LABORATORY EXPERIMENT

Infrared Transmitter/Receiver

(Note to Teaching Assistant: The week before this experiment is performed, place students into groups of two and assign each group a specific frequency between 5 and 20 kHz so that prelabs can be completed successfully.)

In this laboratory, we will combine all the concepts learned this semester in order to design an infrared (IR) transmitter and infrared receiver. You and a fellow classmate will build the transmitter on one of the small protoboards given to you by your instructor, whereas your receiver will be built on the other protoboard given to you by your instructor. Use the ELVIS board to test your circuits. One of the main problems you will encounter is noise, manifested in the form of ambient light. Therefore, we will need to design a circuit that is immune to the effects of ambient light. Furthermore, the circuit must be designed so that it doesn't interfere with your fellow classmate's circuit. Please note that this laboratory will involve the use of certain circuit components whose physics and engineering courses will be covered in greater detail in other courses. However, we will provide the necessary knowledge required to complete this project. ***It is necessary that you read all the background information of this laboratory BEFORE proceding with the experiment.***

To make the transmitter/receiver circuit immune to noise more immune to noise, the transmitted signal needs "look" different than the noise. This is achieved by modulating the IR LED diode on and off at an appropriate chosen frequency through the use of an astable 555 timer. Then, a receiver will be built that is much more sensitive to this frequency than to other frequencies. A block diagram of the system is provided below in figure 1.

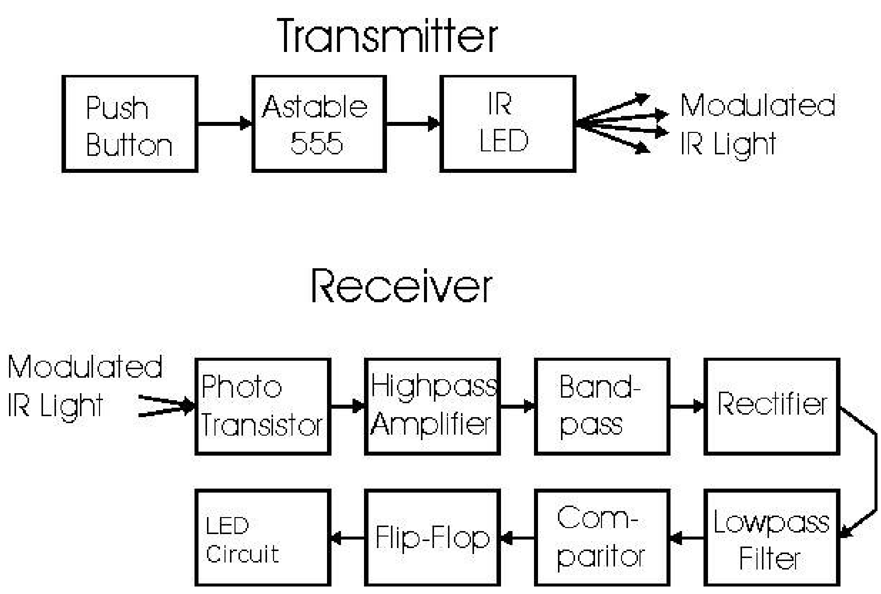


Figure 1: Block diagram of the IR transmitter and receiver

In figure 1, we see that the circuit has been divided into two structures: the transmitter structure and the receiver structure. In the transmitter, we see that when the button is pushed, the astable 555 timer oscillates and causes the IR LED to emit a modulated, or pulsed, infrared signal. This signal is received via our receiver circuit's phototransistor. The highpass amplifier allows us to preserve only the high frequency components of our received signal. The bandpass filter is tuned to our modulation frequency, thus removing more noise at higher and lower frequencies. The signal at this point is a high frequency AC signal. The rectifier and lowpass filter convert the signal from AC to DC, and the comparator allows us to adjust the sensitivity threshold so that we do not detect spurious noise signals. Finally, the flip-flop toggles the output on and off with each subsequent press of the transmission button.

This project can be completed over two laboratory sessions. For the first laboratory session, you will design, build and debug the transmitter and build part of the receiver circuitry. In the second lab session, you will finish your circuit and make any further modifications.

