Subject Name Solutions

4331102 – Summer 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Illustrate steps to minimize that all type of systematic error.

Solution

Steps to minimize systematic errors:

Step	Description
1. Calibration	Periodically calibrate instruments against standard references
2. Correction	Apply correction factors or offset values
3. Control	Maintain constant environmental conditions (temperature, humidity)
4. Technique	Use proper measurement techniques and procedures
5. Equipment	Select appropriate instruments with required accuracy

Mnemonic

"CCCTS: Calibrate, Correct, Control, Technique, Select"

Question 1(b) [4 marks]

Define: Resolution, Precision, Sensitivity and Accuracy.

Solution

Term	Definition
Resolution	The smallest change in input that can be detected by the instrument
Precision	Consistency or repeatability of measurements with minimal random error
Sensitivity	The ratio of change in output to the change in input ($\Delta O/\Delta I$)
Accuracy	Closeness of measured value to the true or accepted standard value

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Measurement Quality] {-{-}{} B[Resolution]}
    A {-{-}{} C[Precision]}
    A {-{-}{} D[Sensitivity]}
    A {-{-}{} E[Accuracy]}
    B {-{-}{} F[Smallest detectable change]}
    C {-{-}{} G[Repeatability]}
    D {-{-}{} H[Output/Input ratio]}
    E {-{-}{} I[Closeness to truth]}
{Highlighting}
{Shaded}
```

Mnemonic

"RSPA: Resolve Signals Precisely and Accurately"

Question 1(c) [7 marks]

Explain a principle of Q Meter and Working of practical Q Meter.

Solution

Q Meter operates on the resonance principle to measure quality factor (Q) of coils and capacitors.

Principle:

- Based on series resonance where Q = XL/R or XC/R at resonance
- Measures voltage magnification at resonance condition

Working of practical Q meter:

Component	Function
Oscillator	Generates variable frequency signal (50kHz to 50MHz)
Work coil	Inductor under test (connected in series with calibrated capacitor)
Capacitor	Variable calibrated capacitor for resonance tuning
VTVM	Measures resonant voltage across capacitor
Shunt resistor	Monitors current through the circuit

Diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
|  RF            |       |               |
|  OSCILLATOR   +{-{-}{-}{-}{-}{-}{-}  WORK COIL    |}
|                |       |   (Lx)        |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+}
                                      |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}{-}{-}{-}v{-}{-}{-}{-}{-}{-}{-}+}
|                |       |               |
|    VTVM       {{-}{-}{-}{-}{-}{-}{-}+  CAPACITOR    |}
|  (Q READING)  |       |   (C)         |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

- **Q factor calculation**: Q = $V_2/V_1 whereV_2isvoltageacrosscapacitorandV_1istheappliedvoltage$
- **Applications**: Testing RF components, coil quality measurement
- **Resonance indication**: Maximum voltage across capacitor indicates resonance

Mnemonic

"VOCAL: Voltage ratio at resonance Oscillator Creates Amplification to measure coiL quality"

Question 1(c OR) [7 marks]

Explain Wheatstone bridge and derive equation for balanced condition. State application and limitation of Wheatstone bridge.

Solution

Wheatstone bridge is a network used to measure unknown resistance with high precision.

Circuit diagram:

```
     A
     o
     |
    +{-+}
```

```
      |R1|
      +{-+}
       |
R      o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}o D}
       |         |
      +{-+       +{-}+}
      |R2|      |Rx|
      +{-+       +{-}+}
       |         |
       o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
       B         C

