Answer any seven (7) of the nineteen (19) questions from this exam paper.
Each question is equally weighted.
Answer in the script book provided.
(Please observe that there is a Formula sheet on the last page.)

Question 1.

(a) Give the name and the symbol for the metric prefixes for ten to the powers of:

(1) Fifteen.
(2) Minus Three.
(3) Eighteen.
(4) Minus Nine.
(5) Twelve.

(b) The SI symbol Cd represents what? (This specific question is multiple choice. Circle the unique correct answer on the examination paper.)

(1) Temperature.
(2) Cadmium metal.
(3) Luminous intensity.
(4) The capacitor in an op amp differentiator.
(5) Current in a diode.

(c) Describe the meanings of both of these constants of nature:

(1) Boltzmann’s constant.
(2) Avogadro’s number.

(d) Give the value of each of these constants:

(1) Electron charge.
(2) Speed of light in vacuo.
(3) Boltzmann’s constant.
(4) Planck’s constant.
(5) The magnetic permeability of the vacuum.

(e) Define the following terms in the theory of measurements:

(1) Relative error.
(2) Validity.
(3) Robustness.
(4) Repeatability.
(5) Resolution.

(f) Give one example for each of the following types of errors.

(1) Range of Validity.
(2) Interpolation Reading Error.
(3) Electromagnetic Interference.
(4) Manufacturing Tolerance.
(5) Hysteresis.
(6) Electronic Dynamic Error.
(7) Classical Insertion Error.

Question 2.

(a) The following figure shows a Wheatstone bridge with $R_1 = 2000\,\Omega$, $R_2 = 800\,\Omega$, $R_3$is the variable resistance, and $R_X$is the unknown resistance. R_3 varies from $1600\,\Omega$ to $16\,\text{k}\Omega$. Calculate the range of the unknown resistance that the bridge can measure.

(b) For each of the following kinds of AC bridges, what is it used to measure?

(1) Schering.
(2) Hay.
(3) Maxwell.

(c) What does the *quality factor* Q describe?

(d) An inductance doesn't have a Q factor, so why does an inductor have one?

(e) The following Schering bridge is in balance, with $R_1 = 500\,\Omega$, $R_2 = 250\,\Omega$, $C_1 = 6$ nF, and $C_2 = 250$ pF. Calculate $R_3$and C_3.

Question 3.

(a) Draw the circuit for an op-amp differentiator.

(b) Draw a simple non-inverting amplifier's circuit. Derive the expression for its voltage gain.

(c) List five properties of a **real** op-amp.

(d) (1) The circuit in the next diagram uses a real op-amp. What is the purpose of the resistor R_c?
(2) Given $R_1 = 6$ kΩ and $R_2 = 9$ kΩ, calculate a suitable value for R_c.

(e) (1) Define the term **offset current**.
(2) How many offset currents does a differential op-amp have?
(3) What causes offset current?

Question 4.

(a) When making measurements of a patient's heart during cardiac surgery, is it better to ground the sensor? Justify your answer.

(b) (1) What is special about an isolation amplifier?
(2) Give two uses for an isolation amplifier.

(c) Instrumentation op-amps reduce what two problems of simpler differential op-amp circuits?

(d) (1) Draw the circuit for an instrumentation amplifier with two inputs V_2 and V_1 and one output V_o, using three op-amps, six resistors of value R, and one variable resistor R_A.
(2) Prove that the input-output relationship for the instrumentation amplifier that you have drawn is $V_o = (V_1 - V_2)(1 + \frac{2R}{R_A})$.
(3) What is the purpose of the variable resistor?

Question 5.

(a) Name three kinds of electronic components that produce significant amounts of noise.

(b) (1) Define **voltage drift** in an op-amp.
(2) What is most often the *cause* of voltage drift?
(3) What *unit* is used for such voltage drift?

(c) How is the effect of noise on an AM radio signal reduced?

(d) If you were a still-life photographic artist, how would you reduce the effect of pepper noise?

(e) The next circuit diagram is of a chopper amplifier.
(1) Draw the signal waveform at each stage through the circuit.
(2) Also draw the control signal for the switch.
(3) The chopper amplifier circuit consists of three stages, one of which is a pulse amplitude modulator (PAM). What are the other two stages?
(4) For accurate sampling of the signal, should the pulse train's repetition rate be high or low?
(5) Why is an AC amplifier used, instead of a DC amplifier?

Question 6.

(a) Define **transducer**.

(b) (1) Give the formula for the **gauge factor** of a strain gauge in terms of its resistance R and length L.
(2) Quote the approximate range of values for the gauge factor of metal alloys, and compare it with that for doped semiconductors.
(3) What problem do semiconductor-based strain gauges have?
(4) Define **sensitivity factor** for a strain gauge bridge circuit.
(5) What is the unit for the sensitivity of a Wheatstone bridge containing light sensitive elements?