The entire IR transmitter and receiver system will work well with the components at hand, provided that is it operated between 5 – 20 kHz. While frequencies outside this range may work perhaps even better, getting the entire circuit to function properly will be more challenging. Therefore, you need to select your design frequency in consultation with adjacent groups in order to maintain a large frequency separation between transmitters.

BACKGROUND

BJT Transistor

A Bipolar Junction Transistor (or BJTs) is a type of transistor which has three terminals, is constructed of doped semiconductor material and is typically used in amplifying and switching applications. BJT's typically come in two varieties: NPNs and PNPs. For the purposes of this laboratory, we will only describe the NPN transistor.

The NPN transistor has three terminals called the Collector (C), the Base (B) and the Emitter (E). These are shown in detail in Figure 2. Your instructor will show you in the lab how to recognize which is C and which E; B is the middle one. A simple way of describing an NPN transistor would be to imagine two diodes which share a common anode region. The internal circuitry and modeling of the NPN transistor will be taught in detail in a later course. For this experiment, the NPN transistor shall be used as a switch in order to turn the IR LED on and off.

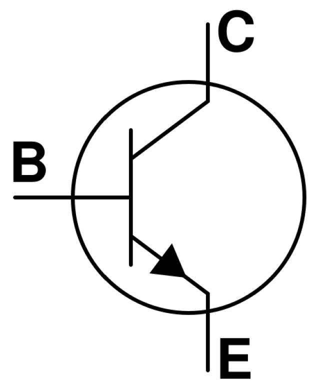


Figure 2: BJT NPN Transistor Diagram

NPN IR Phototransistor

The BPW77N NPN Phototransistor works like a typical NPN transistor, only that the current that is supplied to the Base component of the phototransistor is now powered by the infrared light it receives. The Infrared light it receives on the base of the transistor generates a low-level current that is amplified, with the resulting current flowing out through the collector-emitter junction (flowing through the C and E terminals). Figure 3 shows the circuit diagram of a phototransistor. Note that when a resistor is added to the emitter terminal, a voltage level proportional to the incident light intensity can be observed between the emitter and ground. Depending upon your system specifications, R_e can have values between 500 Ohm and 1 MOhm.

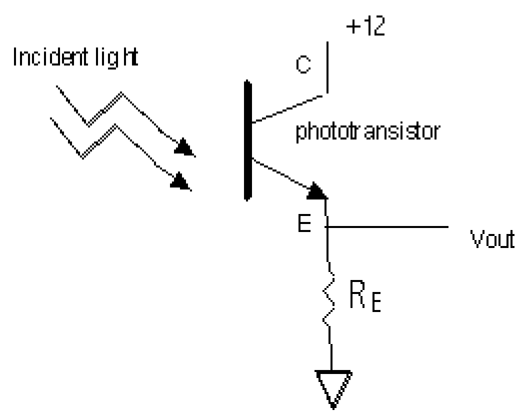


Figure 3: Phototransistor Diagram

Part A: IR Transmitter

In this lab, you will use a 555 timer integrated circuit to modulate the transmitted light, the timing of which is controlled by externally connected resistors and capacitors, as shown in Figure 4. For the IR LED, we want a resistance R that will limit the current to 50 – 100mA. Pin 3 on the 555IC drives the transistor and the indicator LED, and the transistor drives the IR LED. This is necessary, as the 555 cannot supply the necessary current to activate the IR LED. It is necessary that the appropriate resistors are selected, in order to ensure that neither the IR LED nor the 555 chip are damaged.

The period of the timer circuit is defined by the following equation:

$$\tau = 0.693 * [(R1+R2) * CT + R2 * CT]$$

Typically, we want to ensure that R2 >> R1. To make sure that R2 is not too large, R1 usually selected to be near 1KOhm.

