Electronic Instrumentation **Name** _______________
ENGR-4300 **Fall 2004** **Section** ____________

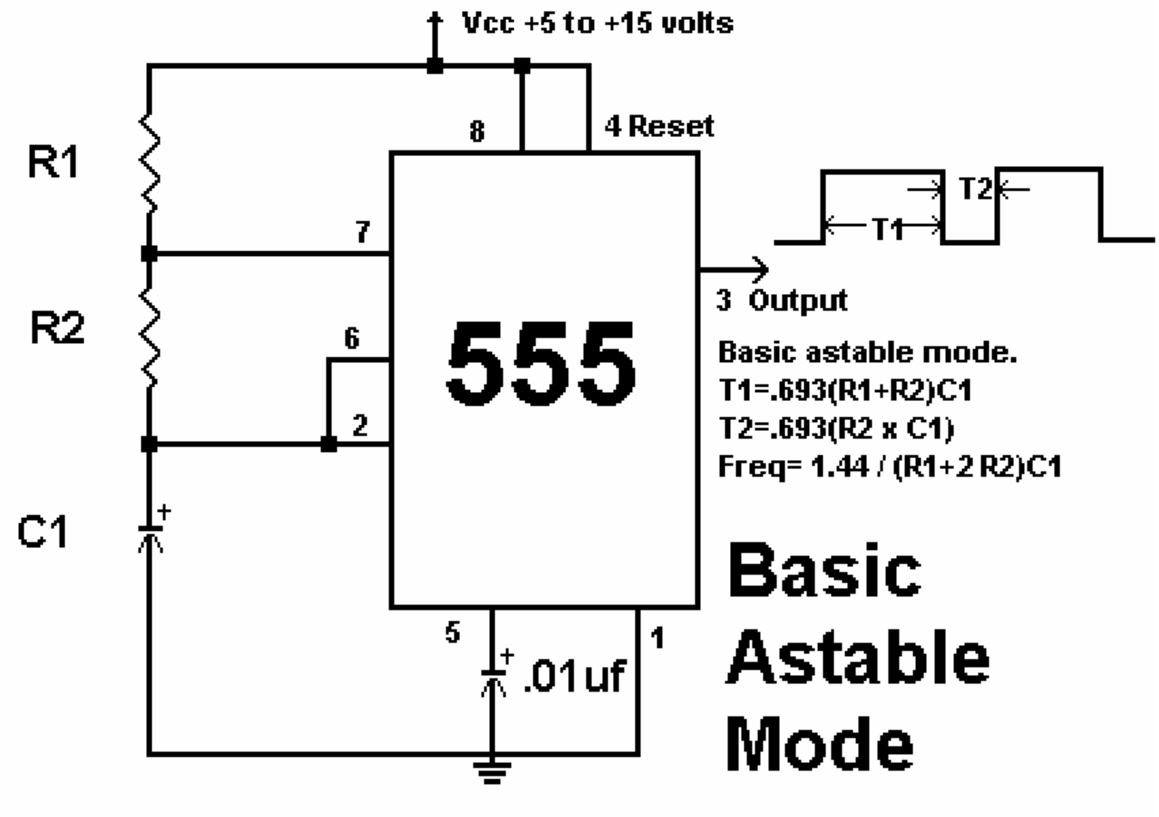
Experiment 7
Introduction to the 555 Timer, LEDs and Photodiodes

Purpose: In this experiment, we learn a little about some of the new components which we will use in future projects. The first is the 555 timer. This is a very useful little device that can produce trains of pulses in a controlled manner. We will not be able to address exactly how it works in this experiment, since we need to go further into how op-amps work and digital electronics. However, the basic rules that govern its behavior are not that difficult to figure out. We have been studying diodes, but have not directly considered how we can use them to generate and detect light. We will perform a simple experiment to see how this is done.

