LABORATORY PROJECT NO. 2
VISUAL PERCEPTION EXPERIMENTS

1. INTRODUCTION

1.1. Visual Perception

The input module of the human visual system is the eye (or oculus—Fig. 1), which has several important optical and neural functions. With its lens and curvature of the cornea, it 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.

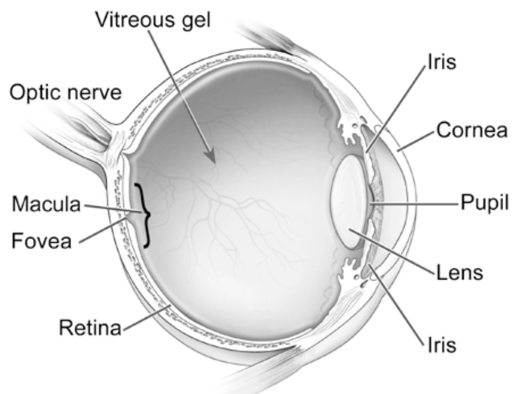

Fig. 1 – Anatomy of the eye (from the National Eye Institute/NIH).

The most important purpose of vision is to give spatial information about the outside world. Thus the region of the retina where the principle focus falls (the fovea in the macula) 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. Progressively away from the fovea along the surface of the retina are found light rays from regions surrounding the region of interest—the *peripheral vision*. Here the cones give way to an increasing proportion of rods, which are very light sensitive but less densely packed, and the perception of spatial detail is much reduced in the periphery. (An engineering explanation of this arrangement is based upon the wise use of spatial bandwidth: employ large numbers of nerves where needed, but avoid excess nerve pathways where detail is less important.)

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. As the frequency is increased, however, there is some frequency—the Critical Fusion Frequency, or CFF—at which the individual flashes are not noticeable and the illumination seems to 'fuse' into a steadily flowing perception. (This phenomenon makes moving pictures and TV, with their frames changing at a rate of about 60 per second, feasible.) The CFF for light focused on the human fovea is about 40-50 Hz, while the CFF for light focused on the peripheral retina is approximately half that value; there is considerable variation among subjects and depending upon the strength of the light source.

Even though they aren't well suited for fine spatial detail, the rods in the periphery still provide overall visual information to perception, e.g., locating objects within a broad field of view and giving the level of surrounding illumination. In addition—especially important to the survival of certain species of animals—the peripheral visual system can serve as an "early warning system" of attacks by predators as well as an adaptation designed for detecting moving prey. To accomplish these latter roles, the peripheral vision has developed the capability to detect *movement*, or motion of objects, in addition to seeing coarse stationary detail. Correspondingly, some of the nerve pathways in the outer portion of the retina are sensitive to time-varying events. (This is evident in certain animals: frogs are adept at catching fast-moving flies; horses are easily spooked by rapid movement.)

In imaging terms, movement is expressed as the time-rate-of-change of an object's position (velocity). Therefore, the nerves in the peripheral part of the retina can be considered, to some degree, to be *time differentiators* of spatial patterns. This is observed in nerve recordings from the so-called ON/OFF ganglion cells of the peripheral retina. This group of cells gets its name from the fact that they respond both when a test illumination is turned on *and* when the illumination is turned off; that is, they are sensitive to *temporal changes* in the illumination, not to the absolute state of the illumination. In this lab, you will investigate the ability of your own peripheral vision to detect the time-rate-of-change of light patterns that you generate.

1.2. The Design Project

Your project is to design a timing circuit that will cause an LED to flash at a controllable rate for visual discrimination experiments measuring fusion rate and peripheral perception. The circuit is an astable multivibrator driving an LED circuit, as shown in Fig. 2. Unlike op-amp circuits with negative feedback that operate in linear mode with input voltages approximately equal, this circuit operates in comparator mode with input voltages unequal. When the input voltages are unequal, the op-amp output is a large positive or negative voltage. The op-amp's power supply voltages (not shown on the schematic), minus small voltage drops occurring inside the op-amp, define the extremes of the output voltage. These extremes are referred to as "rail voltages," harking back to earlier times when circuits were often built between uninsulated wires, or rails, carrying power. The nature of the LED circuit in this laboratory exercise causes the op-amp output to swing back and forth between the rail voltages. In other words, the op-amp output is a square wave. This waveform is seen at the point labeled v_0 in Fig. 2.

