INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 19 Sept., 2022 Time: 1 Hour Total Marks: 15 No. of Students: 47

Quiz-1 Dept. of Avionics

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

Answer All Questions

Question 1

Fill in the blanks. Write the final answer in the script. **(3 Marks)**

(i) SNR of a 12-bit ADC (reference voltage = 3.3 V), when applied with a input of 1.1 V is _____

(ii) Harmonic-content in the output of an ADC increases with _____ in amplitude of the input.

(iii) In a Flash ADC, offset error can be introduced due to _____.

(iv) Dynamic range of 8-bit unipolar ADC is _____.

(v) An 8-bit ADC, oversampled by a factor of 16, can improve the effective number of bits by _____.

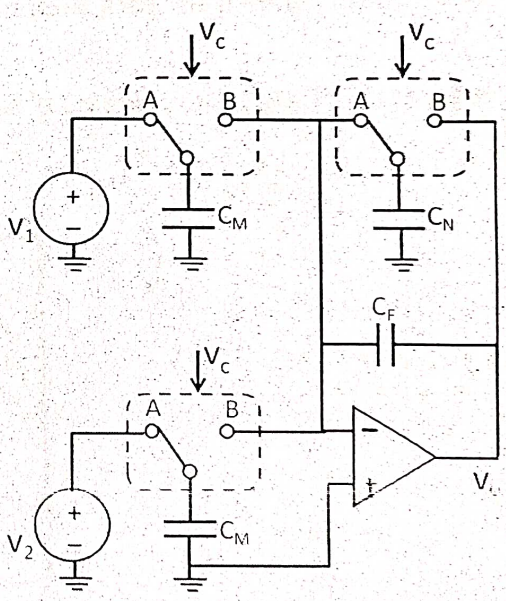
(vi) Second order All pass response can be obtained with the help of a _____ filter response.

Question 2 **(4 Marks)**

Draw the circuit of a HIGH-pass-filter circuit based on universal active filter topology. Design this circuit for a cut-off frequency = 1 kHz, damping ratio = 1, pass-band gain = 0 dB.

Question 3 **(3 Marks)**

Derive the expression for output voltage (V_O), in terms of the inputs V_1 and V_2, of the circuit given in right. 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.



Question 4 **(2 Marks)**

Consider a 10 kΩ resistor at room temperature (300 Kelvin). Find its RMS noise voltage over a range of (10 Hz, 1000 Hz)

Question 5 **(3 Marks)**

Consider a 3-bit ADC having a reference voltage of 8 V and power-supply voltage of 10 V. The DNL associated with the eight codes (in their increasing order) of this 3-bit ADC are specified as 0.2 V, 0.1 V, 0.2 V, -0.5 V, 1.2 V, -0.1 V, 0.2 V, -0.4 V. Compute its INL (in V)

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INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 27 Oct., 2022 Time: 1 Hour Total Marks: 15 No. of Students: 48

Quiz-2 Dept. of Avionics

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

Answer All Questions

Question 1 **(4 Marks)**

Design a 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. Derive the output-expression of the circuit.

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

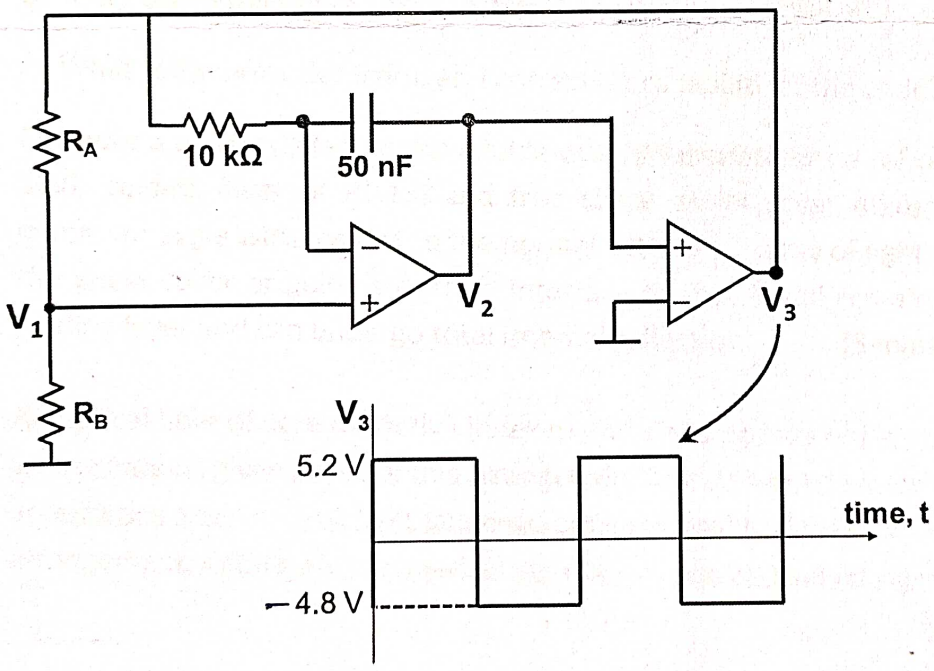
Question 2 **(5 Marks)**

Consider the circuit shown in the following figure. Here, R_B is a resistive sensor and R_A is a fixed resistance. Assume ideal opamps. The waveform at the node $\mathbf{V_3}$ is shown in the figure.

(a) Determine the ON and OFF time of the signal, V_3 if $R_B = 1.25 \times R_A$.

(b) Plot the steady-state waveform at the node $\mathbf{V_2}$, in the above condition. Mark the peak value and relevant time durations of the waveform.

(c) Discuss how this circuit technique could be adapted for measurement of a sensor R_B, present at a remote location.



Question 3 **(2 Marks)**

(a) Discuss how a charge amplifier circuit can be employed to measure sensor capacitances, while nullifying the effect of parasitic elements.

(b) Give reason on why a GMR sensor unit cannot be used for through-shaft angle measurement.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
DEPARTMENT OF AVIONICS

Satellite and Optical Communication (AV412)

B.Tech Electronics and Communication, **Quiz 1**

Answer all questions. Every steps of any derivations must be logically explained.

Date: 13/09/22, Total Mark: 15

1. Neo receives a 7-bit string, $[D_1\ D_2\ D_3\ D_4\ P_1\ P_2\ P_3]$ from Morpheus, sent using a code C, with parity equations

$$P_1 = D_1 + D_2 + D_3$$

$$P_2 = D_1 + D_2 + D_4$$

$$P_3 = D_1 + D_3 + D_4$$

   a. Write down the generator matrix G, for C. [1.5 marks]

   b. Write down the parity check matrix H, for C. [1.5 marks]

   c. What is the error detection and correction capability of the code? [2 marks]

2. Consider a planar dielectric waveguide whose substrate has a refractive index (RI) of 1.56, guiding layer of RI=1.6 and free space as its cover material. Calculate the minimum angle with respect to the normal with which a ray of light can be incident at the guide-cover or guide-substrate interface so that it still remains confined to the guiding layer and can undergo total internal reflection. [5 marks]

3. An optical fiber of core refractive index n_1 and cladding index n_2 is placed in a medium whose index is given by n. For this arrangement, obtain an expression for the maximum acceptance angle so that light launched can undergo total internal reflection. For this arrangement, define what numerical aperture is, and explain its significance. [5 marks]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B.Tech Quiz-II – October 2021

AV 412 – Satellite and Optical Communication

Time: 1 hour Date: 20/10/2022 Max. Marks: 15

Answer the following

1. Verify that the generator polynomial $g(X) = 1 + X + X^2 + X^3$ generates a binary cyclic code C(8, 5) and determine the code vector for the message vector $m = (10101)$ in systematic form using the encoding circuit. [4]

2. Determine the length and technique to correct the burst error using cyclic codes. [3]

3. Determine the generate sequence and the time domain equation for the encoder in Figure 1. [3]

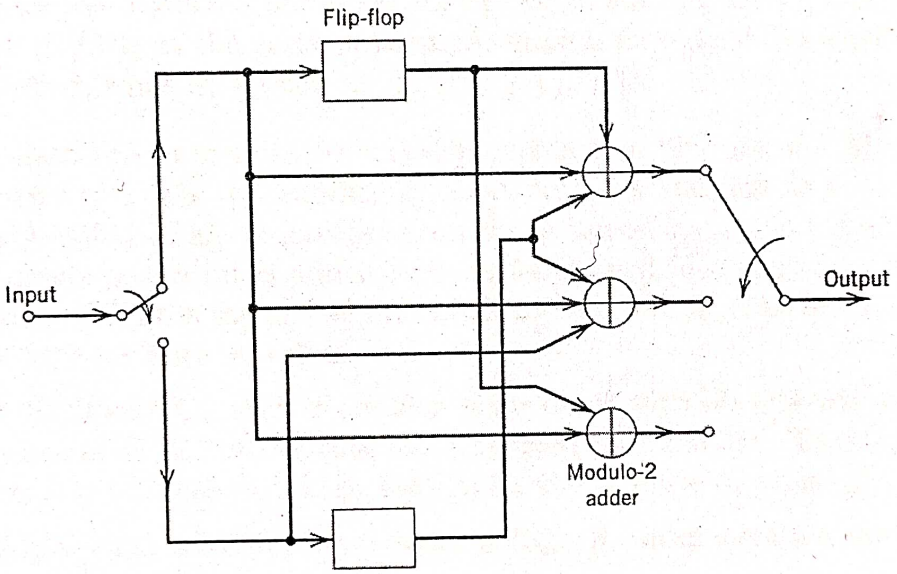


Figure 1:

4. Prove that, by using a laser diode, chromatic dispersion can be the least in optical fibers. [3.5]

5. Optical power of 5 mW coupled into an optical fiber reduces to 3.8 mW after propagating through a distance of 10 km. Determine the attenuation coefficient α of this fiber in dB/km. [1.5]

End of exam.

B.Tech End Semester Exam – November 2022

SC19B101

AV 412 – Satellite and Optical Communication

Time: 3 hour Date: 29/11/2022 Max. Marks: 100

Please answer Part A and Part B in separate sheets

Part A-Satellite Communication

1. A receiver front end (RF front end) has a noise figure of 10 dB, a gain of 80 dB, and a bandwidth of 6 MHz. The input signal power is 10^{-11}W. Assume that the line is lossless and the antenna temperature is 150 K.