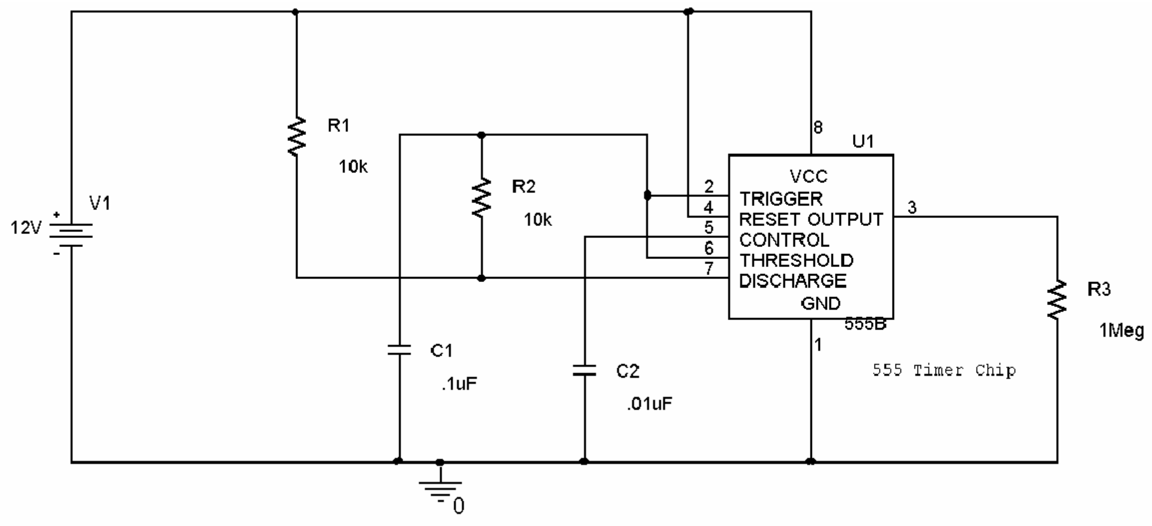
Equipment Required:

- HP 34401A Digital Multimeter
- HP 33120A 15 MHz Function / Arbitrary Waveform Generator
- HP E3631A Power Supply
- HP 54603B 2 Channel 60 MHz Oscilloscope
- Protoboard
- Some Resistors
- LM555 or MC1455 Timer Chip (See the course webpage for a datasheet in pdf format.)
- Infrared Transmitter/Detector Pair (either an LED and a photodiode or a phototransistor)

Part A Controlling Oscillation Frequency with Resistors and Capacitors



We have seen that when current flows through a series combination of a resistor R and a capacitor C, that the circuit responds with a characteristic time constant $\tau = RC$. It turns out that we can use this effect with a 555 timer chip to make an oscillator. The circuit we will use is shown generically above and more specifically below (at least in the form we will use for PSpice simulation). This chip has 8 pins with some relatively strange sounding names (see figure). The DC voltage source connected to pin 8 sets the value of the voltage called V_{CC}. In this case $V_{CC} = 12$ volts. By selecting just the right values for the resistors and capacitors in this circuit, we can make the voltage at pin 3 (the OUTPUT) go from zero to V_{CC} in a repeated pattern that looks like a square wave. The operation of the 555 timer is as follows. When an applied THRESHOLD voltage (pin 6) is $V_6 \geq (2/3)V_{CC}$, then the OUTPUT voltage V_3 is low (about equal to zero) and, in addition, a switch (transistor) that is internally connected between the DISCHARGE (pin 7) and GND (pin 1) is turned ON. Conversely, when an applied TRIGGER voltage (pin 2) is $V_2 \leq (1/3)V_{CC}$, then the OUTPUT V_3 is high (about equal to V_{CC}) and, in addition, the DISCHARGE transistor is turned OFF. When the RESET voltage (pin 4) V_4 is low, the DISCHARGE transistor is ON. However, the reset is disabled when the RESET pin is tied (directly connected) to the supply voltage.