(c) Semiconductor temperature transducers contain two identical transistors for which the difference in their base-emitter voltages depends on temperature.
(1) Write the formula for that difference voltage, ΔV_{be} in terms of temperature T, Boltzmann's constant k, the electron charge q, and the two transistors' emitter currents $I_1$and I_2.
(2) Given that $I_1 = 2I_2$, calculate the slope of the ΔV_{be} versus T curve.
(3) For that same condition, if the value of ΔV_{be} is 50 millivolts, then what is the temperature?
(4) How well will the transducer work at that temperature?

Question 7.

(a) (1) Draw a five-bit ripple counter.
(2) What is the lowest binary number it can count? What is the highest?
(3) What is the main drawback of a ripple counter?
(4) Draw a three-bit synchronous counter.
(5) What is the advantage of a synchronous counter over a ripple counter?
(6) Give one disadvantage of a synchronous counter. Is this a serious problem?

(b) The 74LS163 shown below is a synchronous four-bit binary counter.
(1) For this counter, are the Load and Clear inputs synchronous or asynchronous?
(2) Under what circumstance is the RCO output high?
(3) Design a circuit with the counting sequence 5, ..., 11.
(4) Using 74LS163 chips, design a twelve-bit counter.

Question 8.

(a) Describe what a **frequency counter** does. In particular, what does it count, how long does it count it, what does it display, and what is the meaning of that display?

(b) Below is a diagram of a frequency counter. Add the labels for each of the component blocks, controls, and signals.

(c) Here is a simple Schmitt trigger, for which the minimum output voltage is -6V, the maximum is +6V, $R_1 = 5$ kΩ and $R_2 = 10$ kΩ. Calculate the input voltages at which the transitions occur.

(d) Name two common types of *inherent error* in a frequency counter, and describe what causes them.

(e) What are *trigger errors*, and what causes them? You may be able to explain this better by drawing a picture.

Question 9.

(a) State the **sampling theorem**.

(b) If a DAC has a minimum voltage of zero volts, a maximum voltage of 10.22 volts, with a resolution of 20 millivolts, then how many bits does it have?

(c) In the above DAC, what binary number produces an output of 6.4 V?

(d) Here is the block diagram for a ramp ADC.

(1) Label all the blocks and signals.
(2) Describe the operation of this ADC.

(e) (1) How many clock pulses does it take for a 32-bit ramp ADC to perform a full scale conversion?

(2) Given a 400 MHz clock, how long will that conversion take?

(3) Using the same clock, how long will it take a 32-bit successive approximation ADC to complete the same conversion?

(4) Again using that clock, how long would a 32-bit flash ADC take?

(5) Estimate the linear dimensions (physical size) of a 32-bit flash ADC given current IC technology.

Question 10.

(a) For the following block diagram of an RF signal generator, name all numbered blocks, inputs, and outputs.

(b) (1) Name five types of RF oscillator circuit.
(2) Over what frequency range does each operate?

(c) (1) What kind of circuit would one use to generate a square wave?
(2) Name a common IC that performs that function.
(3) What are two technical advantages of generating a square wave instead of a sine wave as the primary waveform for a function generator?

(d) Define the following terms:
(1) Sag.
(2) Undershoot.
(3) Preshoot.
(4) Settling time.

Question 11.

(a) (1) Name the five principal subsystems of an oscilloscope.
(2) Very briefly, describe the purpose of each of those subsystems.

(b) How is the electron beam shielded from external magnetic fields?

(c) Describe the operation of an oscilloscope's **horizontal sweep**. (You may find it helpful to draw a picture.)

(d) What is the purpose of the two horizontal dashed lines on the graticule of some CROs?

(e) For the following block diagram of a **digital storage oscilloscope**, name all the numbered inputs, outputs, and blocks.

Question 12.

(a) Describe a **coaxial cable**.

(b) If you accidentally connect the shield of a probe to an active AC power line, what two effects are likely?

(c) (1) Give the formula for the angular frequency ω_s above which a times-one probe suffers severe attenuation and phase shift.
(2) Calculate this for a source resistance of 500 Ω, a cable capacitance of 100 pF, an oscilloscope input capacitance of 35 pF, and an oscilloscope input resistance of 1 MΩ.

(d) (1) Give one advantage of a times-ten probe over a times-one probe.
(2) What would you adjust in a times-ten probe to achieve precise frequency compensation?

(e) (1) Above what voltage is it generally unsafe to use a CRO?
(2) What would you use to enable a CRO to measure higher voltages?

(f) Describe the purpose and operation of a **demodulator probe**.

Question 13.

(a) Name the numbered blocks in the following block diagram of a **spectrum analyser**.

(b) Describe the operation of a **Fourier analyser**.

(c) (1) What three quantities does a **frequency selective voltmeter** measure?
(2) Describe how this instrument works.

Question 14.

(a) Over what frequencies do the following three types of untuned amplifier operate?
(1) ECG.
(2) Audio.
(3) Video.

(b) State, in detail, the measurement procedure for **voltage gain**.

(c) Define **input sensitivity**.

(d) Sketch the distorted waveforms that result from feeding a square wave into:
(1) a **low** pass amplifier;
(2) a **high** pass amplifier;
(3) a **band** pass amplifier.

(e) (1) What does 'IMD' stand for?
(2) Describe in detail how an IMD analyser works.

