EE 100 Final Project

Part I: General instructions

1. The final project will count for 10% of your grade.
2. Every effort must be made to team up as a team of 2 or 3. NO EXCEPTIONS!!! One of your team members will keep the board and components during the project period. Try to protect your progress and keep it in good condition.
3. Every group will get a project kit with a piece of breadboard and all the components. Keep it in a good condition during the whole project. We don't have many extra parts to supply if you lose any of them.
4. The grading will be mainly based on the circuit functionality AND the neatness of your wiring!

Part II: PROJECT: Light Sensor

1. Function analysis

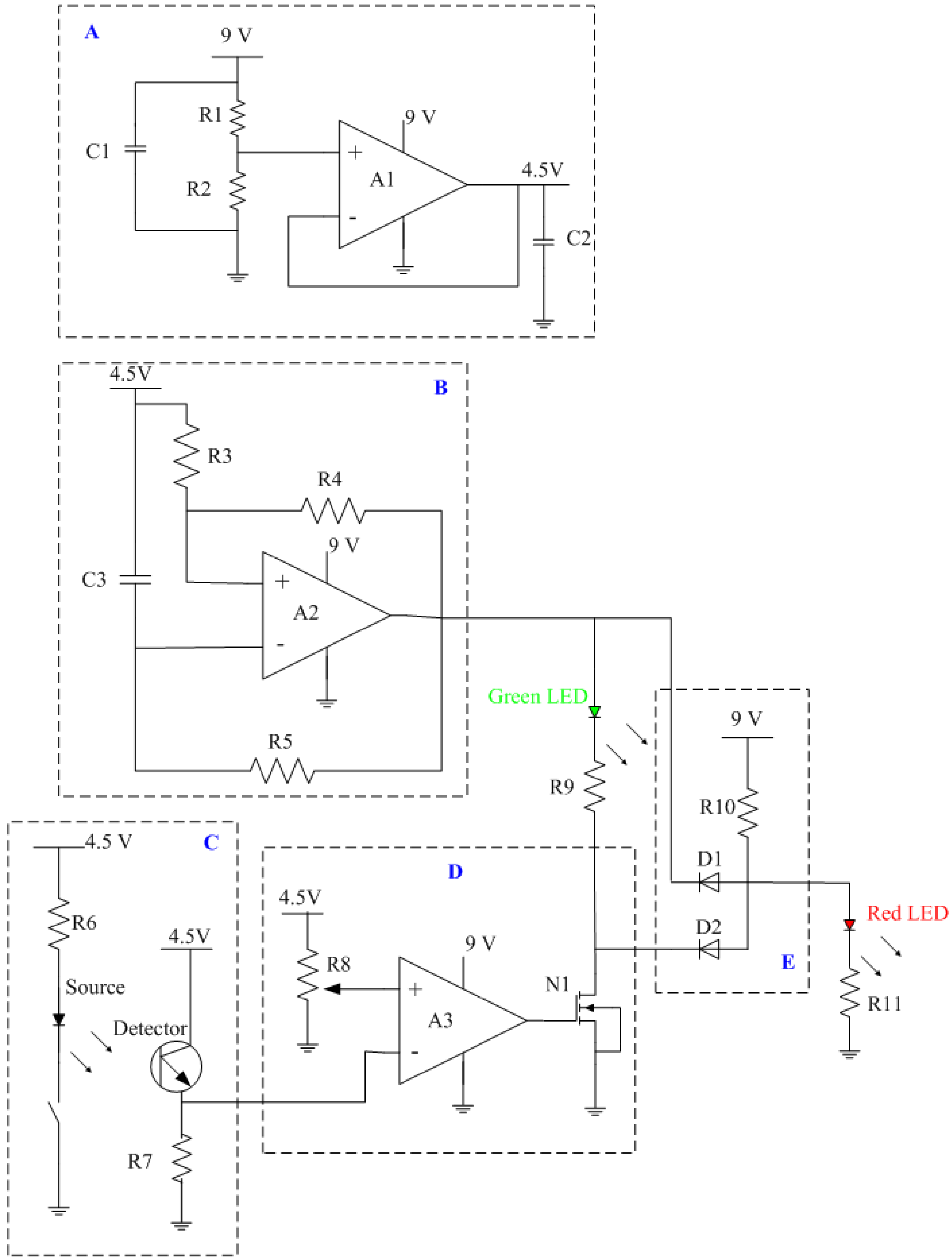

Figure 1. Basic circuit diagram

This is a light sensing circuit. When there is no light shinning on the circuit (mainly the detection part), the green LED will be flashing. When light is shinning on the circuit (mainly the detection part), the red LED will start flashing instead of the green