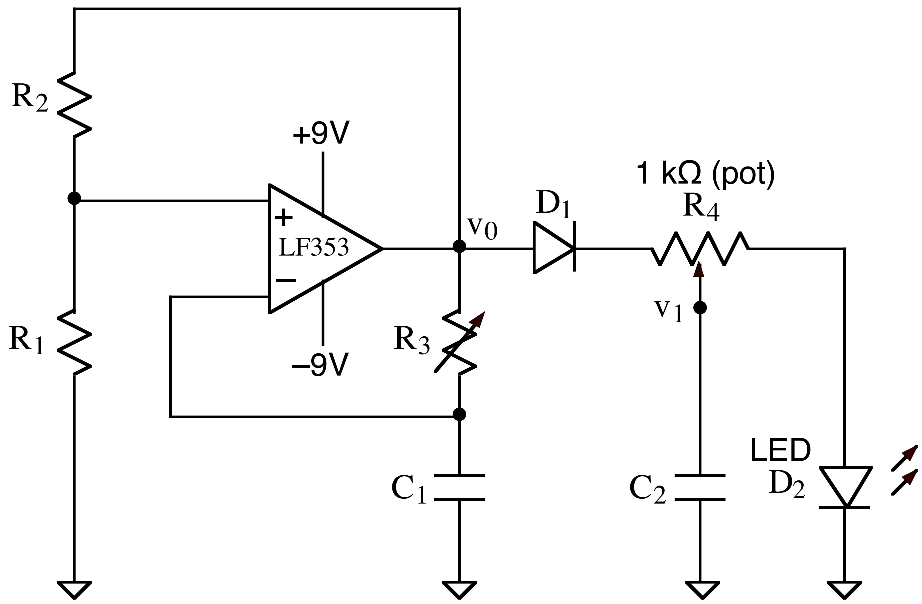

Fig. 2. Diagram of the timing circuit.

The square wave results from two sources. First, capacitor C_1 induces a difference between the + and – op-amp input voltages by effectively delaying the feedback signal from v_0 to the – input. Second, resistors R_1 and R_2 form a voltage divider, driven by v_o, that provides a changing reference voltage at the + input of the op-amp. The circuit has both negative and positive feedback. C_1 and R_3 provide negative feedback with op-amp output, v_0, changing in a direction that pulls the – input voltage toward the + input voltage. C_1 slows down this process, however, by slowly charging toward v_0. Eventually, however, the + input voltage and the – input voltage will be approximately equal. In a typical amplifier, v_0 would then reach an equilibrium value and remain constant. In this circuit, however, R_1 and R_2 provide positive feedback by feeding a portion of the change in v_0 back to the + input. The voltage at the + input drops as v_0 drops. This causes the op-amp input voltages to be different again, and that in turn causes v_0 to change polarity and swing all the way to the rail voltage. At this point, C_1 again charges toward the voltage at the + input and the entire process described above repeats with all signal polarities inverted. The reversals in v_0 continue indefinitely, with their timing being determined by resistor and capacitor values. Thus, the op-amp outputs a square wave.

The square wave drives an LED circuit whose purpose is to control the current flowing in the LED. The LED allows current to flow only in one direction, namely the direction that the "arrow" in the LED points. The LED also has a nonlinear current–versus–voltage response that lends itself to being modeled as a constant voltage drop when the LED is on and an open circuit when the LED is off. In other words, the LED behaves like a passive voltage source or an open circuit. You will determine the value of total resistance that will light the LED with the proper intensity for the fusion rate experiment. You will also determine the value of capacitance that will light the LED at a controlled rate for the peripheral vision experiment.

