Name: **SOLUTION** **Roll No.** …………….

Signature : ……………..……………. **Room No.:** …………

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MS101 – Makerspace 2024-25/II (Spring Semester)

Feb 27, 2025 (Thu) **EE Mid-semester Examination** **Time: 2 hours**

Marks: 46

1. This **Question-cum-Answer Booklet has 8 pages and 20 questions.**
2. Write your **answers only in the space provided for answers**. Answers written at any other place will not be checked. You may use the page margins also for rough work.
3. No explanations / clarifications will be given to any of the questions.
4. No negative marks for wrong answers, **however, steps are required for all numerical answers**.
5. **In case of questions with multiple-choices, credit will be given only if all correct options are identified.**

Q.no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Marks							X					
Q.no.	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**			**TOTAL**	
Marks												

1. An RC low-pass filter is designed with a resistor R and a capacitor C for use with an input signal containing multiple frequency components. Write all the correct options out of the following statements regarding the filter's behaviour.
   A) Frequencies much lower than the cut-off frequency (f_c) pass through the filter to the output with minimal attenuation.
   B) Frequencies much higher than the cut-off frequency (f_c) pass through the filter to the output with minimal attenuation.
   C) Frequencies much higher than the cut-off frequency (f_c) are significantly attenuated.
   D) Frequencies much lower than the cut-off frequency (f_c) are significantly attenuated.
   E) At the cut-off frequency (f_c), amplitude of the output voltage is reduced to approximately 70.7% of the input voltage.

Answer(s): **A, C, E** Mark: 1

No partial marks.

2. Write all the correct options out of the following statements for an N-channel enhancement mode MOSFET.
   A) The channel exists only when a gate voltage less than the threshold voltage is applied.
   B) The channel exists only when a gate voltage greater than or equal to the threshold voltage is applied.
   C) Holes form the conduction channel.
   D) Electrons form the conduction channel.
   E) The threshold voltage is negative.
   F) The threshold voltage is positive.

Answer(s): **B, D, F** Mark: 1

No partial marks.

Rough work

3. A practical voltage source is modelled as an ideal voltage source of 15 V in series with a source resistance R_S. When a load resistance was connected across this source, the current drawn from the source was 400 mA and its terminal voltage V_{Term} dropped to 13 V.
A) Evaluate R_S in ohms.
B) If a 400 Ω resistance is connected across the voltage source what will be V_{Term} in V?
No marks without steps.

Marks: 2[=1+1]

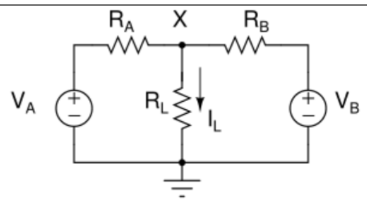
A) R_S = [V_{Term} (no load) – V_{Term} (with load)] /Current drawn = (15-13) V / 0.4A = 5 Ω

B) For load = 400 Ω, V_{Term} = V_{Term} (no load) x Load/(Load + R_S) = 15 x 400/(400+5) = 14.81 V

A) R_S = **5 Ω** B) V_{Term} = **14.81 V** (range: 14.80 to 14.82**)**

No partial marks for this question.

4. A resistive network is given below. V_A = 12 V, V_B = 9 V, $R_A = R_B = R_L$ = 300 Ω.
Evaluate the node voltage V_X and current I_L . Hint: Use superposition method.
No marks without steps.



Method 1: Find V_X and then evaluate I_L
Applying superposition method:
$V_X = V_{X1} + V_{X2}$
i) Find V_{X1} (V_A = 12 V, V_B = 0 V);
$V_{X1} = 12 \times (R_B \| R_L)/[R_A + R_B \| R_L]$
$= 12 \times (150)/(300+150) = 4$ V

ii) Find V_{X2} (V_A =0, V_B = 9 V);
$V_{X2} = 9 \times (R_A \| R_L)/[R_B + R_A \| R_L]$
$= 9 \times (150)/(300+150) = 3$ V
Hence, $V_X = V_{X1} + V_{X2}$ = **7 V**; $I_L = V_X/300$ Ω = **23.33 mA**