    G = Galvanometer
    Rx = Unknown resistance
```

Balanced condition equation derivation:

- At balance, no current flows through galvanometer
- Potential at point D = Potential at point B
- Voltage across $R_1 = VoltageacrossRx$
- Voltage across $R_2 = VoltageacrossR_3$

Therefore:

- $(R_1/R_2) = (Rx/R_3)$
- $Rx = R_3(R_1/R_2)$

Applications:

Application	Description
Precision resistance measurement	Accurate measurement of unknown resistors
Temperature sensing	When used with RTD or thermistor
Strain measurement	With strain gauges for stress analysis
Transducer interface	Converting physical quantities to electrical signals

Limitations:

Limitation	Description
Low resistance measurement	Poor accuracy for very low resistances (<1Ω)
Sensitivity	Limited by galvanometer sensitivity
Range	Limited range of measurement (typically 1Ω to 100kΩ)
Contact resistance	Affects accuracy in low resistance measurements

Mnemonic

"BEAR: Balance Equation at Arms Ratio"

Question 2(a) [3 marks]

Differentiate between moving iron and moving coil type instruments.

Solution

Parameter	Moving Iron Instrument	Moving Coil Instrument
Operating principle	Magnetic attraction or repulsion	Electromagnetic force on current-carrying conductor
Scales	Non-uniform scale	Uniform scale
Accuracy	Lower (1-2.5%)	Higher (0.1-1%)
Frequency range	Works for both AC and DC	Only DC (unless rectified)
Damping	Air friction damping	Eddy current damping
Power consumption	Higher	Lower

Mnemonic

"IRON-COIL: Iron uses Repulsion with Non-uniform scale; COIL uses Current with Organized, Improved, Linear scale"

Question 2(b) [4 marks]

Solution

Construction diagram of clamp-on ammeter:

```
                 +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    +{-{-}{-}{-}+       |   Display  |}
    |    |       +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    |    |       +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    | C  |       |    CT      |
    | L  |       |            |
    | A  +{-{-}{-}{-}{-}{-}{-}+    |       |}
    | M  +{-{-}{-}{-}{-}{-}{-}+    |       |}
    | P  |       | Circuit    |
    |    |       |            |
    |    |       +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    +{-{-}{-}{-}+       +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
                 |  Controls  |
                 +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Components and working:

- **Core**: Split laminated ferromagnetic core that can be opened/closed
- **Coil**: Secondary winding wrapped around the core
- **Conductor**: Primary conductor (current to be measured) passes through the core
- **Measurement circuit**: Processes induced current and displays reading
- **Spring mechanism**: For easy opening and closing of the jaw

Working principle: Based on transformer principle where conductor acts as single-turn primary winding, creating magnetic flux proportional to current.

Mnemonic

"CLASP: Conductor-Loop Amperes Sensed by Primary-secondary relationship"

Question 2(c) [7 marks]

Solution

Integrating-type Digital Voltmeter converts analog voltage to digital value using dual-slope integration.

Block diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-
| Input        |     | Integrator |     | Comparator  |     | Counter  |
| Circuit     +{-{-}{-}{-}+          +{-}{-}{-}{-}+          +{-}{-}{-}{-}+         |}
| Buffer       |     |            |     |             |     |          |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-
       \^{                                      \^{}                 |}
       |                                       |                 v
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+                         +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
| Reference    |                        | Control     |    | Display  |
| Voltage      |{{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+ Logic       |{-}
| Source       |                        | \& Clock     |    |          |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+                         +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
```

Working principle:

Phase	Description
1. Run-up	Unknown input voltage is integrated for fixed time T_1
2. Run-down	Reference voltage (opposite polarity) is integrated until output returns to zero
3. Measurement	Time $T_2 ofrun - downisproportionaltoinputvoltage$
4. Display	Digital value based on $T_2/T_1 \times Vrefisdisplayed$

Advantages:

- **Noise rejection**: Excellent rejection of power line noise (50/60Hz)
- **Accuracy**: Highly accurate (0.005% to 0.05%)
- **Resolution**: High resolution (up to 6½ digits)
- **Stability**: Less affected by component tolerances
- **Common mode rejection**: High CMRR

Mnemonic

"RISES: Ramp Integration Samples and Eliminates Spikes"

Question 2(a OR) [3 marks]

Solution

Parameter	Digital Voltmeter	Analog Voltmeter
Display	Numeric display (digits)	Pointer movement on scale
Reading error	No parallax error	Subject to parallax error
Resolution	Higher (limited by number of digits)	Limited by scale divisions
Accuracy	Better (typically 0.05% to 0.5%)	Lower (typically 1% to 3%)
Output	Can provide digital output for interfacing	No direct digital output
Power requirement	Requires power supply	Can be passive (PMMC type)

Mnemonic

"DAPPER: Digital Accuracy and Precise readings; Parallax Error in Reading analog"

Question 2(b OR) [4 marks]

Solution

Construction diagram of moving iron meter:

```
                 +{-{-}{-}{-}+ Pointer}
                /
        +{-{-}{-}{-}{-}+  }
        |     |
        | +{-+ | }
Scale   | |\^{| | Moving iron}
+{-{-}{-}{-}{-}{-}{-}{-}+ +{-}+ |}
|       |     |
|       |  \#  | Fixed iron
|       |  \#  |
|       +{-{-}{-}{-}{-}+}
|         | |
```

```
|          | | Coil
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}{-}{-}+}
             Spring
```

Working principle and components:

- **Coil**: Creates magnetic field proportional to current
- **Iron vanes**: Two soft iron pieces (one fixed, one movable)
- **Movement**: Magnetic repulsion between similarly magnetized iron pieces
- **Control**: Spring provides opposing torque
- **Damping**: Air friction damping mechanism
- **Scale**: Non-uniform scale due to non-linear magnetic force

Types:

- Attraction type: Works on magnetic attraction principle
- Repulsion type: Works on magnetic repulsion principle

Mnemonic

"MIRROR: Magnetic Interaction Requires Repulsion/attraction Of Related iron pieces"

Question 2(c OR) [7 marks]

Solution

Electronic energy meter measures electrical energy consumption in kilowatt-hours.

Construction diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
|        Display            |
|    +{-{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+  |}
|    | 0 | 0 | 0 | 0 | 0 |  |
|    +{-{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+  |}
|                           |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
|  |    Microcontroller  |  |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
|             \^{            |}
|             |             |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}+   |}
|  | Signal Conditioning|   |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}+   |}
|             \^{            |}
|             |             |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
|  | Voltage \& Current   |  |
|  | Sensing Circuits    |  |
|  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
|             \^{            |}
|      Input Terminals      |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Components and working:

Component	Function
Voltage sensor	Potential transformer or resistive divider to measure voltage
Current sensor	Current transformer or shunt resistor to measure current
Multiplier	Multiplies instantaneous voltage and current values

Integrator	Integrates power over time to calculate energy
Microcontroller	Processes signals and calculates energy consumption
Display	LCD or LED to show consumption in kWh
Pulse LED	Blinks at a rate proportional to power consumption

Working principle:
1. Voltage and current are sensed by respective sensors
2. Signals are multiplied to obtain instantaneous power
3. Power is integrated over time to calculate energy
4. Energy is displayed as kilowatt-hours (kWh)

Mnemonic

"WATTAGE: Work And Time Tracked As Generated Electrical energy"

Question 3(a) [3 marks]

Solution

Lissajous patterns on oscilloscope screen help measure frequency ratio and phase difference.

Frequency measurement:
- Apply reference signal to X-axis and unknown signal to Y-axis
- Frequency ratio = Number of tangent points on Y-axis / Number of tangent points on X-axis
- Frequency of unknown = Frequency of reference $\times Frequencyratio$

Pattern	Frequency Ratio (Y:X)
	1:1
	2:1
	n:m

Phase angle measurement:
- If both frequencies are equal, phase angle ( ) can be measured
- $= \sin^{-1}(A/B) where$

A = minor axis and
B = major axis of ellipse

Mnemonic

"LIPS: Lissajous Indicates Phase and Signal frequency"

Question 3(b) [4 marks]

Solution

Graticules are reference markings on CRO screen for measurements.

Graticule Type	Description	Application
Internal graticule	Markings inside CRT glass	Eliminates parallax error
External graticule	Plastic overlay on screen	Replaceable, economical
Electronic graticule	Generated electronically	Digital storage oscilloscopes

Standard graticule features:

- 10 $\times 8 divisions typically$
- Center lines darker for reference
- Small hash marks for subdivisions
- Percentage markings (rise time)

Diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{
|                                      |
|                                      |
|     |           |           |       |
|{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{
|     |           |           |       |
|     |           |           |       |
|     |           |           |       |
|{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{
|     |           |           |       |
|     |           |           |       |
|                                      |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{
```

Mnemonic

"GRID: Graticule References for Intensity and Distance"

Question 3(c) [7 marks]

Solution

Digital Storage Oscilloscope (DSO) converts analog signals to digital for storage and processing.