2. DESIGN ASTABLE MULTIVIBRATOR

2.1. Selection of R_1 and R_2

The astable multivibrator is the part of the circuit to the left of diode D_1. Your initial design problem is to choose component values for this part of the circuit.

First, we observe that with the op-amp operating as a comparator, the output voltage, v_o, is equal to $\pm V_{rail}$ where $+V_{rail}$ is the maximum possible v_o, and $-V_{rail}$ is the minimum possible v_o. ($+V_{rail} \approx$ positive supply voltage – 1.1 V and $-V_{rail} \approx$ negative supply voltage + 1.3 V.) To simplify our analysis, we will assume $+V_{rail}$ = positive supply voltage = 9 V and $-V_{rail}$ = negative supply voltage = –9 V. (Since voltages that control timing for the most part scale with v_o, this assumption introduces only small errors.)

Second, we observe that the op-amp acts like either a positive or negative voltage source, with symmetrical timing for both. Thus, we may analyze the case of a positive voltage source and merely invert our results to account for the case of a negative voltage source.

Third, we observe that treating the op-amp as a voltage source means that we may analyze the circuit as three separate circuits, each driven by voltage source v_o, as shown in Fig. 3:

i. R_1 and R_2, (a voltage divider)
ii. R_3 and C_1, (an RC charging circuit)
iii. D_1, R_4, C_2, and LED (LED circuit)

Fourth, we observe that the length of time it takes C_1 to charge to the voltage set by the voltage divider is the length of time v_o stays positive. Thus, R_1 and R_2 set the trip point of the circuit, and R_3 and C_1 set the charging rate. To design the circuit, we first set the trip point by choosing the values of R_1 and R_2.

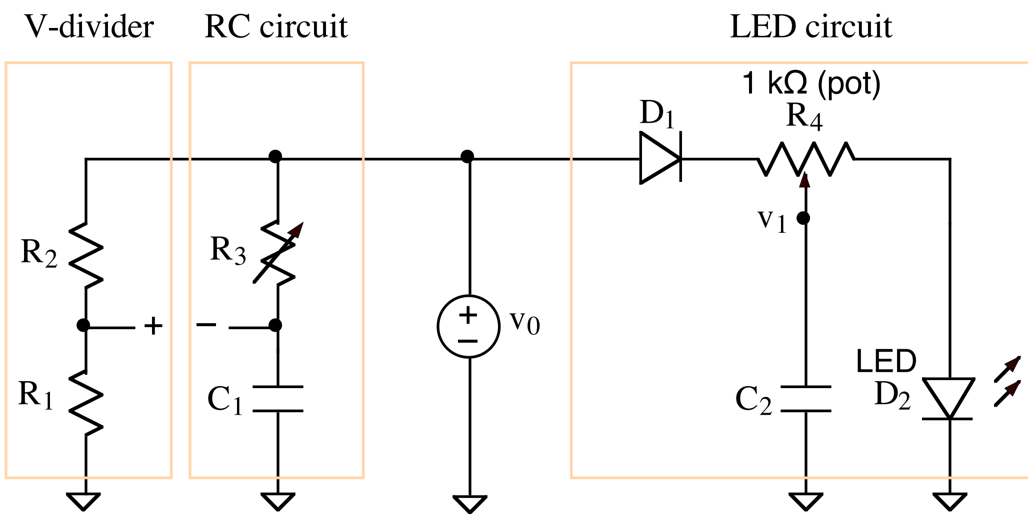

Fig. 3. Op-amp acting as voltage source driving three separate circuits.

Use the following design criteria (and solve appropriate voltage divider equations) to choose R_1 and R_2 values for the astable multivibrator part of the circuit:

i. Choose R_1 and R_2 to set the trip point, (i.e., the voltage at the + input), close enough to the rail voltage for v_o that as many time constants as possible elapse before the capacitor voltage at the – input charges up to the trip point.

ii. Choose R_1 and R_2 to set the trip point far enough from the rail voltage for v_o that the voltage at the – input, (i.e. across C_1), will reach the trip point even after being scaled down by 5 %. (This compensates for the addition of a scope probe at the – input that lowers the voltage at that point in the circuit, as noted in the discussion of the design for the peripheral vision experiment, below.)

iii. Choose R_1 and R_2 to limit the current through R_1 and R_2 to as small a value as possible so that the op-amp is able to drive other parts of the circuit without exceeding its maximum output current of approximately 10 mA. (The LED will use about 7 mA of current.)

iv. Choose R_1 and R_2 to avoid currents less than 10 μA so that noise currents remain small compared to signal currents.