Steps: Marks: 3[=1.5 +1.5]

Method 2: Find I_L and then evaluate V_X
$I_L = I_{L1} + I_{L2}$
i) Find I_{L1} (V_A = 12 V, V_B = 0 V);
$I_{L1} = 0.5 \times 12/[R_A + R_B \| R_L] = 6/450 = 13.33$ mA

ii) Find I_{L2} (V_A =0, V_B = 9 V);
$I_{L2} = 0.5 \times 9 /[R_B + R_A \| R_L] = 4.5/450 = 10$ mA

Hence, $I_L = I_{L1} + I_{L2}$ = 23.33 mA.
$V_X = I_L \times R_L$ = 23.33 mA x 0.3 k = 7 V

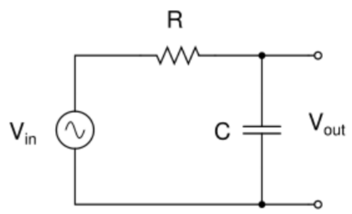
V_X = **7 V** ; I_L = **23.33 mA**
==========================
Allowed range for V_X: 6.99 to 7.00 V.

Allowed range for I_{LI}: 23.30 to 23.33 mA

5. An RC filter circuit is shown below. R = 2.5 kΩ.
Its cut-off frequency f_c was found to be 1570 Hz.
Its gain A is given by:

$$A = \left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{[1+(\omega CR)^2]^{1/2}} = \frac{1}{[1+(f/f_c)^2]^{1/2}}$$

where $\omega = 2\pi f$ and $f_c = 1/(2\pi RC)$.



A) Evaluate C in μF.
B) Evaluate the magnitude of A at f = 0 and at $f = f_c$.
(No partial credit for this part; 1 mark only if both answers are correct)..

Marks: 2[=1+1]

Answers:

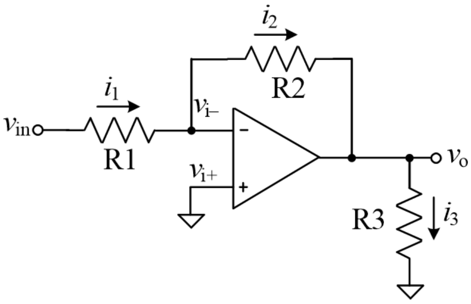
A) C = **0.0405 μF.** (Range: 0.040 to 0.041)
No partial marks.

B) Magnitude of A at f = 0 : **1**

Magnitude of A at $f = f_c$: **0.707** (Range: 0.70 to 0.71)
No partial marks.

Rough work

6. In the op-amp circuit shown in the figure, R1= 40 kΩ, R2 = 10 kΩ, R3 = 1000 Ω.
Find the voltage, current, and power gains.
Is it serving as an amplifier?



Marks: 4 [= 1 x 4]

A) Voltage gain $A_v = v_o / v_{in}$
Steps:
$A_v = -$ R2/R1 = −10 kΩ/40 kΩ
Answer: **−0.25**
(*No marks if the sign is wrong*)

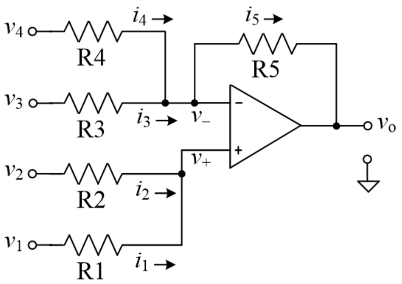
B) Current gain $A_i = i_3 / i_1$
Steps: $i_3 / i_1 = (v_0/\text{R3})/(v_{in}/\text{R1}) = (v_0/ v_{in})\text{x}(\text{R1/R3})$
$= A_v$ x (R1/R3) = −0.25 x 40 = −10
Answer: **−10**
(0.5 *marks penalty if the sign is wrong*)

C) Power gain $A_p = A_v A_i$
Steps: $A_p = A_v A_i$ = −0.25 x −10 = 2.5
Answer: + **2.5**
(0.5 *marks penalty if the sign is wrong*)

D) Is it serving as an amplifier? Write Yes or No.

