2020 DUSO Circuit Lab Test

Instructions

• Do not flip over this page until you are told to do so

• You will have 50 minutes to complete this exam
  – You will have 20 minutes designated to be at the lab station and complete the lab portion of the exam
  – You can work on the theoretical portion of this exam at any time within the testing period, including the designated "lab time"

• All numerical answers must be to the correct number of significant digits to receive full credit

• This exam is divided as follows:
  – Theoretical Portion
    * Section I: Matching (20 points)
    * Section II: Multiple Choice/Select All That Apply (30 points)
    * Section III: Multi-part/Free Response (52 points)
  – Lab Portion
    * Section IV: Analysis of Pre-Built Circuits (25 points)
    * Section V: Circuit Construction (25 points)

• Unless otherwise noted, no work is necessary for full credit, but showing work can result in partial credit

• When drawing circuits, include the known values of all elements

Competitor Names: ______________________________

Team Name/Number: ______________________________

Score = [ ] / 152

Questions? Feel free to reach out to Megan Pramojaney (pramoj23@live.unc.edu) or Byron Qi (byronicq@gmail.com).
Theoretical Portion

Section I: Matching

All questions in this section will be worth 1 point each.

Part I: History

Write the letter of the corresponding scientist next to the statement that pertains to them. The answer choices may be used more than once, or not at all.

A. Volta  B. Ohm  C. Tesla  D. Faraday  E. Ampere  F. Coulomb  G. Kirchhoff

A 1. Discovered that voltage and charge are proportional when capacitance is held constant A
E 2. Inventor of the solenoid and electrical telegraph, among other things E
D 3. Popularized the terms "electrode," "cathode," "anode," and "ion" D
G 4. Coined the term "black body radiation" G
A 5. Discovered "contact electricity," which resulted from two different materials coming in contact with one another A
C 6. Used near-field inductive and capacitive coupling to invent wireless lighting C
F 7. Experimented on the torsional force for metal wires, specifically within a torsion balance F
G 8. Formulated laws that are essentially corollaries of Maxwell’s equations at cases of low frequencies or when the frequency is equal to zero G
E 9. Showed that two parallel wires carrying electric currents repel or attract each other E
G 10. Applied Fourier’s analysis of heat conduction to electrical conduction B

Part II: Units

Match the units shown with the answer choice that they measure. Answer choices may be used more than once or not at all.

A. Current  B. Voltage  C. Resistance  D. Power  E. Energy

D 1. J/s  D
A 2. V/Ω  A
E 3. W * min  E
A 4. Coulombs/s  A
C 5. S/m²  C
Part III: Direct vs. Alternating Current

Indicate which of the following are characteristics of Direct Current (DC), Alternating Current (AC), both or neither.

1. Can be produced by stationary charges  **Neither**
2. Can be produced with a generator  **Both**
3. Used to interconnect major power grids  **DC**
4. Transformers can "step up" and "step down" voltage levels when utilizing this type of current  **AC**
5. Always flows uniformly through the cross-section of the wire  **DC**

Section II: Multiple Choice/Select All That Apply

*All questions in this section will be worth 2 points each. “Select all that apply” questions need to be correct in their entirety to receive any points. Answers MUST be put in the box to receive points!*

1. What circuit element were Leyden jars a primitive version of?
   - [A] Capacitor
   - [B] Inductor
   - [C] Battery
   - [D] Diode

2. Which of the following permutations of colored bands would indicate a 6.2 kΩ resistor with a tolerance of ±5%?
   - [A] Green, red, red, blue
   - [B] Blue, red, red, blue
   - [C] Blue, red, orange, green
   - [D] Black, black, black, black
3. Which of the following does not output DC?

A. Commutator
B. Dynamo
C. Rectifier
D. Inverter
E. None of the above

Refer to the diagram below for Questions 4 and 5.

4. The diagram shows a positively charged rod held above a device that is electrically neutral. What is this device called?

A. Leyden Jar
B. Vandegraft Generator
C. Wimshurst Machine
D. Electroscope
E. None of the above

5. As the charged rod is brought closer to the device, would the leaves have a charge? What would happen to the leaves, if anything at all?

A. Neither of the leaves would have a charge, so the leaves would not move.
B. One of the leaves would have a negative charge and one of the leaves would have a positive charge, causing the leaves to stick together.
C. The leaves would both have a negative charge and separate from one another.
D. The leaves would both have a positive charge and separate from one another.
6. An electron is fired into a current-carrying wire from outside. How will entering the wire affect the electron?

