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

<u>Question 1</u> **(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.

<u>Question 2</u> **(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.

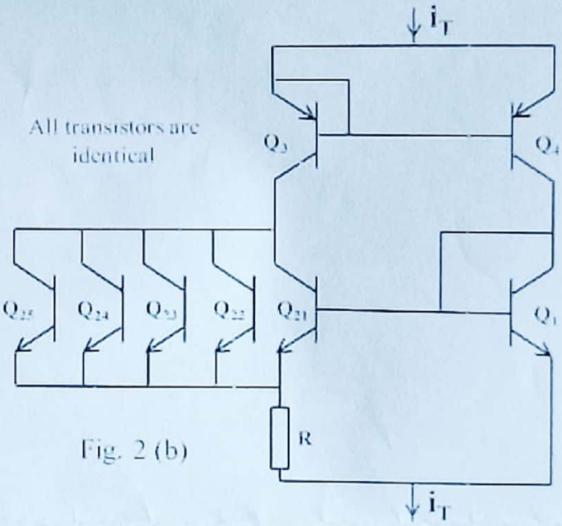

Fig. 2 (b)

<u>Question 3</u> **(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.

<u>Question 4</u> **(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:	Cable specifications:
Charge sensitivity to force = 2 pC N^{-1} Capacitance = 95 pF	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.

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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

(10 Marks)

Question 1: *Fill the blanks.*

(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.

(15 Marks)

Question 2

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.

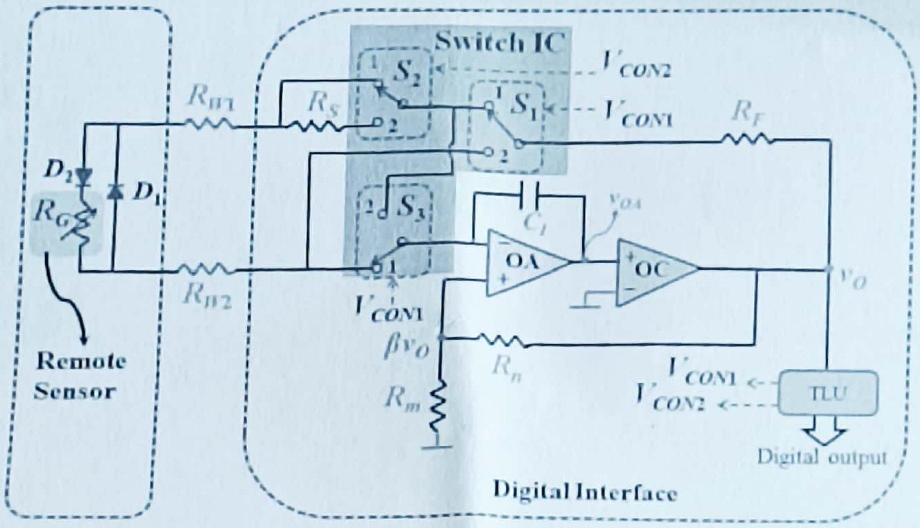

Fig. 1

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.

$-j\omega^3 L C_1 C \ast - \omega^2 C_1 C R_1 C + j\omega C + j\omega L$

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.