Answer: **YES**

~~7. In the summer circuit shown in the figure,~~
~~$R_1 = R_2 = R_3 = 10$ kΩ, $R_4 = R_5 = 80$ kΩ.~~
~~Find the voltage gain and input resistance for the second and third inputs.~~



~~Marks: 4 [=2+0.5+1+0.5]~~
~~A) $A_{v1} = v_o/v_1$~~
~~Steps:~~
~~Answer:……………..~~
~~B) $R_{in1} = v_1/i_1$~~
~~Answer:……………..~~
~~C) $A_{v4} = v_o/v_4$~~
~~Steps:~~
~~Answer:……………..~~
~~D) $R_{in4} = v_4/i_4$~~
~~Answer:……………..~~

Note: Q7 is dropped.

8. Convert the decimal number 251 to its binary format.
Mark: 1
It will be an 8-bit number: $b_7\ b_6\ b_5\ b_4\ b_3\ b_2\ b_1\ b_0$.
These bits can be obtained by repetitively dividing the decimal number by 2, and assigning the remainder as the bits starting from the LSB all the way to the MSB, i.e. the first remainder will b_0 (the LSB), second one will be b_1, …. and the eighth one will be b_7 the MSB.

Binary format: **1111 1011**
No partial marks.

9. Convert the decimal number 190 to its hexadecimal format. Mark: 1

N = 190. Divide N by 16. 190 = 16 x 11 + 14. Hence 190 decimal = B E in Hex.

Hexadecimal format: **BE**
No partial marks.

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Rough work:

10. Convert the binary number 11001101 to its decimal format. Mark: 1

The binary number 1100 1101 = C D in Hex = 16x12 + 13 = 205

Decimal format: **205**
No partial marks.

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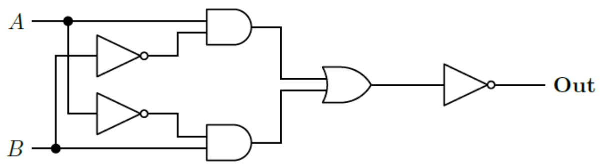
11. A digital circuit is shown below.
A) Write the truth table for **Out.**
B) Write the Boolean expression for **Out.**



Marks: 2[=1+1]

A) Truth table

A	B	Out
0	**0**	**1**
0	**1**	**0**
1	**0**	**0**
1	**1**	**1**

No partial marks.

B) Out = $\bar{A}\bar{B} + AB$, or

Out $= \overline{A\overline{B} + \overline{A}B}$

No partial marks.

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12. Consider the 2's complement representation which occupies a total of 5 bits, including the sign bit.
Marks: 4[=2+1+1]

A) Obtain the 2's complement representation of −12.
Steps: To obtain the 2's complement representation, invert the number and add 1. Decimal 12 = 01100 binary
i.e. 2's complement representation of −12 = 10011 + 00001 = 10100

Answer: **10100**

B) Give the 2's complement representation of 3.
2's complement representation of 3 = 00011

Answer: **00011**

C) Obtain the 2's complement representation of 3−12.
Steps:
To get the 2's complement representation of 3−12, add the corresponding 2's complement representations.
i.e. 00011 + 10100 = 10111

Answer: **10111**
No partial marks for parts A, B or C.

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13. A battery operated DC motor runs on 10 V and its coil resistance is 100 Ω.
A) Calculate the current consumed by the motor at the start (no 'back emf').
B) The motor is rotating and it takes 20 mA of current. Calculate the 'back emf' offered by the motor coil.

Marks: 2[=1+1]

Steps:
A) $V_{DC} = V_a = I_a R_a + E_b$, where E_b is the back emf.
Since $E_b = 0$, $I_a = V_{DC} / R_a = 10$ V/100 Ω = 0.1 A = 100 mA

B) $V_{DC} = V_a = I_a R_a + E_{b;}$ $I_a = 20$ mA; i.e. $10 = (0.02) \times 100 + E_b$. Hence $E_b = 8$ V

A) Current at start = **100 mA**   B) Back emf = **8 V**
Partial marks.