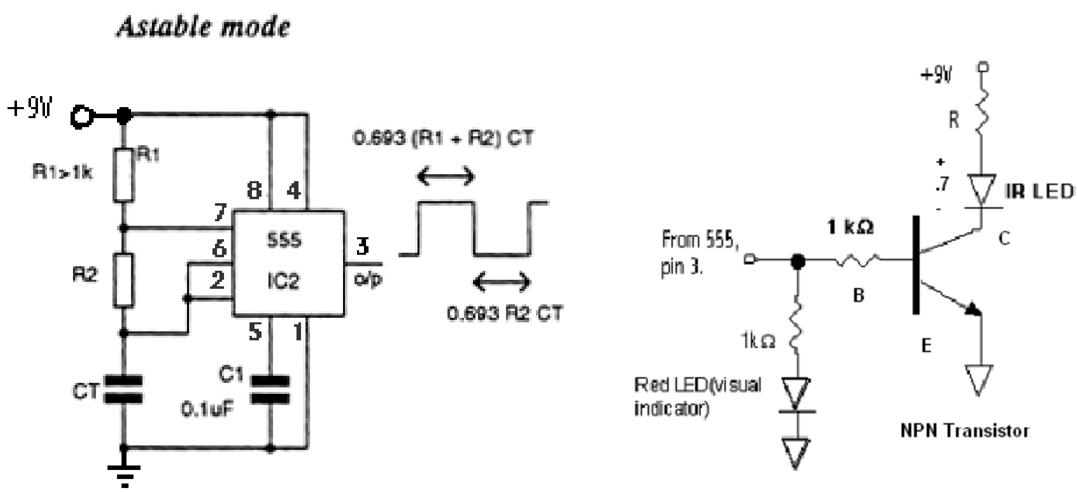


Figure 4: Astable 555 timer circuit and IR LED driver circuit.

Prelab (a)

1) Choose R for a 90 mA current, assuming the voltage at the collector of the transistor is 0.3 V.
2) Choose R1, R2, and CT for an oscillation system frequency to match your assigned frequency. Ensure that you use capacitor values that are available in your lab kit.

Procedure

1) Build the circuit in Figure 3 (Re = 1K or 3.3K). Connect Vout to the multimeter. Test your circuit what happens when you: a) obstruct the phototransistor with your hand; b) partially block the overhead lights using your body c) point the phototransistor at the room lights. Record your observations.

2) Determine the voltage corresponding to the normal "background level" of ambient light in the room. Record this voltage.
3) Select a value for Re. Connect Vout now to the oscilloscope. This signal corresponds to the noise you'll need to overcome. With the circuit stationary and exposed to normal ambient light, note by how much does the output vary (in percent). Also, what is the signal's period? What can be the cause of this variation present?
4) Construct the circuit in Figure 4 (transmitter), taking into account your selected system frequency. DO NOT DISMANTLE THE RECEIVER CIRCUIT FROM FIGURE 3. This circuit should be constructed on an independent breadboard and powered by a 9V battery. Use a pushbutton switch to connect the battery to the circuit. Please note that the transmitter circuit should only be powered when you press the button. Verify that the red visual indicator glows when the button is pressed. Should you be able to see the diode flicker on and off?
5) Use the oscilloscope to measure the output of the 555 timer IC. Does it agree with your desired frequency? Does it deviate by much?
6) Use the receiver built in step 1 to receive the signal. Connect the output of the receiver to the oscilloscope and verify that you are receiving the signal.

PART B: The Receiver

Highpass Amplifier (Second Part)

In this laboratory, most of our filters correspond to a class of filters known as active filters. They behave just like the passive filters taught previously, only that they provide a gain to the signal. For this part, we will use an active highpass filter in order to filter out signals below our cutoff frequency F_o, while at the same time amplifying our desired high frequency signals. Figure 5 illustrates an active high-pass filter.