one. The whole circuit can be torn down into 5 basic building blocks labeled A-E in the diagram. We will analyze them one by one in order to understand the functions.

A. 4.5 V DC power supply.
The circuit is going to be powered by a 9 V battery, but lower DC power is also needed in the circuit. Part A is using an op-amp to build up a simple voltage follower which gives 4.5 V output. Since 4.5 V is half of 9 V, resistors R1 and R2 are equal. C1 and C2 are filtering capacitors, which are usually connected in parallel with the DC output in order to filter out any high frequency AC signal coming from the noise.

B. Square wave oscillator.
NOTE: YOU ALREADY KNOW HOW TO ANALYZE THIS CIRCUIT BASED ON NONLINEAR DYNAMICS. THIS EXPLANATION IS FROM THE EE40 WRITEUP.
Let's analyze it in a time sequence and use 4.5 V as the voltage reference. The circuit diagram can be redrawn as shown in Figure 2 (b).

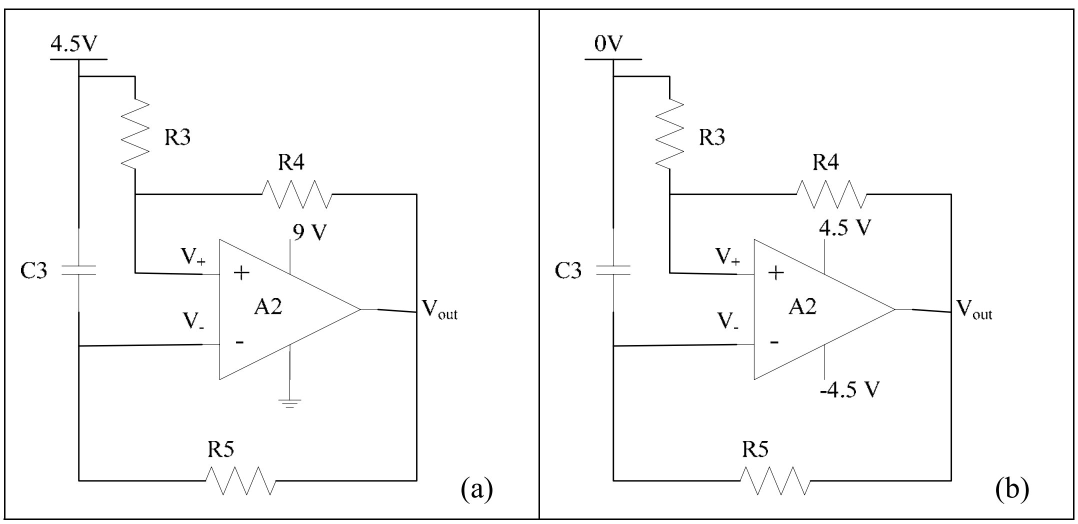

Figure 2. Square wave oscillator (a) with reference at 0 V. (b) with reference at 4.5 V.