2.2. Selection of R_3 and C_1

Use the following design criteria to choose R_3 and C_1 values for the astable multivibrator:

i. Choose C_1 to be 1 μF. (Since the voltage across it switches polarity, use a non-electrolytic capacitor for C_1.) This capacitor value allows us to use practical resistor values for square waves in the frequency range we require for our visual experiments.

ii. Choose R_3 to be a potentiometer that allows for the rate of the square wave at v_o to vary from 10 to 200 cycles per second. You will use this R_3 for the fusion frequency experiment. Note that one cycle of a square wave consists of a positive half and negative half, meaning it is *twice as long* as the time it takes for C_1 to charge to the set point. Also, note that the initial condition on C_1 will be the negative set point determined by R_1 and R_2, rather than 0 V, when v_o switches from negative to positive.

iii. Choose a second value of R_3 that causes the rate of the square wave at v_o to be 3 cycles per second. You will use this R_3 for the peripheral vision experiment later on.

3. CONSTRUCT AND TEST ASTABLE MULTIVIBRATOR

3.1. Measured Component Values

Obtain components for the circuit and measure the actual values of the resistors and capacitors. To use R_3 as a variable resistor, short the center tap to one side tap and connect to the side taps. Adjust R_3 to achieve a frequency of 200 cycles per second.

3.2. Square Wave Frequency

Construct the astable multivibrator circuit that you have designed and use an oscilloscope to determine the frequency of the square-wave output.

3.3. Predicted and Measured C_1 and v_o Waveforms

Store the v_o waveform from the oscilloscope and use Matlab® to make a plot superimposing the predicted and measured capacitor voltage and v_o waveforms. (Use actual component values for the predicted waveform.) Note any discrepancies and comment on possible causes.

3.4. Measured Value of R_4

Attach the LED circuit to the astable multivibrator but omit C_2. Without C_2, the potentiometer acts like a 1 kΩ resistor. Measure the actual resistance across the 1 kΩ potentiometer for later calculations. For D_1, use a 1N4148 diode.

3.5. Flashing LED Rate

Adjust R_3 in the astable multivibrator until the square wave slows down enough for the LED to appear as flashing rather than being continuously on. Using the oscilloscope, measure the actual rate for the square wave.

4. MEASURE VISUAL FUSION RATE

4.1. Critical Fusion Frequency

While watching the LED, slowly adjust R_3 until the flashing LED appears to be continuously on. This is the visual fusion frequency. Using the oscilloscope, measure the lowest rate of the square wave where the flashing appears to fuse. (The LED is actually only on half the time when the flashes fuse.)

4.2. LED Voltage

Referring to Fig. 4 below, adjust the R_4 potentiometer so that $R_{4left} = 800\ \Omega$ and add $C_2 = 0.1\ \mu F$ to the circuit. Measure the actual voltage, v_{LED}, across the LED when it is at its lowest value. (You will use this later on.)

4.3. LED Current

Using two oscilloscope probes, measure the voltage on both sides of R_4. Set the oscilloscope to measure the voltage drop across R_4 when the LED is on and, from this measurement, calculate the maximum current flowing in the LED when it is turned on. Verify that this value is less than the maximum rated value of 20 mA for the LED.

5. DESIGN AND CONSTRUCT LED CIRCUIT

5.1. Equations for v_1

The LED circuit, with C_2 included, controls how rapidly the LED current rises after it is turned on. For the peripheral vision experiment, using a current waveform that is differentiable makes tractable the mathematical analysis of peripheral vision, (see below).