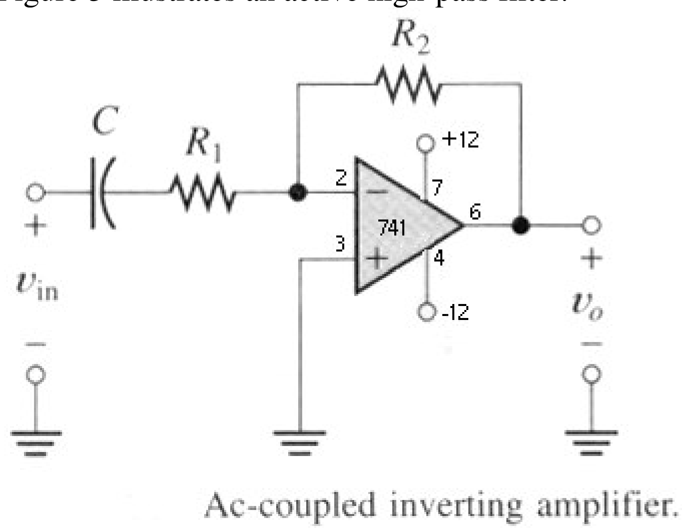


Figure 5: Highpass Amplifier

The cutoff frequency, F_o, of this circuit is defined to be $F_o = 1/(2\pi R_{eq}C)$, where R_{eq} is the series combination of R1 and Re from Figure 3. Please not that this filter DOES NOT have a sharp cutoff. Therefore, select your cutoff frequency to be much larger than 120Hz, yet still below the modulation frequency of your transmitter. As you saw in step 4 of the previous procedure, there will be a small 120 Hz wave across RE of the photo transistor circuit. This is due to a flickering that is associated with the fluorescent lights in the room (But, why do they flicker?). The gain of this circuit is defined as R_2/R_1 for frequencies above the cutoff frequency.

Prelab (b)

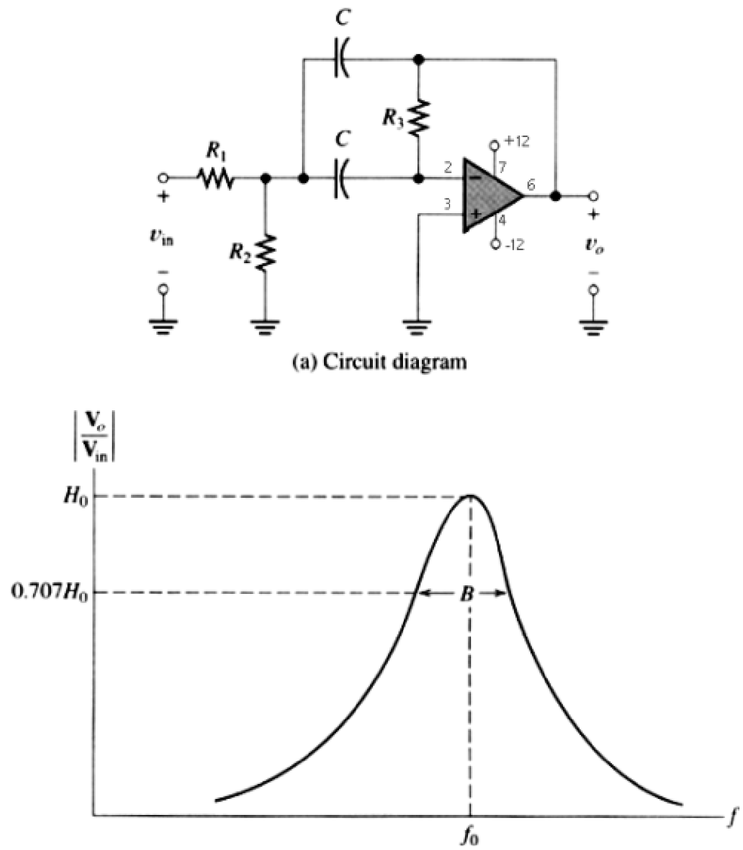
1) Design a high pass amplifier with a gain of 15 and a cutoff frequency of f_c= (your assigned frequency -2 kHz). Use the capacitor and resistor values from your lab kit.

Procedure

1) Construct the high pass amplifier in figure 5 using your chosen frequency, then connect the input of the amplifier to the output of your phototransistor receiver. (Debugging: If things aren't what you expect try hooking up your high pass amplifier directly to the function generator.)
2) Test the operation of the high pass amplifier by observing the output from the phototransistor receiver and the output of the high pass amplifier on the oscilloscope. Does it amplify the signal as desired? Vary the distance between the receiver and transmitter. Describe the differences in the signal before and after it passes through the high pass amplifier.