Block diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{
| Vertical |     | ADC   |     | RAM  |     | DAC   |     | CRT/  |
| Amplifier+{-{-}{-}{-}+      +{-}{-}{-}{-}+      +{-}{-}{-}{-}+      +{-}{-}{-}{-}+ LCD   |}
+{-{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{
      \^{                           \^{}                         \^{}}
      |                            |                           |
+{-{-}{-}{-}{-}{-}{-}{-}{-}+                 +{-}{-}{-}{-}{-}{-}{-}+                 +{-}{-}{-}{
| Input    |                  | CPU   |                  | Display|
|Attenuator|{{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{
+{-{-}{-}{-}{-}{-}{-}{-}{-}+                 +{-}{-}{-}{-}{-}{-}{-}+                 +{-}{-}{-}{
                                 \^{}
                                 |
                              +{-{-}{-}{-}{-}{-}{-}+}
                              | Timing|
                              |Circuit|
                              +{-{-}{-}{-}{-}{-}{-}+}
```

Working principle:

1. **Signal acquisition**: Analog signal is sampled at high speed
2. **A/D conversion**: Continuous signal converted to discrete digital values
3. **Storage**: Digital values stored in memory
4. **Processing**: Microprocessor analyzes stored data
5. **Display**: Data converted back to analog for display or shown directly on LCD

Advantages of DSO:

Advantage	Description
Pre-trigger viewing	Can see signal before trigger event

Single-shot capture	Can capture transient events
Waveform storage	Can save waveforms for later analysis
Signal processing	Advanced mathematical operations on signals
Automated measurements	Automatic parameter measurements
Digital interfaces	Can transfer data to computers

Mnemonic

"SAMPLE: Storage And Memory Processes Live Events"

Question 3(a OR) [3 marks]

Solution

Parameter	Analog CRO	Digital Storage Oscilloscope
Signal processing	Real-time analog	Digitized and stored
Storage capability	None (phosphor persistence only)	Can store waveforms in memory
Bandwidth	Typically higher for same price range	Limited by sampling rate
Pre-trigger view	Not possible	Available
Single-shot events	Difficult to capture	Easily captured
Signal analysis	Basic measurements only	Advanced mathematical analysis

Mnemonic

"ASPAD: Analog Shows Present; Digital Archives Data"

Question 3(b OR) [4 marks]

Solution

10:1 probe reduces signal amplitude by 10 times to extend oscilloscope range.
Structure:

```
   Probe tip       Cable           Compensation
     \^{              \^{}                 \^{}}
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+   +{-}{-}{-}{-}+{-}{-}{-}{-}+   +{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-
|     |     |   |         |   |        |        |
+{-{-}+{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+
  |                                  |
  |                                  |
  |  Rm=9MΩ                         |
  +{-{-}///{-}{-}+                       |}
  |         |                       |
  |      Cm=12pF                    |
  |        ||                       |
  |        ||                       |
  +{-{-}{-}{-}{-}{-}{-}{-}{-}++{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
            |
            v
          Ground
```

Components:

Component	Description
Probe tip	Metal contact point that touches circuit
Ground clip	Reference connection to circuit ground
Compensation network	RC circuit for frequency compensation
Probe body	Insulated housing for components
Cable	Low-capacitance coaxial cable
Connector	BNC connector for oscilloscope input

Working principle:

- Forms voltage divider with oscilloscope input (9MΩ probe + 1MΩ scope = 10:1 division)
- Compensating capacitor ensures flat frequency response
- Reduces circuit loading effect by increasing effective input impedance

Mnemonic

"TAPER: Ten-to-one Attenuation Preserves and Extends Range"

Question 3(c OR) [7 marks]

Solution

CRO (Cathode Ray Oscilloscope) displays and measures electrical signals.
Block diagram:

```
                +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
                | Cathode Ray |
                |    Tube     |
                +{-{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}
                       \^{}
       +{-{-}{-}{-}{-}{-}+      |      +{-}{-}{-}{-}{-}{-}+}
       |      |      |      |      |
+{-{-}{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}
|Vertical |     |             |      |Horizontal|
|Amplifier|     |  Deflection |      |Amplifier |
+{-{-}{-}+{-}{-}{-}{-}{-}+     |   System    |      +{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
    \^{           |             |           \^{}}
    |           +{-{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+           |}
+{-{-}{-}+{-}{-}{-}{-}{-}{-}+          |           +{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
|Vertical  |          |             |Horizontal|
|Attenuator|          |             |Time Base |
+{-{-}{-}+{-}{-}{-}{-}{-}{-}+          |           +{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
    \^{                 |                  \^{}}
    |                 v                 |
+{-{-}{-}+{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}+{-}{-}{-}{-}+}
| Signal |      |   Power     |      | Trigger |
| Input  |      |   Supply    |      | Circuit |
+{-{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}
```

Working principle:

1. **Electron beam generation**: CRT produces focused electron beam
2. **Vertical deflection**: Y-plates deflect beam proportional to input signal
3. **Horizontal deflection**: X-plates sweep beam across screen
4. **Triggering**: Synchronizes sweep with input signal
5. **Display**: Beam strikes phosphor screen creating visible trace

Applications of CRO:

Application	Description
Waveform analysis	Visualize signal shape and characteristics

Frequency measurement	Measure time period and calculate frequency
Phase measurement	Compare phase relationship between signals
Voltage measurement	Measure signal amplitude
Component testing	Check behavior of electronic components
Transient analysis	Observe fast-changing events

Mnemonic

"VIEW: Voltage Inspection and Electrical Waveform observation"

Question 4(a) [3 marks]

Solution

Parameter	RTD (Resistance Temperature Detector)	Thermistor
Material	Pure metals (Pt, Ni, Cu)	Semiconductor materials
Resistance-temp relation	Linear (positive)	Highly non-linear (usually negative)
Temperature range	-200^{t}o850	-50^{t}o300
Sensitivity	Lower (0.4%/$^{)}$	Higher (4%/$^{)}$
Accuracy	Higher	Lower
Cost	Higher	Lower
Response time	Slower	Faster

Mnemonic

"METAL-SEMI: Metal Elements Temperature-Linear vs. SEMIconductor Exponential Measurement Instrument"

Question 4(b) [4 marks]

Solution

Type	Examples	Explanation
Primary Transducers		
1. Thermocouple	Directly converts temperature difference to voltage using Seebeck effect	Two dissimilar metals generate voltage proportional to temperature difference
2. Piezoelectric crystal	Directly converts mechanical force to electrical charge	Quartz crystal develops charge proportional to applied pressure
Secondary Transducers		
1. Strain gauge	Requires intermediate conversion; change in dimension alters resistance	Mechanical strain $\rightarrow resistancechange \rightarrow electricalsignal$
2. LVDT	Requires intermediate conversion; displacement changes magnetic coupling	Mechanical displacement $\rightarrow magneticcoupling \rightarrow electricalsignal$

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Transducers] {-{-}{} B[Primary]}
    A {-{-}{} C[Secondary]}
    B {-{-}{} D[Direct conversion]}
    C {-{-}{} E[Uses intermediate steps]}
    D {-{-}{} F[Thermocouple: Temperature  Voltage]}
    D {-{-}{} G[Piezoelectric: Force  Charge]}
    E {-{-}{} H[Strain Gauge: Force  Resistance  Voltage]}
    E {-{-}{} I[LVDT: Displacement  Magnetic coupling  Voltage]}
{Highlighting}
{Shaded}
```

Mnemonic

"PIDS: Primary Is Direct; Secondary is Stepwise"

Question 4(c) [7 marks]

Solution

Thermocouple is a temperature sensor based on the Seebeck effect.
Working principle:

- When two dissimilar metals are joined, a voltage is generated proportional to temperature difference
- Seebeck effect: Temperature gradient creates electromotive force

Diagram:

```
                  Hot Junction
                       V
  Metal A {-{-}{-}+        /         +{-}{-}{-} Metal A}
             |       /   {       |}
             +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}+}
             |      |     |      |
  Metal B {-{-}{-}+      +{-}{-}{-}{-}{-}+      +{-}{-}{-} Metal B}
                       \^{}
                  Cold Junction
                       |
                       v
                   Voltmeter
```

Types of thermocouples:

Type	Materials	Temperature Range	Application
Type J	Iron-Constantan	-40to750	General purpose, reducing atmosphere
Type K	Chromel-Alumel	-200to1350	Oxidizing atmosphere, high temperatures
Type T	Copper-Constantan	-200to350	Low temperature, food industry
Type E	Chromel-Constantan	-200to900	Highest sensitivity, cryogenics
Type R/S	Platinum-Rhodium	0to1600	High temperature, laboratory standards

Applications:

- Industrial temperature measurement
- Furnace and kiln temperature control
- Chemical processing
- Food processing
- Automotive engine sensors
- Medical equipment

Mnemonic

"STEVE: Seebeck Thermoelectric Effect Verifies Elevated temperatures"

Question 4(a OR) [3 marks]

Solution

LM35 is a precision integrated-circuit temperature sensor that provides output voltage proportional to temperature.