   (i) Find system noise temperature, $(C/N)_{input}, (C/N)_{output}$ [3]

   (ii) If a preamplifier is used before the receiver front end with a noise figure of 3 dB, a gain of 13 dB. Find the improvement in $(C/N)_{output}$ [2]

   (iii) If a coaxial feeder is connected between the preamplifier and receiver front end and has a loss of 2 dB, calculate the system noise temperature [2]

   (iv) If a feeder cable is connected between the antenna and the preamplifier, calculate the system noise temperature and Comment on the result. [3]

2. (i) Draw the block-level diagram for the bent-pipe and regenerative transponder. [4]

   (ii) Derive the overall C/N ratio for bent-pipe transponder. [3]

   (iii) The following parameters apply to a satellite downlink: EIRP 22.5 dBW, free-space loss 195dB, other losses 1.5 dB, earth station (G/T) 37.5 dB/K. Calculate the $(C/N)_o$ at the earth station. Assuming an output Back off power of 6dB is applied, what is the new value of $(C/N)_o$? [3]

3. (i) A data link transmits 7-bit ASCII words at a bit rate of 1 Mbps with a single parity bit. The probability of a bit error on the link is $p = 10^{-3}$. Find the probability of an undetected error when uncoded data is transmitted and when a single parity bit is added to each 7-bit word [decoder can detect 1 and 3-bit error]. What is the probability of an undetected bit error when BER on the link is 10^{-6} for both cases? [4]

   (ii) A LEO satellite is in a circular polar orbit with an altitude h of 1000 km. A transmitter on the satellite has a frequency of 2.6GHz. The mean radius of the earth is 6378km. Find the velocity of the satellite in orbit. [3]

   (iii) What is the advantage and disadvantage, if communication satellites are placed in LEO and GEO orbit? [3]

4. A convolutional code is described by $g_1 = [110]$ $g_2 = [101]$ $g_3 = [111]$. Find the transfer function and free distance for this code. [10]

5. (i) Design a Meggitt decoder circuit for (7,4) cyclic code generated by $g(x) = 1 + x^2 + x^3$. [6]

   (ii) When linear block code is called self dual code? [2]

   (iii) What is the dual code for repetition code and why it is called dual code ? [2]

Please go on to the next page...

Part B-Optical Communication

6. Using energy band diagrams, explain the operation of an Erbium Doped Fiber Amplifier. What is the importance of metastable state in the energy band diagram? What are the sources of noise in this amplifier?. Can a two level system work as a laser? Explain. [8]

7. A fibre optic communication link has the following parameters. (i) Source power = 0 dBm (ii) Detector sensitivity = –45 dBm (iii) Connector loss = 1 dB/connector (iv) Splice loss = 0.06 dB/Splice. If the total link length of 100 km is spanned by connecting two-hundred 500 m cables of attenuation coefficient 0.3 dB/km and a system margin of 5 dB is required, determine whether or not an amplification of the optical signals is required in the link. If yes, determine the required minimum amount of amplification in dB. Assume that the fibre cables are connected to the source, detector and amplifier using connectors and individual fibre cables are connected through splicing. [8 marks]

8. Define Quantum efficiency and Responsivity of a Photodiode. Use a graph to show how the responsivity vary as a function of photon wavelength for a photodiode? Define cut-off wavelength for a Photodiode. What are the draw backs of conventional p-n photodiode? How does p-i-n photodiodes help in overcoming them? What parameters of the diode decide its dark current? [8 marks]

9. A quantum well laser is to be designed using GaAs/$Al_xGa_{1-x}As$ with GaAs as the active layer. The thickness of the active layer is 10 nm and the Al composition for the barrier is 0.3. Given that ΔE_c is 60 % of ΔE_g and ΔE_v = 40 % of ΔE_g; where ΔE_g is the bandgap difference between $Al_xGa_{1-x}As$ and GaAs. Assuming that the effective mass of the electron is 0.067 m_0 and that of hole is 0.082 m_0 where m_0 is the rest mass of the electron, calculate the wavelength of the photon emitted from this laser. Assume that the bandgap of $Al_xGa_{1-x}As$ is 1.424 +1.248x eV [8]

10. A phase modulator made of $LiNbO_3$ has rectangular cross-section shaped waveguide made by diffusing Ti into $LiNbO_3$ having an index of 2.355 while the refractive index of $LiNbO_3$ is 2.30. The diffused waveguide is 3 μm wide and has a depth of 500 nm. A Silica step index single mode optical fiber which has a clad index of 1.55 and a core index which is 1% higher than that of the clad index has to be coupled at the Input and Output ports of the modulator. Explain the various coupling losses that can occur in this scheme and techniques to minimize them. How do you ensure that the fiber is mechanically well connected with the $LiNbO_3$ substrate? [8]

11. For a symmetric dielectric slab waveguide of core index n_g and cladding index n, derive the expression for the V parameter and use it to obtain the eigenvalue equation for the symmetric TE mode. What is the significance of V parameter in designing single mode waveguides? [8]

12. Mention the approximate wavelength at which Silica optical fiber has the least dispersion and least attenuation. [2]

End of exam.

SC19B101

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 1 – September 2022
AV411 – Navigation Systems and Sensors
Time: One hour Date: 12/09/2021 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. Define Navigation, Guidance and Control and explain the NGC loop using a neat block diagram. (3)

2. With a neat block diagram explain briefly the the concept of stabilised platform system. (3)

3. Define synodic coordiate system with Earth and Moon as primary and secondary bodies respectively. (3)

4. With a suitable diagram, define the ECEF coordinate system and the NED coordinate system at a station whose Geodetic Latitude is $\Phi = \pi/4$ radians) and Longitude is $\lambda = \pi/4$ radians. Obtain the expression for the DCM(Direction Cosine Matrix) for NED to ECEF transformation and evaluate the matrix. (3)

5. Let $\vec{r}$ be a vector which is rotated with respect to the axis of rotation along the unit vector $\vec{u}$ by an angle θ. With a neat diagram derive the solution to express the final rotated vector $\vec{r'}$ in terms of $\vec{u}$, $\vec{r}$ and θ. (3)

End of exam.

SC19B101
Harsh Agarwal

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 2 – October 2022
AV411 – Navigation Systems and Sensors
Time: One hour Date: 19/10/2022 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. With neat diagrams, show that the quaternion operator $L_p(\vec{q}) = p^* \vec{q} p$ with $||p|| = 1$ represents rotation by clearly showing the axis of rotation and angle of rotation. (5)

2. Derive the Euler angle rates in terms of body axis angular rates for rotation along Y and Z axes by using perturbations of rotations. Assume that the perturbed rotation matrix to be $S = QR$, where Q is the unperturbed rotation matrix and R is the incremental rotation. Assume the basic rotation operation to be $Q_\theta Q_\psi$ where Q_θ is w.r.t Y and Q_ψ is w.r.t Z. (5)

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

4. Find the quaternion corresponding to the DCM matrix (3)

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

End of exam.

SC19B101

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – End Semester – December 2022
AV411 – Navigation Systems and Sensors
Time: Three hours Date: 01/12/2022 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.

1. An archer in the Ayodhya, ancient India observes a bird flying due North. He wishes to bring down the bird. So he faces North and shoots the arrow. Assuming both the bird and the arrow to be point objects with the mass of bird and arrow, respectively, will the archer succeed in bringing down the bird. Justify your answer. If not, then how does the arrow move in relation to the North direction? Justify your answer. (2)

2. Foucaults Pendulum
   (a) What is the direction of rotation of vibrational plane of a Foucault's pendulum located in Perth, Australia? Justify. (2)
   (b) An observer is located at the equator uses Foucault's pendulum to detect the rotation of earth. Will the observer succeed? Why? (2)

3. Derive the two different ways in which the expression for the moment inertia term occurs in a rotating rigid body. Hint: Consider kinetic energy and angular momentum. (4)

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

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

   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 $\hat{n}$.

5. State the properties of Tensor of Inertia matrix. (3)

6. For planar mass show that $\Theta_{zz} = \Theta_{xx} + \Theta yy$ (2)

7. Which of the following are candidates for tensor of inertia: Justify. (3)

$$\Theta_1 = \begin{bmatrix} 4 & 3 & 1 \\ 2 & 5 & 2 \\ 4 & 3 & 6 \end{bmatrix} \quad \Theta_2 = \begin{bmatrix} 4 & -2 & -1 \\ -2 & 5 & -2 \\ -1 & -2 & 6 \end{bmatrix} \quad \Theta_3 = \begin{bmatrix} 4 & -2 & -1 \\ -2 & -5 & -2 \\ -1 & -2 & 6 \end{bmatrix}$$

8. A spinning wheel pivoted by a frictionless support is rotating with angular velocity w as shown in Fig. 1.
   (a) What is the direction of the angular velocity vector? (1)

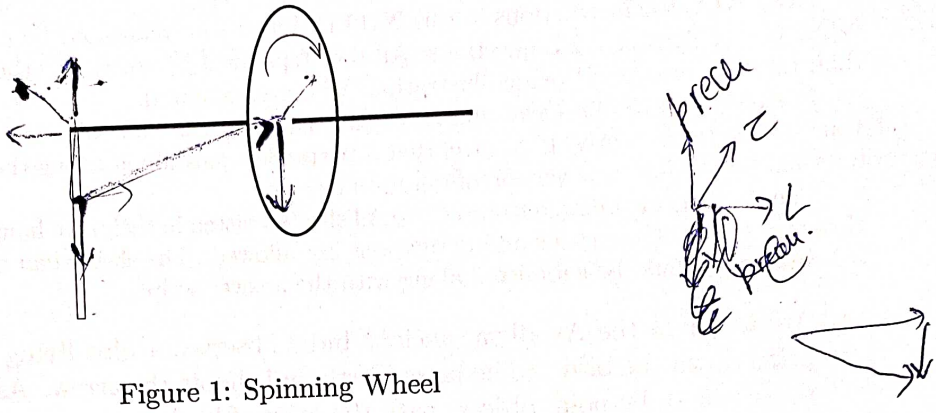


Figure 1: Spinning Wheel

(b) Are there any torques at the support point? Justify. (1)

(c) If there is a torque at the support point what force is the cause for it and give the direction of the torque vector. (1)

(d) Does the unsupported end move? If so in what direction will the unsupported end move? Assuming that the precession due to torque is given by precession x angular momentum = torque, Justify. (1)

9. Define moment of couple and show that torque due to couple is independent of the choice of the coordinate system. (2)

10. A rigid body consists of 4 particles of mass m, $2m$, $3m$ and $4m$, respectively situated at points (a, a, a), $(a, -a, -a)$, $(-a, a, -a)$, $(-a, -a, a)$, and connected together by a massless framework.