Bandpass Filter (Third Block)

Figure 6 (a) shows the bandpass circuit to be constructed. This will allow us to further reduce the amount of noise that could affect our circuit. The transfer function is shown in figure 6 (b), Ho is the voltage gain |Vo/Vin|, at the center of the passband. The other parameters of interest are the width of the passband, which is proportional to the reciprocal of the parameter Q, and the center frequency, fo.



(b) Transfer function

From A.R. Hambly, Electronics, 1994.

Figure 6 Second-order bandpass filter.

Figure 6: Bandpass Amplifier and Transfer Function

Active High Pass Filter Design Equations

This is a second-order bandpass circuit having the transfer function shown in Figure 9.70b. The center frequency f_0, center-frequency gain magnitude H_0, and bandwidth B are given by

$$f_0 = \frac{1}{2\pi\sqrt{(R_1 \| R_2) R_3}\, C}$$

$$H_0 = \frac{R_3}{2R_1}$$

$$B = \frac{1}{\pi R_3 C}$$

where $R_1 \| R_2$ denotes the parallel combination of R_1 and R_2. The ratio of center frequency to bandwidth is called the **quality factor** of the circuit, denoted by Q.

$$Q = \frac{f_0}{B} = \frac{1}{2}\left(\frac{R_3}{R_1 \| R_2}\right)^{1/2}$$

From the designer's point of view, it is convenient to have formulas for the resistors in terms of the parameters of the transfer characteristic. These formulas are

$$R_3 = \frac{Q}{\pi f_0 C}$$

$$R_1 = \frac{R_3}{2H_0}$$

$$R_2 = \frac{R_3}{4Q^2 - 2H_0}$$

From A.R. Hambly, Electronics, 1994.

Prelab (c)**:**

1) Design the bandpass filter for your assigned system frequency. First select your capacitance, and then select the appropriate resistors. Choose a capacitance such that R1 is at least 500 Ohms.

Procedure

1) Build the bandpass filter.

2) Finding the peak frequency of your bandpass filter and tuning your filter and transmitter to the same frequency is one of the most critical and important parts of your design project. The best way to do this is to disconnect the bandpass filter from the first two stages and use the sine wave output of your signal generator as the input of your bandpass filter. Set the function generator at the frequency of the square waveform produced by the 555 timer. (Make sure that you reduce the amplitude from the signal generator so that you don't overdrive and saturate your bandpass stage.) Put a potentiometer in the bandpass circuit (R3) to tune your bandpass center frequency at the frequency of the square waveform. Tune the transmitter by varying R3 until the amplitude of the ouput sinusoidal wave is maximized.

3) Reconnect the bandpass stage to the rest of the circuit. Test your circuit while moving your transmitter closer and away from the receiver. Describe what occurs. Do you see any clipping in your output? If so, what could be causing it?

Rectifier (Fourth Block)

While most of the signal's noise has been eliminated thus far, it is still an AC signal. The following components of this project will allow us to detect the signal and turn on our LED light circuit.

Unfortunately, not much can be done with an AC signal, as it would constantly turn our light circuit on and off. As such, we need to transform our AC signal into a DC source. We can do this using a Rectifier/Lowpass circuit, as described below in Figure 7.