Initially $V_{out} = 0$ and there is no charge on the capacitor. However to the reference 4.5 V, $V_{out} = -4.5\text{ V}$ and $V_{-} = -4.5\text{ V}$. Since this circuit has a positive feedback loop, any slight difference between V+ and V- may make V_{out} high or low clamped to the power supply value. In this initial condition, $V_{+} = -4.5\frac{R_3}{R_3 + R_4} > V_{-} = -4.5\text{ V}$, so the output goes high and get clamped to 4.5 V immediately after the circuit is on. Now the circuit is in state 1: $V_{out} = 4.5\,\mathrm{V}$, $V_+ = 4.5\dfrac{R_3}{R_3 + R_4}$ and capacitor C3 is being charged from V_{out}. So V- is rising up. When V- is as high as or just slightly higher than V+, the circuit toggles because of the positive feedback. Output will be clamped at -4.5 V since $V_- > V_+$. Now the circuit is in state 2: $V_{out} = -4.5\,\mathrm{V}$ and $V_+ = -4.5\dfrac{R_3}{R_3 + R_4}$. The capacitor is being discharged from V_{out}. And V- is falling down. When V- is as low as V+ or just slightly lower than V+, the circuit toggles again because of the positive feedback. Then the output is clamped at 4.5 V again, $V_+ = 4.5\dfrac{R_3}{R_3 + R_4}$ and the capacitor is being charged from V_{out} again.

Therefore, we see that the circuit is toggling between the two states, and the output voltage is either 4.5 V or -4.5 V, which forms a periodic square wave. To understand the oscillation function better, we draw wave forms at V_+, V_- and V_{out} on the same scale as shown in Figure 3(b). It's clear that the threshold voltages of output high and low are $4.5 \times \dfrac{R_3}{R_3 + R_4}$ V and $-4.5 \times \dfrac{R_3}{R_3 + R_4}$ V. Go back to the original circuit with reference at 0 V. We just need to add a DC offset 4.5 V to all the result and waveforms as shown in Figure 3 (a). The threshold voltages changes to $4.5\dfrac{2R_3 + R_4}{R_3 + R_4}$ and $4.5\dfrac{R_4}{R_3 + R_4}$.

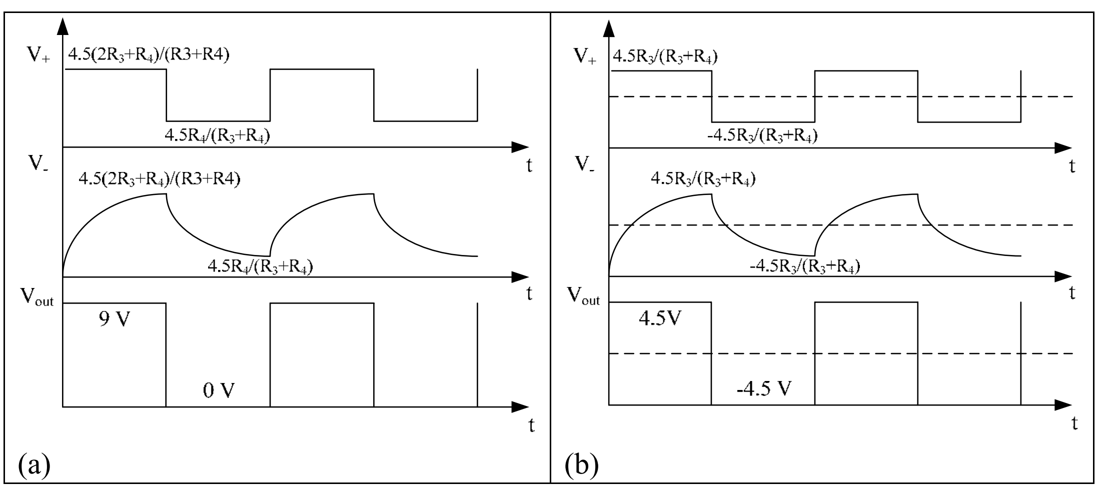

Figure 3. Waveforms of V_+, V_- and V_{out} (a) with reference of 0 V. (b) with reference of 4.5 V

C. Light generation and detection.

Light generation can be realized by a visible LED or any white light source (room light, flash light etc.). Light source intensity is determined by the detector

sensitivity. Phototransistor can be used as a detector. Light exposure will increase the current flowing through the phototransistor. Photoresistor is another choice, whose resistance will change when exposed to the light.
Infrared (IR) LED and detector are also available for light generation and detection.