(a) Find the tensor of inertia matrix (5)

(b) Determine the torque required to rotate the rigid body in free space at constant angular velocity of 2 rad/s along x axis (2)

(c) Compute the principal axis and principal moments of inertia (6)

11. Consider an accelerometer mounted on a nanosatellite InspireSat1. The satellite is placed in the polar orbit (approximately 530km above the surface of Earth). Compute the accleration measured by the accelerometer by assuming the acceleration due to gravity at the height of 700km above the Earth is 9.66m/s^2. Justify your answer. (1)

12. 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. (3)

13. Let $\vec{u} = (a, b, c)$ be a unit vector and $\theta \in [0, \pi]$. Then show that $A = I + (\sin\theta)U + (1 - \cos\theta)U^2$ is a rotation matrix where $U = \begin{bmatrix} 0 & -c & b \\ c & 0 & -a \\ -b & a & 0 \end{bmatrix}$ (6)

End of exam.

SC19B101

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Quiz-1 **AVM 612 Introduction to MEMS** **16th Sep 2022**

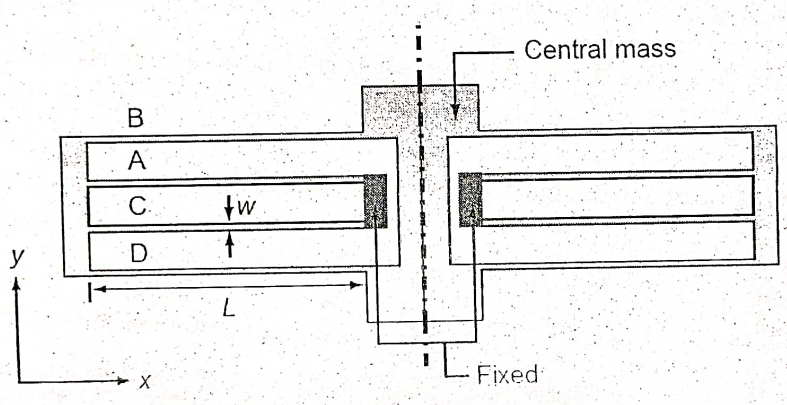
Marks (20)

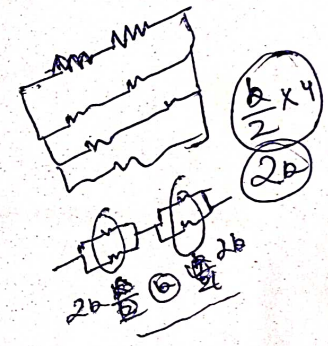
Q.1. (A) What is the application of a MEMS device for Scanning Porbe Microscopy (SPM) or Atomic Force Microscopy (AFM).

(B)Consider a triangular shaped microcantilever used for AFM. Plot the stress profile along the x-axis and cross section of the beam. **[4]**

Q. 2. Consider the following MEMS device with beams and a central mass. Assume that this subjected to force in the central mass in the 'Y' direction. Based on the fundamental understanding, can you predict the maximum permissible 'Y' displacement of the central mass for reliable operation of this sensor. Assume the maximum permissible stress is 900 MPa.

Given : Young's modulus E=150 GPa, L = 200 μm; w = 5 μm and t =3 μm

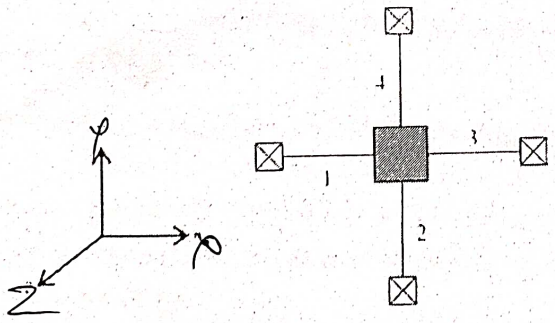




[6]

Q. 3 (A)Find the stiffness expression of the below MEMS suspension with square proof mass in the x-, y-, and z directions.

(B) Plot the stress profile for beams 1 and 2 for load in x direction.



[5]

Q. 4. Discuss the working principle two types of MEMS thermal sensors with their device schematic. Discuss the parameters (geometric as well material) of these devices on sensitivity of these sensors. **[5]**

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)

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

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

Harsh Agarwal
SC19B101

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Quiz-2 **AVM 612 Introduction to MEMS** **26th Oct 2022**

Marks (20)

Q.1. Discuss the working principle of a piezoresitive MEMS tactile sensor. Discuss the placement /location preference of piezoresistor in the MEMS structure.

(B) Application of MEMS tactile sensor.

[5]

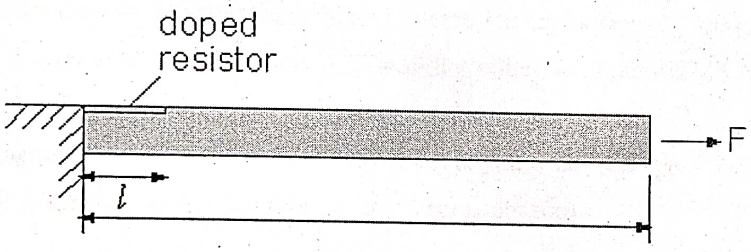
Q. 2. Consider thermal oxidation for 500 nm of silicon dioxide film on silicon wafer of thickness 675 microns. The film was stress free at the growth temperature of 925 oC. However, when the furnace was cooled and the sample was brought to room temperature (25oC), the stress condition in film and substrate was not known. The thickness of silicon dioxide film was 0.5 μm. As per thin film laser characterization, the cooled sample was seen to have certain curvature. (A)What is the reason for the curvature. Can you illustrate the case showing the nature of curvature (curved up or down). (B)Compute the curvature from the information provided above.

Assume for silicon E = 150 GPa ; Poisson's ratio= 0.40; $\alpha=2.8\times10^{-6}/k$;

For silicon dioxide, E = 69 GPa ; Poisson's ratio= 0.17; $\alpha=0.7\times10^{-6}/k$;

[5]

Q. 3 Consider the cantilever below with a width w. Find the analytical expression of the resistance change as a function of F.



[5]

Q. 4 Write one line/one word/1 figure answer for the following: -

(A) Consider a MEMS accelerometer with piezoresistive transduction. Define cross axis sensitivity and scale factor for the sensor

(B) 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.

(C)Difference between a Nanomechanical cantilever sensor used for AFM (atomic force microscopy) and bio/chemical sensing (eg. Gas sensor, explosive sensor etc.) [5]

(D) With the help of Stress profile for a MEMS square membrane pressure sensor and Indicate location for placement of piezoresistor.

(E)Advantage of anisotropic nature of single crystal silicon (p-silicon) for MEMS sensor (structural and electrical property)

[5]

Equations

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

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

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

Curvature

$$\frac{1}{\rho} = \frac{6\sigma_0 h}{\tilde{E} H^2}$$

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

End Semester Examination **AVM 612 Introduction to MEMS** **2/12/2022**

Marks (50)

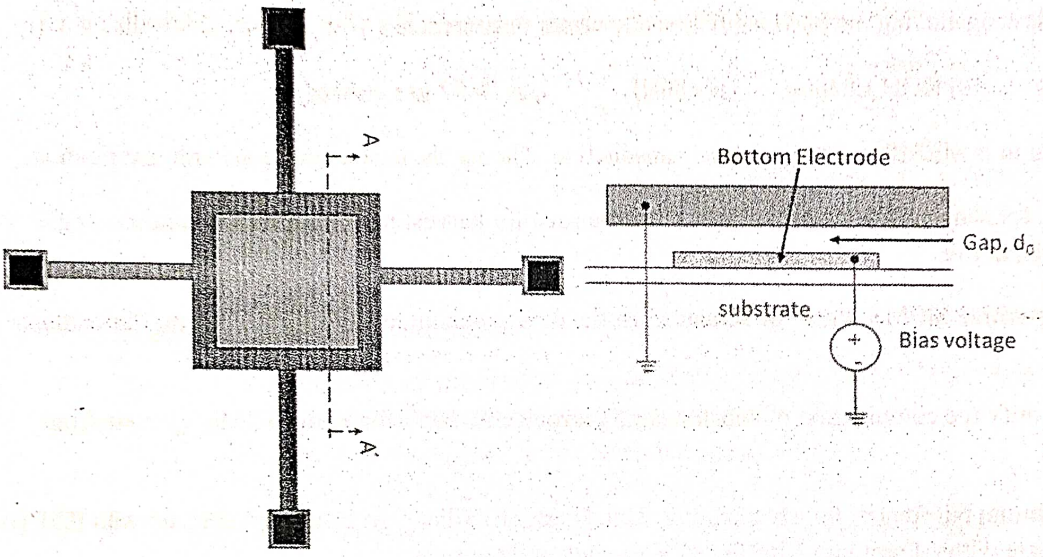
SC19B101

Q. 1. Consider the following electrostatic sensor.

(A) What is the concept of electric spring constant. Is it same as mechanical spring constant?

(B) Assume that this is a MEMS accelerometer. Discuss the design constraints in deciding (i)the bias voltage and (ii) range of acceleration that could be sensed without any reliability issue.

(C) The bottom electrode is connected to a voltage supply of value $V = 2$ V, while the suspended electrode on the proof mass is grounded. Assume the gap between the lower electrode and the plate is $do = 1$ µm. Find the area A of the lower electrode such that the electrostatic force on the plate is 100 nN.



[3+4+3]

Q.2. Take the role of MEMS design and integration engineer and discuss the

[A]A design with device schematic & working principle of the MEMS device you have come across as part of your term paper

[B] The new device architecture or scheme that you want to propose for the MEMS device

(Don't forget to mention the title of your term paper too) [3+3]

Q 3. Consider an oxidized silicon wafer which was subjected to photolithography followed by etching of silicon dioxide to open a mask window of size 500 um x 500 um. After an etch period of 5 hours, the cross sectional profile looks as below.