A. The electron will be quickly expelled from the wire by the other electrons in the wire
B. The electron will experience a force in the same direction as the current
C. The electron will experience a force in the opposite direction of the current
D. The electron will continue travelling unaffected in its initial direction

7. In the circuit below, $V_1 = 5.0\, V$, $R_1 = 0.01\, \Omega$, $R_2 = 2.0\, k\Omega$, $R_3 = 3.0\, k\Omega$, $R_4 = 0.0\, \Omega$, $R_5 = 5.0\, k\Omega$, and $R_6 = 6.0\, k\Omega$. What is the power dissipated by $R_3$?

A. 8.2 $\text{mW}$
B. 0.77 $\text{mW}$
C. 0.082 $\text{W}$
D. 0.077 $\text{W}$
E. None of the above

8. Which of the following is a possible way to double the strength of the magnetic field of a wire inside a given radius, where that given radius is smaller than the radius of the wire? Assume that all other factors are held constant for each of the options. Select all that apply.

A. Decrease the wire's radius to a quarter of its original value and decrease the given radius to half its original value
B. Double the current, radius inside the wire being considered, the wire's radius, and the magnetic permeability of the wire
C. Increase the current by a factor of $\sqrt{2}$
D. Double the current
E. None of the above
9. Which of the following is characteristic of a non-Coulomb electric field? Select all that apply.

A. It can be created by a changing magnetic field  
B. It can be created by either positive or negative stationary charges  
C. It is conservative  
D. It is present regardless of whether there is a conductive material in its vicinity or not.  
E. None of the above

A, D

10. For the Boolean logic circuit with the truth table below, would it make more sense to use a sum of products or product of sums circuit representation?

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A. Sum of products because it minimizes the number of gates needed  
B. Sum of products because the output has more 1s than 0s  
C. Product of sums because it minimizes the number of gates needed  
D. Product of sums because the output has more 1s than 0s

A

11. Which of the following correctly characterizes magnetic and electric field lines?

A. Magnetic field lines flow from north poles to south poles, while electric field lines flow from positive charges to negative charges  
B. Magnetic field lines flow from south poles to north poles, while electric field lines flow from positive charges to negative charges  
C. Magnetic field lines flow from north poles to south poles, while electric field lines flow from negative charges to positive charges  
D. Magnetic field lines flow from south poles to north poles, while electric field lines flow from negative charges to positive charges

A
12. Why would a polarized capacitor be used over a nonpolarized counterpart?

A. They can handle larger voltages  
B. They can handle larger currents  
C. They have larger capacitance to size ratios  
D. They have larger voltage-tolerance to size ratios

**C**

13. In transistor-transistor logic, what is the fewest number of PNP and NPN transistors needed to make a NOT gate?

A. 1 PNP transistor, 1 NPN transistor  
B. 2 PNP transistors  
C. 1 PNP transistor  
D. 2 NPN transistors

**A**

14. Which of the following effects does not have an inverse?

A. Photoelectric effect  
B. Triboelectric effect  
C. Piezoelectric effect  
D. Pyroelectric effect

**B**

15. The measurement of large magnetic fields on the order of a Tesla can often be done through making use of what phenomenon?

A. Proximity effect  
B. Nernst effect  
C. Skin effect  
D. Hall effect

**D**
Section III: Multi-part/Free Response

1. (10 pts) Consider the diagram below of a metal sheet exiting a magnetic field region through being pulled by an external force F.

(a) (3 pts) Sketch the eddy currents in the metal sheet on the diagram. If they exist, also indicate (either by writing or drawing) on the diagram the direction of the force produced by the eddy currents. If they do not exist, write "No Force Produced".

(b) (3 pts) Indicate the direction of the magnetic field produced by the eddy currents on the diagram. What law of physics describes why the magnetic field in question travels in this direction?

   Lenz's Law

(c) (2 pts) If the force pulling the metal sheet through the magnetic field were to suddenly stop pulling, how would the eddy currents change, if at all?

   A. They would change directions to follow the path of the magnetic field lines
   B. They would dissipated completely without reversing directions
   C. They would momentarily reverse directions along the same path before dissipating
   D. They would continue moving along exactly as if nothing had happened

   [B]

(d) (2 pts) Give an example of one application of eddy currents.

   - Cooking pots and other uses of induction heating
   - Train braking
   - Magnetic levitation
   - Hyperthermia in Cancer Treatment
2. (10 pts) Suppose you have a 10.0V DC source. You want to build a device that requires 5.00V at a constant level in order to run.

(a) (2 pts) What general type of circuit would be best for you to build to power your device?