D. Comparator and buffer.
Open loop op-amp can be used as a comparator. Positive input connects to a fixed DC voltage used as a reference. Negative input connects to the detector end. When detector detects light, current increases. Therefore the voltage across R7, which is connected to the negative input of the op-amp, increases. When it's lower than the reference voltage, the output will be high—9 V. When it's higher than the reference, the output is low—0 V. Thus the light on/off is converted to L/H of the op-amp output. An NMOS will be connected to the output of the comparator as a buffer since the output will be driving the LED and the logic circuit following. When comparator output (gate voltage of the NMOS) is low, the NMOS is off, thus the drain is high or floating. When comparator output is high, the NMOS is on, thus the drain is grounded. This way, we realize the light on/off to output H/L conversion.

E. AND gate.
Only when both inputs are high, the output is high, which will light up the red LED.

Based on the functions of all the building blocks, the function of the whole circuit is as follows. When light is off, the comparator buffer output is low. So the AND output is low, thus red LED is off. However, the oscillator output will make the green LED flashing. When the light is on, the comparator buffer output is high (9 V), so the AND gate output is high when the oscillator output is in the high period, thus the square wave signal is transmitted to the red LED, which will be flashing then. In addition, because of LED is a diode, which can only work in one direction, the green LED is off when comparator buffer output is high.

2. Hands-on

To build and debug each block separately and then combine them together to realize the whole function will make the process faster and easier. Try to make your circuit clear, compact and neat. It will be nice-looking and easy to debug.
We give general considerations of how to select values of the components and provide recommended values and specifications for some parts.

A. Op-amp is LMC 6482, the same as we used in Lab 6. Power supply will be from a 9 V battery. So V+ (pin 8) is 9 V and V- (pin 4) is 0 V or ground of the circuit. Since the output is 4.5 V, half of the power, we need two equal resistors for R1 and R2. To make the power consumption low, we use 10kΩ for R1 and R2. Filter capacitors C1 and C2 can be 10μF. Smaller values can be used if high frequency noise exists. BE CAREFUL THE POLARITY OF THE CAPACITORS, when connecting them to

DC voltage.

B. Human eyes can differentiate frequency smaller than 30 Hz. So we need to make the oscillator frequency in the range 1 ~ 30 Hz. In order to express the frequency in terms of R3, R4 and R5 and C3, let's do some calculations based on the analysis in the above section. Since the two threshold values are symmetric as shown in Figure 3, we know that the duty cycle of the square wave is 50% (half period 9 V and half period 0 V). The period of the square wave is decided by the capacitor charging time constant R5×C3. Let's use the rising half period of V- in Figure 3(a). Since this is a first order RC circuit, the rising part can be express as: $V_- = 9\left(1-e^{-\frac{t}{R_5C_3}}\right)$. At time t_1, $V_- = 9\left(1-e^{-\frac{t_1}{R_5C_3}}\right) = 4.5\frac{R_4}{R_3+R_4}$; at time t_2, $V_- = 9\left(1-e^{-\frac{t_2}{R_5C_3}}\right) = 4.5\frac{2R_3+R_4}{R_3+R_4}$. The time period $t_2 - t_1 = \frac{T}{2}$, where T is the period of the square wave. So

$$\frac{T}{2} = t_2 - t_1 = R_5C_3 \ln\frac{2(R_3+R_4)}{R_4} - R_5C_3 \ln\frac{2(R_3+R_4)}{2R_3+R_4} = R_5C_3 \ln\frac{2R_3+R_4}{R_4}.$$

So the period is $T = 2R_5C_3 \ln\frac{2R_3+R_4}{R_4}$, and the frequency is $f = \frac{1}{T} = \frac{1}{2R_5C_3 \ln\frac{2R_3+R_4}{R_4}}$. The falling half period of V- will give the same solution of the period or frequency since the signal is symmetric. So to control the frequency in the range of 1~30 Hz, we use R3=R5=10 kΩ, R4=510 Ω and C3=10 μF. Plug all these numbers in the frequency equation, we have the frequency of 1.35 Hz, which is detectable by human eyes.