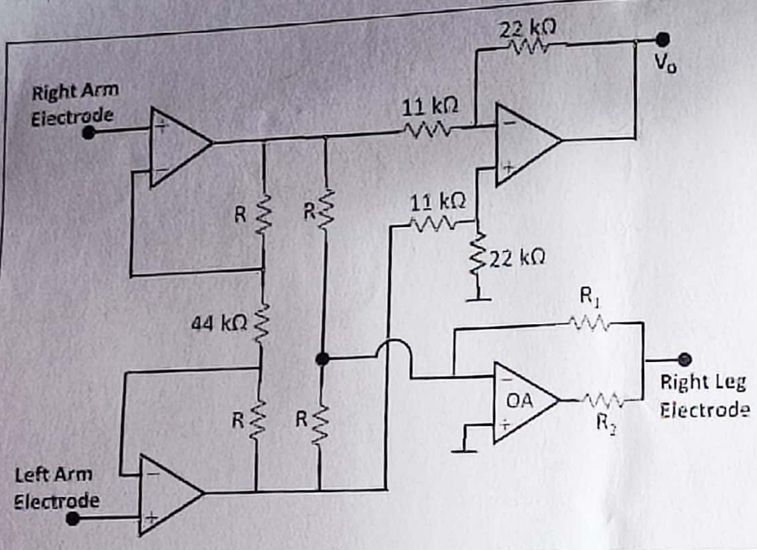

Fig. 2

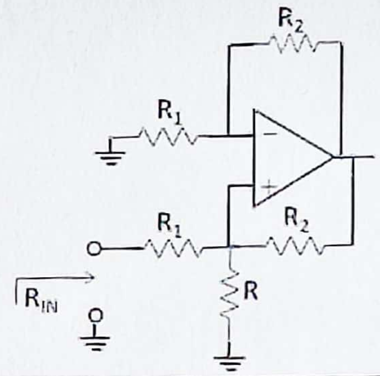

Fig. 3

(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.

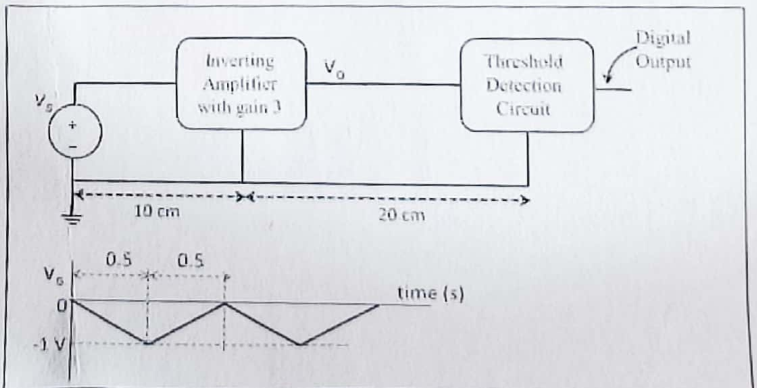

Fig. 4

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INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 19 Sept., 2023

Quiz-1 Time: 1 Hour Total Marks: 30 No. of Students: 35

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 ± 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.

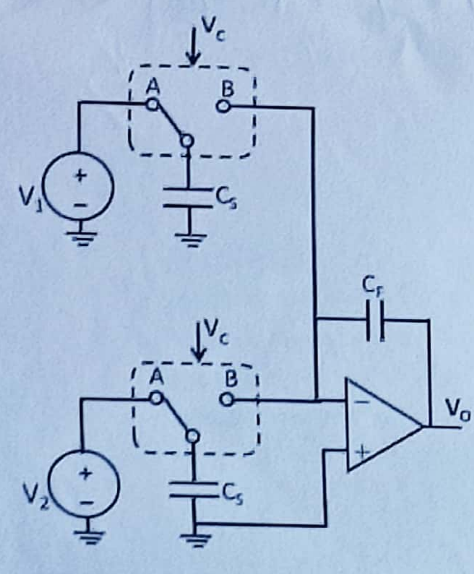

Fig. 1

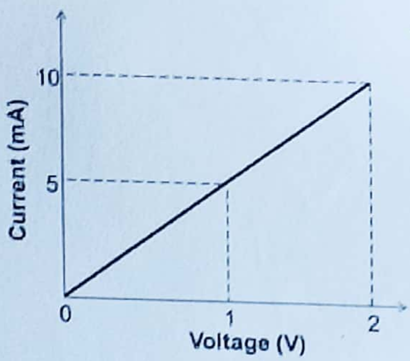

Fig. 2

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.

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INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Date: 06 Dec., 2022 | Time: 3 Hours | Total Marks: 100 | No. of Students: 47

End-Sem | Dept. of Avionics

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

Answer all questions in Part A. Answer any 6 of 7 questions in Part B.

Part A

(10 Marks)

Fill the blanks.

(1) DNL specification is important for Image processing application.

(2) Input Resolution of a 4-bit unipolar Flash ADC (reference voltage = 8 V) is $V_R/2^n$

(3) The SNDR of an ADC closely follows its SNR

(4) An application of Negative Resistance Converter is Control damping in electronic loops

(5) Two merits of GMR technology over Hall Effect are high sense and compact, cost

(6) A 1 kΩ resistor can be realized using a switched capacitor circuit with ____ valued-capacitor and clock signal of 100 kHz frequency. $\frac{1}{f C_s} = R$

(7) The output of a GMR-based angle sensor varies as a Cosine function of the input angular position.