Diode D_1 allows current to flow only in the direction of the arrow in the diode symbol. Consequently, D_1 looks like an open circuit when v_0 is negative. Being a silicon diode, D_1 looks like voltage drop, which may be modeled as a voltage source of approximately 0.7 V, when v_0 is positive. The LED is also a diode, but its voltage drop is approximately the value v_{LED} measured in Subsection 4.2 above. The presence of C_2 prevents the LED from turning completely off, allowing us to model it as a voltage source that is on all the time. Fig. 4 shows equivalent models for the LED circuit when v_0 is high and low. Both models are RC circuits, with the final conditions for one circuit being the initial conditions for the other as v_0 alternates between positive and negative values. By finding the Thevenin equivalent of the circuit to which C_2 is connected, we may solve each circuit in Fig. 4 as a simple RC circuit with a single voltage source.

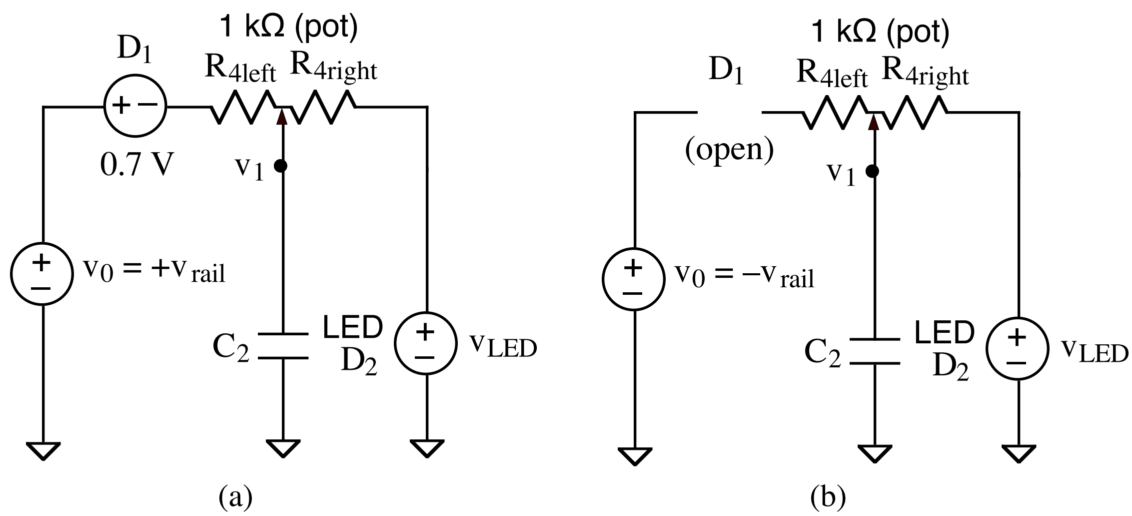

Fig. 4. Circuit models for LED circuit when v_0 *is high, (a), or low, (b).*

Derive symbolic equations for v_1 as a function of time for both of the circuits in Fig 4. Use the notation R_{4left} when referring to the left portion of potentiometer R_4, and R_{4right} when referring to the right portion of potentiometer R_4. Assume that the time constant for charging C_2 is short enough that v_1 reaches its final value before v_0 changes state in both circuits. For both equations for v_1, assume v_0 switches from low to high or high to low at time $t = 0$. In other words, reset the clock each time v_0 changes state.

5.3. Sketch of v_1 vs Time

Using the above results, sketch the waveforms for v_1 versus time starting when v_0 switches from $-V_{rail}$ to $+V_{rail}$ and from $+V_{rail}$ to $-V_{rail}$. Since the RC time constant is unknown at this point, this sketch may be drawn by hand and need only capture the shape of the charging and discharging curves and initial and final values of v_1.

5.4. Equation of i_{LED} vs Time

Because v_1 is easily measured in the circuit, the equations for v_1 are of interest. The brightness or luminosity of the LED depends on its current, i_{LED}, however. Using the circuits in Fig. 4, find equations for the current, i_{LED}, versus time starting when v_0 switches from $-V_{rail}$ to $+V_{rail}$ and from $+V_{rail}$ to $-V_{rail}$.

