First Semester Examination
2021/2022 Academic Session

February/March 2022

EMC301 – Measurement & Instrumentation

Duration : 3 hours

Please check that this examination paper consists of SEVEN [7] printed pages before you begin the examination.

INSTRUCTIONS : Answer **ALL FOUR [4]** questions.

In the event of any discrepancies, the English version shall be used.

1. [a] Generic model of a measurement system.

(i) Briefly explain why accuracy of measurement can only be approximated using confidence interval but not standard deviation.

(ii) Briefly explain why the reading at elapsed time, t = 5τ (5 times of the time constant) for a first-order system, is generally accepted as good reading.

(30 marks)

[b] Measurement error & uncertainty. The resistance of a conductor is related as:

$$R = \frac{\rho L}{A}$$

where $R = resistance\ (\Omega)$
$L = the\ length\ of\ the\ conductor\ (m)$
$A = cross - sectional\ area\ of\ the\ conductor\ (m^2)$
$\rho = the\ resistivity\ of\ material\ (\Omega \cdot \mathrm{m})$

In a laboratory testing, the resistance of a piece a nickel is to be determined. The nickel was shaped into a cylindrical form with a length L and the circular cross-sectional diameter D. The length L and circular cross-sectional diameter D were measured repeatedly and summarized in Table 1b as follow:

Table 1b

Attempt	**Length, *L*(mm)**	**Diameter, *D* (mm)**
1	25.016	4.984
2	25.012	5.008
3	24.984	4.986
4	24.978	5.004
5	25.026	5.002
6	25.006	4.988
7	25.002	4.992
8	24.992	5.006
9	24.994	4.986
10	25.008	5.008

…3/-

Based on the information given, determine the best estimate of the resistance (with 95% level of confidence) of the nickel. The resistivity of the nickel is given as 7×10−8Ω·m at 20°C (± 5% uncertainty) and assuming that there is no bias error in any measurement.

(70 marks)

2. [a] Fourier analysis & dynamic behavior.

Figure 2[a] shows an electrical signal resembling a sawtooth wave. A sampling rate of 250 Hz is to be used for signal sampling.

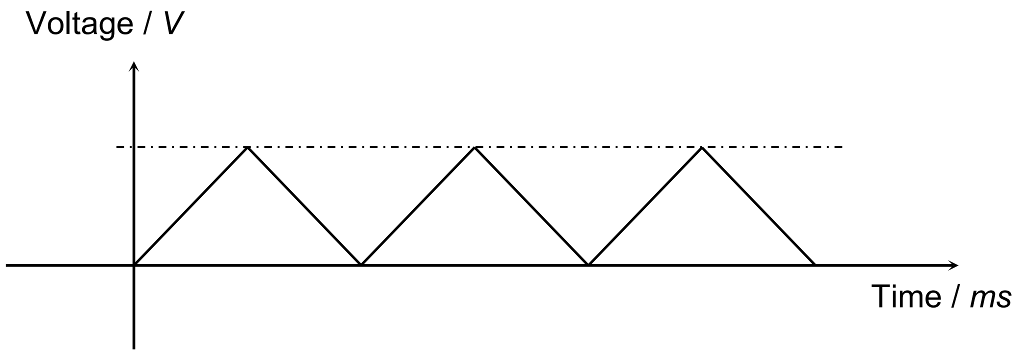

Figure 2[a]

(i) Draw the electrical signal on a graph paper and show the temporal locations at which it is to be sampled.

(ii) Estimate the apparent frequency that can be observed using the sampling rate.

(iii) Determine the highest frequency component of the electrical signal that can be resolved accurately using the sampling rate. What will happen to other frequency components that cannot be resolved?

(iv) Determine the minimum sample rate so that the electrical signal can be accurately resolved up to the 9th harmonic.

(50 marks)

[b] First order system response.

