Math Lab 11 MS 3

Solving Problems That Involve Electrical Transducers

For best results, print this document front-to-back and place it in a three-ring binder. Corresponding teacher and student pages will appear on each opening.

TEACHING PATH - MATH SKILLS LAB - CLASS M

RESOURCE MATERIALS

Student Text: Math Skills Lab

CLASS GOALS

1. Teach your students how to solve problems that involve electrical transducers.

CLASS ACTIVITIES

1. Take five or ten minutes to go through the Student Exercises. Make sure that students understand the correct answers.
2. Complete as many activities as time permits. Students already should have read the discussion material and looked at the examples for each activity before coming to this class. (How much you accomplish will depend on the math skills your students already have.) Summarize the explanatory material for the activity: "Solving Problems That Involve Electrical Transducers." Then have students complete the Practice Exercises given at the end of the activity.
3. Supervise student progress. Help students obtain the correct answers.
4. Before the class ends, tell your students to read Lab 11E1, "Flow Measurement With a Transducer."

Math Skills Laboratory

Lab 11 MS 3

MATH ACTIVITY

Activity: Solving Problems That Involve Electrical Transducers

MATH SKILLS LAB OBJECTIVES

When you complete this activity, you should be able to do the following:

1. ***Solve problems that involve the use of electrical transducers in practical applications.***
2. ***Rearrange equations and substitute correct units to solve for an unknown quantity.***

LEARNING PATH

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Work the problems.***

ACTIVITY

Solving Problems That Involve Electrical Transducers

MATERIALS

In this lab, you'll need paper, pencil and a calculator.

DISCUSSION

This lab will give you experience in solving problems that involve electrical transducers. A technician might encounter these problems in selecting a transducer or troubleshooting a transducer system. The variety of uses for transducers is limited only by the imagination of the user. Therefore, the problems that follow represent only a small sample.

ANSWERS TO STUDENT ACTIVITY

Problem 1: Use the formula and data from the specification sheet

$R_t = R_L + (R_D - R_L)C_t$

where: $R_L = 30\ k\Omega$

$R_D = 100\ k\Omega$

$C_t = 0.1296$ (computed for you; see below)

$R_t = 30\ k\Omega + (100\ k\Omega - 30\ k\Omega)(0.1296)$

$R_t = 30\ k\Omega + (70\ k\Omega)(0.1296)$

$R_t = 30\ k\Omega + 9.072\ k\Omega$

$R_t = 39.072\ k\Omega.$

NOTE: $C_t = (1 - e^{-t/\tau})$ where: $t = 10$ msec

$\tau = 72$ msec

$$C_t = \left(1 - e^{\frac{-10\ \cancel{msec}}{72\ \cancel{msec}}}\right) = 1 - e^{-\frac{10}{72}}$$

$$C_t = \left(1 - e^{-0.1389}\right) \quad \text{where } e^{-0.1389} = 0.8703$$

$$C_t = (1 - 0.8703)$$

$$C_t = 0.1297$$

You will discuss time constants in Unit 14.

Answer to Problem 2 is on page T-82c.

Problem 2: The circuit is the traditional diamond-shaped Wheatstone bridge circuit.

The bridge is balanced when:

$\frac{R_1}{R_2} = \frac{R_3}{R_X}$. Then no current flows through the load (alarm).

In the problem: R_1 = no-smoke resistance value of photoconductor

$R_2 = 1\ \text{k}\Omega$

$R_3 = 180\ \text{k}\Omega$

$R_X = 6\ \text{k}\Omega$ adjustable resistor adjusted to no-smoke condition to balance bridge

Solve equation for "R_1" by multiplying both sides of equation by "R_2."

