terms of the inputs V_1 and V_2, of the circuit given in Fig. 1. Assume that the frequency (say, f_C) of the clock signal (v_C) is sufficiently high when compared to the frequency of V_1 and V_2. Switches will be at position A when v_C is high and at position B, otherwise.

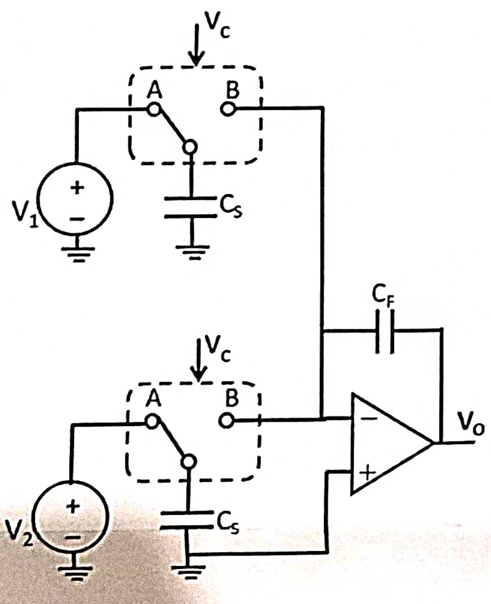


Fig. 1

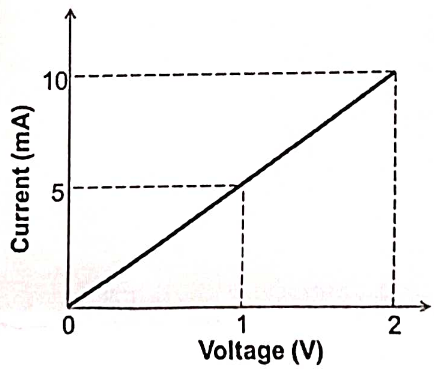


Fig. 2

Question 5 **(4 Marks)**

The approximate I-V characteristic of a diode is shown in Fig. 2. Draw its noise-equivalent model. Find the noise voltage across its terminals for a forward current of 5 mA and noise-bandwidth of 100 Hz.

****

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 31 Oct., 2023 Time: 1 Hour Total Marks: 30 No. of Students: 37

Quiz-2 Dept. of Avionics

Sub. Name: **Advanced Sensor & Interface Electronics,** Course code: **AV491**

Answer All Questions

Question 1 **(7 Marks)**

Consider a three-input summing amplifier realized using four 10 Ω resistors. The amplifier offers a gain of -1 to each input. Find the total output-noise at the amplifier output above 0.1 Hz.

Assume that OPAMP used has following specifications: (e_{nw} = 20 nV/√Hz, f_{CE} = 200 Hz, i_{nw} = 500 fA/√Hz, f_{CI} = 2 kHz, open-loop-gain = 10^6, gain-bandwidth-product = 1 MHz). Make valid approximations to simplify your solutions.

Question 2 **(7 Marks)**

Internal circuit of a Semiconductor-based Linear Temperature Sensor is shown in the figure. **Derive** and find the value of resistance R will give an overall-sensitivity of 1 μA/K for this sensor. Take Boltzmann constant k = 1.4×10^{-23} J/K.

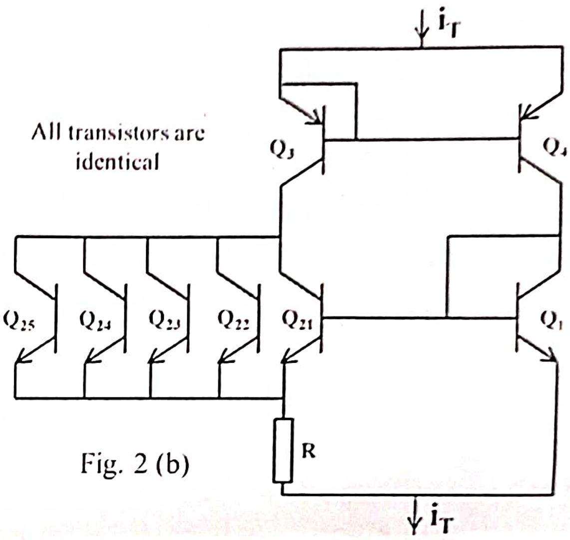


Fig. 2 (b)

Question 3 **(8 Marks)**

*Justify any **TWO** of the following statements. Use illustrative diagrams to aid your explanation.*

(a) A GMR sensor unit cannot be used for through-shaft angle measurement.

(b) Special-shaped electrode structures are required for capacitive sensing of liquid level of a conductive liquid.

(c) Two-wire measurement technique can be used for interfacing remotely-located resistive sensor and provide lead-wire compensation.

Question 4 **(8 Marks)**

(a) Briefly discuss how a phase-detector circuit (with 360° range) can be used for linearization of sine/cosine characteristics of a TMR angle sensor. Draw a neat circuit diagram of this phase detector.

(b) A piezoelectric crystal, acting as a force sensor, is connected using a cable to a voltmeter of purely resistive impedance of 10 MΩ. Crystal and Cable specifications are tabulated next:

Crystal specifications: Charge sensitivity to force = 2 pC N^{-1} Capacitance = 95 pF	Cable specifications: Capacitance = 5 pF Resistance = 1 GΩ

Obtain the transfer function of this force sensor system, and show that it follows a high-pass filter response.

****

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 11 Dec., 2023 Time: 3 Hours Total Marks: 100 No. of Students: 37

End-Sem Dept. of Avionics

Sub. No. AV491, Sub. Name: **Advanced Sensors and Interface Electronics**

Answer all questions in Part A. Answer any 5 of 6 questions in Part B.

Part A

Question 1: Fill the blanks. (10 Marks)

(1) Typical frequency span used in Impedance Plethysmography lies between _____ and _____

(2) GMR and TMR sensors works on the principle of ________ and ___________, respectively.

(3) In a Flash ADC, zero-offset error can be introduced due to __________, while gain-error can be introduced due to __________.

(4) Capacitive level sensing of a conductive liquid in a metallic tank requires ________ electrodes to be placed _______ the tank.

(5) A 5 kΩ resistor can be realized using a switched-capacitor circuit with capacitor of value _____ and clock signal of _____ frequency.

Question 2 (15 Marks)

The following table lists a number of sensing problems and some measurement electronics schemes. Choose the most feasible measurement scheme (from second column) for each sensing problem (given in first column). Draw Illustrative figures and briefly explain, in few sentences, for justifying your choice.

Sensing Problem	Measurement Electronics Techniques
1. Through-shaft angle sensing	A. Piezoelectric sensor probe at tank-top
2. Average temperature measurement of eight vertices of a room	B. Piezoelectric sensor probe at tank-bottom
3. Flow-rate measurement of impure fluids	C. Doppler Effect Ultrasonic Flowmeters
4. Welding Defects in Sub-surface regions	D. Twin Hall-Sensor-Based Ring Module
5. Non-invasive arrangement of measurement of water level in a tank.	E. High-frequency Eddy current Testing
	F. Set of Thermistors
	G. Giant Magneto-Resistance Sensor Unit
	H. Low frequency Eddy current Testing
	I. Transit time Ultrasonic Flowmeters
	J. Set of AD590 ICs

Part B (answer any 5 of 6 questions)

Question 3 (6 + 6 + 3 = 15 Marks)

(a) Draw the structure and equivalent circuit of a capacitive sensor probe that can be used for non-contact measurement of 50 Hz AC line voltage (v_X). Show that an analog signal conditioner, coupled with an FFT approach, can be used with the sensor probe to estimate the unknown voltage, without the effect of unwanted capacitances.