$$\frac{1}{CR_4} \ll \omega$$

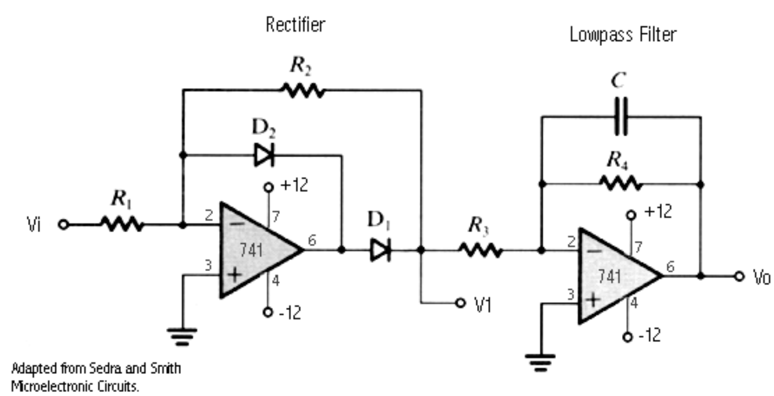


Figure 7: Rectifier and Lowpass Filter

The rectifier component allows us to rectify the signal, ensuring that we only receive positive values of the signal. Because this signal still varies around the transmitted frequency, we will add a lowpass filter in order to preserve just the DC component of the signal.

When building the rectifier, please note that the rectifier has a gain of R2/R1. This can be used to further amplify the signal, if desired. Reasonable resistances for the rectifier circuit are between 1 and 100 kΩ, and reasonable values to try for the gain range from 3 on up depending on your noise level.

Prelab (d)

1) Design a rectifier with a gain of approximately 6

Procedure

1) Build the rectifier circuit with your desired gain. Observe the input and output waveforms and make note of them. Is the circuit operating as expected? Vary the amount of transmitted light reaching the receiver and comment on the variations in the output waveform. Is it clipped for high light intensities?

Lowpass Filter (Fifth Block)

As in the other filters, the lowpass filter uses a resistor and a capacitor to define an RC time constant. The circuit diagram is shown in Figure 7. In this case the time constant is given by R_4C, and the associated cutoff frequency is $1/(2\pi R_4C)$. At this point in the circuit you want the filter to be very effective in removing the modulation frequency, so the cutoff frequency should be set quite low. If it is set too low, the response of the circuit to a transmitted signal will be slow, on the order of the reciprocal of the cutoff frequency, so $5R_4C$ should not be more than about 0.5 second. Because of the capacitors that are available you will probably want to use a large resistor (around 1 MΩ) for R_4. The gain for low frequency signals is set by the ratio R_4/R_3.

Prelab (e)

1) Design a lowpass filter with a cutoff frequency of between 5 and 20 Hz (your choice) and a low frequency gain of 4

Procedure

1) Build the lowpass filter. Observe the input and output waveforms on the oscilloscope and make note of them. Is the circuit operating as expected? Again, vary the distance between the transmitter and receiver and record any variations on the output waveform.

End of First Part of the Project

Second Part of the Project

In this part of the project, a comparator will be added to give the circuit the ability to decide whether a signal is present or not. We will then use a flip-flop circuit to toggle the output between on and off with subsequent transmissions. This flip-flop circuit is necessary as it enables us to change whether we turn on or off our LED light circuit with the press of a button, enabling the circuit to only respond to our constructed transmitter. These types of circuits are called sequential logic circuits, and will be further studied in future courses.

Comparator (Sixth Block)

The comparator circuit is a type of circuit that allows us to compare the value of two voltages. The comparator works by outputting a high voltage if the + input voltage is larger than the – input voltage, and a low voltage if the – input voltage is larger than the + input voltage. The operation of the first five blocks of the circuit (through the lowpass filter) should give you an output signal that is near zero volts when no transmitted signal is present, and that becomes more negative when a transmitted signal is present. Using this signal as an input to the negative (-) input of the comparator should result in a high output from the comparator when a signal is present and a low signal otherwise, provided that the reference voltage is set properly.

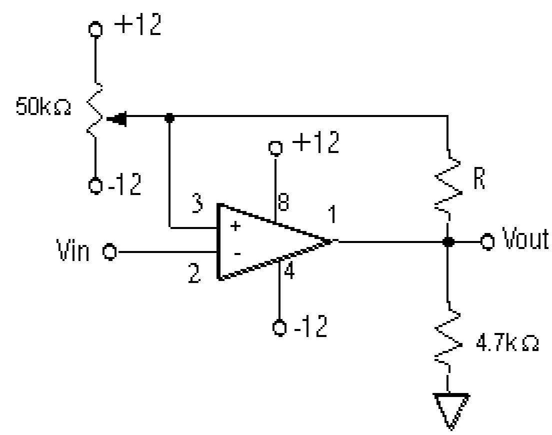


Figure 8: Comparator circuit using LM393 comparator chip and positive feedback (adjustable R)

A resistor (the 4.7 kΩ resistor) is used to pull the output up to the high logic level voltage (which in this case is ground or 0 V). Therefore the comparator circuit here has possible outputs of 0V and -12V. The 50 kΩ potentiometer provides the reference voltage to set the detection threshold.