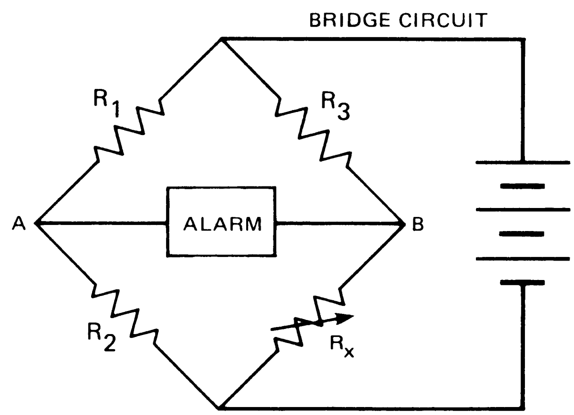
$$\cancel{(R_2)}\ \frac{R_1}{\cancel{R_2}} = (R_2)\ \frac{R_3}{R_X} \qquad \text{(Cancel like terms.)}$$

$$R_1 = R_2\ \frac{R_3}{R_X} = \frac{1\ \text{k}\Omega \times 180\ \text{k}\Omega}{6\ \text{k}\Omega}$$

$$R_1 = \left(\frac{1 \times 180}{6}\right) \frac{\cancel{\text{k}\Omega} \cdot \text{k}\Omega}{\cancel{\text{k}\Omega}}$$

$$R_1 = 30\ \text{k}\Omega.$$

Bridge is balanced when $R_1 = 30\ \text{k}\Omega$, the no-smoke condition.



Problem 1: *This problem involves using a photoconductive transducer as a counting device.*

Given: A cadmium sulfide (CdS) photoconductive cell is used on a conveyor line to count cans of soft drinks. The specification sheet for the cell gives the following information:

- Dark resistance (R_D) = 100 kΩ (dark resistance is that resistance when a photoconductor is exposed only to ambient room light in the nearby area)
- Light resistance (R_L) = 30 kΩ (when placed in a light beam)
- Time constant (τ) = 72 msec
- Response value* $C_t = (1 - e^{-t/\tau}) = 0.1297$

  *The value for t = 10 milliseconds and τ = 72 milliseconds has been computed for you. You'll study time constants and how to calculate them in Unit 14.

  The response time for the conveyor-belt system is based on t = 10 msec. When each can passes through the light beam and blocks the light to the cell, the photoconductive cell needs time to react to raise the resistance value from R_L = 30 kΩ to R_D = 100 kΩ.

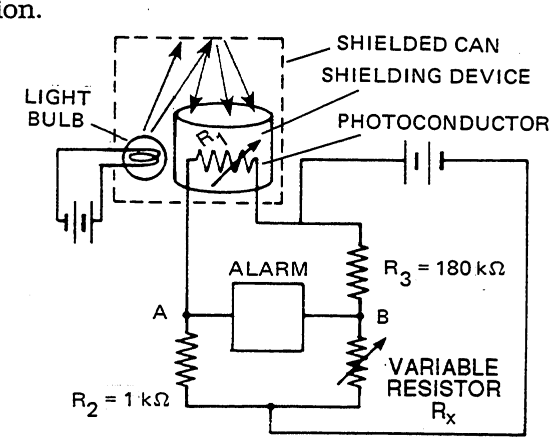
  It also needs time to reverse the action when the can no longer blocks the beam and light falls on the cell. This time interval is known as "response" or "recovery time." If the cans move too quickly (conveyor speed too fast) for photoconductive cell recovery, the count will be incorrect.
- Resistance at given response time $R_t = R_L + (R_D - R_L)\,C_t$.

Find: The resistance (R_t) required from the photoconductive cell to provide a voltage signal within 10 msec of beam interruption. (Use the equation and information provided.)

Solution:

Problem 2: *This problem involves the use of transducers in smoke detectors.*

A photoconductor is mounted in a shielding device. A nearby light bulb is mounted in a shielded can. Light from the bulb can't travel directly to the photoconductor. (See the drawing.) When smoke is in the air, it causes some of the light to scatter and be deflected onto the photoconductor. This causes a reduction in resistance value in the light-sensitive photoconductor. The photoconductor acts as a resistive component (R_1) in the fourth arm of a Wheatstone Bridge. The bridge initially is balanced to a "no-smoke" condition by adjusting the bridge's variable resistor arm (R_x). The alarm goes off when smoke is present, since a change in resistance (R_1) upsets the balanced condition.