(b) Discuss how a PSD stage, followed by a dual-slope ADC, can be used to provide a digital count, proportional to the RMS value of v_X. Indicate the values of the integration time and clock time period that you will choose in the electronic system (note: frequency of v_X is 50 Hz).

(c) Explain the principle of twin-rod flux-gate magnetometer.

Question 4 (7 + 8 = 15 Marks)

(a) Design, and derive the output-expression of, a simple linearizing circuit that can be used for the typical GMR-based magnetometer (present in bridge-circuit form). Assume that opamps (OP07 ICs) and passive components are only available.

Draw the noise equivalent model of the above linearization circuit, assuming GMR as a noiseless sensor.

(b) Consider the relaxation-oscillator circuit given in Fig. 1. It is used to interface a remotely located resistive sensor (say, R_G). It is known that R_G can vary from 500 Ω to 600 Ω. Assume ON resistances of the switches as 100 Ω and the wire resistance of each wire is 50 Ω (i. e., $R_{W1} = R_{W2} = 50$ Ω). The circuit uses 1 kΩ resistors to implement other resistors of this circuit. Output saturation levels of OC is given as + 10 V and – 10 V.

(i) Mention the position of the switches (S_1, S_2, S_3) and compute the equivalent-input resistances of the integrator for different modes of operation of this circuit.

(ii) Mention the various measurements/actions/computations that should be done by the Timing and Logic Unit (TLU) so that effect of long connecting wires can be nullified.

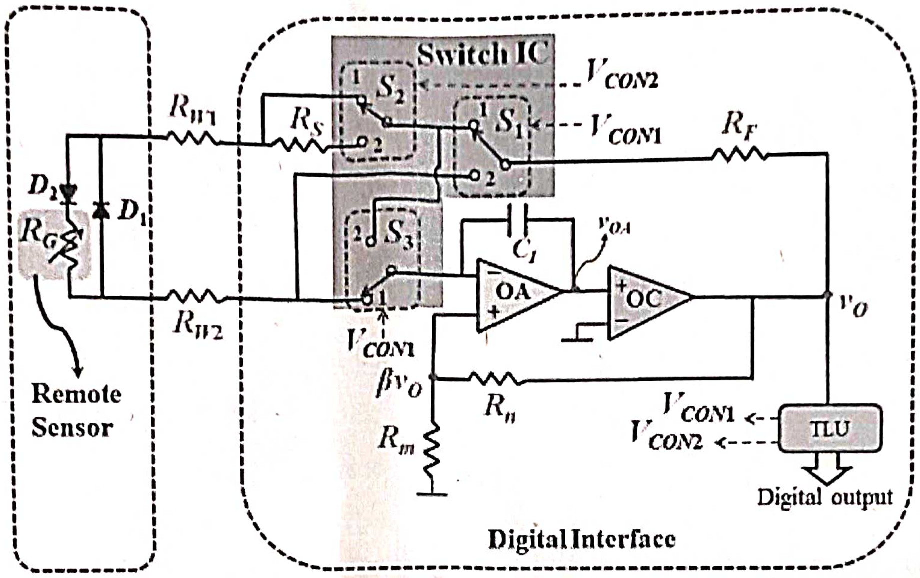


Fig. 1

Question 5 (6 + 5 + 4 = 15 Marks)

(a) *In a lead-2* ECG system, assume that the arm-electrode impedances are 110 kΩ and 90 kΩ, and ground-electrode impedance is 100 kΩ. Assume the availability of a 3-opamp instrumentation amplifier (IA) of CMRR = ∞. The differential ECG signal and common-mode signal at the input of the IA is, respectively, 10 μV and 30 mV. Determine the minimum input resistance of the IA that will ensure the SNR of 40 dB at its output.

(b) Write the transfer function of a second-order band reject filter (BRF). Draw the circuit diagram of BRF using Universal Active Filter approach.

(c) Discuss the circuit and an application of frequency-dependant negative resistance circuit.

Question 6 (10 + 5 = 15 Marks)

(a) A piezoelectric crystal has an effective mass of 10 g, stiffness of 10^{10} N m^{-1} and damping constant of 200 Ns m^{-1}. Electrical capacitance of crystal is 1000 pF and its charge to force sensitivity is 2 × 10^{-10} C N^{-1}.

(i) Incorporate the crystal into a Closed-Loop Oscillator System (CLOS) which can oscillate at the crystal parallel resonant frequency. Design the specifications of the amplifier that should be used in the CLOS. Draw **neatly labelled** circuits/waveforms/responses of the CLOS system to explain your design methodology.

(ii) Mention 1 practical application of the above CLOS system. Justify why the designed CLOS should be used in the application that you mentioned.

(b) Discuss the circuit and operation of a programmable-gain amplifier (PGA), whose gain varies as a linear function of a control voltage. Mention the conditions that should be satisfied for proper operation of the PGA.

Question 7

(8 + 4 + 3 = 15 Marks)

(a) Consider the following circuit diagram (Fig. 2) used to acquire Lead-1 ECG signal, where R = 22 kΩ, R_1 = 220 kΩ and R_2 = 330 kΩ. Assume that the impedance of the electrodes is equal to 20 kΩ. ± 15V dual power supplies are used. Then, determine the

(i) function of R_1, R_2, and the opamp, OA.

(ii) common-mode signal from the human body, assuming a nominal displacement current of 10 μA.

(iii) displacement-current in case the human subject gets exposed to a high common mode voltage.

