A. Introduction

Public concern about possible health hazards from exposure to electromagnetic fields is increasing. People are constantly exposed to electromagnetic fields from power lines, appliances, radio and television stations, and many other sources of electromagnetic fields. The use of devices that emit electromagnetic fields is increasing. For example, development in personal communications services (PCS) is proceeding at a rapid rate. The day has arrived when an individual carrying a wireless handheld communicator (that radiates electromagnetic fields) could be reached at any spot on earth by voice or data. As early as 1993, more than 200 companies in the United States had received experimental PCS licenses from the Federal Communications Commission and had spent an estimated 200 million dollars in conducting experiments (Personal Communications Services, *IEEE Spectrum*, p. 20, June, 1993). Now wireless communications is a multibillion-dollar industry.

Although much research has been aimed at answering the question of whether exposure to weak electromagnetic fields is hazardous, no one knows the answer to that difficult question. Studies are complex and difficult, and results are often contradictory and inconsistent. Perhaps because answers are not known, the public seems to be easily alarmed, as illustrated by the cellular telephone scare. On January 21, 1993, David Reynard, St. Petersburg, Florida, appeared on the "Larry King Live" television show and alleged that use of a cellular telephone had caused or exacerbated the brain cancer that killed his wife. He had filed a lawsuit against NEC America Inc., the company that made the phone, and the local carrier, GTE Mobilnet. Within days the debate over the safety of cellular phones was the center of media attention and within a week the stock prices of McCaw Cellular Communications Inc., the country's largest cellular carrier, and Motorola Inc., the world's largest supplier of cellular phones had each dropped by 17 percent. Dosimetry calculations by Dr. Om Gandhi (our department chairman) and his colleagues were prominently featured in the debate (The Cellular Phone Scare, *IEEE Spectrum*, p. 43, June, 1993). Although public statements by leaders of the FCC, the
FDA, and the EPA all indicated that no evidence linking cellular telephone use to brain cancer had been found, as Dr. John Osepchuk, Chairman of the IEEE Committee on Man and Radiation (COMAR), said, "All it takes is one plaintiff, a lawyer, and the media to start a controversy, even in the face of a huge base of scientific research."

Much research is still needed to determine what effects electromagnetic fields have on people. Behavioral studies are an important component of this research. Dr. John D'Andrea, a leading authority on the effects of electromagnetic fields on behavior, conducted pioneering studies here at the University of Utah in the late 1970s and early 1980s of how electromagnetic fields affect the behavior of rats. One of the techniques he used in his research is called time discrimination (John A. D'Andrea, Brenda L. Cobb, and John O. de Lorge, "Lack of Behavioral Effects in the Rhesus Monkey: High Peak Microwave Pulses at 1.3 GHz," Bioelectromagnetics, 10: 65-76 (1989)). Here is an example of a time-discrimination paradigm. The animal is trained to press three levers for a reward of a food pellet. Pressing the center lever turns on two lights, a red one and a green one. The lights flash with one of two patterns: P1, the red light stays on x times as long as the green light, or P2, the green light stays on x times as long as the red light. A computer randomly selects either P1 or P2 when the center lever is pressed, records the responses of the animal, and analyzes the data. If the pattern is P1, the animal receives a food pellet if it presses the left lever. If the pattern is P2, the animal receives a food pellet if it presses the right lever. After the animal is trained in time discrimination, it is exposed to electromagnetic fields and tested to see if the electromagnetic fields affect its timing ability.

B. Your Design Project

Your design project is to design a timing circuit that will cause a red and a green light to flash in patterns that could be used in time-discrimination behavioral studies.

The basic timing circuit, which is a modification of a common astable multivibrator circuit, is shown in Fig. 1. With proper design, it will produce the output voltage waveform shown in Fig. 2. The diodes D1 and D2 allow Tp and Tn to have different values. Without these diodes, Tp and Tn would be equal. The red light-emitting diode (LED) will glow while v0 is positive, and the green LED will glow while v0 is negative. By choosing proper values of R1, R2, R3, R4, and C, you will produce the desired values of Tp and Tn to create the timing pattern P1 or P2 described above. In practice, two separate circuits would be used, one to produce P1 and the other to produce P2. The circuit design that produces P2 can be obtained from the one that produces P1 simply by interchanging the polarities of the LEDs.
Fig. 1. Diagram of the timing circuit.

Fig 2. The output voltage of the circuit of Fig. 1. The red LED will glow while $v_0$ is positive, and the green LED will glow while $v_0$ is negative.

C. Derive Equations
1. Derive equations for $\pm v_1$ and $\pm v_2$. If $R_1$ and $R_2$ are greater than a thousand ohms, the diodes $D_1$ and $D_2$ may be adequately modeled as ideal diodes; i.e.,
when forward biased, the diode is a short circuit (zero resistance), and when reverse biased, the diode is an open circuit (infinite resistance). In this device the operational amplifier operates in the switching mode; i.e., \(v_0\) is either \(v_R\) or \(-v_R\), and it switches from one to the other.

2. Derive expressions for \(T_p\), \(T_n\), and \(T_p/T_n\).
3. Make consistency checks on your expressions.

D. Design the Circuit
1. Choose \(C\) to be 1 \(\mu\)F. Use a potentiometer for \(R_4\) and for \(R_1\) so that \(T_p\) and \(T_n\) may be adjusted without replacing circuit components.
2. Choose component values so that the circuit can be made to produce:
   (a) \(T_p = 1\) s and \(T_n = T_p/2\), and
   (b) \(T_p = 30\) ms and \(T_n = T_p/2\)
Because \(T_p/T_n\) does not depend on either \(R_4\) or \(C\), a good strategy is to choose values of \(R_1\), \(R_2\), and \(R_3\) to produce the desired ratio \(T_p/T_n\), and then adjust \(R_4\) to give the desired values of \(T_p\) and \(T_n\).
3. Using MATLAB, plot \(T_p/T_n\) versus \(R_1\), with \(R_2\) and \(R_3\) fixed at some reasonable values, showing how the one resistance can be varied to adjust \(T_p/T_n\).
4. Using MATLAB, plot \(T_p\) versus \(R_4\) for a fixed \(T_p/T_n\).
5. \(R_5\) is used to prevent excessive current from burning out the LEDs. For the LEDs sold in the EE stockroom, the maximum allowable current is 18 mA, and typical operating current is 8 mA. The voltage drop across an LED is typically about 2 volts. Choose \(R_5\) for proper operation of the LEDs.

E. Construct and Test the Circuit
1. Construct the circuit and test it. Adjust the circuit components to produce the timing patterns specified in D2(a) and D2(b) above. Record descriptions of the timing patterns for each case. Is the blinking of the LEDs discernible for the parameters of D2(b)?
2. For \(T_p = 30\) ms and \(T_n = T_p/2\), display \(v_1\) and \(v_2\) simultaneously on an oscilloscope and record the waveform for a typical positive and a typical negative half cycle. Display \(v_1\) and \(v_0\) simultaneously and record the waveforms. Remember that the input resistance of a typical oscilloscope is about 1 M\(\Omega\); if \(R_4\) is about 1 M\(\Omega\), you will probably need to use the 10x probe to display \(v_1\).
3. On the same set of axes, plot calculated and measured values of \(v_1\), \(v_2\), and \(v_0\) versus time when \(T_p = 30\) ms and \(T_n = T_p/2\). Use measured values of circuit
components in making the calculations. You may make two separate plots, one for the negative half cycle and one for the positive half cycle. Clearly label calculated and measured points.

F. Write a Formal Report

Write a formal report describing your work on this project. See instructions in "Course Procedures" about how to write the report. Include at least the following in your report:

1. A short introduction. You may attach this handout to the report and refer to it so that you don't have to copy the information in it.

2. A careful description of the work that you did in parts C through E above.
   a. Give clear derivations of the mathematical expressions. Include consistency checks.
   b. Explain how you chose the value of the components and include a table listing the component values.
   c. Explain all measurements carefully and include data appropriately in clearly labeled tables and graphs in the body of the report.
   d. Include a listing of your computer program in an appendix.
   e. Give a clear comparison of measured and calculated values on the same set of axes for $v_1$, $v_2$, and $v_0$. Explain why calculated and measured values are not the same.

3. Conclusions, including:
   a. A discussion of the validity of the models used to represent circuit components.
   b. A discussion of the success of your design procedure and the usefulness of your device for producing the desired timing patterns.

G. Your Grade

Your report will be graded according to the following:

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<tr>
<th>Category</th>
<th>Points</th>
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<tbody>
<tr>
<td>Communications, including conclusions</td>
<td>30</td>
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<tr>
<td>C. Equation derivations</td>
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<td>D. Circuit design</td>
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<td>E. Circuit measurements</td>
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<td>Total</td>
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