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14. The truth table for a digital circuit with output **Fn** and inputs *A*, *B*, *C*, and *D* (with *A* as the most significant bit) is shown below.

A	*B*	*C*	*D*	**Fn**
0	0	0	0	**0**
0	0	0	1	**0**
0	0	1	0	**0**
0	0	1	1	**1**
0	1	0	0	**0**
0	1	0	1	**1**
0	1	1	0	**1**
0	1	1	1	**1**
1	0	0	0	**0**
1	0	0	1	**1**
1	0	1	0	**1**
1	0	1	1	**1**
1	1	0	0	**1**
1	1	0	1	**1**
1	1	1	0	**1**
1	1	1	1	**1**

A) Express **Fn** in canonical form as a sum of products.

B) Fill entries in the Karnaugh map shown for **Fn** as a function of *A*, *B*, *C*, and *D*. Show the maximal groupings of 1's in the Karnaugh map and derive the minimal logic expression for **Fn** in terms of *A*, *B*, *C*, *D* and their complements.

Marks: 6[=3+3]

A) **Fn** =

$$\bar{A}\bar{B}CD + \bar{A}B\bar{C}D + \bar{A}BC\bar{D} + \bar{A}BCD + A\bar{B}\bar{C}D + A\bar{B}C\bar{D} + A\bar{B}CD$$
$$+ AB\bar{C}\bar{D} + AB\bar{C}D + ABC\bar{D} + ABCD$$

Penalty of 0.5 marks each for any missing or wrong term.

B) K-map and minimized **Fn**

Note: From the K-map we see that SIX circling are possible, giving rise to SIX terms, each obtained by combining four adjacent cells as shown below.

AB \ CD	00	01	11	10
00	0	0	1	0
01	0	1	1	1
11	1	1	1	1
10	0	1	1	1

Fn = $\boldsymbol{AB + BC + CD + AC + AD + BD}$

Distribution of marks for Part B:

(i)*Correct K-map entries:* 1 *mark,* (ii) *Correct circling (all six):* 1 *mark,* (iii) *Correct* **Fn** *terms (all six):* 1 *mark.*

Penalty: 0.5 *marks for each wrong or missing item. More than two errors will result in* 0 *marks for that sub-part).*

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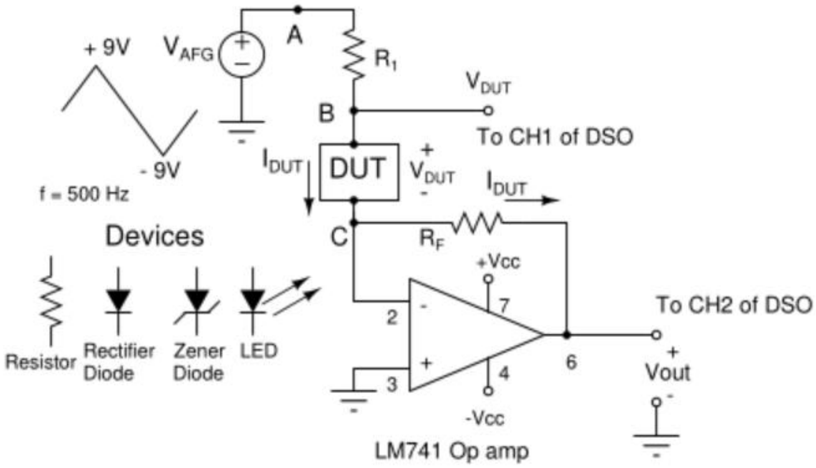
15. Op amp based current-to-voltage converter circuit of Expt 2 is shown below. Given: $R_1 = 2$ kΩ, $R_F = 3$ kΩ, +Vcc = +12 V, −Vcc = −12 V. A Zener diode is connected as the device-under-test (DUT) with its anode at terminal B and cathode at terminal C. The Zener voltage is 6.5 V. Calculate the current through the Zener diode (I_{DUT}), V_{DUT} and V_{out} at the instant when $V_{AFG} = -9$ V.