Smoke alarm system.

Problem 3: $I = \dfrac{V}{(R_{Int} + R_{Load})}$ Rearrange and solve equation for "R_{Int}." Multiply by sides by "$\dfrac{(R_{Int} + R_{Load})}{I}$."

$$\frac{(R_{Int} + R_{Load})}{\cancel{I}} \cancel{I} = \frac{V}{(\cancel{R_{Int} + R_{Load}})} \left(\frac{\cancel{R_{Int} + R_{Load}}}{I}\right);$$ cancel like terms

$R_{Int} + R_{Load} = V/I$

Substract R_{Load} from both sides.

$R_{Int} + R_{Load} - R_{Load} = V/I - R_{Load}$

Simplifying, equation for R_{Int} becomes:

$R_{Int} = V/I - R_{Load}$ where: $V = 0.33\ V$

$I = 2.2\ mA = 2.2 \times 10^{-3}\ A$

$R_{Load} = 100\ \Omega$

$$R_{Int} = \frac{0.33\ V}{2.2 \times 10^{-3}\ A} - 100\ \Omega = \left(\frac{0.33}{2.2 \times 10^{-3}}\right) \frac{V}{A} - 100\ \Omega; \quad (1 \frac{V}{A} = 1\ \Omega)$$

$R_{Int} = 0.15 \times 10^3\ \Omega - 100\ \Omega$

$R_{Int} = 150\ \Omega - 100\ \Omega$

$R_{Int} = 50\ \Omega.$

Problem 4:

a. The current flow is roughly 500 μA at the intersection of the 278.7 lumen/m^2 curve and the 10-V line on the graph.

b. This is a relatively flat curve that intersects 5 volts at approximately 100 μA on the graph.

c. The 278.7 lumen/m^2 curve starts near 2.5 V at 400 μA range and continues to 40 V at 600 μA. The curve is nearly linear from about 10 volts to 40 volts.

Given: Study the drawing. When the ratio of resistance R_1/R_2 equals the ratio of resistance R_3/R_x, ***no current*** will flow through the alarm. When the ratio changes, because smoke-reflected light causes a decrease in the photoconductor resistance (R_1), current flows between points A and B. It sets off the alarm.

Find: The "no-smoke" value of the photoconductor resistance (R_1) when R_x is adjusted to 6 kΩ to balance the bridge. (No light is shining on the photoconductor. This is the "dark" condition.)

Solution: (Use the ratio, $R_1/R_2 = R_3/R_x$ to solve R_1.)

Problem 3: *This problem involves a photoconductive transducer used to control street lights.*

Given: A photovoltaic cell used to turn street lights off at dawn produces 0.33 volt when illuminated by 10 watts per square meter of light radiation. A current of 2.2 mA is delivered to a 100-Ω resistance load at that light level.

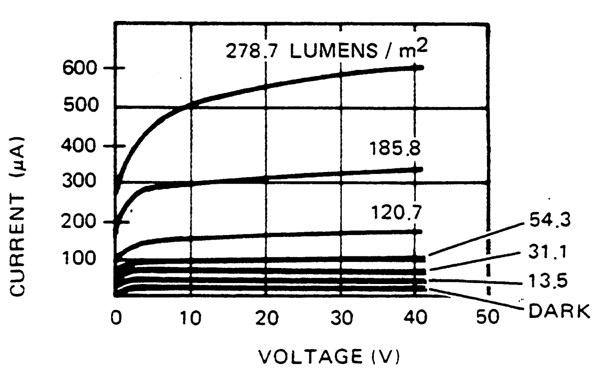
Find: The internal resistance of the cell, R_{int}.

Solution: (***Note:*** Let $R = [R_{int} + R_{load}]$ in the Ohm's law equation $I = V/R$. Hence, the equation becomes $I = V/[R_{int} + R_{load}]$. Rearrange this equation to isolate "R_{int}". Then solve for "R_{int}.")

Problem 4: *This problem involves photoconductors used as relays to control current.*

A relay is a device that uses electric current from one circuit to switch current on and off in another circuit. An optical semiconductor relay is composed of a light-emitting diode (LED) and a photodiode. In operation, when a current passes through the LED it emits light. This light strikes the photodiode which then conducts current as long as the LED emits light. The photodiode acts like a switch that is turned on and off by the LED.

Given: A graph of the illumination curves in lumens/m² for a photodiode used in an optical semiconductor relay. A "lumen per square meter" is a common unit used in industry to measure how much visible light falls on a work surface. In the graph, current versus voltage is plotted for different levels of light falling on the photodiode, ranging from dark to 278.7 lumens/m².



Find:

a. The current flow at 10 volts and 278.7 lumens/m².
b. The current flow at 5 volts and 54.3 lumens/m².
c. The voltage range (lower and upper voltages) that produces currents of 400 μA to 600 μA at 278.7 lumens/m².

Solution:

Problem 5: Use the equation, $V = IR$. Solve for R.

$R = V/I$ where: $I = 40\ \mu A = 40 \times 10^{-6}$ A

a. $R_1 = \frac{V_1}{I}$ where: $V_1 = 10$ V

$$R_1 = \frac{10\ V}{40 \times 10^{-6}\ A} = \left(\frac{10}{40 \times 10^{-6}}\right)\frac{V}{A}, \text{ but } 1\ \frac{V}{A} = 1\ \Omega.$$

$R_1 = 0.25 \times 10^6\ \Omega$ or $250{,}000\ \Omega$.

b. $R = \frac{V}{I}$ where: $R = R_1 + R_2$
$R_1 = 250{,}000\ \Omega$
$V = V_2 = 100$ V

$R_1 + R_2 = \frac{V_2}{I}$ Solve for "R_2" by subtracting "R_1" from both sides of the equation.

$$R_2 = \frac{V_2}{I} - R_1 = \left(\frac{100\ V}{40 \times 10^{-6}\ A}\right) - 0.26 \times 10^6\ \Omega$$

$$R_2 = \left(\frac{100}{40 \times 10^{-6}}\right)\frac{V}{A} - 0.25 \times 10^6\ \Omega; \left(1\ \frac{V}{A} = 1\ \Omega\right)$$

$R_2 = 2.5 \times 10^6\ \Omega - 0.25 \times 10^6\ \Omega$

$R_2 = 2.25 \times 10^6\ \Omega$.

$R = \frac{V}{I}$ where: $R = R_1 + R_2 + R_3$
$R_1 = 0.25 \times 10^6\ \Omega$
$R_2 = 2.25 \times 10^6\ \Omega$
$V = V_3 = 500$ V

$R_1 + R_2 + R_3 = \frac{V_3}{I}$ Solve for "R_3" by subtracting "$(R_1 + R_2)$" from both sides of the equation.

$$R_3 = \frac{V_3}{I} - (R_1 + R_2) = \left(\frac{500\ V}{40 \times 10^{-6}\ A}\right) - (0.25 \times 10^6\ \Omega + 2.25 \times 10^6\ \Omega)$$

$$R_3 = \left(\frac{500}{40 \times 10^{-6}}\right)\frac{V}{A} - 2.5 \times 10^6\ \Omega = 12.5 \times 10^6\ \Omega - 2.5 \times 10^6\ \Omega$$

$R_3 = 10 \times 10^6\ \Omega$.

$R = \frac{V}{I}$ where: $R = R_1 + R_2 + R_3 + R_4$
$R_1 = 0.25 \times 10^6\ \Omega$
$R_2 = 2.25 \times 10^6\ \Omega$
$R_3 = 10 \times 10^6\ \Omega$
$V = v_4 = 1000$ V

$R_1 + R_2 + R_3 + R_4 = \frac{V_4}{I}$ Solve for "R_4" by subtracting "$(R_1 + R_2 + R_3)$" from both sides of the equation.

$$R_4 = \frac{V_4}{I} - (R_1 + R_2 + R_3)$$

$$R_4 = \left(\frac{1000\ V}{40 \times 10^{-6}\ A}\right) - (0.25 \times 10^6\ \Omega + 2.25 \times 10^6\ \Omega + 10 \times 10^6\ \Omega)$$

$R_4 = 25 \times 10^6\ \Omega - 12.5 \times 10^6\ \Omega$

$R_4 = 12.5 \times 10^6\ \Omega$.

--Problem 5c solved on T-84c--

The answer to Problem 5 is continued on page T-84c.

c. On the 10 V linear scale, with 10 μA flowing through "R_1":

   40 μA gives a 10 V reading; so 10 μA (1/4 of 40 μA) gives 1/4 of 10 V or a 2.5 V reading.

   On the 100 V linear scale, with 10 μA flowing through "R_1" and "R_2":

   40 μA gives a 100 V reading; so 10 μA (1/4 of 40 μA) gives 1/4 of 100 V or a 25 V reading.

   On the 500 V linear scale, with 10 μA flowing through "R_1," "R_2" and "R_3":

   40 μA gives a 500 reading; so 10 μA (1/4 of 40 μA) gives 1/4 of 500 V or a 125 V reading.

   On the 1000 V linear scale, with 10 μA flowing through "R_1," "R_2," "R_3" and "R_4":

   40 μA gives 1000 V reading; so 10 μA (1/4 of 40 μA) gives 1/4 of 1000 V or a 250 V reading.

Problem 5: *This problem involves a moving-coil transducer in a multirange voltmeter.*

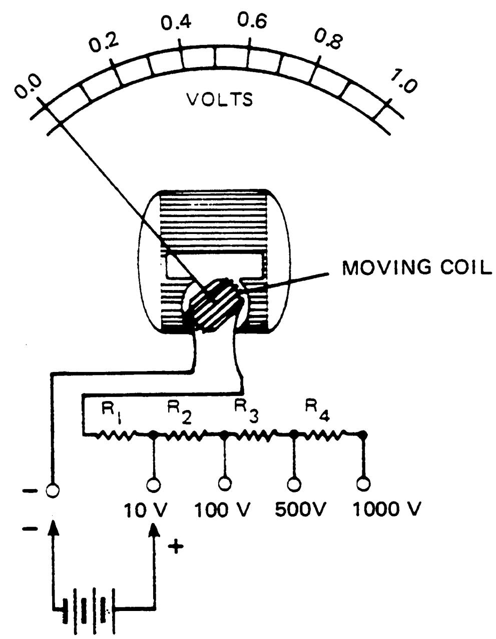
Given: The moving coil meter movement in the diagram below deflects full scale (0.0 - 1.0) when 40 μA of current flow through the moving coil and the meter probes are connected to a source at the (–) terminal and the (+ 10 V) terminal.

Find:

a. The value of "R_1" for the meter when the source is connected at the "–" terminal and the "+ 10 V" terminal.

b. Repeat for connections at the "–" terminal and the "+ 100 V," "+ 500 V" and "+ 1000 V" terminals. Remember that current must pass through R_1, R_2, R_3 and R_4 when source is connected to the "+ 1000 V" terminal.

c. Assuming that the scale is linear, what are the source voltages for each connection when only 10 μA of current is flowing through the moving coil?



Solution: (*Note:* Use Ohm's law and $R = R_1 + R_2 + R_3 + ... + R_n$ for series resistors.)