C. For the light generation, if room light or flash light is being used; there is no need for light generation circuit. If infrared (IR) LED is being used; the maximum current is around 30 mA, and threshold voltage is about 1.7 V. So we use R6 = 200 Ω or similar to keep the current below 30 mA.
For the detection part, we use different R7 for different detectors. If phototransistor is being used, which can detector intense white light (flash light has to be the source), R7 can be 10 kΩ to keep the current smaller than the maximum 25 mA and also keep the power consumption low. Please see Figure 4 for the pin configuration and connection of the phototransistor.

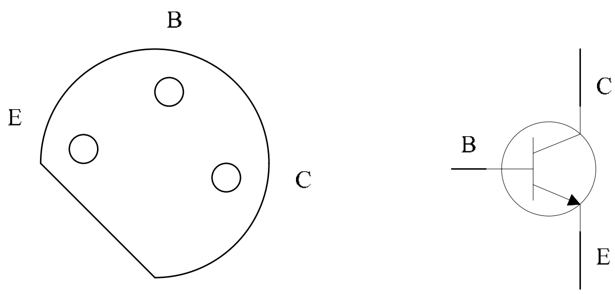

Figure 4. Phototransistor FPT100 pin configuration.

If photoresistor is being used, which can detect just the room light with lower sensitivity, R7 = 1 kΩ would be a good choice. With room light on, the resistance can be about 50 Ω, depending on the light intensity. With room light off or simply blocking the surface of it, the resistance can be as high as 1 MΩ. Then R7 and the photoresistor form a simple voltage divider. So $V_+ = \frac{R_7}{R_7 + R_{\text{detector}}} \times 4.5\ \text{V}$. Table 1 gives a summary of components, values as well as output voltage ranges of different source/detector schemes.

Source/Detector	**R6 (Ω)**	**R7 (Ω)**	**Output /V-(V)**
Flash light / phototransistor	-	10 k	0~4
Room light / photoresistor	-	1 k	2~4
IR LED / IR detector	200	10 k	0~4

Table 1. Light source and detector schemes

D. Pot R8 is a voltage divider too. It needs to be tuned to the value that makes the output voltage roughly in the middle of the on-off range of V- in order to distinguish light-on and light-off states. 5kΩ pot will be used to provide the voltage reference. Turn it until the output voltage is about 2.5-3 V or even higher, depending on which detector is being used. The NMOS is BS170. The gate threshold voltage is about 2.2 V. Please refer to the spec for more information.

E. D1and D2 can be 1N4148. To keep the current smaller than 30 mA for all the diodes (D1, D2 and LEDs), we use R9 = 1kΩ, R10 = R11 = 510Ω. Any other similar values will be fine too.

Table 2 summarizes all the components you may need to build the basic circuit.

R1	10 kΩ	**C1**	10 µF
R2	10 kΩ	**C2**	10 µF
R3	10 kΩ	**C3**	10 µF
R4	510 Ω	**D1/D2**	1N4148
R5	10 kΩ	**N1**	BS170
R6	-/-/ 200 Ω	**Op-amp**	LMC 6482
R7	10kΩ/1 kΩ/10 kΩ	**Light source**	Flash / Room / IR LED
R8	5 kΩ pot	**Detector**	phototransistor/ photoresistor/ IR detector
R9	1 kΩ		
R10	510 Ω	**Battery**	9 V
R11	510 Ω	**LEDs**	Green and Red

Table 2. Basic circuit components summary

Part III: Component list

Component	Value	Quantity
Resistor	**10 kΩ**	**8**
	1 kΩ	**3**
	510 Ω	**3**
	200 Ω	**1**
Pot	**10 kΩ**	**2**
	5 kΩ	**1**
Capacitor	**10 µF**	**3**
	0.1 µF	**1**

Component	Model	Quantity
Op-amp	**LMC 6482**	**2**
NMOS	**BS170**	**3**
PMOS	**ZVP2106A**	**1**
Diode	**1N4148**	**2**
LED	**Green, Yellow, Red**	**3**
IR LED	**512-QED423**	**1**

IR detector	**512-QSD723**	**1**
Phototransistor	**FPT100**	**1**
Photoresistor	**-**	**1**
Buzzer	**-**	**1**
Battery	**9 V**	**1**
Breadboard	**-**	**1**