5.5. Potentiometer Setting

Adjusting the setting of the potentiometer changes the time constants for charging and discharging C_2. The design criteria result in a rapid but differentiable rise in the LED current, which we use in Section 6. Using your equations from Subsection 5.4 and the following assumptions and design criteria, determine the value of R_{4left} and R_{4right}:

i. The value of C_2 is exactly 0.1 μF.
ii. The total resistance of R_4 is exactly 1 kΩ.
iii. LED luminosity is directly proportional to LED current.
iv. After turning on, LED luminosity rises from 0 to 95 % of maximum, (i.e., 95 % of its final value), in 25 μs. (Hint: translate a 95 % change in current into an equivalent number of time constants.)
v. The maximum total current supplied by the op-amp must be less than 10 mA.

5.6. Plot of v_1 vs Time

Test the LED circuit by setting R_4 to its proper value and adding C_2. Record the value of R_{4left} and R_{4right}. Using LabView®, measure the voltage at v_1 and plot it versus time for 25 μs.

5.7. Plot of i_{LED} vs Time

Using Matlab® and the measured values of v_1, calculate and plot the value of i_{LED} versus time for 25 μs.

6. MEASURE AND ANALYZE PERIPHERAL VISUAL PERCEPTION

6.1. Perceived LED Flash Rate for Central Field of View

In your circuit, use the value of R_3 calculated in Subsection 2.2.iii, above. This should produce a flash rate of approximately 3.3 Hz. Look directly at the LED and visually determine the rate at which the LED flashes in units of cycles per second. It may be helpful to tap your finger at rate the LED appears to be flashing while someone else counts seconds.

6.2. Perceived LED Flash Rate for Peripheral Vision

Now 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. Again, 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.

6.3. Sketch of Peripheral Vision Response Waveform

To understand the effect you have observed, consider the following mathematical expression that models how our peripheral vision responds to the intensity of light:

$$r = \left| \frac{dI}{dt} \right| \quad (1)$$

where

r is the magnitude of the visual response

I is the intensity of light

t is time

This simple model expresses the idea that our peripheral vision responds to the magnitude of changes in light intensity as opposed to detailed patterns. Substitute i_{LED} for I in (1) and sketch the waveform for r. Count the cycles per second for r (i.e., the number of times per second that the signal rises and falls). Comment on how this compares with the result from Section 6.2.

7. WRITE FORMAL REPORT

Write a formal report describing your work on this project. See instructions in "Course Procedures" about how to write the report. (Also, look for detailed point breakdowns for Lab 2 grading on the course web site.) Include at least the following in your report:

i. An abstract. The abstract is a one paragraph succinct summary of the entire results. It should describe the key result of the experiments performed.

ii. A short introduction. You may attach this handout to the report in the appendix and refer to it so that you don't have to copy the information in it. Your introduction, however, must introduce your report and will be unique to your report. The introduction gives the motivation for the experiments performed and describes the organization of the report.

iii. A careful description of the work that you did in Sections 2 through 6, above.

  a. Discuss and give appropriate quantitative results for each of the numbered subsections in Sections 2 through 6. Every subsection corresponds to a specific task with a specific quantitative result that must be described in your report. To facilitate grading, number the subsections of your report with the same numbers used in this handout.

  b. Give clear derivations of mathematical expressions, including explanations in words for every equation in every derivation. Include consistency checks of final results whenever possible.

  c. Explain how you chose the values of circuit components and include a schematic diagram showing component values for the final circuit.

  d. Explain all measurements carefully and include data appropriately in clearly labeled tables and graphs in the body of the report.

e. Include listings of all your Matlab® programs in an appendix, and explain how the code works in comments.
f. Show plots of your astable multivibrator output, the voltage across the capacitor in the LED circuit, and the current in the LED.
g. List the visual fusion rate and peripheral perceived flashing rate that you measured.

iv. A succinct conclusion. The conclusion must list the most salient quantitative results of this laboratory project. As a guide to what the conclusion should say, consider what information would be most useful to a student about to start the lab.