(8) Resting potential of a human cell is around −80 mV.

(9) Minimum number of Hall sensors required in anti-differential current probe is 2.

4 2

Part B (answer any 6 of 7 questions)

Question 1

(3 + 5 + 7 = 15 Marks)

(a) Draw a neat labelled schematic showing the electrode and amplifier connections in a unipolar chest ECG.

(b) Consider a typical lead-1 ECG system. It is given that the arm-electrode impedances are 120 kΩ and 100 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, around 10 µV and 10 mV.

What should be the minimum input resistance of the IA that will ensure the SNR of 40 dB at its output.

(c) Draw the schematic of a right-leg driver circuit for the system in (b). Suppose a set of ideal operational amplifiers, nine 20 kΩ resistors, and two 1 MΩ resistors as well as +/- 15V dual power supplies are available to implement the IA and driver-leg driver circuit. Then, determine the

(i) factor by which the common-mode signal from human body can decrease, for a given displacement current.

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

Question 2

(4 + 5 + 6 = 15 Marks)

(a) Fluid velocity (v) in a pipe was measured using an ultrasonic flowmeter set-up as shown in Fig. 1. Following procedure was followed during the experimentation.

(1) Piezoelectric crystals, A and B were configured, respectively, as transmitter and receiver & transit time was noted.

(2) The roles of crystal A and B were interchanged and transit time was again noted.

(3) Difference of transit times noted in above steps was 75 µs.

Using the above data, calculate the velocity of the fluid. Assume that the velocity of the sound in the fluid is 500 m/s. (you can make suitable assumptions to simplify the calculations.)

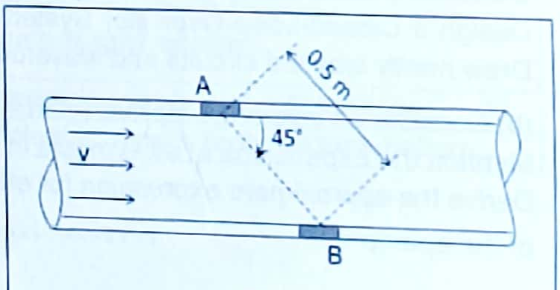

Fig. 1

(b) Draw the structure and equivalent circuit of a capacitive sensor probe that can be used for non-contact measurement of AC line voltage. 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.

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(c) In the circuit (Fig. 2), the switch SW2 will be at position-A if the signal, V_c = HIGH and at position B, if V_c = LOW. Determine the output, Vo when the SW1 is wired to position-A (as shown in the figure). Also, compute the output, Vo when SW1 is shifted to position-B.

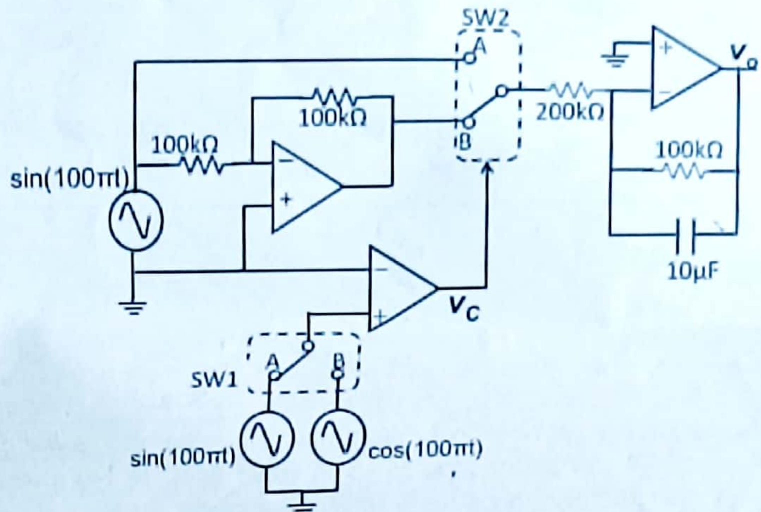


Fig. 2

Question 3 (8 + 7 = 15 Marks)

(a) 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 Natural frequency = 40 kHz Damping ratio = 0.01
Cable specifications: Capacitance = 5 pF Resistance = 1 GΩ

(i) Calculate the transfer function of the force-sensor system, considering all of the above parameters.