Marks: 4[=1.5+1.5+1]



Show steps:

Zener voltage (V_Z), = 6.5 V ; $V_{DUT} = -V_Z =$ **−6.5 V**

$I_{DUT} = (V_{AFG} - V_{DUT})/R_1$ = [–9 –(–6.5)]/ 2 k = **–1.25 mA**

$V_{out} = -I_{DUT}$ x R_F = –1.25 mA x 3 k = **+3.75 V**

I_{DUT} = –1.25 mA. **V_{DUT} = –6.5 V.** **V_{out} = +3.75 V.**

Penalty of 1 mark each for each wrong sign in the results.

16. In an attracted armature relay, the coil proportionality constant is $K = 2.4$ N.A^{-2}. And the restraining force (C) of the coil is 0.184 N. Find the current through the coil so that the force on the armature is 0.2 N. (Force equation: $F = K \times I^2 - C$)

Steps: Mark: 1

Substituting, $0.2 = 2.4\,I^2 - 0.184$, or $2.4\,I^2 = 0.2 + 0.184 = 0.384$; $I^2 = 0.384/2.4 = 0.16$

I = sqrt (0.16) = 0.4 A

Current through the coil = **0.4 A**

No partial marks.

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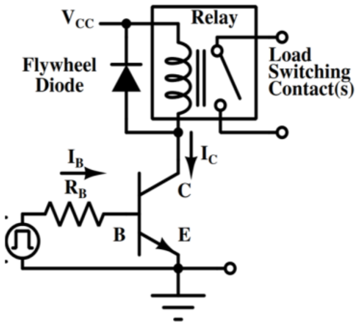
Rough work:

17. A relay circuit is shown below where an input control pulse of 10 V is applied to base resistor (R_B). The relay coil activation current is 80 mA and R_B= 4.6 kΩ. Assume V_{BEsat}= 0.8 V and V_{CEsat}= 0.2V and V_{CC} = 10 V.

   A) What should be the minimum value of β (i.e.β_{min}) for the relay to operate?
   B) If the relay coil resistance is 100 Ω, and the BJT has β =50, what will be the current through the relay?
   C) If the load connected across the 'load switching contacts' of the relay is changed to half the current, will the relay coil current change?



Marks: 4[=1+2+1]

A) β_{min}

Steps: KVL in the B-E loop: $V_{IN} = I_B R_B + V_{BE}$

Or $\mathbf{I_B = (V_{IN} - V_{BE})/R_B = (10\text{-}0.8)/4.6\ k = 2\ mA}$

I_C = 80 mA; Hence, β_{min} = 80/2 = 40

β_{min} = 40

Partial credit only if clear steps are shown.

B) Current through the relay in mA:

Steps:

KVL in the C-E loop: $V_{CC} = I_C R_{coil} + V_{CE}$.

Maximum possible $I_C = I_{Cmax} = (V_{CC} - V_{CEsat})/R_{coil}$

Substituting, $\mathbf{I_{Cmax} = (10\text{-}0.2)/100 = 98\ mA}$

When β = 50, $I_C = \beta I_B$ = 50 x 2 mA = 100 mA (assuming active mode of operation).

But I_C = 100 mA is not possible as I_{Cmax} = 98 mA.

Current through the relay = **98 mA**

Partial credit only if clear steps are shown.

C) Answer: choose the correct option from below.

i) will increase

ii) will decrease

iii) will remain the same

Answer: iii) will remain the same

18. Which of the following interfaces does the Arduino Nano board support? Write all the correct options.
   A) 4 Analog inputs.
   B) 10 Digital I/Os.
   C) 14 Digital I/Os.
   D) 8 Analog inputs.
   E) An SPI bus interface.
   F) A UART interface.

Answer(s): C, E, F (**Answers: C, D, E, F** will also be given full credit) Mark: 1

No partial marks.