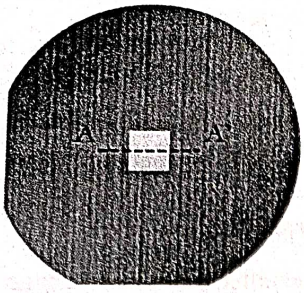
(A) What is the depth of the etched pit in silicon? Assume the etch rate is 1 microns/min.

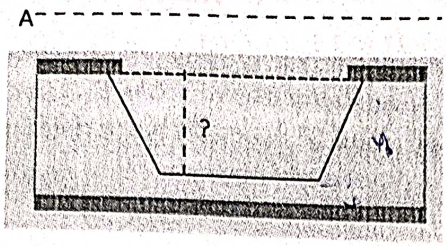
(B) Comment on the angle of side wall of the pit with respect to the wafer surface with concept of anisostropic etching characteristics of silicon.

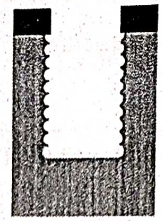
(c)Considering the ideal and real conditions of etching, discuss about the planar dimensions of the etched pit after removal of silicon dioxide.

(D) The same etching step was carried out using Deep reactive ion etching in silicon can be done using the Bosch process. Explain what you see in the scanning electron micrograph (SEMs) below and why these effects occur in DRIE process?

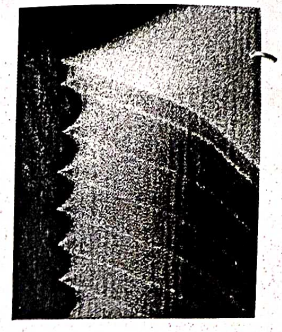
[2+2+2+4]







Bosch Etch Profile
(not to scale)



Q. 4 Write the answer in 2-3 sentences supported by relevant equation/schematic or drawing to support the answer for the following: - **[5x2]**

(A) Which among the following etching methods is preferred to create deep trenches with vertical sidewalls on a Si {100} wafer . Justify

(i) TMAH Etching (ii) KOH Etching (iii) DRIE (iv) XeF2 gas etching

(B) Piezoelectric transduction is MEMS is a strain-based transduction. Choose the correct answers with justification.

(i)It could be used for sensing and actuation (ii)It could be used for harvesting energy (iii) It requires single crystal silicon (iii) All of the above

(C) For a parallel plate capacitive MEMS sensor or actuator, list the device parameters that device the pull in voltage.

(D) uses the following Identify the combination of substrate and piezoelectric layer for PiezoMUMPs process from MEMSCAP.

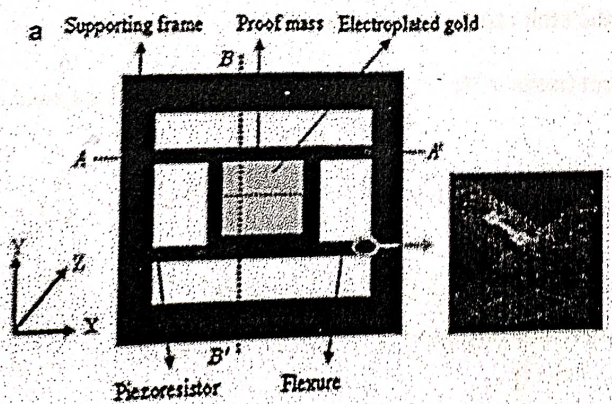
(i) Polished silicon, Aluminium Nitride (ii) Polished silicon, Zinc Oxide (ii) Silicon on Insulator substrate with PZT (iv) Silicon on Insulator substrate with Aluminium Nitride (v) Write any other answer

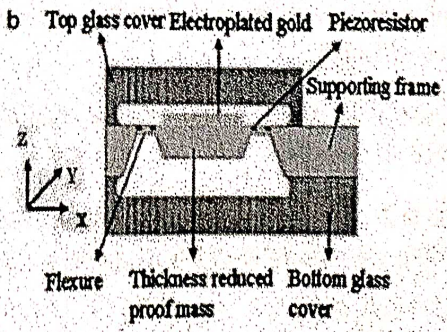
(E) Longitudinal comb drive is better than transverse comb drive as MEMS actuator. True or False. Justify

Q. 5 Consider the silicon piezoresistive MEMS the accelerometer with 8 doped si piezoresistors in the beams.

[A]What is the significance of 8 piezoresistors when 4 piezoresistors are sufficient.Discuss using the working principle of this device.

[B]Make a fabrication process integration scheme to realize this device. Assume the structural material is single crystal silicon and the resistors are doped region. The electrodes for contacts are not indicated. You may assume aluminium as the contact and incorporate it in the fabrication. **[4+10]**





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Indian Institute of Space Science and Technology Trivandrum

I SEMESTER , 2022

ExamType: Quiz 1

DEPARTMENT OF AVIONICS

Machine learning for Signal Processing

(Time allowed: ONE hours)

NOTE: Read all questions first. **There are questions worth 30 marks.** If something is missing in a problem description, clearly mention your assumptions with your solution. If require use sketches to illustrate your findings.

1. Basics of Prob and linear algebra (7 marks)

(a) Let A be a real, symmetric $n \times n$ matrix. Which of the following are true about $A's$ eigenvectors and eigenvalues?(choose all that applies)

(i) A can have no more than n distinct eigenvalues

(ii) The vector θ is an eigenvector, because $A\theta = \lambda\theta$

(iii) A can have no more than 2n distinct unit-length vectors

(iv) We can find n mutually orthogonal eigenvectors of A

(b) The decision boundary of a two-class classification problem where the data of each class is modeled by a multivariate Gaussian distribution is always linear.(True or False, give one line reasoning in support of your response)

(c) A probability density function (PDF) cannot be less than 0 or bigger than 1.(True or False)

(d) Bernoulli and Gaussian distributions are both probability density functions (pdfs).(True or False)

(e) A cumulative distribution function (CDF) cannot be less than 0 or bigger than 1.(True or False)

(f) Given a distribution $p(X, y)$, it is always (in theory) possible to compute $p(y|X)$.(True or False)

(g) Show that if a matrix A is positive definite, its eigenvalues must be positive also.

2. Let $u_1, u_2, , u_n$ be a set of n orthonormal vectors. Similarly let $v_1, v_2, , v_n$ be the another set of n orthonormal vectors. (4 marks)

(a) Show that $u_1 v_1^T$ is rank-1 matrix.

(b) Show that $u_1 v_1^T + u_2 v_2^T$ is a rank-2 matrix.

(c) Show that $\sum_{i=1}^{n} u_i v_i^T$ is a rank-n matrix.

3. The below fig illustrates a simple class of probability density functions of real-valued variables. $(x, y) = Rect(x_{lo}, y_{lo}, x_{hi}, y_{hi})$

$$p(x, y) = \frac{1}{(x_{hi} - x_{lo})(y_{hi} - y_{lo})} \quad if \quad x_{lo} \leq x \leq x_{hi} \quad and \quad y_{lo} \leq y \leq y_{hi}$$

(5 marks)

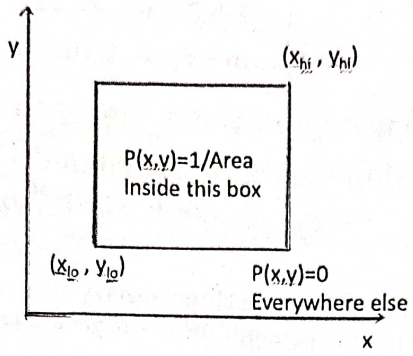

Figure 1: Rectangular pdf $Rect(x_{lo}, y_{lo}, x_{hi}, y_{hi})$

(a) Assuming (x,y)=Rect(0,0,0.5,2), compute the value of the density ($p(x = \frac{1}{4}.y = \frac{1}{4})$

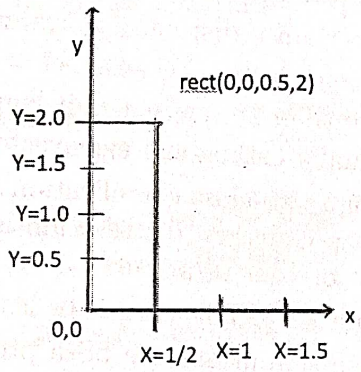

Figure 2: Rectangular pdf

(b) Under the same assumptions, compute the density $p(y = \frac{1}{4})$

(c) Under the same assumptions, compute the density $p(x = \frac{1}{4})$

(d) Under the same assumptions, compute the density $p(x = \frac{1}{4}|y = \frac{1}{4})$

4. Distinguish between linear classifier and a nonlinear classifier. Give some examples of both. (2 marks)

5. The 3-nearest neighbor classifier is always more accurate than the 2-nearest neighbor classifier.(true or false)give a good reasoning for your answer. (2 marks)

6. Quadratic Discriminant Function (5 marks)

(a) Consider 12 labeled data points sampled from three distinct classes:

$$class - \omega_0 = \{\begin{bmatrix}0\\2\end{bmatrix}, \begin{bmatrix}-2\\0\end{bmatrix}, \begin{bmatrix}5\\3\end{bmatrix}, \begin{bmatrix}-3\\-5\end{bmatrix}\}$$

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$$class - \omega_1 = \{\begin{bmatrix}\sqrt{2}\\ \sqrt{2}\end{bmatrix}, \begin{bmatrix}-\sqrt{2}\\ \sqrt{2}\end{bmatrix}, \begin{bmatrix}4\sqrt{2}\\ -\sqrt{2}\end{bmatrix}, \begin{bmatrix}-4\sqrt{2}\\ -\sqrt{2}\end{bmatrix}\}$$

$$class - \omega_2 = \{\begin{bmatrix}3\\ 5\end{bmatrix}, \begin{bmatrix}1\\ 3\end{bmatrix}, \begin{bmatrix}8\\ 6\end{bmatrix}, \begin{bmatrix}0\\ -2\end{bmatrix}\}$$

For each class $\omega_i \in (0, 1, 2)$, compute the class sample mean μ_ω , the class sample covariance matrix $\sum_\omega$, and the estimate of the prior probability p_{ω_i} that a point belongs to class ω_i.