The feedback resistor, R, provides the positive feedback seen in Figure 8. This positive feedback gives the circuit hysteresis, which makes the input voltage level required to turn off the circuit to be different from the one required to turn it on. This is useful, as it allows us to ignore the high frequency noise component still present in our signal. This noise could force the circuit to turn on and off undesirably, as the highly variable noise causes the circuit to constantly increase and decrease below a set threshold voltage. However, with hysteresis, once the circuit is triggered by the input voltage, the reference voltage is changed by the feedback resistor so that switching it back to another state requires a larger change in the input, making the circuit impervious to small amounts of noise. Figure 9 illustrates best how hysteresis improves the circuit.

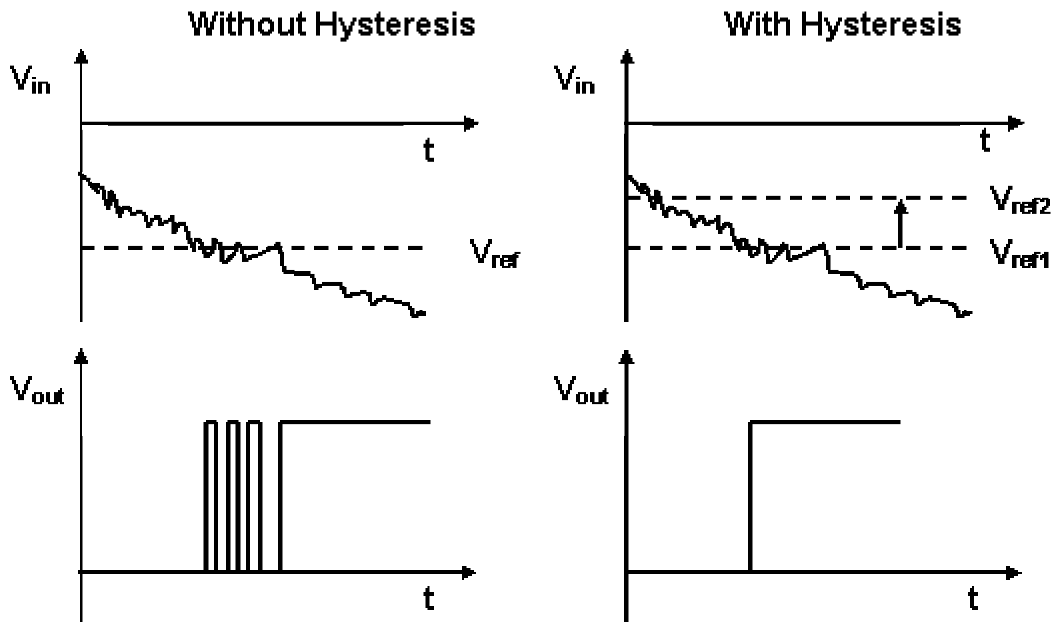


Figure 9: The input and output voltage of the comparator as a function of time, with and without hysteresis caused by positive feedback. Smaller feedback resistance R will cause a larger shift of V_{ref} when the output switches initially.