A. Voltage Divider
B. Current Divider
C. Voltage Regulator
D. Current Regulator

(b) (3 pts) Suppose you had an unlimited supply of identical Zener diodes whose turn-on voltages are 0.500V and reverse-breakdown voltages are 5.00V. You also have an unlimited supply of 100.Ω resistors. Sketch the circuit you would need to build in order to provide the appropriate voltage to your device that uses the fewest necessary parts. Don’t forget to include to include the power source and the load!

(c) (3 pts) If the device has 50.0mΩ of resistance, how many megajoules of energy are used up by the device if the circuit you constructed in Part (c) is run for a whole day?

\[ E = P \cdot t = \frac{V^2}{R} \cdot t = \frac{5.00^2}{0.0506} \cdot 60 \cdot 60 \cdot 24 = 43.2 \text{ MJ} \]

(d) (2 pts) If the reverse voltage applied across the Zener diode exceeds the rated voltage of the device, what process will occur?

Avalanche Breakdown
3. (10 pts) Consider the circuit below. The output voltage of $U_1$ is measured to be $-9.62V$.

(a) (3 pts) Calculate the resistance of $R_4$.

$V_3 = V_4 = 4.0V$

By KCL: 
$$\frac{V_2 - V_4}{R_3} = \frac{V_4 - V_{out}}{R_4}$$

$$R_4 = \frac{R_3}{V_2 - V_4} (V_4 - V_{out}) = \frac{3.7 \times 10^3}{25 - 4.0} (4.0 - (-9.62)) = 2.4 \, k\Omega$$

(b) (3 pts) Calculate the current flowing through $R_8$.

By KVL

$$V_3 - R_8 (I_1 + I_2) - R_7 I_2 = 0$$

$$I_2 = \frac{V_3 - R_8 I_1}{R_7 + R_8} = -3.90A$$

$$I_{R_8} = I_1 + I_2 = 7.2 - 3.90 = 3.3A$$

(c) (4 pts) Suppose $I_1$ were replaced with a dependent current source controlled by the current flowing through $R_6$ such that $I_1 = \beta I_{R_6}$, where $\beta = 200$. Calculate the new current through $R_8$.

$$I_1 = \beta I_{R_6} = \frac{R}{R_{out}} \Rightarrow I_2 = \frac{V_3 - \beta \left(\frac{R_8 V_{out}}{R_6}\right)}{R_7 + R_8} = 0.616A$$

$$I_{R_8} = I_1 + I_2 = -1.13 + 0.616 = -0.52A$$
4. (10 pts) Consider the following truth table:

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(a) (2 pts) Draw the Karnaugh map for this table.

(b) (3 pts) What are the minterms represented? Use them to write the Sum-Of-Products form.

Minterms: \( A \overline{B} \overline{C} \overline{D} \overline{E} \)
\( A \overline{B} C \overline{D} \overline{E} \)
\( A \overline{B} \overline{C} \overline{D} E \)
\( A B C D \overline{E} \)

Out = \( BC + ABC + A'BC' \)

(c) (5 pts) Suppose we didn't care what the output was for \( A'B'C \) and \( ABC' \). Draw a new Karnaugh map to account for this change, then write the new Sum-Of-Products expression.

Out = \( A'B'C + A'C + B'C + AK \)
5. (12 pts) Consider the circuit diagram below. Assume that both switches, S1 and S2, are initially open and that capacitor C1 is uncharged.

(a) (4 pts) Suppose that S1 was to be closed. How many seconds after being closed would C1 reach 75% of its full charge? What would the potential energy of the capacitor be at this time?

\[ V = V_0 \left(1 - e^{-\frac{t}{RC}}\right) \rightarrow 0.75 = 1 - e^{-\frac{t}{4.5 \times 10^3 \cdot 13 \times 10^{-6}}} \]

\[ t = 0.081 \]

\[ U = \frac{1}{2} CV^2 = \frac{1}{2} \cdot 13 \times 10^{-6} \cdot 4.5^2 = 1.3 \times 10^{-4} \text{ J} \]

(b) (4 pts) After C1 reaches its full charge, S1 is opened as S2 is simultaneously closed. Right after S1 opens and S2 closes, calculate the current flowing through R2, as well as the voltage drop across it. Assume that Q1 is ideal, its forward voltage drop is 0.7V, and \( \beta = 100 \).

\[ V_{c1} = i_B R_4 + 0.7 + i_E R_2 \]

\[ 6.6 = i_B \cdot 2.3 \times 10^3 + 0.7 + (1+\beta) i_B \cdot 1.2 \times 10^{-3} \]

\[ 5.3 = 12.35 + 0.7i_B \rightarrow i_B = 4.3 \times 10^{-5} \text{ A} \]

\[ V_{R2} = 5.2 \text{ V} \]

(c) (4 pts) Rearrange the elements in the right hand side of the circuit (C1, V2, Q1, R2, R3, R4, and S2) to form a common collector amplifier that has a voltage output of 5.19V when S2 is initially closed and draw the resulting diagram. Keep C1 as the input voltage source and V2 as the common emitter voltage. Assume that C1 has been fully charged by the configuration in Part (a).
Bonus!