(b) Sketch one or more iso-contours of the Quadratic discriminant Analysis-produced normal distribution or quadratic discriminant function (they each have the same contours) for each class. The isovalues are not important; the important aspects are the centers, axis directions, and relative axis lengths of the isocontours. Clearly label the centers of the isocontours and to which class they correspond.

(c) Plot decision boundary for all the three classes.

7. Explain why Bayes classifier is an optimal classifier(mention various conditions under which the Bayes classifier will be an optimal classifier. Further, derive the expression for Bayes error. Now, Consider the following 2-class (w_1, w_2) classification problem involving a single feature x. Assume equal class priors. The class conditional distributions are: (5 marks)

$$p(\bar{x}/w_1) = \begin{cases} 2x, & \text{if } 0 \le x \le 1 \\ 0, & \text{otherwise} \end{cases}$$

$$p(x/w_2) = \begin{cases} 2 - 2x, & \text{if } 0 \le x \le 1 \\ 0, & \text{otherwise} \end{cases}$$

(a) Derive the Bayes decision boundary?

(b) What is the Bayes classification error?

(c) What is the new decision boundary if the a-priori probability of class w1 is changed to 0.7?

Indian Institute of Space Science and Technology Trivandrum

I SEMESTER , 2022

ExamType: Quiz 2

DEPARTMENT OF AVIONICS

Machine learning for Signal Processing

(Time allowed: ONE hours)

NOTE: Read all questions first. **There are questions worth 30 marks.** If something is missing in a problem description, clearly mention your assumptions with your solution. If require use sketches to illustrate your findings.

1. Basics of Machine Learning (5 marks)

(a) In terms of the bias-variance trade-off, which of the following is/are substantially more harmful to the test error than the training error?(Only one answer is correct)

(i) Variance
(ii) Bias
(iii) none of the Above
(iv) Loss

(b) If the prior is uniform, solution to MLE and MAP are identical. (T / F)

(c) Suppose we have an estimator θ^* for a parameter θ . State two conditions for θ^* to be a good estimator of θ .

(d) Name one key difference between ML and Bayesian parameter estimation.

(e) List two drawbacks of bin counting. What is the advantage of Parzen Windows compared to bin counting?

2. In this problem, we have n trials with k possible types of outcomes $\{1, 2, ..., k\}$. Suppose we observe $X1, ..., Xk$ where each Xi is the number of outcomes of type i. If p_i refers to the probability that a trial has outcome i, then $(X1, ..., Xk)$ is said to have a multinomial distribution with parameters $p_1, ..., p_k$, denoted $(X1, ..., Xk)$ Multinomial$(p_1, ..., p_k)$. It may be useful to know that the probability mass function of the multinomial distribution is given as follows:

$$P(X_1 = x_1, ..., X_k = x_k) = \frac{n!}{x_1!x_2!...x_k!} p_1^{x_1} ... p_k^{x_k}$$

We want to find the maximum likelihood estimators for $p_1, ..., p_k$. You may assume that $p_i > 0$ for all i.

(a) What is the log-likelihood function, $l(p_1, ..., p_k | X_1, ..., X_k)$? (2 marks)

(b) You might notice that unconstrained maximization of this function leads to an answer in which we set each $p_i = \infty$. But this is wrong. We must add a constraint such that the probabilities sum up to 1. Now, we have the following optimization problem. (2 marks)

3. Highlight the salient difference between the ordinary Bayes classifier and Naive Bayes classifier. (Write Mathematical expressions for clear descriptions). (2 marks)

4. Suppose that you are trying to solve a binary classification problem, and your data set has 4 attributes. Each attribute can take 3 possible values

   (a) If you modeled the full joint distribution of the attributes and the class label, how many parameters would you need (1 mark)

   (b) If instead you use a Naive Bayes classifier, how many parameters will you have to fit? (1 mark)

5. We will use the dataset below to learn a decision tree which predicts if people pass machine learning (Yes or No), based on their previous GPA (High, Medium, or Low) and whether or not they studied.

Table 1: Data For Decision Tree.

GPA	Studied	result
L	N	N
L	Y	Y
M	N	N
M	Y	Y
H	N	Y
H	Y	Y

For this problem, you can write your answers using log2, but it may be helpful to note that $log_2 3 \approx 1.6$. (5 marks)

   (a) What is the entropy H(Passed)?

   (b) What is the entropy $H(Passed \mid GPA)$?

   (c) What is the entropy $H(Passed \mid Studied)$?

   (d) Draw the full decision tree that would be learned for this dataset. You do not need to show any calculations.

6. You are given a dataset D = 0, 1, 1, 2, 3, 4, 4, 4, 5. Using techniques from non-parametric density estimation, answer the following questions: (4 marks)

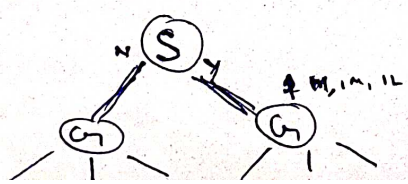
   (a) Draw a histogram of D with a bin-width of 1 and bins centered at 0, 1, 2, 3, 4, 5.

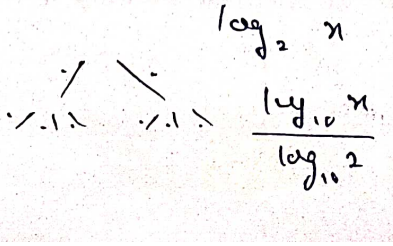
   (b) Write the formula for the kernel density estimate given an arbitrary kernel K.

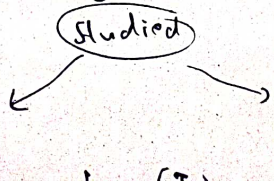
   (c) Select a triangle kernel as your window function:

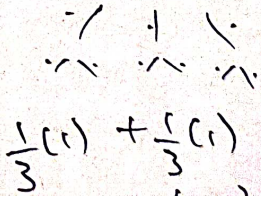
$$K(u) = (1 - |u|)\ \delta(|u| \leq 1)\ and\ \ 0\ \ otherwise.$$

where u is a function of the distance of sample x_i to the value in question x divided by the bandwidth. Compute the kernel density estimates for the following values of $x = \{2, 4\}$ bandwidths of 2. Compare the kernel density estimate of these values to the histogram estimate.









(d) A kernel needs to satisfy certain conditions. Specify those conditions.

7. Suppose that $X1, X2, ..., Xn \approx Poisson(\lambda)$. Suppose that λ has a $Gamma(a, b)$ prior. Find the posterior distribution for λ. (4 marks)

8. Let us understand the EM algorithm. Suppose that we generated a sequence of n random variables $Y_i \approx N(\theta, \sigma^2)$ for $i = 1, ..., n$. Imagine that we have only observed $Y = \{Y_1, Y_2, ..., Y_m\}$ where $m < n$. How should we estimate θ based on Y ? Intuitively, the estimated θ should be the sample mean of the m observations $\hat{\theta} = \frac{1}{m}\sum_{i=1}^{m} Y_i$. However, in this question we would like to derive the Expectation Maximization (EM) algorithm and see if the EM algorithm would match with our intuition. (4 marks)

$$\frac{b^a}{\Gamma(a)} \frac{\lambda^{a+\sum x_i - 1} e^{-\lambda(n+1)}}{x_1! \cdots x_n!}$$

Table 1: Common distributions and densities.

Distribution	Notation	Density
Bernoulli	$\text{Bern}(\theta)$	$f(y\|\theta) = \theta^y(1-\theta)^{1-y}$; $y = 0, 1$
Binomial	$\text{Bin}(n, \theta)$	$f(y\|\theta) = \binom{n}{y}\theta^y(1-\theta)^{n-y}$; $y = 0, 1, \ldots, n$
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Weibull	$\text{Weibull}(\alpha, \lambda)$	$f(y\|\alpha, \lambda) = \lambda\alpha y^{\alpha-1}\exp(-\lambda y^\alpha) I_{(0,\infty)}(y)$

Table 2: Some conjugate families.

$f(y\|\theta)$	$p(\theta)$	$p(\theta\|y)$
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$\text{NegBin}(r, \theta)$	$\text{Beta}(a, b)$	$\text{Beta}(a+y-r, b+r)$
$\text{Pois}(\theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a+\sum y_i, b+n)$
$\text{Exp}(\theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a+n, b+\sum y_i)$
$\text{Gamma}(k, \theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a+nk, b+\sum y_i)$

Figure 1: important distributions

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Indian Institute of Space Science and Technology Trivandrum

I SEMESTER , 2022

ExamType: Quiz 2

DEPARTMENT OF AVIONICS

Machine learning for Signal Processing

(Time allowed: ONE hours)

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$\text{NegBin}(r, \theta)$	$\text{Beta}(a, b)$	$\text{Beta}(a + y - r, b + r)$
$\text{Pois}(\theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a + \sum y_i, b + n)$
$\text{Exp}(\theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a + n, b + \sum y_i)$
$\text{Gamma}(k, \theta)$	$\text{Gamma}(a, b)$	$\text{Gamma}(a + nk, b + \sum y_i)$

Figure 1: important distributions

Indian Institute of Space Science and Technology Trivandrum

I SEMESTER , 2022

ExamType: EndSem

DEPARTMENT OF AVIONICS

Machine Learning for Signal Processing

(Time allowed: 3 hours)

NOTE: Read all questions first. **Attempt the questions worth 50 marks.** If something is missing in a problem description, clearly mention your assumptions with your solution. If require use sketches to illustrate your findings. Date of Exam : **30 November, 2022**

1. Objective type questions (multiple answers may be right, wrong answers will be penalised by negative marking.) (10 marks)

(a) Which of the following are true of convolutional neural networks (CNNs) for image analysis?

(i) Filters in earlier layers tend to include edge detectors ✓

(ii) Pooling layers reduce the spatial resolution of the image ✓

(iii) They have more parameters than fully- connected networks with the same number of layers and the same numbers of neurons in each layer ✗

(iv) A CNN can be trained for unsupervised learning tasks, whereas an ordinary neural net cannot ✗

(b) Neural networks

(i) optimize a convex cost function ✗

(ii) can be used for regression as well as classification ✓

(iii) always output values between 0 and 1 ✗

(iv) can be used in an ensemble ✓

(c) Which of the following are true about generative models?