A student was investigating smoking effect of waste cooking oil at 120°C. To maintain the oil temperature, a constant heat was supplied. The student then used a mercury-in-glass thermometer for temperature check every 60 seconds. The thermometer was assumed to be approximating a first-order system with a known time constant of 25 seconds. The room temperature was confirmed to be 30°C during the investigation.

…4/-

(i) Sketch the time response of the thermometer when it was immersed to the oil, from 30°C to 120 °C. Indicate t = τ and its corresponding temperature.

(ii) Determine whether the response of the mercury-in-glass thermometer was suitable for the task if the error of temperature measurement should less than 0.5°C.

(50 marks)

3. [a] List any THREE factors that affect the inductance of a coil whose flux path includes both a magnetic material and an air gap.

(15 marks)

[b] State the operation for the listed sensors below. Suggest ONE (1) application that is suitable for each sensors.

(i) Potentiometer
(ii) Thermocouple
(iii) Variable inductance coil

(30 marks)

[c] The following Figure 3[c] shows a capacitive displacement sensor designed to monitor small changes in work-piece position. The two metal cylinders are separated by a plastic sheath/bearing of thickness 1 mm and dielectric constant at 1 kHz of 2.5. Given that the capacitance *C* between parallel plates with an overlapping area *A* and distance *d* is given by

$$C = \frac{K\epsilon_0 A}{d}$$

where *K* is the dielectric coefficient of the substance between the plates (*K* = 1 for air) and ε_0 is the permittivity of free space (8.85 pF/m).

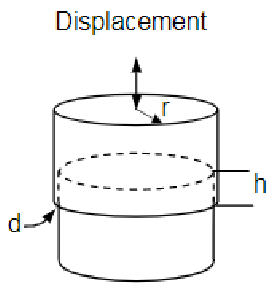

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Figure 3[c]

(i) If the radius is 2.5 cm, find the sensitivity in pF/m as the upper cylinder slides in and out of the lower cylinder.

(ii) What is the range of capacity if *h* varies from 1.0 to 2.0 cm?

(iii) Suggest TWO (2) methods to double the sensitivity of the capacitive displacement sensor in this application. Justify your method mathematically.

(55 marks)

4. [a] List FOUR (4) characteristics of a ideal operational amplifier

(10 marks)

[b] Figure 4[b] shows an amplifier circuit.

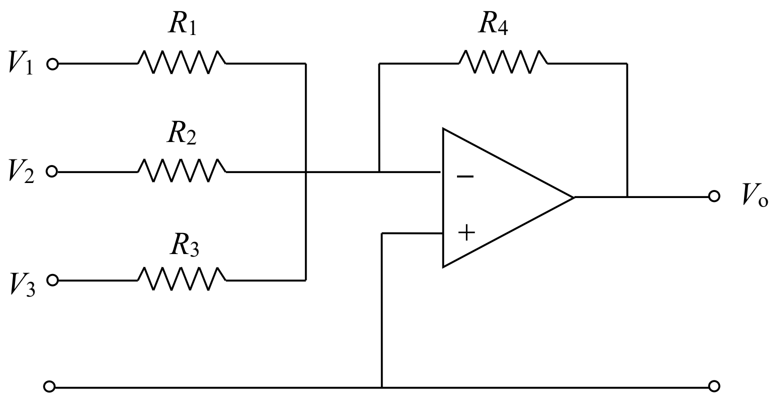

Figure 5[b]

(i) State ONE [1] application of this type of amplifier.

(ii) Derive an expression for the gain of the amplifier in terms of the other variables shown in Figure 4[b].

(iii) Given that $R_1 = R_2 = R_3 = 1\ k\Omega$ and $V_1 = V_2 = V_3 = 10$ V, determine the value of R_4 required so that the amplifier circuit will produce a gain of 1000.