(ii) Assume that the piezoelectric crystal is connected to a charge amplifier with feedback capacitance C_F = 1000 pF and feedback resistance R_F = 100 MΩ. Sketch the frequency response characteristics of the modified system. Is this system suitable for thrust measurement frequency of an engine, where thrust varies as a pulse wave of period 10 ms. Give reason.

(b) Design an efficient capacitive measurement scheme for level measurement of a conductive liquid present in a plastic (cylindrical) tank. With the help of equivalent circuits and diagrams of the electrodes used in the tank, explain how your measurement scheme can nullify the effect of undesired parameters.

Question 4 (7 + 8 = 15 Marks)

(a) A piezoelectric crystal has an effective mass of 0.1 kg, stiffness of 10^{10} N m^{-1} and damping constant 200 Ns m^{-1}. Electrical capacitance of the crystal is 1000 pF and the charge to force sensitivity is 2×10^{-10} C N^{-1}. Calculate the series and parallel resonant frequencies of the crystal.
Design a Closed-Loop Oscillator System which will oscillate at the series resonant frequency of the crystal. Draw neatly labelled circuits and waveforms to explain your design methodology.

(b) Consider an inverting amplifier (gain = -1) realized using two equal resistors. Draw its noise-equivalent model. Mention the expansions of all symbols in the noise model.
Derive the approximate expression for effective output spectral density of the amplifier. Assume open-loop-gain of the opamp = ∞.

Question 5 (4 + 4 + 3 + 4 = 15 Marks)

(a) Prove that the sigma-delta ADC architecture provides noise shaping feature.

(b) A half-rectified sine-wave of 1 V amplitude is applied to a unipolar 10-bit ADC whose reference voltage (V_R) is 5 V. Find the SNR of the ADC for this case.

(c) Draw the schematic of a ring-core flux gate magnetometer. Label its important parts.

(d) Find the equivalent capacitance (C_{EQ}) at the node A (see Fig. 3) with respect to ground.

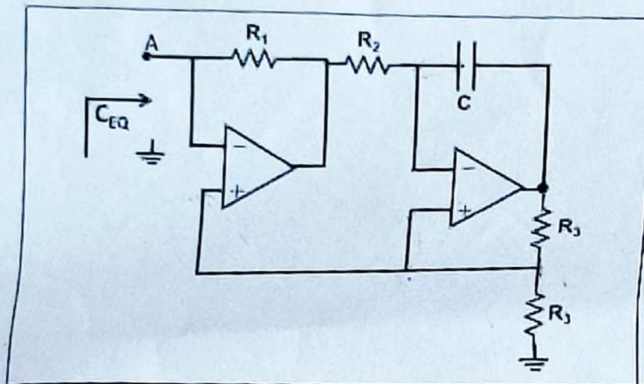


Fig. 3

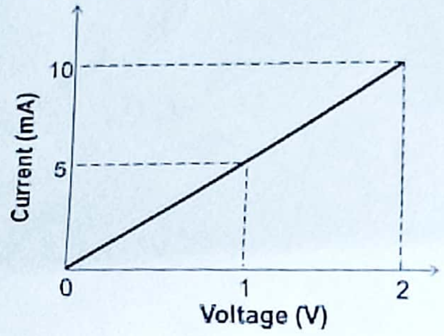


Fig. 4

Question 6 (4 + 4 + 7 = 15 Marks)

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

(b) The approximate I-V characteristic of a diode is shown in Fig. 4. 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.

(c) A push-pull type capacitive sensor is given. Design a signal conditioning circuit such that following properties are obeyed.

Circuit output should be independent of the stray capacitances present in the sensor system and should have zero-offset, and be independent of the nominal sensor capacitance.

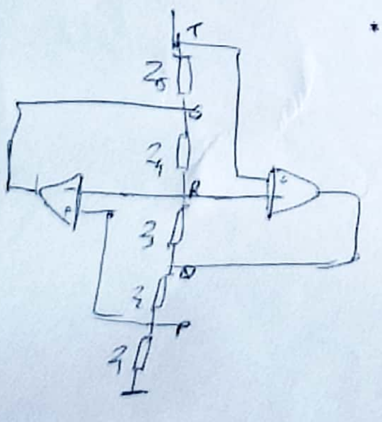
Explain, with the help of suitable waveforms, on how your circuit provides the aforesaid features.