(i) They model the joint distribution P(class = C AND sample = x)

(ii) The perceptron is a generative model ✗

(iii) They can be used for classification model

(iv) Linear Discriminant analysis is a generative model?

(d) Lasso can be interpreted as least-squares linear regression where

(i) weights are regularized with the l1 norm ✓

(ii) the weights have a Gaussian prior ✗

(iii) weights are regularized with the l2 norm ✗

(iv) Lssso can be used in SVMs nd CNNs too? ✓

(e) Which of the following methods can achieve zero training error on any linearly separable dataset?

✓(i) Decision tree

✓(ii) Hard-margin SVM

✓(iii) Perceptron

✗(iv) 15-nearest neighbors

(f) The kernel trick

(i) can be applied to every classification algorithm

(ii) changes ridge regression so we solve a d d linear system instead of an n n system, given n sample points with d features

(iii) is commonly used for dimensionality reduction

(iv) exploits the fact that in many learning algorithms, the weights can be written as a linear combination of input points

(g) Which of the following are properties that a kernel matrix always has?

✓(i) Invertible

(ii) At least one negative eigenvalue

(iii) All the entries are positive

✓(iv) Symmetric

(h) During backpropagation, as the gradient flows backward through a sigmoid non-linearity, the gradient will always:

(i) Increase in magnitude, maintain polarity

(ii) Increase in magnitude, reverse polarity

✓(iii) Decrease in magnitude, maintain polarity

(iv) Decrease in magnitude, reverse polarity

(i) Which of the following would you consider to be valid activation functions (elementwise non-linearities) to train a neural net in practice?

✓(i) f(x)=-min(2,x)

(ii) f(x)=0.9x+1

✓(iii)

$$f(x) = min(x, 0.1x) | x \geq 0 \quad (1)$$
$$= min(x, 0.1x) | x < 0 \quad (2)$$

(iv)

$$f(x) = max(x, 0.1x) | x \geq 0 \quad (3)$$
$$= min(x, 0.1x) | x < 0 \quad (4)$$

2. PCA : You are given a data matrix

$$X = \begin{bmatrix} 6, & -4 \\ -3, & 5 \\ -2, & 6 \\ 7, & -3 \end{bmatrix}$$

Lets use PCA to reduce the dimension from 2 to 1. (5 marks)

(a) Compute the covariance matrix for the sample points. (Warning: Observe that X is not centered.) Then compute the unit eigenvectors, and the corresponding eigenvalues, of the covariance matrix. Hint: If you graph the points, you can probably guess the eigenvectors (then verify that they really are eigenvectors).

(b) Suppose we use PCA to project the sample points onto a one-dimensional space. What one-dimensional subspace are we projecting onto? For each of the four sample points in X (not the centered version of X!), write the coordinate (in principal coordinate space, not in R2) that the point is projected to.

(c) Given a design matrix X that is taller than it is wide, prove that every right singular vector of X with 2 singular value is an eigenvector of the covariance matrix with eigenvalue σ^2.

(5 marks)

3. Short questions

(a) Why stochastic approximation is important in Machine learning. Explain Robbins-Munro algorithm for stochastic approximation.

(b) As we increase the number of parameters in a model, both the bias and variance of our predictions should decrease since we can better fit the data. (State true or false with a proper reasoning)

(c) The k-means algorithm is guaranteed to converge to the global minimum. (State true or false with a proper reasoning)

(d) When optimizing a regression problem where we know that only some of our features are useful, we should use L1 regularization.(State true or false with a proper reasoning)

(e) Evaluate the Kullback-Leibler divergence between two Gaussians $p(x) = N(x|\mu, \sigma^2)$ and $q(x) = N(x|m, s^2)$.

4. CNN: Say you have an input image whose shape is $128 \times 128 \times 3$. You are deciding on the hyperparameters for a Convolutional Neural Network; in particular, you are in the process of determining the settings for the first Convolutional layer. Compute the output activation volume dimensions and number of parameters of each of the possible settings of the first Convolutional layer, given the input has the shape described above. You can write the activation shapes in the format (H, W, C) where H, W, C are the height, width, and channel dimensions, respectively (5 marks)

(a) The first Convolutional layer has a stride of 1, a filter size of 3, input padding of 0, and 64 filters. 126 1792

(b) The first Convolutional layer has a stride of 1, a filter size of 5, input padding of 2, and 16 filters. 128 1216

(c) The first Convolutional layer has a stride of 2, a filter size of 2, input padding of 0, and 32 filters. 64 416

(5 marks)

5. Basics of ML

(a) Let k(x, y) be a kernel function, positive semidefinite function. Prove that

$$k(x, y)^2 \leq k(x, x)k(y, y) \forall x, y$$

(b) Given a kernel k(x,y) and a function f(x),prove that f(x)f(y)k(x,y) is also a kernel.

(c) Show that maximizing the likelihood function under the conditional distribution $p(t|x,w) = N(t|y(x,w),\beta^{-1}I)$ for a multioutput neural network is equivalent to minimizing the sum-of-squares error function $E(w) = \frac{1}{2}\sum_{n=1}^{N}||y(x_n,w) - t_n||^2$.

6. Consider the task of building a binary classifier. You have a training dataset $\{(x_i,y_i)\}_{i=1...n}$, where $x_i \in R^d$ and $y_i \in \{0,1\}$. Consider the statistical model where $P(y=1|x) = \sigma(\theta^t x)$, where σ is the logistic function. Write down the optimization problem that would be solved to perform MAP estimation of θ provided that θ has a prior distribution where each component θ_i is independent and normally distributed with mean 0 and variance σ^2 (5 marks)

7. For a data set $\{\phi_n, t_n\}$, where $t_n \in \{0,1\}$ and $\phi_n = \phi(x_n)$, with $n = 1,...,N$, the likelihood function can be written as ($\phi(x)$ is some nonlinear transformations)

$$p(t|w) = \prod_{n=1}^{N} y_n^{t_n}(1-y_n)^{1-t_n}$$

where $t = (t_1,...,t_N)^T$ and $y_n = p(C_1|\phi_n)$. Write the error expression for cross entropy. Compute the derivative of the error function. Show that for a linearly separable data set, the maximum likelihood solution for the logistic regression model is obtained by finding a vector w whose decision boundary $w^T\phi(x) = 0$ separates the classes and then taking the magnitude of w to infinity. (5 marks)

8. SVM (5 marks)

(a) Let $\{(x_i,y_i)\}_{i=1}^{l}$ be a set of l training pairs of feature vectors and labels. We consider binary classification, and assume $y_i \in \{-1,+1\}\forall i$. The following is the primal formulation of L2 SVM, a variant of the standard SVM obtained by squaring the hinge loss:

$$min_{w,b,\xi} = \frac{1}{2}w^T W + \frac{C}{2}\sum_{i=1}^{l}\xi^2$$

$$s.t. y_i(w^T x_i + b) \geq 1\xi, i \in \{1,...,l\},$$

$$\xi_i \geq 0, i \in \{1,...,l\}.$$

(i) Show that removing the last set of constraints $\{\xi_i \geq 0\ \forall i\}$ does not change the optimal solution to the primal problem

(ii) After removing the last set of constraints, we get a simpler problem:

$$min_{w,b,\xi} = \frac{1}{2}w^T W + \frac{C}{2}\sum_{i=1}^{l}\xi^2$$

$$s.t. y_i(w^T x_i + b) \geq 1-\xi_i, i \in \{1,...,l\},$$

give the Lagrangian of above equation

(iii) Derive the dual of previous equation. How is it different from the dual of the standard SVM with the hinge loss?

9. Feature extraction: Write short notes on feature extraction for speech, text and image features. Suppose you wish to develop a machine learning application for an automatic attendance system for our class. Please suggest various important steps and with a brief justification. if possible draw the block diagram. (5 marks)

Indian Institute of Space Science and Technology
Thiruvananthapuram-695 547
Department of Earth and Space Sciences
B. Tech AE/ECE Sem VII
ES411/Introduction to Space Science and Applications
Quiz 1
September 2022

Part A: Introduction to Atmospheric Science
Instructions:

1) Answer all questions.
2) Questions 1 & 2 carry 2.5 marks each, and questions 3-12 carry 1 mark each.
3) Show diagrams and equations wherever necessary.

Total Marks: 15

Question 1. The intensity of visible light scattered by air molecules is about 6-fold higher than infrared (IR) light. Calculate the wavelength of ~~visible light~~ IR if the wavelength of red light is 650 nm.

Question 2. Why tropical cyclones are not formed in 5degree N-S zones of the Equator?

Question 3. Find the correct statement

(a) Sinking air parcel expands adiabatically and creates clouds, while rising air shrinks and creates clear sky.
(b) Rising air parcel expands adiabatically and creates clouds, while sinking air parcel create clear sky.
(c) Rising and sinking air parcels movement are diabatic processes.
(d) Rising and sinking air parcels expand adiabatically and create cyclone.

Question 4. Write the correct option
Cyclonic circulations occur mostly in late summers (August-September) because

a) Whirling motion is enhanced when the ITCZ over oceans are farthest from the equator.
b) The air is overheated and the sun is exactly over the equator.
c) Both (a) and (b)
d) Neither (a) nor ((b)

Question 5. Write the correct option
Tropical cyclones originate and intensify over warm tropical oceans but not in the lake or pond because

a) It requires large sea surface with temperature higher than 27° C.
b) It requires large ambient temperature higher than 27° C.
c) It requires strong wind shear (variations in the vertical wind speed) and upper divergence above the sea level system.
d) (a) & (c)

Question 6. Write the correct option

a) Cyclones are rapid inward air circulation around a low-pressure area.
b) Cyclones are rapid outward-spiralling air circulation around a high pressure centre.
c) Cyclones are rapid outward-spiralling around a low-pressure area.
d) Cyclones are rapid inward air circulation around a high pressure centre.