Principle:

- Based on the predictable change in base-emitter voltage (VBE) of a transistor with temperature
- Output voltage linearly proportional to Celsius temperature (10mV/$^)$

Circuit diagram:

```
   +{-{-}{-}{-}{-}{-}{-}+}
   |       |
+{-{-}+ Vs   |}
|  |       |
|  | LM35 +{-{-}{-}+ Vout (10mV/^)}
|  |       |
|  | GND  +{-{-}{-}+}
|  |       |   |
|  +{-{-}{-}{-}{-}{-}+   |}
|              |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
      GND
```

Working characteristics:

- Linear output: 10mV/$^(0.01V/^)scalefactor$
- Range: -55$^to+150$
- Accuracy: $\pm$0.5$^(typical)$
- Low self-heating: 0.08$^instillair$
- Low impedance output: 0.1Ω for 1mA load

Mnemonic

"LOTUS: Linear Output Temperature Units from Semiconductor"

Question 4(b OR) [4 marks]

Solution

Incremental optical encoder generates pulses as shaft rotates to measure position, speed, and direction.

Construction:

```
+{-{-}{-}{-}{-}{-}{-}{-}+}
| LED     |
|    {    |}
```

```
           |     {   |}
           |      {  |}
           |       { |}
           |        {|}
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+         |}
| Rotating |         |
| Disk     |         |
| with     |         |
| slots    |         |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+         |}
           |        /|
           |       / |
           |      /  |
           |     /   |
           | Photo   |
           | detector|
           +{-{-}{-}{-}{-}{-}{-}{-}+}
```

Output waveform:

```
Channel A: \_\_\_\_\_          \_\_\_\_\_          \_\_\_\_\_
                |\_\_\_\_\_\_\_\_\_|     |\_\_\_\_\_\_\_\_\_|     |\_\_\_\_\_\_\_\_\_

Channel B: \_\_\_      \_\_\_\_\_       \_\_\_\_\_       \_\_\_\_\_
             |\_\_\_\_\_\_|     |\_\_\_\_\_\_|     |\_\_\_\_\_\_|     |\_\_\_\_\_\_

          {{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} One Rotation {-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
```

Working principle:

- Light source (LED) shines through slotted disk
- Photodetectors receive light pulses as disk rotates
- Two output channels (A and B) are $90° out of phase$
- Direction determined by which channel leads
- Resolution depends on number of slots on disk

Mnemonic

"PADS: Pulses from A and Determine Speed"

Question 4(c OR) [7 marks]

Solution

LVDT (Linear Variable Differential Transformer) is an electromechanical transducer that converts linear displacement into electrical signal.

Construction:

```
                   Core
              +{-{-}{-}{-}+{-}{-}{-}{-}+}
              |    |    |
              v    v    v
      +{-{-}{-}{-}{-}{-}+++++++++++++{-}{-}{-}{-}{-}{-}+}
      |      |    |    |        |
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
|     |Primary|    |    |Secondary    |
|     |  Coil |    |    |   Coil      |
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
      |      |    |    |        |
      +{-{-}{-}{-}{-}{-}+++++++++++++{-}{-}{-}{-}{-}{-}+}
                   \^{}
```

```
                |
            Moving Core
```

Operation:

1. AC excitation applied to primary coil
2. Magnetic flux couples to secondary coils
3. Core position determines differential voltage output
4. Null position: Equal voltage in both secondaries
5. Movement: Voltage increases in one secondary, decreases in other

Advantages:

Advantage	Description
Frictionless	No mechanical contact between core and coils
Infinite resolution	Analog output with no quantization
Robustness	Long operational life, high reliability
Null position stability	Highly stable reference position
High sensitivity	Small displacements can be measured

Disadvantages:

Disadvantage	Description
AC excitation required	Needs AC power source
Temperature sensitive	Output varies with temperature
Position limited	Measurement range is limited
Bulky	Larger size compared to other sensors

Applications:

- Machine tool positioning
- Hydraulic and pneumatic systems
- Aircraft and missile systems
- Automated manufacturing
- Structural testing

Mnemonic

"MOVE-AC: Magnetic Output Varies with Exact Armature Core position"

Question 5(a) [3 marks]

Solution

Capacitive pressure transducer uses changes in capacitance to measure pressure.