(f) (1) Define **common mode rejection ratio (CMRR)**.
(2) How does this differ from **common mode rejection (CMR)**?

Question 15.

(a) Define **tank circuit**.

(b) (1) State the formula for the total impedance of a **parallel LC** resonant tank circuit.
(2) Calculate this impedance at a frequency of 1 kHz if L is 5 mH and C is 1 μF.

(c) Give the formula for the **quality factor Q** of a tank circuit.

(d) Draw the frequency responses for these five kinds of filters:
(1) low pass, (2) high pass, (3) band pass, (4) band stop, (5) notch.

(e) (1) Define **varactor**.
(2) The frequency of a **varactor-tuned oscillator** varies according to what mathematical power of the capacitance of the varactor?
(3) If you *decrease* the reverse bias on a varactor, what happens to its capacitance?

Question 16.

(a) (1) What is **automatic test equipment (ATE)** used for?
(2) Give six advantages of ATE over manual testing.

(b) (1) In what year was the GPIB first publically specified?
(2) When was the IEEE-488 standard published?
(3) What is the full name of IEEE-488?

(c) Name the six features specified by the **GPIB standard**.

(d) (1) What are the two network topologies permitted by the GPIB?
(2) Draw them.

(e) (1) Name the four classes of device allowed on a GPIB.
(2) Give an example of an instrument or device in each class.

(f) (1) What are the three constituent buses of the GPIB?
(2) One of the buses carries addresses. What four other types of information does it carry?

(g) (1) Describe the input/output circuit used in each bus in the GPIB. (Use a circuit diagram for clarity.)
(2) What is the purpose of each of the components in this circuit?

(h) If a measurement instrument sends a DAV (Data Valid) signal, what does this imply?

Question 17.

(a) (1) What is **interference** noise?
(2) From where does **intrinsic** noise originate?

(b) (1) What is the origin of **shot** noise?
(2) Give the formula for the RMS current of shot noise in terms of the electron charge, the DC current, and the effective noise bandwidth.

(c) Define **flicker** noise.

(d) (1) At a temperature of 30 Celsius, a 500 kΩ resistor with an effective noise bandwidth of 4 MHz generates how much thermal power?
(2) What is its RMS thermal noise voltage?

(e) **Magnetically** coupled interference voltage decreases with what two quantities?

(f) Name the three principal sources of **electrically** coupled interference.

(g) How would you reduce **electromagnetic** interference (EMI) from a remote RF source such as an AM radio station?

Question 18.

(a) What is a **ground fault**? (Draw a diagram to assist your explanation.)

(b) Describe the structure and operation of a **ground-fault interrupter (GFI)**.

(c) (1) What is **leakage capacitance**?
(2) Give an example of what may cause a leakage capacitance.

(d) Name two probable effects of an AC current of between 100 mA and 300 mA passing through a living human body.

(e) Describe three kinds of **grounds** that occur in electronic systems.

(f) (1) What is a typical impedance of a **ground loop** that is ten metres in circumference?
(2) What is **inductive pickup**, and how does it contribute to a ground loop?
(3) Describe one situation that causes **capacitive coupling**.
(4) Draw a diagram of an instrument in which capacitive coupling is occurring.

(g) (1) Define common-mode noise voltage.
(2) When does it occur?

(h) Describe two methods for dealing with **ground loops**.

Question 19.

(a) Calculate the **signal-to-noise ratio (S/N)** when the signal has an RMS amplitude of 2 V and the noise has an RMS amplitude of 0.5 V.

(b) Give the formula for **noise figure (NF)**.

(c) Calculate the **SINAD ratio** when the signal power is 16 W, the noise power is 4 W, and the distortion power is 1 W.

(d) (1) Why are **AC meters** *not* suitable for measuring the RMS voltage of a *triangular* wave?
(2) Name one type of *high quality* RMS meter.

(e) (1) Describe one valuable use of a **twin-T RC filter**.
(2) Give the formula for its notch frequency, in terms of the two components R_1 and C_1.
(3) Calculate the notch frequency if $R_1 = 14.4\,\Omega$ and $C_1 = 220$ nF.

(f) If an **electric shield** has an opening in the shape of a cylinder with a diameter if 3.5 cm and a sleeve of length 7 cm, then what is the attenuation of an interference waveform with a wavelength of 63 cm that enters that opening?

FORMULAS

$L_4 = R_2R_3C_1$

$P = 4kT.\Delta f$

$V^2_{RMS} = P.R$

$\lambda_c = \pi r$

Attenuation = $54.5(\frac{L}{\lambda_c})\sqrt{1-(\frac{\lambda c}{\lambda})^2}$ (dB)

$k = 1.38 \times 10^{-23}\,W.Hz^{-1}K^{-1}$

$e = 1.609 \times 10^{-19}\,C$

$\varepsilon_0 = 8.85 \times 10^{-12}\,F.m^{-1}$

$\mu_0 = 4\pi \times 10^{-7}\,H.m^{-1}$

$h = 6.626 \times 10^{-34}\,J.s$

$c = 2.9979 \times 10^{8}\,m.s^{-1}$

$\pi = 3.141592654$

$0^{o}C = 273.15\,K$