Question 7. Write the correct option

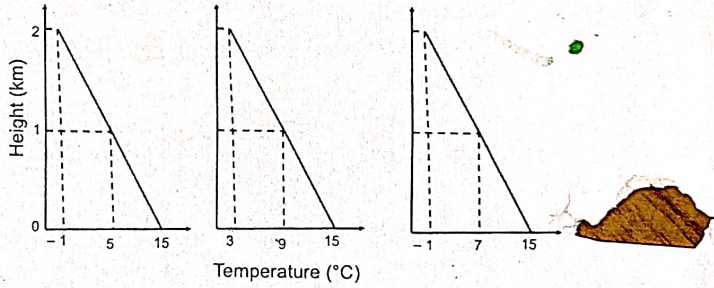
a) In Cyclones, the air circulates in an anticlockwise direction in the Northern hemisphere and clockwise in the Southern hemisphere around a center of high pressure.
b) In Cyclones winds rotate clockwise in the Northern Hemisphere around a center of high pressure.
c) In Cyclones winds rotate an anticlockwise direction in the Northern Hemisphere around a center of low pressure.
d) In Cyclones, the air circulates in an anticlockwise direction in the Northern hemisphere and clockwise in the Southern hemisphere around a center of low pressure.

Question 8. Write the correct option
Air parcel cools at much faster rate in adiabatic lapse rate compared to moist adiabatic lapse rate due to

(a) Latent heat of evaporation (vaporization) released due to change in the phase from to liquid to vapor.
(b) Latent heat of condensation released due to change in the phase from vapor to liquid.
(c) Both (a) & (b) are correct
(d) Both (a) & (b) are not correct

Question 9. Write the correct option about atmospheric stability condition from graphs given below

a) Stable
b) Unstable
c) Neutral if saturated, and stable if unsaturated
d) Conditionally unstable



Question 10. Write the correct option
Without rotating earth general circulation will have

a) Only Trade winds
b) Only Sub-tropical jet stream
c) Only Polar Easterly
d) None of the above

Question 11. Write the correct option
El Niño-Southern Oscillation (ENSO) is associated with

a) Small difference in ambient temperature between the Eastern and Western Pacific.
b) El Niño-Southern Oscillation can increase the rainfall over India.
c) Creates stable atmospheric condition in the Western Pacific, while instability in the Eastern Pacific.
d) None is correct.

Question 12. Write the correct statement about zonal (E-W) and meridional wind (N-S) wind components.

(a) Walker Circulation is a meridional, while Hadley is a zonal circulation
(b) Both Walker and Hadley are zonal circulation.
(c) Walker Circulation is zonal, while Hadley is a meridional circulation.
(d) Both Walker and Hadley are meridional circulation.

Indian Institute of Space Science and Technology

Introduction to Space Science and Applications - ESA411

BTech Elective - Quiz II

03 November 2022

Time: 9.00 - 10.00 hrs
Total Marks – 30

Answer all the questions

1. The absolute magnitude of a star in Andromeda galaxy (distance 720 kpc) is $M = 4.3$. It explodes as a supernova becoming 0.1 billion (10^8) times brighter. What is its apparent magnitude? [5 marks]

2. Write the conservations laws of nuclear reactions, and the steps of nucleosynthesis in main-sequence stars like the Sun. [6 Marks]

3. Consider a cluster of stars having different masses, all of which can be assumed to have formed at the same time. If the current estimate of the effective temperature of the most massive main-sequence star in the cluster is 6100 K, estimate the age of the cluster. Justify your answer. [6 Marks]

4. The mass of Vega (spectral class A0) is 2 $M_\odot$, radius 3 $R_\odot$ and luminosity is 60 $L_\odot$. Find its nuclear timescale assuming that $\sim$ 10% hydrogen at its core is converted to helium. [6 marks]

5. Write the Planck function and derive Wien's law. [7 Marks]

Appendix D

Physical and astronomical constants and conversion factors

Table D.1 Fundamental constants

Constant	*Symbol*	*Value*	*Units*	
			SI	*cgs*
Speed of light	c	2.99792458	$10^{8}\,\mathrm{m\,s^{-1}}$	$10^{10}\,\mathrm{cm\,s^{-1}}$
Permeability	μ_0	4π	$10^{-7}\,\mathrm{C^{-2}\,N\,s^{2}}$	1
Permittivity	ε_0	$1/4\pi$	$10^{7}/c^{2}\,\mathrm{C^{2}\,N^{-1}\,m^{-2}}$	1
Gravitational	G	6.67259	$10^{-11}\,\mathrm{m^{3}\,kg^{-1}\,s^{-2}}$	$10^{-8}\,\mathrm{cm^{3}\,g^{-1}\,s^{-2}}$
Planck	h	6.6260755	$10^{-34}\,\mathrm{J\,s}$	$10^{-27}\,\mathrm{erg\,s}$
Boltzmann	k	1.380658	$10^{-23}\,\mathrm{J\,K^{-1}}$	$10^{-16}\,\mathrm{erg\,K^{-1}}$
Stefan-Boltzmann	σ	5.67051	$10^{-8}\,\mathrm{J\,m^{-2}\,s^{-1}\,K^{-4}}$	$10^{-5}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,K^{-4}}$
Radiation	a	7.5646	$10^{-16}\,\mathrm{J\,m^{-3}\,K^{-4}}$	$10^{-15}\,\mathrm{erg\,cm^{-3}\,K^{-4}}$
Wien		2.897756	$10^{-3}\,\mathrm{m\,K}$	$10^{-1}\,\mathrm{cm\,K}$
Avogadro	N_A	6.0221367	$10^{23}\,\mathrm{mol^{-1}}$	$10^{23}\,\mathrm{mol^{-1}}$
Atomic mass unit	m_{H}	1.6605402	$10^{-27}\,\mathrm{kg}$	$10^{-24}\,\mathrm{g}$
Ideal gas	$\mathcal{R}$	8.314510	$10^{3}\,\mathrm{J\,kg^{-1}\,K^{-1}}$	$10^{7}\,\mathrm{erg\,g^{-1}\,K^{-1}}$
Electron charge	e	1.60217733	$10^{-19}\,\mathrm{C}$	$10^{-20}c\,\mathrm{esu}$
Electron mass	m_e	9.1093897	$10^{-31}\,\mathrm{kg}$	$10^{-28}\,\mathrm{g}$
Proton mass	m_p	1.6726231	$10^{-27}\,\mathrm{kg}$	$10^{-24}\,\mathrm{g}$
Neutron mass	m_n	1.6749286	$10^{-27}\,\mathrm{kg}$	$10^{-24}\,\mathrm{g}$
Angström	Å	1	$10^{-10}\,\mathrm{m}$	$10^{-8}\,\mathrm{cm}$

Note: $a = 4\sigma/c$. $m_{\mathrm{H}} = 1/N_A$. $\mathcal{R} = k/m_{\mathrm{H}}$. Fundamental constants are from E. R. Cohen and B. N. Taylor, (1987), *Rev. Mod. Phys.* 59, p. 1121; *CODATA Bulletin* (1986), 63 (Nov.); *Physics Today* (1995), Part 2, BG9 (Aug.).

Table D.2 Astronomical constants

Constant	*Symbol*	*Value*	*Units*	
			SI	*cgs*
Solar mass	$M_\odot$	1.9891	$10^{30}\,\mathrm{kg}$	$10^{33}\,\mathrm{g}$
Solar radius	$R_\odot$	6.9598	$10^{8}\,\mathrm{m}$	$10^{10}\,\mathrm{cm}$
Solar luminosity	$L_\odot$	3.8515	$10^{26}\,\mathrm{J\,s^{-1}}$	$10^{33}\,\mathrm{erg\,s^{-1}}$
Year (solar)	yr	3.1558	$10^{7}\,\mathrm{s}$	$10^{7}\,\mathrm{s}$
Light-year	ly	9.463	$10^{15}\,\mathrm{m}$	$10^{17}\,\mathrm{cm}$
Parsec	pc	3.086	$10^{16}\,\mathrm{m}$	$10^{18}\,\mathrm{cm}$
Astronomical Unit	AU	1.496	$10^{11}\,\mathrm{m}$	$10^{13}\,\mathrm{cm}$
Earth mass	$M_\oplus$	5.976	$10^{24}\,\mathrm{kg}$	$10^{27}\,\mathrm{g}$
Earth radius	$R_\oplus$	6.378	$10^{6}\,\mathrm{m}$	$10^{8}\,\mathrm{cm}$

Note: Astronomical constants are from C. Caso et al., (1998), *European Physical Journal*, C3, p.1.

Table D.3 Energy conversion factors

Units	*erg*	*eV*	s^{-1}	cm^{-1}	*K*
erg	1	1.60217733(-12)	6.6260755(-27)	1.9864475(-16)	1.380658(-16)
eV	6.2415064(11)	1	4.1356692(-15)	1.23984244(-4)	8.617385(-5)
s^{-1}	1.50918897(26)	2.41798836(14)	1	2.99792458(10)	2.083674(10)
cm^{-1}	5.0341125(15)	8.0655410(3)	3.335640952(-11)	1	6.950387(-1)
K	7.242924(15)	1.160445(4)	4.799216(-11)	1.438769	1

Note: Powers of 10 are given in parentheses. The units of energy are related as follows: $1\,\mathrm{J} = 10^{7}\,\mathrm{erg}$; $1\,\mathrm{erg} = 1/e\,\mathrm{eV} = 1/h\,\mathrm{s^{-1}} = 1/(hc)\,\mathrm{cm^{-1}} = 1/k\,\mathrm{K}$. Energy conversion factors are from E. R. Cohen & B. N. Taylor, *Rev. Mod. Phys.* 59, p.1121 (1987); *CODATA Bulletin*, 63 (Nov. 1986); *Physics Today*, Part 2, BG9 (Aug. 1995). Values within the same column are equivalent.

SC19B101

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
Valiamala, Thiruvananthapuram – 695547

Introduction to Space Science and Applications (ES411)
Final Examination
BTech Aerospace / Avionics – VII Sem

28 Nov 2022
Time: 9:30 – 12:30 hrs
Max Marks: 100

Section A – ATMOSPHERIC SCIENCE (35 marks)

Instructions:
1) *Answer all questions.*
2) *Show diagrams and equations wherever necessary.*
3) *Questions (A1-A5) carry three marks each, and questions (A6-A15) carry two marks each.*

A1. What is the temperature of a saturated air parcel that is lifted 2 km if its initial temperature is 15 °C?

A2. A warm cloud suspended in the mid troposphere mixed with the cold cloud. Explain the possible mechanism and consequences.

A3. Explain why cyclones do not form during peak monsoon months like July and August over the Indian region?