Procedure

1) Build the comparator circuit described in Figure 8. Reasonable values for R range from 100kΩ to a few MΩ. Adjust the potentiometer so that the comparator is switched by the transmitted signal, but not the noise. The function of R is to prevent spurious switching of the comparator by noise at the input, as discussed above. If R is too large, you may see unwanted switching; if R is too small, it will reduce the sensitivity of your circuit.
2) Test your circuit by turning your transmitter on and off. What is the size of the DC component of the noise signal at the input of the comparator? (This may vary depending on the amount of stray light that is present). Can you observe an ac component? (If not, it does not mean none is present.).
3) Try different values of R, and describe how you decide which value to use. What value of R did you finally choose? This value of R should give you two reference voltages at the + input to the comparator, depending on the state of the output – this is what produces the hysteresis. Measured and write down the values of the reference voltage (+ input to comparator at Pin 3) with: a) the output high, and b) the output low. How large is the difference between V_{ref1} and V_{ref2}? How does this compare with the noise level of your signal at the input to the comparator?

The flip-flop (Seventh Block)

In this part of the project, a flip-flop will be added so that with each transmitted pulse, the LED circuit will change its state from ON to OFF, and vice versa. The operation of the flip-flop circuit shown in Figure 10 is as follows. The set and reset lines are held low because we will not use them in this circuit. With each positive transition of Vin (once for each pulse) the logic level present on the data line is transferred to the output Q. Q bar (which is normally written as a Q with a bar on top) is the complementary logic level, and is connected to the data line. Since the logic level transferred is the original level on the data line, this means that for every pulse of Vin from the comparator, Q and Q bar will change logic levels as desired.

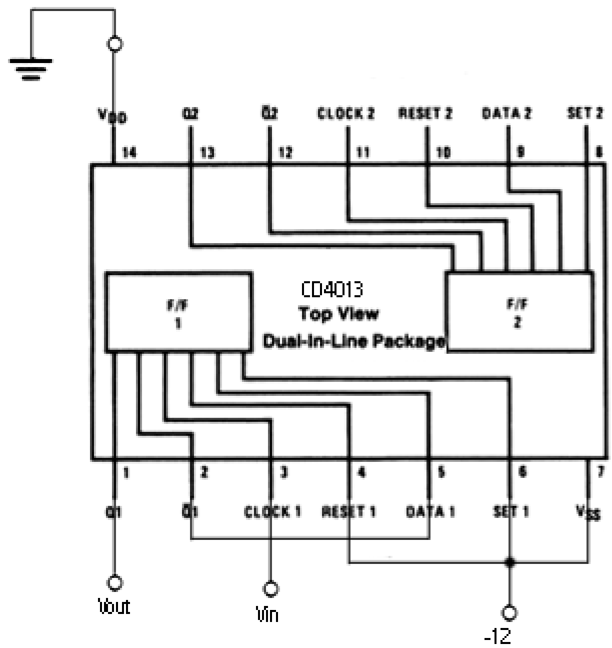


Figure 10: Flip-flop wiring diagram. The input comes from the comparator

Procedure

1) Connect the flip-flop shown in Figure 4 to the output of the comparator in your circuit to provide an on/off latch for your circuit. We will connect the comparator output to the clock input, thus toggling the lamp from on to off, and vice versa, every time the comparator output goes high, which should be every time the transmitter button is pushed.
2) After completing the wiring, test the operation of the circuit using your IR transmitter, and debug the circuit if necessary. Verify that the output toggles from high to low each time the transmit button is pushed. Correct operation of this part of the circuit depends on the setting of the reference level on the comparator and on the feedback resistor on the comparator, in addition to

correct wiring of the flip-flop, so you may have to tune the comparator circuit for proper operation.

LED Circuit (Eight Block)

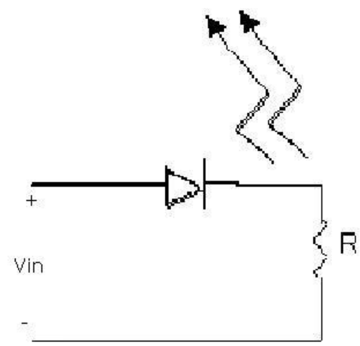


Figure 11: LED Circuit

Procedure

1) Select the resistor R such that the current flowing through it is at least 20 mA.
2) Connect the rest of the circuit to the LED diode circuit, using the output of the flip-flop circuit as the input to your LED circuit. Make any further refinements and modifications to your circuit.
3) Ensure that you can get a range of at least 10 ft. between your transmitter and receiver.