Congratulations, you’ve made it to the end of the theoretical portion! Or, you’re too cool and just skipped to the end. Whatever, I don’t care how you got here.

The point is, you’re here. Take a break and enjoy the comic below, compliments of XKCD. :)

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Okay, I get it, you don’t like wasting time for breaks when you’ve got the clock to worry about. Really, it’s understandable.

How about this: if you can tell me in the space below how the time-traveler’s actions will affect the future development of convention, electromagnetic theory, or anything in that general area, I’ll give you 1 point per relevant example for up to 3 bonus points. I’ll even use it as a tie-breaker, too. Be specific with your examples, though!

Sound like a deal? I hope so.

Anything that mentions how conventional current or the assignment/definition of positive/negative charged counts, as long as they are distinct examples.
1. (10 pts) Refer to the circuit labelled "Circuit 1" on your breadboard. This question will require you to find the value of a resistor of an unknown value, which is covered in black electrical tape.

(a) (2 pts) Draw a diagram of the circuit. Include the values of known elements.

(b) (3 pts) Draw the Thevenin equivalent of the circuit, with the resistor of unknown value as the load resistor. Leave the LED as is.

(c) (2 pts) What is the voltage drop across the mystery resistor?

\[ \approx 1.6 - 2.0 \text{ V} \]

(depending on what LED you use)

(d) (3 pts) Given that the mystery resistor has four color bands, what are the colors of its first three bands (in order)?

Yellow, Violet, Brown
2. (15 pts) Refer to the circuit labelled "Circuit 2" on your breadboard. The operational amplifier is a 741 op amp.

(a) (3 pts) Draw a diagram of the circuit. Include the values of known elements.

(b) (2 pts) What is the bias voltage of the circuit (Part B)?

1.6 - 1.7 V

(c) (2 pts) What specific type of operational amplifier circuit is Part A of the circuit? Be specific!

Unity Gain Buffer

(d) (2 pts) What specific type of operational amplifier circuit is Part B of the circuit? Be specific!

Non-inverting

(e) (4 pts) Given the configuration of the circuit, what is the theoretical output voltage of Part B of the circuit?

\[
V_{\text{out}} = \frac{4.7 \times 10^3 \cdot 3.3 + 22 \times 10^3 \cdot 3.3 - 22 \times 10^3 \cdot 1.7}{4.7 \times 10^3} \approx 4.0 V
\]

(4.1V also okay if \( V_{\text{bias}} = 0.6 V \))

(f) (2 pts) What is the measured gain of Part B of the circuit?

\[
V_{\text{out}} = 3.9 V \quad \rightarrow \quad \text{Gain} = \frac{V_{\text{out}}}{V_{\text{in}}} \approx \frac{3.9}{1.7} \approx 2.2 - 2.6
\]

(Theoretical is 4.1V)

(\text{depending on \text{values used}})
Section V: Circuit Construction

1. (5 pts) Suppose you want to build a balanced Wheatstone bridge using the materials in your bag. Draw a circuit diagram that would match this criteria. Don't forget to indicate the values of the components as appropriate!

*Note: If needed, you can use more than one resistor per leg of the bridge.

![Wheatstone Bridge Diagram]

2. (10 pts) Suppose you want to build a NAND gate using the materials in your bag to make an LED (included in the bag) light up. Draw a circuit diagram that would match this criteria. Don't forget to indicate the values of the components as appropriate!

![NAND Gate Diagram]

3. Build ONE circuit that would match the criteria of either Question 1 OR Question 2 of this section. Then, present it to the event supervisor or a volunteer and let them fill out the section below. You will receive points for this section ONLY if the diagram drawn for your chosen question is correct!

(a) (5 pts) **Wheatstone Bridge**: Record the voltage drop across the bridge in the box below and sign off.

![Voltage Drop](0.0)

(b) (10 pts) **NAND Gate**: Record the outputs in the table below and sign off.

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Materials For Section V

- 9V battery + breadboard
- 6 resistors
  (20Ω, 20Ω, 47Ω, 100kΩ, 470kΩ, 1MΩ)
- 1 1000 µF 25V Capacitor
- 2 2N2222 Transistors
- 1 LED