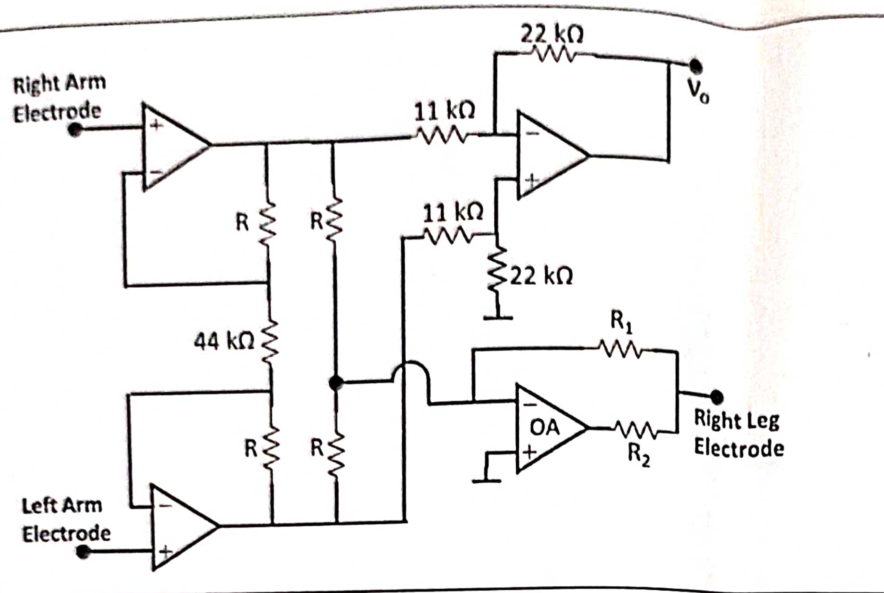


Fig. 2

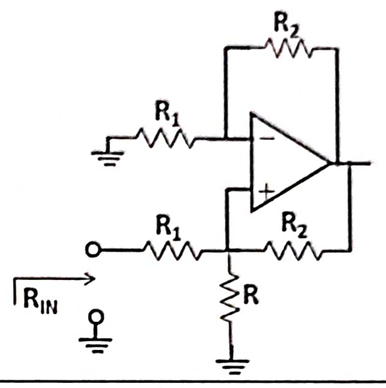


Fig. 3

(b) A transit time ultrasonic flowmeter is used to measure the velocity of a fluid in a pipe. Transit time during zero flow was found to be 1 ms. When there is a flow, the differential transit-time is found as 87 μs. The angle between the line connecting the transmitter/receiver and flow direction is 30°.
Find the velocity of the fluid. Velocity of the sound in the fluid is 500 m/s.

(c) Discuss how eddy-current principle can be used for non-destructive evaluation of metallic plates.

Question 8

(5 + 5 + 5 = 15 Marks)

(a) Find the expression for input resistance (R_{IN}) of the circuit shown in Fig. 3. Discuss and plot the variation of R_{IN} as R varies over the range $0 \le R \le 2R_1$.

(b) A triangular wave, v_S is applied to the circuit in Fig. 4. The circuit consists of an inverting amplifier and a threshold detector. The output of threshold detector becomes logic-high (say, 5 V) when the voltage v_o is greater than 2 V and remains logic-low (say, 0 V), otherwise. This detector has an output capacitance of 100 pF and its output-transition time is 1 ns. Predict the waveforms of v_o and the digital-output for the input, v_S. Assume circular copper wires (0.01 cm radius, lengths shown in Fig. 4) are used for realizing the circuit. Take resistivity of copper as 1.57 * 10^-8 Ωm.

(c) Draw the circuit-schematic of a sigma-delta ADC. Illustrate how the concepts of oversampling and noise shaping help in improving the SNR.

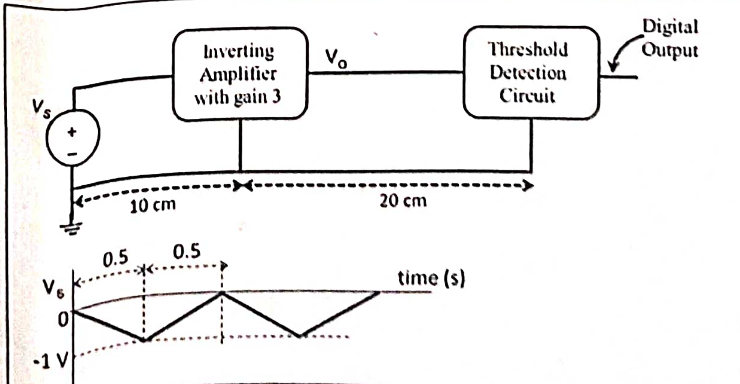


Fig. 4

****

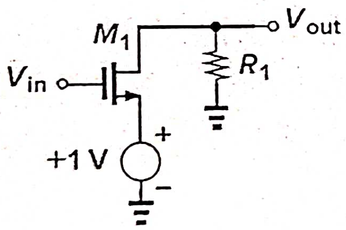
Indian Institute of Space Science and Technology
Department of Avionics
AVM 613 Analog VLSI Circuits
Quiz 1

Time: 1 hour **Max. marks:** 15

For all the questions, assume the following:
$V_{DD} = 3$V
$\mu_n C_{ox} = 1$mA$/V^2$. $V_{THN} = 0.7$V.
$\mu_p C_{ox} = 0.7$mA$/V^2$. $V_{THP} = -0.7$V.
$\lambda_N = 0.1$, $\lambda_P = 0.2$.
You can assume square law model for MOSFET operation.

1. A NMOS transistor is biased with a drain current of 50 μA. What is the W/L ratio required if the transconductance required is 0.5 mS? (2 marks)

2. Explain the behaviour of V_{out} as a function of V_{in} as V_{in} varies from 0 to V_{DD} for the following circuit. *Hint: You need to identify the regions of operation of the transistor at different V_{in}. Numerical values of V_{out} is not required. Just a descriptive explanation of how the voltages and currents would change and what are the points at which they start to change is sufficient.* (4 marks)

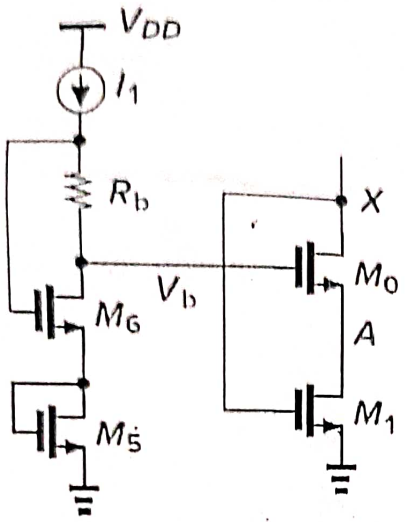


3. A metal-insulator-metal (MIM) capacitor offered by a particular foundry has pelgrom's co-efficient of $A_{\frac{\Delta C}{C}} = 5 \times 10^{-7}$. The density of the MIM cap is $1fF/\mu m^2$. The designer requires a value of 500fF. If the minimum dimension of each side is 10 μm, can you suggest a suitable W and L to achieve the required value of capacitance? What is the expected standard deviation ($\sigma_{\frac{\Delta C}{C}}$ due to random mismatch? (3 marks)

4. For the circuit shown below, assume all the transistors are identical and have a W/L = 10/0.5. Let $I_1 = 40$ μA and V_A is designed to be

$\lambda = 0$

250 mV. (6 marks)



(a) What is the V_{GS} of the transistors? (1 mark)

(b) What is the value of V_b required? (1 mark)

(c) What is the required value of R_b? (1 mark)

(d) Consider a cascode current source biased using V_X and V_b for the bottom transistor and the cascode transistor respectively. Derive an expression for the output impedance of the cascode current source and calculate it if the same current ($40\mu A$) flows in the current source as well? (3 marks)

Indian Institute of Space Science and Technology
Department of Avionics
AVM 613 Analog VLSI Circuits
Quiz 2

Time: 1 hour **Max. marks:** 15

For all the questions, assume the following:

$V_{DD} = 1.8V$

$\mu_n C_{ox} = 0.5mA/V^2$, $V_{THN} = 0.35V$

$\mu_p C_{ox} = 0.4mA/V^2$, $V_{THP} = -0.35V$

$\lambda_N = 0.1$, $\lambda_P = 0.09$.