Question 7 (3 + 12 = 15 Marks)

(a) Write the transfer function of a second-order all pass filter (APF). Draw the circuit diagram of APF using Universal Active Filter approach.

(b) The following table lists a number of sensing problems and some measurement electronics schemes. Choose the most optimal measurement scheme (from second column) for each sensing problem (given in first column). Briefly explain, in few sentences, the reason for your choice. Illustrative figures can be used.

Sensing Problem	Measurement Electronics Techniques
1. Conductivity Measurement of Metals C	Twin Hall Effect Sensing
2. Flow-rate measurement of clean fluids D	B. Low frequency Eddy current Testing
3. Flow-rate measurement of impure fluids C	C. Doppler Effect Ultrasonic Flowmeters
4. Non-Destructive Sub-surface Evaluation of Metallic Plates B	D. Transit time Ultrasonic Flowmeters
5. Geophysical Surveys F	E. High-frequency Eddy current Testing
6. Non-invasive arrangement of measurement of water level in a tank. H	F. Flux-gate Magnetometers
	Piezoelectric sensor probe at tank-top
	H. Piezoelectric sensor probe at tank-bottom



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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.

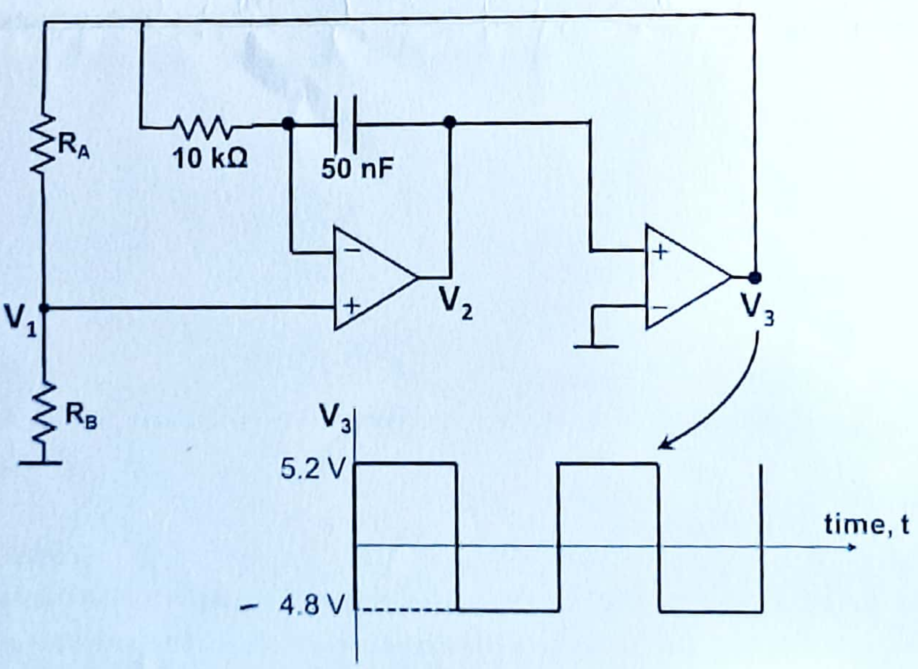
Question 2 **(5 Marks)**

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 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 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.

$V_o = \frac{I}{j\omega C}$, IZ

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 (3 Marks)

Fill in the blanks. Write the final answer in the script.

(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 ________

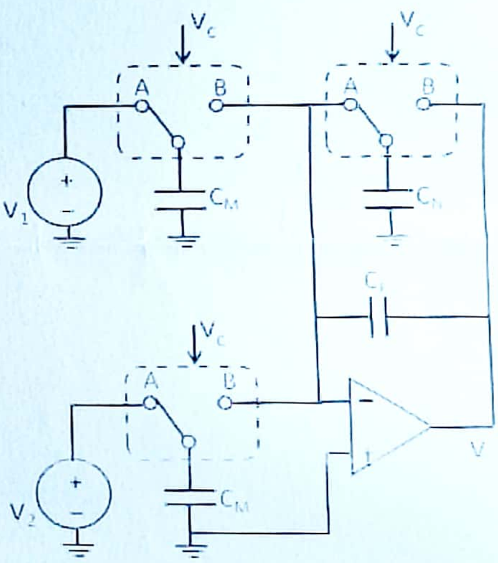
(vi) Second order All pass response can be obtained with the help of a ______________ filter response

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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