A4. Calculate the equivalent blackbody temperature of the Earth as depicted in Fig. 1. assuming a planetary albedo (i.e., the fraction of the incident solar radiation that is reflected back into space without absorption) of 0.30. Assume that the Earth is in radiative equilibrium; i.e., that it experiences no net energy gain or loss due to radiative transfer.

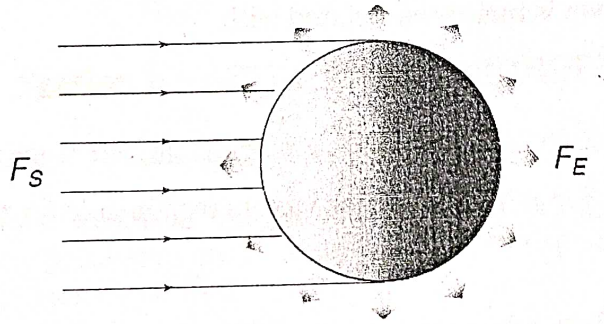


Fig.1 Radiation balance of the Earth.

A5. Estimate the relative efficiencies with which red light (0.64 μm) and blue light (0.47 μm) are scattered by air molecules.

Find the correct statement/option (A6-A15) (each 2 marks)

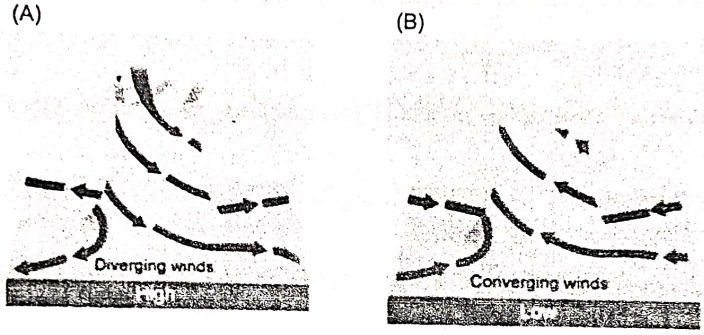
A6. Temperature measurements from a Radiosonde indicate that the environmental lapse rate in a layer of the atmosphere is 6 deg C / km. Based on this information the stability of this layer of the atmosphere would be

(a) Stable
(b) Unstable
✓(c) Neutral if saturated, stable if unsaturated
(d)Neutral if unsaturated, unstable if saturated

A7. Variations in the length of daytime and night time from season to season are due to
(a) the earth's rotation on its axis
(b) the earth's revolution round the sun in an elliptical manner
(c) latitudinal position of the place
✓(d) revolution of the earth on a tilted axis

A8. For an unsaturated air parcel becoming a saturated air parcel, which ELR would allow the parcel to continue rising?
(a) Low ELR
✓(b) High ELR
(c) Both low and high ELR
(d) Neither low or high ELR .

A9. Refer to schematic diagrams (A) and (B) shown below



(a) (A) indicates cyclonic while (B) anticyclonic circulation
✓(b) (A) indicates anticyclonic while (B) cyclonic circulation
(c) A) indicates cloudy while (B) clear weather
(d) Both (a) and (c) are correct.

A10. The Indian monsoon is mainly associated with
(a) Cyclonic
✓(b) Convectional
(c) Orographic
(d) Both (a) and (c)

A11. Which of the following is/are the major factors responsible for the monsoon
(a) Land breeze
(b) See breeze
(c) Upper air circulation
✓(d) all the above

A12. The annual range of temperature in the interior of the continents is high as compared to coastal areas. What is / are the reason / reasons?
✓(a) Thermal difference between land and water
(b) Variation in altitude between continents and oceans ✗
(c) Presence of strong winds in the interior
(d) Heavy rains in the interior as compared to coasts ✗

A13. Consider the following factors:
1. Rotation of the Earth
2. Air pressure and wind
3. Density of ocean water
4. Revolution of the Earth

Which of the above factors influence the ocean currents?
(a) 1 and 2 only
(b) 1, 2 and 3
(c) 1 and 4
(d) 2, 3 and 4

A14. Consider the following statements

1. The winds which blow between 30 N and 60 S latitudes throughout the year are known as westerlies.
2. The moist air masses that cause winter rains in the North Western region of India are part of westerlies.

Which of the statements given above is/are correct?

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

A15. Consider the following statements

1. La Nina is characterized by unusually cold ocean temperature in equatorial Indian Ocean whereas El Nino is characterized by unusually warm ocean temperature in the equatorial Pacific Ocean.

2. El Nino has adverse effect on south-west monsoon of India, but La Nina has no effect on monsoon climate.

Which of the statements given above is/are correct?
(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

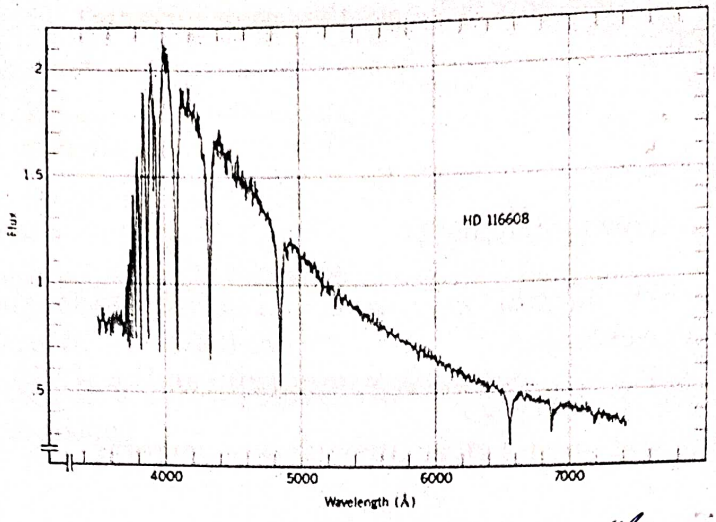
Section B – ASTRONOMY & ASTROPHYSICS

Answer any six questions. Each question carries 6 marks.

B1. Two stars have apparent magnitudes m_{V1} and m_{V2}, colors $(B\text{-}V)_1$ and $(B\text{-}V)_2$, respectively. If their parallaxes are p_1 and p_2, derive an expression for the ratio of B-band luminosities using these quantities.

B2. List the evolutionary phases of low mass and massive stars beyond the main-sequence phase.

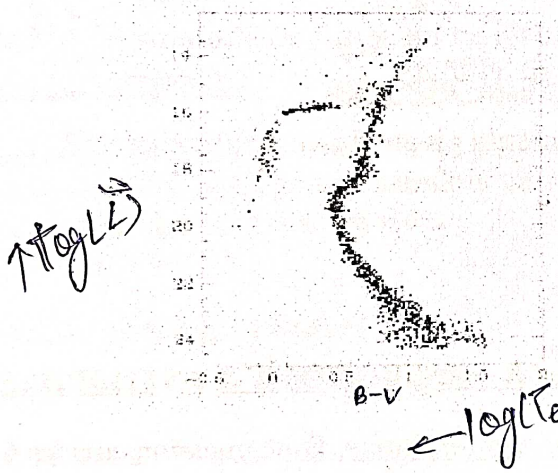
B3. The following figure shows the spectrum of star HD 116608



a) Comment on the shape of the curve. 7245K
b) Estimate its effective temperature. Is this an O type star or B type star? ✓ 2.898×10^{-3} m K
c) Find the energy emitted by the star per unit area per second. 1.56×10^{8}

B4. What is Schwarzchild radius? Estimate the Schwarzchild radius (in km) of a 12 $M_\odot$ black hole. 35.4km

B5. Using the diagram below, answer the following questions.



a) Giving justification, explain which type of cluster is this? ✓ Globular
b) How can the quantities plotted on X and Y-axes be related to axes of an H-R diagram.

B6. Consider this conversation between two students:

Student A: *If we measured the parallax from Mars, the angle would have to be smaller because Mars is farther from the Sun, so the star would also have to be farther away.*

Student B: *I think that if we measured the parallax of a star from Mars, the angle would be larger than if we measured from Earth. This would cause the star to move in a circle of size comparable to Mar's orbit.*

With whom do you agree? Explain with a figure.

B7. Suppose a star experiences an outburst in which its surface temperature doubles but its mass density decreases by a factor of eight. Find the new radius and luminosity of the star assuming that there is no mass lost during the outburst.

Section C - Remote Sensing

Please answer all the questions. Each question from 1 to 5 carries five marks, and 6 to 10 has one mark.

C1. You just can't have it all!" what are the trade-offs between a spatial, spectral, and radiometric resolution that must be considered when engineers design a sensor?

C2. What is a spectral signature? Draw the spectral signatures of vegetation and snow.

C3. What is a sun-synchronous orbit? Why are earth observing remote sensing satellites usually placed in sun synchronous orbit?

C4. What are the typical resolutions of a remote sensing satellite? Define each of these resolutions and give the name of an example real satellite.

C5. What are spectral indices? What is their role in the interpretation of remote sensing images? What can NDVI tell about?

Choose the correct answer to the following multiple-choice questions.

C6. Which of the following helps to identify the objects on the earth's surface?
✓A. Signature B. Radiometric error C. Atmospheric window D. None of the above

C7. The basic requirement of any sensor system is
A. Spatial resolution B. Spectral resolution C. Radiometric resolution ✓D. All of the above

C8. The optical property of a water body depends on?
A. Absorption by the dissolved material B. Absorption by the suspended particulate matter C. Scattering by the suspended particulate matter ✓D. All of these

C9. Leaf reflectance depends primarily on_____?
✓A. The pigments B. Internal cell structure C. Equivalent water content D. All of these

C10. The satellite orbit is fixed in the inertial space
2. During successive across-track imaging, the earth rotates beneath the sensor
3. The satellite images a skewed area
Which one of the following statements is/are correct?
A. 1, 2, 3 B. 1, 3 C. 2, 3 D. 1, 2

Consider the following statements

1.

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Constants

1 AU = 1.5×10^{11} m
1 pc = 3.086×10^{16} m
1 $L_\odot$ = 3.84×10^{26} W
1 $M_\odot$ = 1.989×10^{30} kg
1 $R_\odot$ = 6.9598×10^{8} m
Stephen Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/(m^2 K^4)
Wiens constant = 2.898×10^{-3} m.K