Working principle:

- Pressure deforms diaphragm, changing distance between capacitor plates
- Capacitance inversely proportional to distance (C = ${}_{0a}A/d$)
- Change in capacitance is measured and converted to pressure reading

Diagram:

```
     Pressure
        ↓
    +{-{-}{-}+{-}{-}{-}+}
    |       | Metal housing
+{-{-}{-}+{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
|   |       |   |
|   |       |   |
|   |    | Diaphragm (movable plate)
|   |       |   |
+{-{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+}
```

```
|    |    |    |    |
|    |    |    |    | Air gap
|    |    |    |    |
+{-{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+ Fixed plate}
|                   |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    Insulator
```

Application: Industrial process monitoring, atmospheric pressure measurement, liquid level sensing

Mnemonic

"CAPS: Capacitance Alters as Pressure Shifts"

Question 5(b) [4 marks]

Solution

Parameter	Definition
Rise Time	Time taken for pulse to rise from 10% to 90% of its maximum amplitude
Fall Time	Time taken for pulse to fall from 90% to 10% of its maximum amplitude
Pulse Width	Time interval between 50% amplitude points on rising and falling edges
Duty Cycle	Ratio of pulse width to total period, expressed as percentage

Diagram:

```
     \^{ Amplitude}
     |
     |    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
     |    |         |
90\%  |{-{-}{-}{-}+         +{-}{-}{-}{-}}
     |   /|         |{}
     |  / |         | {}
     | /  |         |  {}
50\%  |/   |         |   {}
     +{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-} Time}
     |    |         |    |
10\%  |    |         |    |
     |    |{{-}Pulse{-}|    |}
     |    | Width   |    |
     |    |         |    |
     |{{-}{-}|         |{-}{-}|}
     Rise |         |Fall
     Time |         |Time
     |    |{{-}{-}{-}Period{-}{-}{-}|}
```

Mnemonic

"RPFD: Rise Pulses, Fall Determines"

Question 5(c) [7 marks]

Solution

Function generator produces various waveforms over a range of frequencies.
Block diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-
| Frequency|     | Waveform |     | Amplitude|     | Output   |     | Output   |
| Control  +{-{-}{-}{-}+ Generator+{-}{-}{-}{-}+ Control  +{-}{-}{-}{-}+ Buffer   +{-}{-}{-}{-}+
| Circuit  |     | (VCO)    |     | Circuit  |     | Amplifier|     |          |
+{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-
      \^{              |                                             \^{}}
      |             v                                              |
      |         +{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+
      |         | Waveshape|     | DC Offset|                  | Attenuator|
      |         | Circuit  |     | Circuit  |                  | Circuit   |
      |         +{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+
      |             |               |                            \^{}
      |             v               v                            |
      |         +{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-
      +{-{-}{-}{-}{-}{-}{-}{-}{-}+ Sync     |     | Duty     |     | Trigger  |    | Protection|}
                | Output   |     | Cycle    |     | Circuit  |     | Circuit   |
                +{-{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-
```

Function and operation of each block:

Block	Function
Frequency Control	Sets the operating frequency using variable capacitor/resistor network
Waveform Generator	Voltage-controlled oscillator producing basic waveform (usually triangle)
Waveshape Circuit	Converts triangle wave to sine/square waves through shaping circuits
Amplitude Control	Adjusts output amplitude of the generated waveform
DC Offset	Adds DC bias to shift the waveform up or down from zero reference
Output Buffer	Provides low output impedance for proper loading
Attenuator	Controls final output level with calibrated steps
Protection Circuit	Protects output from short circuits or overload

Output waveforms:

Waveform	Generation Method
Sine	Shaped from triangle wave using non-linear shaping circuit
Square	Derived from triangle wave using comparator
Triangle	Basic output from integrator circuit
Ramp	Modified triangle wave with different rise/fall times
Pulse	Square wave with variable duty cycle

Mnemonic

"FASTEST: Frequency Amplitude Shaping Together Ensures Signal Types"

Question 5(a OR) [3 marks]

Solution

Strain gauge converts mechanical deformation to electrical resistance change.
Construction:

```
          Terminals
             ||
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}++{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
   |                       |
   | +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
   | |  /{////// |  |}
   | | /{/////// |  | Resistive}
   | |/{/////// |  | Grid}
   | |{/ ////// |  |}
   | | {/////// |  |}
   | +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+  |}
   |                       |
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
         Backing material
```

Working principle:

- Based on piezoresistive effect: resistance changes with mechanical deformation
- When bonded to object, strain gauge deforms along with it
- Resistance increases with tension (elongation)
- Resistance decreases with compression (shortening)
- Resistance change is measured using bridge circuit

Resistance change relation:

- $\Delta R/R = GF \times$
- Where: ΔR = resistance change,
  R = initial resistance
- GF = gauge factor (sensitivity),
  = strain

Materials used:

- Foil: Constantan, Karma, Nichrome alloys
- Semiconductor: Silicon, Germanium for higher sensitivity

Mnemonic

"SERB: Strain Effects Resistance by Bonding"

Question 5(b OR) [4 marks]

Solution

Digital IC tester verifies functionality of integrated circuits by applying test patterns.

Block diagram:

```
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
    | Keypad/     |      | Display     |
    | Interface   |      | LCD/LED     |
    +{-{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+      +{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}
           |                    \^{}
           v                    |
    +{-{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+
    |                                  |
    |         Microcontroller          |
    |                                  |
    +{-{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
        |            |             |
        v            v             v
+{-{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}+{-}{-}{-}{-}
| Test Pattern | | IC Socket | | Result     |
| Generator    | | Interface | | Comparator |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}{-}{-}{-}{-}
                      |               \^{}
```

```
          v               |
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
|                        |
|     IC Under Test       |
|                        |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Working principle:

1. IC is inserted into test socket
2. User selects IC type/number using keypad
3. Microcontroller loads appropriate test pattern
4. Test patterns applied to IC inputs
5. Output responses compared with expected values
6. Pass/Fail result displayed

Features of digital IC tester:

- Tests TTL, CMOS, HCMOS logic families
- Can identify unknown ICs by analyzing pin functions
- Performs functional and parametric tests
- Checks for static and dynamic characteristics

Mnemonic

"PIPE: Pattern Input, Pin Examination"

Question 5(c OR) [7 marks]

Solution

Spectrum analyzer displays signal amplitude versus frequency, showing frequency components.

Block diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{
| RF Input  |     | Attenuator |    | Mixer     |    | IF         |    | Detector |
| Circuit   +{-{-}{-}+ \& Filters  +{-}{-}{-}+ Circuit  +{-}{-}{-}+ Filter    +{-}{-}{-}+ Circuit  |}
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}+{-}{-}{-
                                     \^{                                |}
                                     |                                v
                                  +{-{-}{-}{-}+{-}{-}{-}{-}{-}+                    +{-}{-}{-}{-}+{-
                                  | Local    |                    | Video    |
                                  | Oscillator|                    | Filter   |
                                  +{-{-}{-}{-}+{-}{-}{-}{-}{-}+                    +{-}{-}{-}{-}{-
                                     \^{                                |}
                                     |                                v
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}+{-}{-}{-
| Control   |     | CPU \&      |    | Sweep    |    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+     | Display
| Panel     +{-{-}{-}+ Processor  +{-}{-}{-}+ Generator+{-}{-}{-}+ Horizontal |{-}{-}{-}{-}+ Circuit   |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{
                                            +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Working principle:

1. **Superheterodyne conversion**: Input signal mixed with local oscillator
2. **Frequency sweep**: Local oscillator sweeps across frequency range
3. **IF filtering**: Narrow bandpass filter selects frequency components
4. **Detection**: Amplitude of each frequency component is measured
5. **Display**: Amplitude vs. frequency plot shown on screen

Types of spectrum analyzers:

Type	Principle	Application
Swept-tuned	Superheterodyne with swept LO	RF and microwave signals

FFT (Fast Fourier Transform)	Digital conversion and FFT algorithm	Audio and low-frequency signals
Real-time	Combination of FFT with high-speed processing	Transient and dynamic signals

Applications:

- EMI/EMC testing
- Signal purity measurement
- Harmonic distortion analysis
- Communication system testing
- Modulation analysis

Mnemonic

"SHAFT: Sweep, Heterodyne, Analyze Frequency and Time"