(50 marks)

[c] Figure 4[c] shows a simple 8-bit digital-to-analog converter (DAC). Given that R = 1000 Ω, R_G = 100 kΩ and E_{ref} = 5 V. Calculates the output voltage for

(i) digital input 1000 0001
(ii) digital input 1001 0010

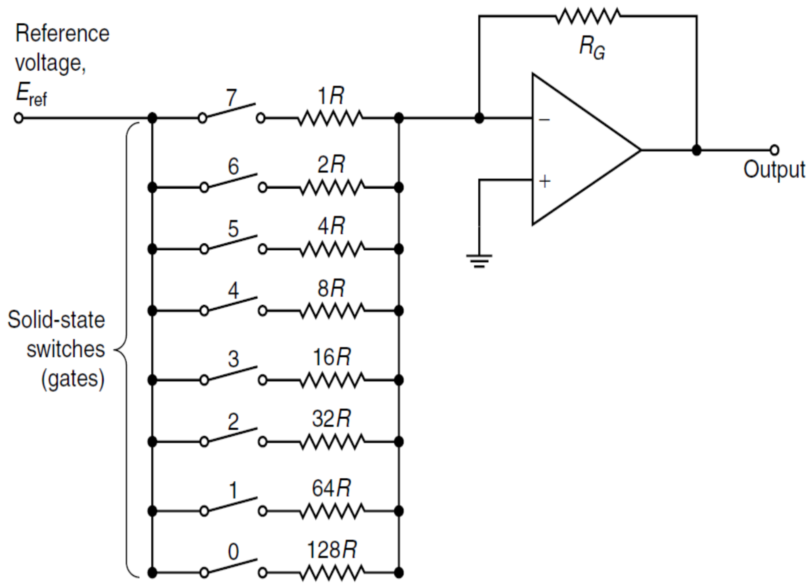

Figure 4[c]

(40 marks)

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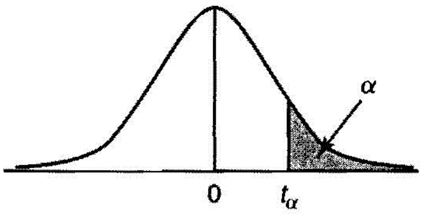
Appendix A

Student's t-Distribution (Values of $t_{\alpha,\nu}$)



ν	$t_{0.10,\nu}$	$t_{0.05,\nu}$	$t_{0.025,\nu}$	$t_{0.01,\nu}$	$t_{0.005,\nu}$	ν
1	3.078	6.314	12.706	31.821	63.657	1
2	1.886	2.920	4.303	6.965	9.925	2
3	1.638	2.353	3.182	4.541	5.841	3
4	1.533	2.132	2.776	3.747	4.604	4
5	1.476	2.015	2.571	3.365	4.032	5
6	1.440	1.943	2.447	3.143	3.707	6
7	1.415	1.895	2.365	2.998	3.499	7
8	1.397	1.860	2.306	2.896	3.355	8
9	1.383	1.833	2.262	2.821	3.250	9
10	1.372	1.812	2.228	2.764	3.169	10
11	1.363	1.796	2.201	2.718	3.106	11
12	1.356	1.782	2.179	2.681	3.055	12
13	1.350	1.771	2.160	2.650	3.012	13
14	1.345	1.761	2.145	2.624	2.977	14
15	1.341	1.753	2.131	2.602	2.947	15
16	1.337	1.746	2.120	2.583	2.921	16
17	1.333	1.740	2.110	2.567	2.898	17
18	1.330	1.734	2.101	2.552	2.878	18
19	1.328	1.729	2.093	2.539	2.861	19
20	1.325	1.725	2.086	2.528	2.845	20
21	1.323	1.721	2.080	2.518	2.831	21
22	1.321	1.717	2.074	2.508	2.819	22
23	1.319	1.714	2.069	2.500	2.807	23
24	1.318	1.711	2.064	2.492	2.797	24
25	1.316	1.798	2.060	2.485	2.787	25
26	1.315	1.706	2.056	2.479	2.779	26
27	1.314	1.703	2.052	2.473	2.771	27
28	1.313	1.701	2.048	2.467	2.763	28
29	1.311	1.699	2.045	2.462	2.756	29
∞	1.282	1.645	1.960	2.326	2.576	∞