You can assume square law model for MOSFET operation. Some formulae for use in your calculations are provided below:

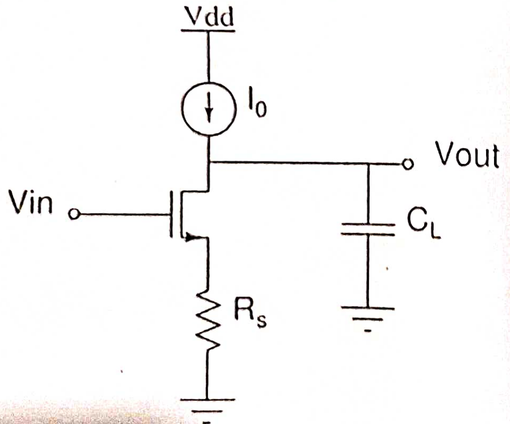
$I_D = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2$

$g_m = \mu C_{ox}(W/L)(V_{GS} - V_{TH}) = \sqrt{2I_D \mu C_{ox}(W/L)} = \frac{2I_D}{(V_{GS}-V_{TH})}$

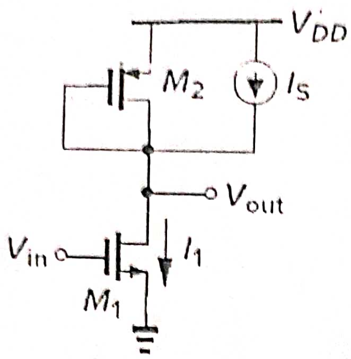
$r_0 = \frac{1}{\lambda I_D}$

Answer all the following questions:

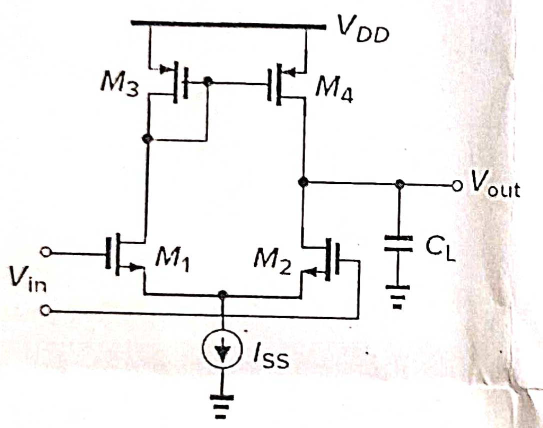
1. For the circuit shown below, derive the effective transconductance, by drawing and analyzing the small signal equivalent circuit. Include the effect of channel length modulation and body effect. (4 marks)



2. For the circuit shown below, calculate the gain, output impedance and bandwidth, if a load capacitance $C_L = 5pF$ is connected to the output. The current source $I_S = 0.75I_1$. $I_S = 75\mu A$. $(W/L)_1 = \frac{1\mu m}{180nm}$ and $(W/L)_2 = \frac{0.5\mu m}{180nm}$ Assume $\lambda = 0$. (4 marks)



3. Consider the OTA shown below. Let $I_{SS} = 0.5$ mA. $C_L = 2$pF.



(a) If the required transconductance is 0.75mS, what is the (W/L) of M1 and M2? (1 mark)

(b) Calculate the output impedance. (1 mark)

(c) Calculate the gain of the OTA. (1 mark)

(d) If the current source I_{SS} requires a minimum of 0.2V across it, what is the minimum input common mode voltage requried? (1 mark)

(e) Calculate the slew rate of this OTA. (1 mark)

(f) Calculate the unity gain frequency of this OTA. (1 mark)

(g) Derive the expression for the input referred noise voltage PSD, including both thermal and flicker noise contributions. (1 mark)

Indian Institute of Space Science and Technology
Department of Avionics
AVM 613 Analog VLSI Circuits
End Semester Examination 2023

Time: 3 hours **Max. marks:** 30

For all the questions, assume the following:

$V_{DD} = 1.8$V

$\mu_n C_{ox} = 0.5\text{mA}/V^2$, $V_{THN} = 0.35$V

$\mu_p C_{ox} = 0.4\text{mA}/V^2$, $V_{THP} = -0.35$V

$\lambda_N = 0.1$, $\lambda_P = 0.1$.

You can assume square law model for MOSFET operation. Some formulae for use in your calculations are provided below:

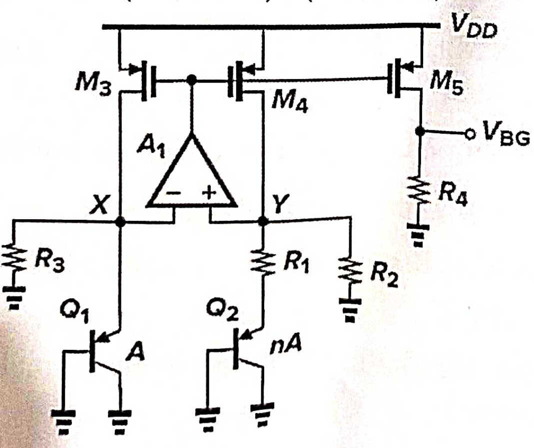
$I_D = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2$

$g_m = \mu C_{ox}(W/L)(V_{GS} - V_{TH}) = \sqrt{2 I_D \mu C_{ox}(W/L)} = \frac{2I_D}{(V_{GS}-V_{TH})}$

$r_0 = \frac{1}{\lambda I_D}$

Answer all the following questions:

1. Consider the circuit shown below. Let V_T = 25mV. n=31. $|V_{BE1}|$ = 0.8V. R1=2KΩ, R2 = R3 = 4KΩ, R4 = 2KΩ. For the first four questions, you can provide the answers considering the circuit at room temperature (T=300K). (5 marks)



   (a) In steady state, what is the voltage across R1? (1 mark)

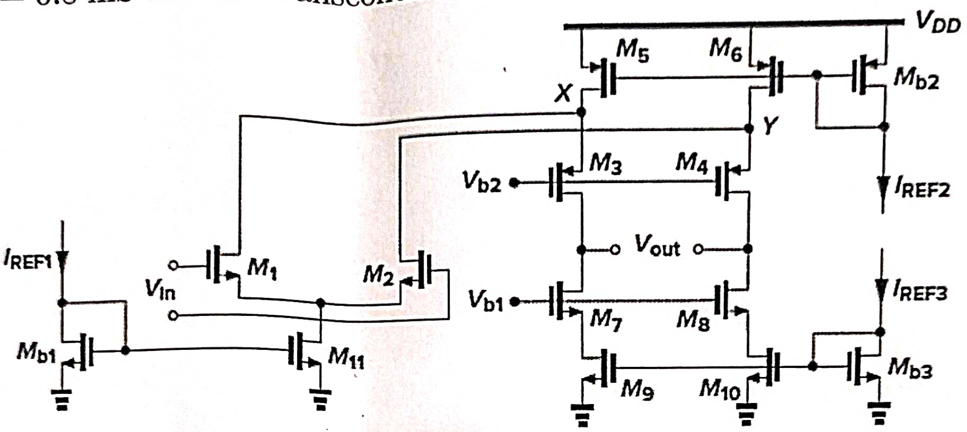
   (b) What is the current through resistors R2, R3? (1 mark)

   (c) What is the current through M4? (1 mark)

   (d) What is the bandgap boltage V_{BG}? (1 mark)

(e) What is the nature of the current through R1 and R2 (PTAT/ CTAT/ independent of temperature)? (1 mark)

2. Consider a folded cascode OTA shown in the figure. Let Iref1=Iref2=Iref3 $= 10\mu A$. You can assume square-law equations for calculations and neglect channel length modulation for the first few questions till it is required explicitly. The transconductance of M3, M4, M7, M8, M9, M10 = 0.5 mS and the transconductance of M5, M6 = 1 mS.(12 marks)



(a) If the minimum voltage required across M11 is 200mV, and $V_{CM,min}$ = 0.6V, what is the current through M1,2 required for a transconductance of 2mS? (2 marks)

(b) What is the W/L ratio of M1,2 ? (1 mark)

(c) The current through M9,10 is $40\mu A$. What is the ratio of $(W/L)_{5,6}$ to $(W/L)_{Mb2}$? (1 mark)

(d) What is the output impedance of the OTA? (3 marks)

(e) What is the open loop gain? (1 mark)

(f) What is the bandwidth if a load capacitance of 2pF is connected at the output? (1 mark)

(g) Write the expression for the input referred noise, including flicker noise ($\overline{V^2_{n,in}}$). (3 marks)

3. A two-stage opamp is being stabilized through miller compensation. Let ω_{p1} and ω_{p2} be the output poles of the 1^{st} and 2^{nd} stages respectively. Also, let $\omega_{p1} < \omega_{p2}$ In the s-plane, show how the poles move when miller compensation is used. (2 marks)

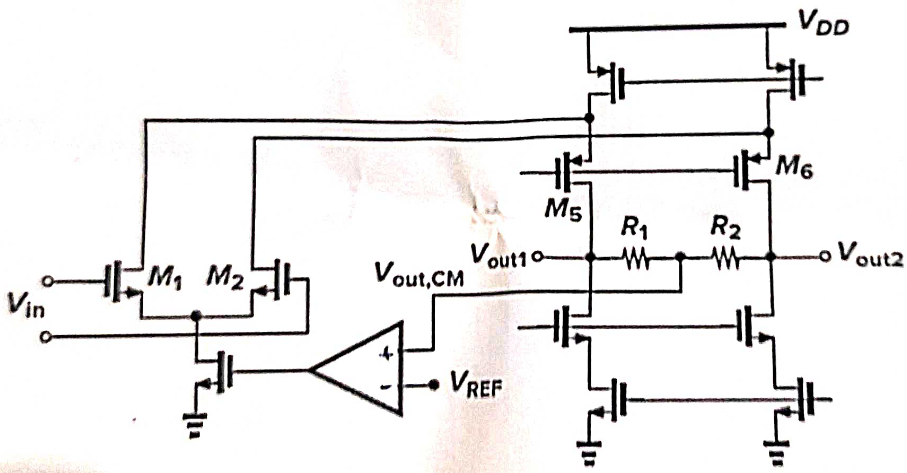
4. An engineer is working on improving the stability of an opamp. When a frequency-independent feedback network with a β of 0.5 is used with

the opamp in negative feedback, the phase margin is observed to be 50°. How do you think the phase margin would change if the feedback factor β is reduced? Why? (2 marks)

5. An opamp is used in negative feedback. The bode plot of the loop gain ($A\beta$) shows that the phase margin is 25°. For the closed loop circuit, what will be the magnitude of peaking at the unity gain frequency in the frequency response? (3 marks)

6. An fully differential opamp with rail to rail output is required to be designed. The designer has employed a simple 5-stage OTA as the first stage. Can you help him complete the design with a second stage that can provide a rail-to-rail output swing? For a differential sinusoidal input, draw the waveforms at different nodes of the second stage. (3 marks)

7. Consider the circuit below. (3 marks)



(a) Identify the correct polarity of the opamp used for CMFB. (1 mark)

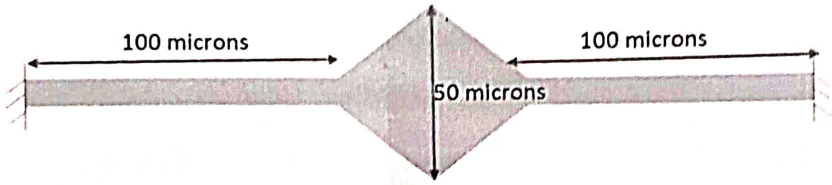
(b) Write the expression of the gain of the folded cascode opamp, and comment on what is the impact of the common mode sensing resistors. (2 marks)

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Quiz-2 **AVM 612 Introduction to MEMS** **26th Oct 2023**

Marks (20)

Q.1. A MEMS Micromirror architecture is as shown below with the micromirror suspended between two torsional bars of length 100 microns and square cross section with thickness of 2 microns. Find the amount of force (Z axis) to be applied at one of the vertices of the micromirror structure to bring a tilt of 5 degree about the axis of torsional bars:-. The transverse dimension of the micromirror is 50 microns as indicated in the diagram (Planar layout of the EMMS device). Assume Poisson's ratio of 0.25 and 150 GPa as the value for Young's modulus for the structural material of torsional bar. [*Note: Ignore the bending or deformation of the mirror segment.*]

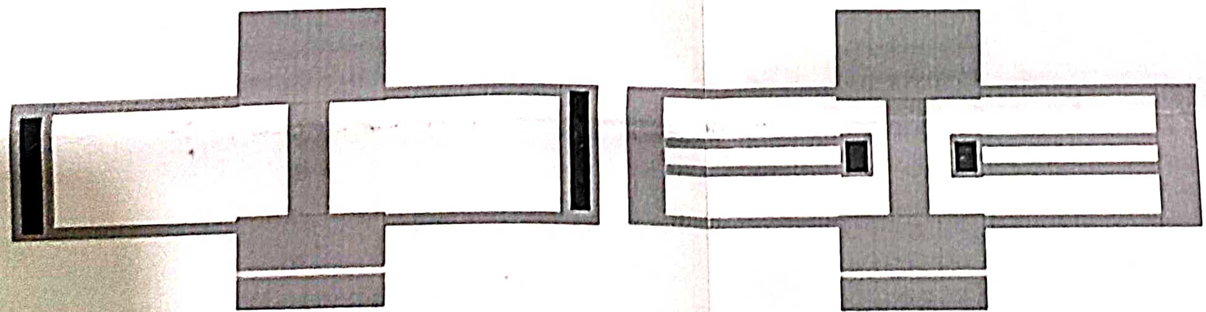


[5]

Q.2. [A] Consider a single crystal silicon-based MEMS piezoresitive MEMS pressure sensor. With the help of Stress profile for a MEMS square membrane pressure sensor Indicate location for placement of piezoresistor. [B] What difference in the scheme if the piezoresistor is polysilicon or any other non-crystalline thin film in place of single crystal silicon. **[4]**

Q.3. Consider the following MEMS devices of (1) Quad flexured MEMS device and (2) Folded beam flexured MEMS device. Compare the stiffnesses of these using suitable quick derivation.

Define cross axis sensitivity and scale factor for these sensors. Can you compare and discuss their performances in terms of prime axis sensitivity and cross axis sensitivities. Assume square cross section for beams and similar proof masses for both the structures. The 'black shaded' regions are the anchored (Fixed) regions. **[8]**



Q.4. Consider a MEMS sensor (cantilever with end mass) packaged in such a way that the damping ratio is maintained at 0.7. The resonant frequency of the sensor is 2 kHz. Suppose the static displacement of the mass of the sensor for an equivalent force corresponding to 2g acceleration is 2 microns. Comment on the maximum displacement of the mass when the sensor is subjected to a vibration of amplitude 2g and frequency 100 Hz. **[3]**

Equations

Displacement and Stress in Fixed Free beam (Case- End point loaded beam)

$$w(x) = \frac{F(3L-x)x^2}{6EI}$$

$$T(x) = \frac{Fh(L-x)}{2I}$$

Displacement and Stress on top of Fixed Guided beam (case -Beams holding a mass of Mass M)

$$w(x) = \frac{Mg}{Ebh^3}x^2\left(\frac{3}{2}a_1 - x\right)$$

$$T_{max} = \frac{3a_1}{2bh^2}Mg$$

Diaphragm (Rectangular)

$$\sigma_x(x) = \frac{3P}{h^2}\left(x^2 - 2ax + \frac{2}{3}a^2\right)$$

Torsional bar

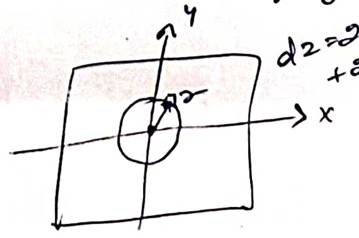
$$\phi = \frac{TL}{GJ_{eq}}$$

$$J_{eq} = \frac{A^4}{4\pi^2 J}$$

$r(x,y) = \sqrt{x^2+y^2}$

$x^2+y^2 = z^2$

$dz = 2x\,dx + 2y\,dy$



$$\iint r^2\, dx\, dy$$

$$= \iint \sqrt{x^2+y^2}\, dx\, dy$$

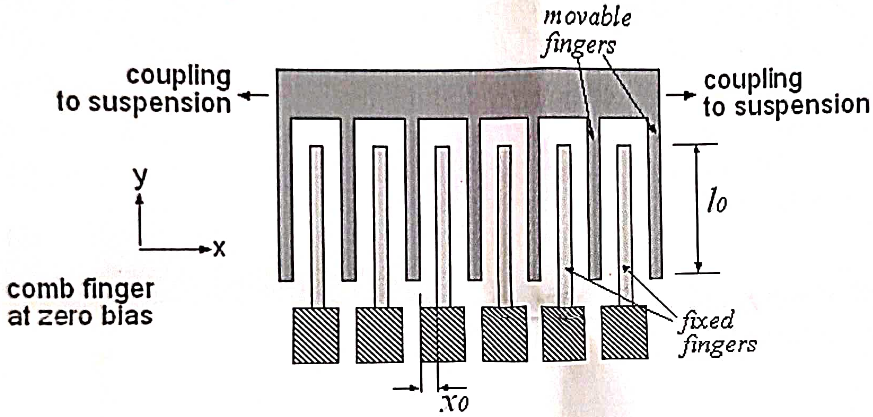
$$= \iint \sqrt{2}$$

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM
M-Tech VLSI and Microsystems
End Semester Examination

Course Name: Introduction to MEMS **Code:** AVM 612
Monday, November 30, 2023 **Marks:** 50

i. *Questions are self-explanatory. Please make suitable assumptions and mention wherever necessary.*

1. Consider a longitudinal comb drive sensor. Derive an analytical expression of capacitive sensitivity with respect to changes in the overlapped distance l_o for this device and prove that the sensitivity is independent of overlap distance. Discuss two strategies for increasing the sensitivity. Compare the sensitivity with transverse comb drive sensor.

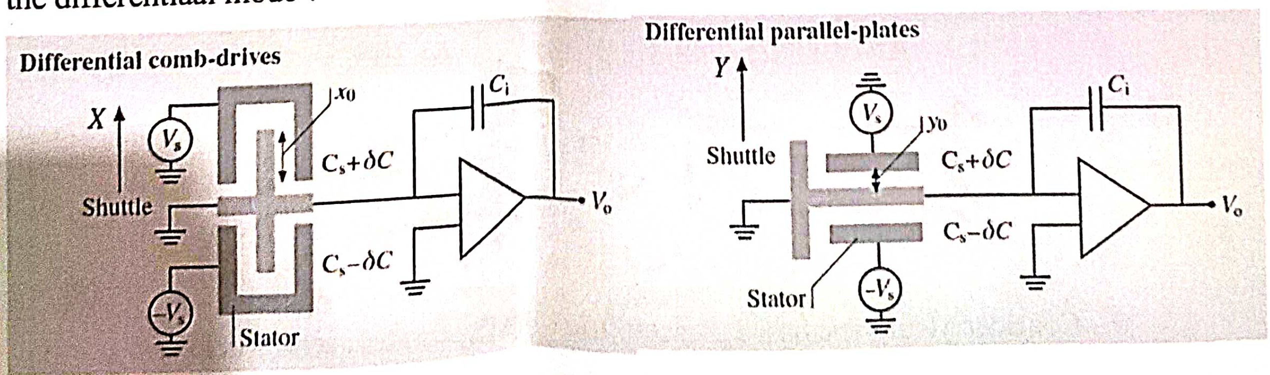


[10]

2. Consider the electrostaic position sensors that could be realized with differential comb drives and differential parallel plates.

(A)Discuss the output response for both these configurtion and compare their performances.

(B) What is the major design constraint if the parallel plate configuration is not used in the differentiaal mode ? **[10]**

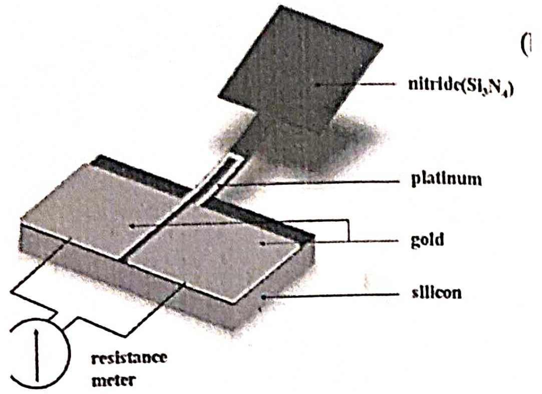


3. Consider a MEMS airflow sensor relized with 'Piezoresistive' Upwards-Bent Cantilever Beams. The schemtic is provided below.

[A]Discuss the working principle of such a device

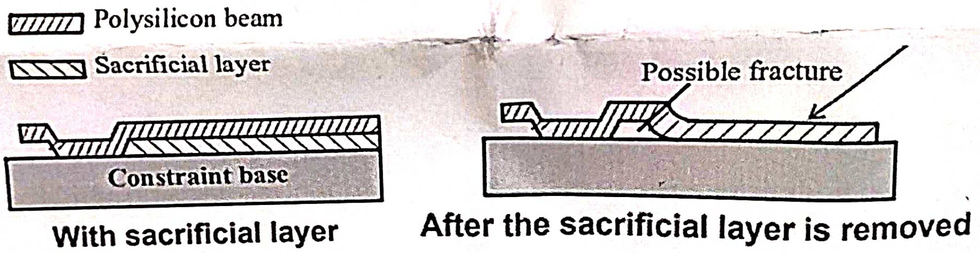
[B] Suppose the piezoresistor is doped silicon itelf in place of platinum (<110> oriented). How can we calculate the gauge factor of a piezoresistor from its elastic property and piezoresistive coefficient ?

[C] process integration scheme to realize this 'Piezoresistive Upwards-Bent Cantilever Beam'.



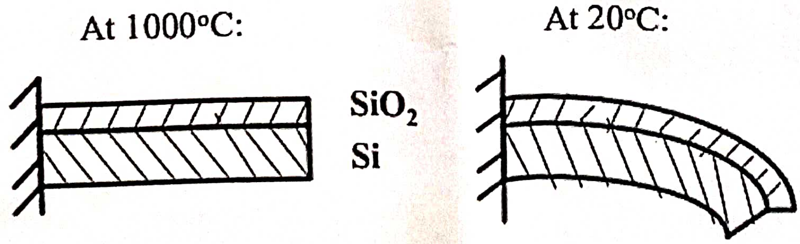
IMP: Illustrate the process integrtion scheme in 2/3 columns (1. Cross section schematic 2. Msk lyout/pttern for that lyer 3. Brief description of each step) **[10]**

4. Consider MEMS surface micromachining process to realize a microcantilever device with poly-si sa structural layer. During the process, the following schematic indicates a process constraint which can even lead to fracture of the suspended device. Discuss this issue in surface micromchining. (b) How can we mitigate this issue and get fuly released MEMS device ? **[5]**



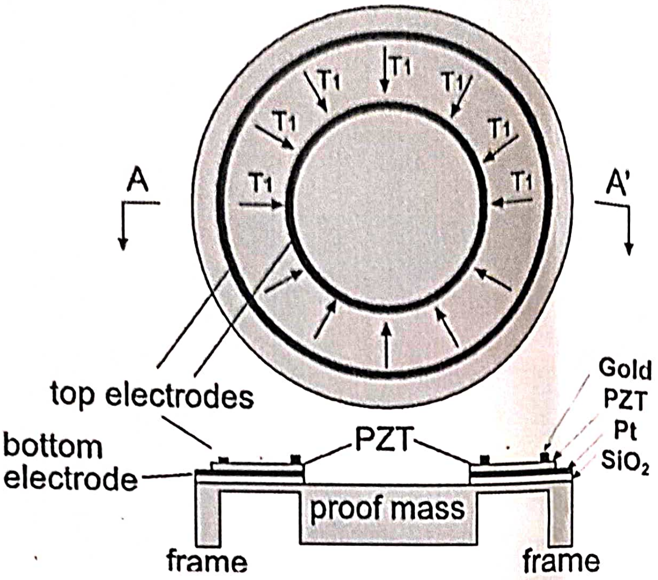
the following MEMS electrostatic force sensor. e)

5. Consider a microcntilever with composite structure s shown below:-. During the process of therml oxidtion ws crried out to relize this stck. The device ws found to be curled down. Discuss the cause for this using suitable concepts.



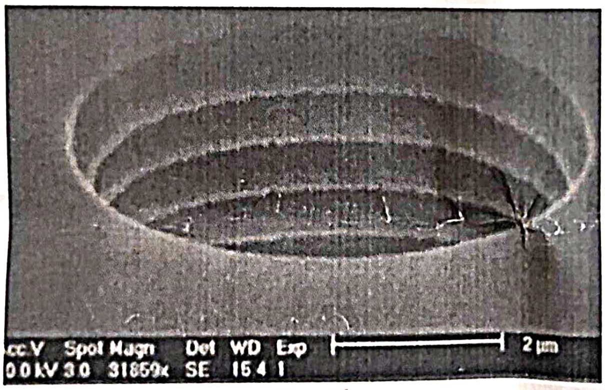
[5]

6. Consider Membrane based piezoelectric MEMS vibration sensor below.
   (a) Draw a diagram illustrating the **sign of stress** one arbitrary cross section when the proof mass is bent down.
   (b) (b) As a process integration engineer, show the cross section of the device (Only device. No need to discuss process) in case you are having the option.



[5]

7. Consider via formed in Silicon using the process of DRIE . You observe ring like structures within the via (not a proper cylindrical via with smooth sidewall). Disucss the cause of this using the process of DRIE .



[5]

Essential Parameters and Equations

Piezoresistive properties of C-Si

TABLE 6.1 Table of piezoresistivity components for single crystal silicon under certain doping values.

Piezoresistance coefficient (10^{-11} Pa^{-1})	n-type (resistivity = 11.7 Ω cm)	p-type (resistivity = 7.8 Ω cm)
π_{11}	−102.2	6.6
π_{12}	53.4	−1.1
π_{44}	−13.6	138.1

TABLE 6.2 Formula for transverse and longitudinal gauge factors for various commonly encountered resistor configurations.

Direction of strain	Direction of current	Configuration	Piezoresistive coefficient
<100>	<100>	Longitudinal	π_{11}
<100>	<010>	Transverse	π_{12}
<110>	<110>	Longitudinal	$(\pi_{11} + \pi_{12} + \pi_{44})/2$
<110>	<1$\bar{1}$0>	Transverse	$(\pi_{11} + \pi_{12} - \pi_{44})/2$
<111>	<111>	Longitudinal	$(\pi_{11} + 2\pi_{12} + 2\pi_{44})/2$

Table 8.1. Mechanical property data for selected microelectronic materials. (Sources: [52, 54, 55, 56])

Material	ρ_m kg/m^3	E GPa	ν	α_T μstrain/K	σ_o MPa	Comment
Silicon	2331	page 193		2.8		Cubic
α-Quartz	2648	page 573		7.4, 13.6		Hexagonal
Quartz (fused)	2196	72	.16	0.5		Amorphous
Polysilicon	2331	160	~0.2	2.8	Varies	Random grains
Silicon dioxide	2200	69	.17	0.7	-300	Thermal
Silicon nitride	3170	270	.27	2.3	+1100	Stoichiometric
	3000	270	.27	2.3	-50 – +800	Silicon rich
Aluminum	2697	70	~.3	23.1	varies	Polycrystalline

Q: Write about device Schematic & Analysis of Term Paper? [5]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM 695 547

Quiz 1
PH638-Quantum Computation

15.09.2023 Time: 09:00am-10.00am Maximum Marks: 30

---

1. Derive the matrix representation of the SWAP gate and Controlled-SWAP gate. Find the matrix corresponding to $Y \otimes Z$. [10]
2. Describe a quantum circuit for teleporting a qubit. [10]
3. Derive the Bloch sphere representation of a qubit. [10]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM 695 547

Quiz II
PH638-Quantum Computation

09.11.2023 **Time: 09:00am-10.00am** **Maximum Marks: 30**

---

1. Draw a quantum circuit, which implements the general Deutsch-Jozsa algorithm. Explain all steps of the algorithm. [10]

2. Find the outputs of Bell state measurement (the circuit includes a CNOT gate, Hadamard gate, followed by two-qubit measurements) of any of the Bell states. [10]

3. Derive the post-measurement state and measurement probability in projective or von-Neumann measurements. Define the average value of the measurement observable using measurement probability in projective measurement. [10]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM 695 547

End Semester Examination
PH638-Quantum Computation

05.12.2023 | Time: 09:30 am-12.30 pm | Maximum Marks: 50

---

1. Draw an explicit circuit for a two-qubit quantum Fourier transform and calculate the two-qubit quantum Fourier transform. [10]

2. Draw a quantum circuit, which implements quantum phase estimation algorithm. Explain all steps of the algorithm. [10]

3. Write a step-by-step description of Shor's algorithm. Illustrate Shor's algorithm for finding the factors of the number 15. [10]

4. Given the definitions of $G, |u\rangle, |\omega\rangle, |s\rangle$, and $|\psi_1\rangle = G|s\rangle$ as discussed in the class, demonstrate the concerning k action of the Grover operator G on the state $|s\rangle$:

$$G^k|s\rangle = \cos\left[(2k+1)\frac{\theta}{2}\right]|u\rangle + \sin\left[(2k+1)\frac{\theta}{2}\right]|\omega\rangle .$$

Find the maximum number of iterations $k_{\max}$ corresponding to the probability $p(\omega) \approx 1$. [10]

5. Provide examples for uncorrelated and correlated quantum systems. Justify. [10]

00 11
1 0 1
0 0 = 0
0 0 0
0 1 1

01 10
0 0 0
1 0 1
0 1 1
0 0 0

$\frac{4\pi}{M}k = n\pi$

$k = \frac{nM}{4}$

$\frac{4\pi}{M}$ ~~$2 \sin(4\pi k) \cos(4\pi k)$~~
~~$2 \sin\left(\frac{4\pi k}{M}\right) \cos\left(\frac{4\pi k}{M}\right)$~~

$= M^2$

$|\beta_{00}\rangle\langle\beta_{00}| + |\beta_{11}\rangle\langle\beta$
$|00\rangle + |11\rangle)(\langle 00| +$
$+ |10\rangle)(\langle$

Department of Avionics
Indian Institute of Space Science and Technology
AC Motor Drives (AVP 612)
Quiz 1

Date: 26 Sep 2023
Max. marks: 15

All questions are compulsory. Make reasonable assumptions where necessary. Spend time thinking about the question before starting to answer. Write the answers clearly and legibly so that they can be graded.

1. Consider a three-phase three-level inverter with a total DC link voltage of 600V. The pole voltage of A phase V_a is shown in Fig. 1.

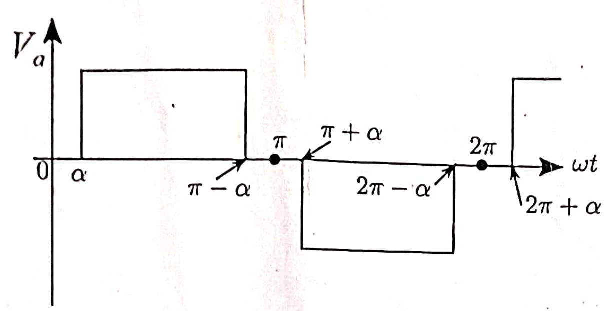


Figure 1: Waveform for Question 1

   (a) (3 points) What is the peak phase fundamental voltage?

   (b) (3 points) Draw the voltage space vector diagram for the converter, label all space vector locations and corresponding pole-voltage levels.

   (c) (3 points) Write down the sequence of space vectors that would be applied by the inverter if A phase is switched as shown in Fig. 1. Assume $\alpha = 5°$.

Total for Question 1: 9

2. Consider a three-phase three-level inverter with a total DC link voltage of 600V. The converter is operated with space vector PWM with a sampling time of $T_s = 100\mu s$. The reference space vector $\overline{V_r} = 150\angle 90°$ should be generated by the converter.

   (a) (3 points) Identify the sector, the smallest triangle and space vector locations that have to be switched to generate $\overline{V_r}$ in averaged sense over T_s duration.

   (b) (3 points) Find the dwell times for vectors identified in the previous part of the question.

Total for Question 2: 6

Department of Avionics
Indian Institute of Space Science and Technology
AC Motor Drives (AVP 612)
Quiz 2

Date: 6 Nov 2023
Max. marks: 15

All questions are compulsory. Make reasonable assumptions where necessary. Spend time thinking about the question before starting to answer. Write the answers clearly and legibly so that they can be graded.

1. Consider an 3-phase squirrel-cage induction motor with the following parameters.
   - Stator Resistance R_s
   - Stator leakage inductance L_s
   - Mutual inductance between stator and rotor M
   - Rotor resistance R_r
   - Rotor leakage inductance L_r
   - Moment of inertia J
   - Viscous friction B

   Voltages $\begin{bmatrix} v_a & v_b & v_c \end{bmatrix}$ are applied to three phases of the motor and the motor draws currents $\begin{bmatrix} i_a & i_b & i_c \end{bmatrix}$ through the respective phases. The motor is applied a load torque of T_L at the shaft and rotates at a speed ω_r.

   (a) (3 points) Draw the reference axis relating abc reference frame, $\alpha-\beta$ stationary reference frame, $d-q$ synchronous reference frame and rotor reference frame. Write equations relating applied voltages in all the above mentioned reference frames.

   (b) (3 points) Derive dynamic model relating applied voltages and currents drawn by the motor in synchronous reference frame.

   (c) (2 points) Derive equations governing dynamics between motor currents and speed of the motor.

Total for Question 1: 8

2. A clock using a synchronous machine is designed to run accurately when connected to the 50 Hz electric grid. The clock shows correct time at 7:00 AM. From 7:00 AM to 1:00 PM, the average frequency is 49.95 Hz and from 1:00 PM to 6:00 PM is 49.90 Hz.

   (a) (2 points) What must be the average frequency for the remainder of the 24 hours such that the clock will be correct again at 7:00 AM?

   (b) (1 point) By how much is the clock incorrect at 6:00 PM?

Total for Question 2: 3

3. A 6-pole, 50 Hz, 3-phase induction motor running at full load develops 162 Nm of useful torque. At this condition, the rotor current completed 90 cycles per minute.

   (a) (2 points) Calculate the power of the motor in hp.

   (b) (2 points) Calculate the rotor copper loss if 13.5 Nm is the torque lost due to friction.

Total for Question 3: 4

4-12 = 6 hot