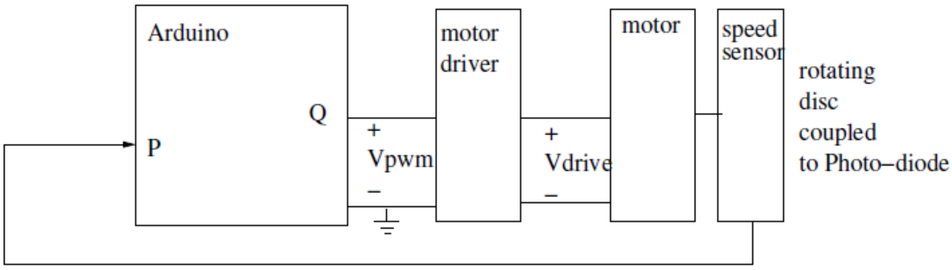
19. "Using the Arduino board for a motor control application, it is possible to implement a digital-to-analog converter". Write all the correct options with regard to this statement.
   A) True, but the Arduino board will need additional circuitry.
   B) False, it is impossible to implement a digital-to-analog converter using the Arduino board.
   C) True, it is possible to do so using only software, without additional circuitry.
   D) True, using only software, i.e. without additional circuitry, the resolution can be better than 5% of the 5 V reference voltage.
   E) True, using only software, i.e. without additional circuitry, the resolution can be better than 0.1% of the 5 V reference voltage.
   F) True, Arduino board has an inbuilt hardware digital-to-analog converter.

Answer(s): C, D Mark: 1

No partial marks.

Rough work:

20. Consider the system setup shown below which is the same speed measurement setup you used in Expt 4 with the BO motor. The BO motor is loaded with a torque *T*.



For the fixed load torque *T* and average of the applied voltage V_{PWM}, assume that the equation for the motor speed is given by: Speed (RPM) = $(k_1 V_{PWM}) - k_2$, where k_1 and k_2 are BO constants.

Assume that you are given all the instruments and accessories used in Expt 4 (i.e. DSO, Keithley Power Supply, L298 Motor driver card, Arduino Nano board, and the Arduino sketch used in Expt 4, the sensor PCB, rotating disc, etc).

A) Using all the Expt 4 setup how will you measure the speed of the motor in RPM? Give your answer in just three to four steps. Give a valid PWM value and give your measurement steps.

Step1: **As per the Expt 4 circuit diagram Connect Arduino, Motor driver card, Sensor PCB, BO motor (with the rotating disc with 8 black and 8 white sectors)**.

Step 2: Run the given Arduino sketch with **PWM value = 128 (or any value > 50). Calculate V_{PWM} for the given value.**

Step 3: Observe the sensor PCB output on the DSO, and **measure period *P* of the waveform. Time taken for one revolution of the BO motor is 8*P*. Calculate Speed (RPM) = 60/(8*P*).**

Step 4: **Optional**: Follow the procedure given in Part A for several PWM values, say 2 or more values. In each case obtain V_{PWM}, measure *P* and calculate Speed in RPM. Tabulate the results.

B) How will you estimate k_1? (Give your answer in just two sentences)

Follow the procedure given in Part A for several PWM values, say 2 or more values. For each case obtain V_{PWM}, measure *P* and calculate the Speed in RPM. Plot the Speed vs V_{PWM} graph (best fit linear plot). Slope of the line will be k_1

C) How will you estimate k_2? (Give your answer in just two sentences)

Follow the procedure given in Part A for several PWM values, say 2 or more values. For each case obtain V_{PWM}, measure *P* and calculate the Speed in RPM. Plot the Speed vs V_{PWM} graph (best fit linear plot). Y intercept of the line will be k_2.

Marks: 5[=3+1+1]

Marking scheme:

A) *Marks will be awarded if all the major points for speed measurement of the BO motor are mentioned. The major points are given in bold. Step 4 is optional.*

B) and C) *Marks will be awarded for clearly mentioning the way k_1 and k_2 are evaluated.*

Rough work: