

Laboratory Project 2: Visual Perception Experiment

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Abstract-You will build an op-amp-based oscillator circuit that flashes an LED at an adjustable rate from 10-100 Hz. Using this circuit, you will determine the fusion rate where the LED transitions from appearing to flash to being on all the time.

I. PREPARATION

For Lab 2, which will last about four weeks, you will need the parts listed in Table I, (in addition to the breadboard and wire kit from Lab 1). You may purchase these parts from the stockroom next to the lab or purchase them elsewhere.

TABLE I
PARTS LIST

Item	Qty	Description
1	1	LF353 Operational Amplifier
2	1	1 μ F Capacitor (non-polarized)
3	1	100 k Ω Potentiometer
4	1	Red LED
5	2	1 k Ω Resistor
6	1	2 k Ω Resistor
7	1	5.1 k Ω Resistor
8	1	10 k Ω Resistor
9	2	Resistors (values determined during lab)

II. LEARNING OBJECTIVES

- 1) Learn about RC circuits.
- 2) Learn how to design an oscillator circuit with an op-amp.
- 3) Determine the rate at which displays must be updated to create an illusion of continuity.

III. INTRODUCTION

A. Critical Fusion Frequency for Human Vision

Fig. 1 shows an illustration of the human eye. With its lens and curvature of the cornea, the eye focuses light from the outside world onto the back of the eye. The iris expands or contracts to control the amount of light collected. On the back surface of the eye is the light-sensitive nerve network of the retina.

At the center of the retina is the fovea, which has a dense arrangement of cones to detect fine detail in the image about the particular portion of the scene the eye is directed to. The cones also give color perception. In the periphery, the cones give way to an increasing proportion of rods, which are very light sensitive but less densely packed. Thus, the perception of spatial detail is much reduced in the periphery.

For time-varying images, different regions of the retina respond differently. For example, when a light is flashing at a low frequency, all parts of the retina will distinguish the individual flashes. However, there is a frequency known as the Critical Fusion Frequency (CFF) at which the individual flashes are indistinguishable and the illumination seems to ‘fuse’ into a steadily flowing perception. The CFF for light focused on the fovea is about 40-50 Hertz (Hz), while the CFF for peripheral vision is half of that value, or 20-25 Hz.

In Laboratory Project 2, you will determine the CFF for the fovea. For those students who are interested, there is an optional part of the lab in which you may explore the CFF for the periphery.

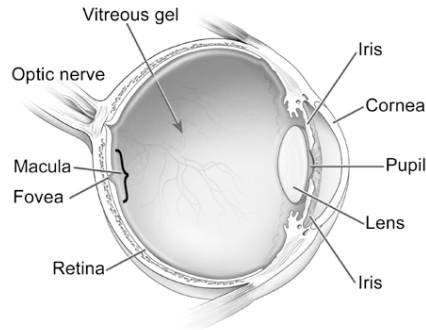


Fig. 1 – Anatomy of the eye (from the National Eye Institute/NIH).

B. Design Project Overview

Your project is to design a square-wave generator circuit that will cause an LED to flash at a controllable rate for visual discrimination experiments that measure fusion rate and (optionally) peripheral perception. Fig. 2 shows a block diagram of the circuit. The oscillator, comprising an op-amp, two resistors, a potentiometer (or variable resistor), and a capacitor will produce a square-wave whose frequency may be varied between a few Hz and 100 Hz. The output of the oscillator drives an LED that turns on when the oscillator output is high and turns off when the oscillator output is low.

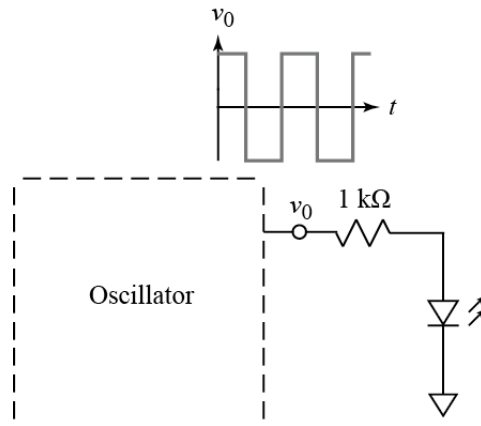


Figure 2. Block diagram of oscillator circuit.

IV. OP-AMP IN COMPARATOR MODE

A. Comparator Circuit Explanation

Fig. 3 shows the first circuit you will build for Lab 2. The purpose of this "comparator" circuit is to characterize the behavior of the op-amp and show that the output of an op-amp without negative feedback is very high or very low. Essentially, the output voltage will get as high or low as it can given the limitation of the power supply voltages for the op-amp and the need for some voltage drops inside the op-amp in order for the op-amp to work. We are interested in this circuit because our oscillator circuit will use the op-amp in comparator mode.

B. Comparator Circuit Analysis

In our comparator circuit, one input of the op-amp is connected to reference, while the other input (from R_3) is varied between the positive and negative power supply levels to switch the output of the comparator high and low.

5) Test the comparator circuit with load: vary v_2 above and below 0 V and measure the high and low values of the output, v_0 , with the load resistors listed in Table III. That is, fill out Table III. Comment on the results.

TABLE III
COMPARATOR OUTPUT VOLTAGE WITH LOAD

R_L	Condition	v_0	Condition	v_0
10 k Ω	$v_2 < 0$ V		$v_2 > 0$ V	
5.1 k Ω				
2 k Ω				
1 k Ω				

V. OP-AMP AS SCHMIDT TRIGGER

A. Schmidt Trigger Circuit Explanation

Fig. 5 shows the second circuit you are to build for Lab 2. This circuit is called a Schmidt trigger and is used to output signals that latch high and low once the input signal (from R_3) passes a threshold voltage. The circuit extends the comparator circuit by using a reference or trigger voltage, v_1 , that is no longer equal to 0 V. The circuit also extends the comparator circuit by using positive feedback from the output to control v_1 . An interesting property of the circuit is that, once the output of the op-amp goes high or low, the trigger voltage, v_1 , shifts so that v_2 has to shift by a large amount to make the output change again. This property is called "hysteresis" and means the circuit has memory. We are interested in the Schmidt-trigger circuit because our oscillator circuit will use this memory feature to temporarily latch high and low as it generates a square wave.

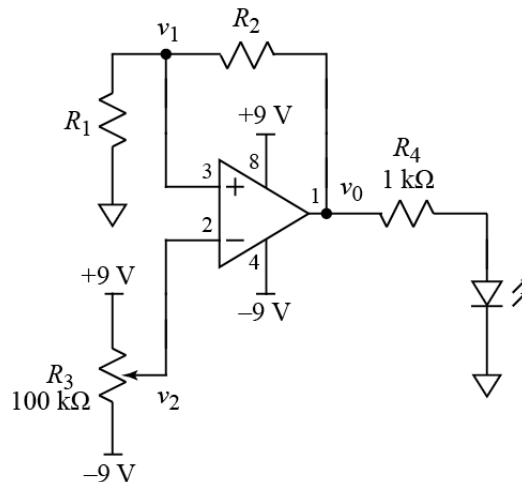


Figure 5. Schmidt trigger.

B. Schmidt Trigger Circuit Analysis

In the Schmidt trigger circuit, the output of the op-amp will be at either the positive or negative rail voltage. Because the load on the op-amp has little effect on the output voltage of the op-amp, we may treat the op-amp as a voltage source that has a value of either the positive rail voltage or the negative rail voltage. Fig. 6 illustrates this model of the Schmidt-trigger circuit. When we use this model, we have two circuits in parallel across the voltage source. The first circuit consists of R_1 and R_2 . The second circuit consists of R_4 and the LED. We can design and analyze these circuits separately. In particular, the first circuit is a voltage divider.

C. Procedure

1) Choose values for R_1 and R_2 to meet the following specifications: v_1 should be 1/11th the value of v_0 , and the total value of R_1 and R_2 should be in the neighborhood of 1 M Ω .

2) Build the complete Schmidt trigger circuit shown in Fig. 5: connect op-amp power supplies, now shown by the flat lines labeled +9 V and -9 V, to the power supply in the same way they were connected in Lab 1.

3) *Test the Schmidt trigger circuit:* vary v_2 above and below 0 V enough to cause the output of the Schmidt trigger to go high and low, i.e., turn the LED on and off.

4) *Measure v_1 with the digital voltmeter:* record the value of v_1 when v_0 is high and low, and verify that the value of v_1 is close to the design value.

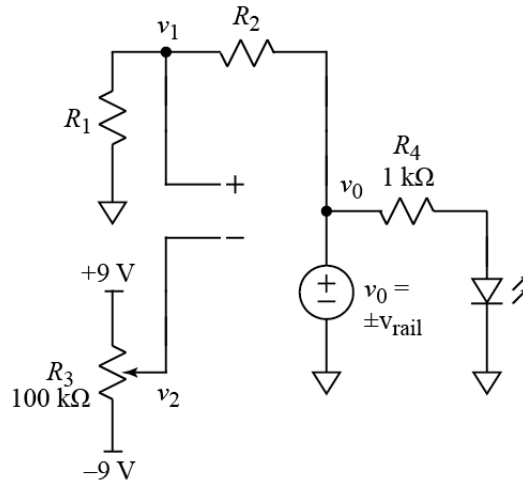


Figure 6. Schmidt trigger with op-amp modeled as voltage source.

VI. RC CIRCUIT

A. RC Circuit Explanation

Fig. 7 shows the third circuit you are to build for Lab 2. (Keep the Schmidt trigger circuit, too, as you will use it again soon.) This third circuit is an RC circuit, meaning it consists of a resistor and capacitor. The C may be thought of as a tank that gets filled up with charge that flows through R_3 . As the C fills up with charge, the voltage across it, v_2 , increases until it reaches the value of the voltage source, v_{s2} , on the left. As v_2 nears v_{s2} , the rate of charging slows down, and v_2 approaches v_{s2} more and more slowly. In our case, we will use a function generator for v_{s2} , and v_2 will move first toward +1 V and then toward -1 V. We are interested in the RC circuit because it will control the frequency of the oscillator circuit we will build later on.

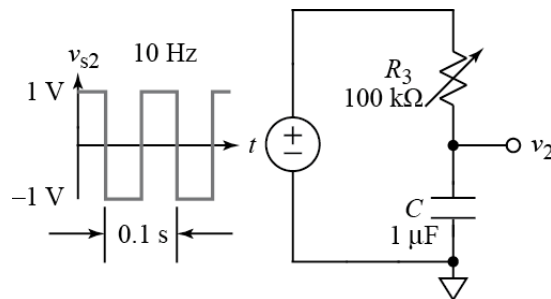


Figure 7. RC circuit.

B. RC Circuit Analysis

The actual form of the v_2 curve is an exponential. You will determine the parameters of this exponential from measurements. Equation (1) gives the general form of the curve during one half-cycle of the input square wave.

$$v_2 = v_2(t \rightarrow \infty) + \left[v_2(t = 0^+) - v_2(t \rightarrow \infty) \right] e^{-\frac{t}{RC}} \quad (1)$$

where

$v_2(t = 0^+) \equiv$ initial voltage on C

$v_2(t \rightarrow \infty) \equiv$ final voltage C will reach as t approaches infinity

We use (1) to describe both the charging and discharging of C . To do so, we reset the time to zero at the start of each half-cycle of the input square wave.

C. Procedure

1) *Calculate R that will cause the time constant to be 50 ms:* the time constant is given by (2), and $C \approx 1 \mu\text{F}$, (use the measured value of C). There is an RLC meter in the lab that you can use to measure C . Using a digital ohmmeter, adjust R_3 to your calculated value of R .

$$\tau = RC \quad (2)$$

2) *Build the RC circuit:* layout the circuit on your breadboard near your Schmidt trigger circuit, and use the arbitrary waveform generator for the v_{s2} input. Use a BNC to alligator clip cable for the output signal from the waveform generator. The BNC connects to the connector in the lower right-hand corner of the front panel of the arbitrary waveform generator. Connect the black alligator clip to the reference side of C , and connect the red alligator clip to the top side of R_3 .

3) *Set up and verify the square wave:* turn on the waveform generator and use the gray knob and the $>$ and $<$ keys to adjust the frequency to 10 Hz. Then press the button on the waveform generator with a square wave on it. Finally, press the AMPL button and adjust the peak-to-peak voltage of the square wave to be 2 V. To measure the square wave input signal, connect a scope probe to the top of R_3 (with the black wire connected to the reference on the bottom of the C). Verify that you have a 10 Hz square wave with amplitude 2 V, (-1 V to $+1$ V).

3) *Measure v_2 :* use a second oscilloscope probe to measure v_2 . Display both the square wave input and the v_2 output waveform on the oscilloscope and save them for later plotting in Matlab[®].

4) *Measure the initial voltage on C :* use the cursor controls on the oscilloscope to determine the initial voltage on the C at the beginning of each half-cycle of the input square wave. You will also need the final voltage that v_2 is headed toward. What will this value be?

5) *Create a simulated RC waveform:* use (1) and the values you have found thus far to create a calculated curve for v_2 . Make a copy of the Matlab[®] file from step 3 and edit it to show only one half-cycle of the square wave and RC charging curve. On a Matlab[®] plot, superimpose your calculated RC charging curve on the measured square wave and RC charging curve. Repeat this process for the half-cycle of discharging.

VII. SCHMIDT TRIGGER WITH RC CIRCUIT INPUT

A. Schmidt Trigger Circuit Explanation

Fig. 8 shows the fourth circuit you are to build for Lab 2. This circuit combines the RC circuit with the Schmidt trigger, using the output of the RC circuit as the input to the Schmidt trigger. As the v_2 signal goes up and down, the Schmidt trigger will switch high and low. We are interested in this circuit because it is just one step away from being the final oscillator circuit.

B. Schmidt Trigger with RC Input Circuit Analysis

The Schmidt trigger will switch high or low when $v_1 = v_2$.

C. Procedure

1) *Determine how long it will take after the square wave goes high for the Schmidt trigger to switch:* use (1), the measured value of v_1 , and your values from the RC circuit measurements above for the calculation.

2) *Build the Schmidt trigger with RC input:* connect the output of the RC circuit to the input of the Schmidt trigger. Use the same set-up for the square wave as before.

3) *Measure v_2 and v_0 :* use two oscilloscope probes to measure v_2 and v_0 at the same time. Save the waveforms for later plotting in Matlab[®].

4) Explain the waveform for v_0 : write an explanation in your lab notebook of the events occurring in the circuit that lead to the observed waveform for v_0 .

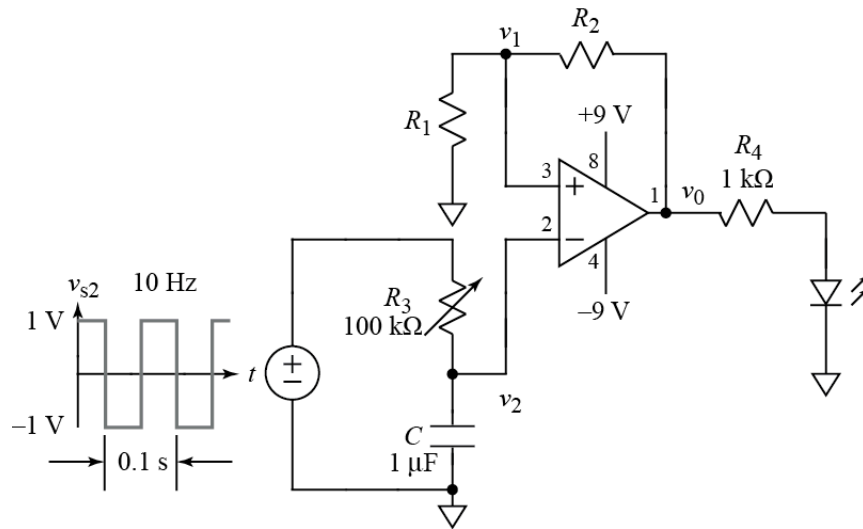


Figure 8. Schmidt trigger with RC input.

VIII. OSCILLATOR CIRCUIT

A. Oscillator Circuit Overview

Fig. 9 shows the fifth and final circuit you are to build for Lab 2. This circuit uses feedback from the op-amp output to drive the RC circuit, resulting in a self-sustaining oscillator circuit. The way this circuit works is that the output of the op-amp acts like a voltage source that sets a trigger point for v_1 . The RC circuit then charges up and v_2 moves toward v_1 , which is like a delayed form of negative feedback with v_2 moving slowly toward v_1 .

When v_2 gets close to v_1 , however, the output of the op-amp will start to switch from high to low or vice versa. The positive feedback from the output of the op-amp to v_1 causes v_1 to shift away from v_2 , which causes the output of the op-amp to switch faster, which causes v_1 to shift away from v_2 more rapidly. The output of the op-amp quickly moves all the way to a rail voltage. Meanwhile, v_2 is the voltage on the C and cannot change instantly, or even very quickly. Once the output of the op-amp has switched, v_2 will slowly charge toward v_1 once again. When v_2 gets close to v_1 , the output of the op-amp will switch again, and an endless cycle of switching will ensue. Thus, the circuit has become a square-wave generator. You will use this oscillator to measure the critical fusion frequency (CFF) for vision.

B. Oscillator Circuit Analysis

To predict the rate of oscillation for our circuit, we once again use the general form of RC solution in (1). We apply (1) to each half-cycle of the square wave. The initial conditions for the charging of the C will be the final conditions from the previous half-cycle. Note that a half-cycle ends when v_1 equals v_2 , and we can calculate v_1 using a voltage-divider formula using the rail voltage for v_0 .

The final value toward which v_2 is charging is v_0 , although v_2 will never reach v_0 since switching occurs when v_1 equals v_2 . Thus, the final value for v_2 in (1) will be a rail voltage.

C. Procedure

1) Find a symbolic expression for how long each half-cycle of the square wave will last: use (1) and represent all component values, including rail voltages symbolically.

2) Find the minimum and maximum duration of each half-cycle: use measured values of your components and rail voltages, and use R_3 values that are equal to 1/10th and 9/10th's of 100 k Ω . From the resulting calculations, determine the minimum and maximum rate of oscillation. Verify that the range of oscillation rates includes 30-50 Hz. If not, adjust the values of R_1 and R_2 as needed.

3) Measure the CFF: watch the LED while adjusting R_3 and determine at what frequency the LED appears to be constantly on.

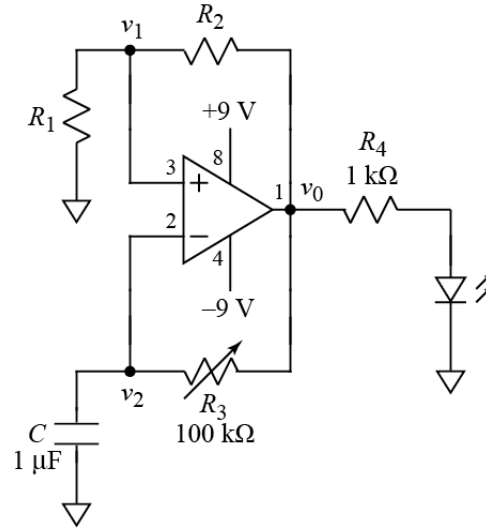


Figure 9. Oscillator circuit.

IX. PERIPHERAL VISUAL PERCEPTION (OPTIONAL)

A. Perceived LED Flash Rate for Peripheral Vision

The CFF for the periphery is approximately half as fast as the CFF for the fovea. One way of explaining this result is to posit that events seen in the periphery seem to occur twice as often as events seen by the fovea. To understand this phenomenon, consider the following mathematical expression that models how our peripheral vision responds to a varying intensity of light:

$$r = \left| \frac{dI}{dt} \right| \quad (3)$$

where

$r \equiv$ magnitude of visual response

$I \equiv$ intensity of light

$t \equiv$ time

Equation (3) expresses the idea that our peripheral vision responds to the magnitude of changes in light intensity as opposed to detailed patterns. If we consider the intensity of light to be a square wave, (3) says that there will be spikes (from taking the derivative) at both the up-going and down-going edges of the square wave. By taking the absolute value, each spike will be positive, and every edge of the square wave will produce an event. It follows that the event rate is twice the oscillation rate.

B. Procedure to Demonstrate the Event Rate for the Periphery

Because observing a light source in the periphery is challenging, (owing to the difficulty of not turning to look directly at the source), it is easier to observe the doubling of the event rate by using a slow but fixed rate of LED flashing.

To demonstrate the peripheral rate-doubling effect, set the flash rate for the LED to approximately 3 Hz. Position your head so the LED is in your peripheral vision, about 60° to the right or left of your line of sight. Determine the rate at which the LED appears to flash in units of cycles per second, (i.e., in Hz). It may be helpful to tap your finger at rate the LED appears to be flashing. If necessary, adjust the angle of view to maximize the effect.

ACKNOWLEDGMENT

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