Simulation of the Astable Multivibrator

Draw the circuit shown. Perform a transient analysis in increments of 2us up to 5ms. Use PROBE to plot the threshold/trigger, discharge and output voltages. The trigger voltage is pin 2 and the threshold voltage is pin 6 (they are tied together), the discharge voltage is pin 7, and the output is taken at pin 3. **Print your PROBE plot.**

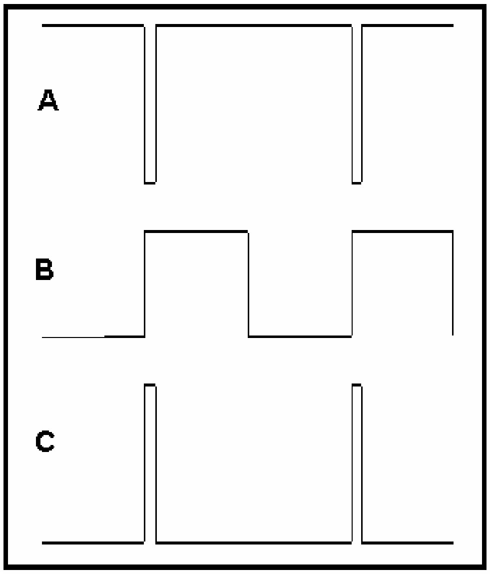
Verify that the timer output changes according to the rules listed above. Find the time period that the output is ON (that is, has a voltage about equal to V_{CC}) and the time period that the output is OFF (that is, has a voltage that is about equal to zero). *Note: Do not use the first cycle of pulses produced by the timer circuit. It takes one cycle to settle in to its steady-state condition.* One of these times should be equal to 0.693(R1+R2)C1 while the other should be equal to 0.693(R2)C1. Which is which? What is the total period of this output (the sum of the two times)?

Change the value of R1 to be R2/10. Repeat the transient analysis. Does the time that the output is ON look closer to the time that the output is OFF than it did when the two resistors where the same? What is the total period of the output now?

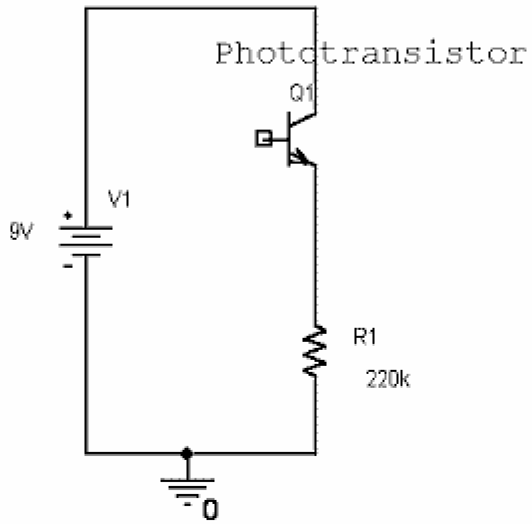
Pulse Width Modulation

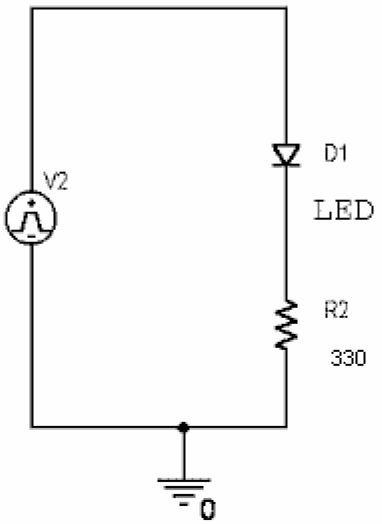
One of the most important methods we have for controlling and driving a large variety of systems is pulse width modulation (also known as pulse duration modulation). Please read over the link on motor control http://www.boondog.com/%5Ctutorials%5C2993pwm%5C2993pwm.htm and the one on flow valve control http://www.theleeco.com/EFSWEB2.NSF/0/893720ad39a7fc18852564bc006f7f2e?OpenDocument. The power of pulse width modulation comes from its simplicity. Rather than controlling the flow of some liquid by carefully opening a valve part way, you can alternately open and close the valve fully in such a manner that the average open time produces the same effect as a partially open valve. In effect, the rate of flow is controlled by the duty cycle of the controlling voltage. (There is an interesting discussion of this idea at http://www.allpar.com/fix/fixcarb.html). It is much easier to fully open or close a valve than to precisely open it part way. One can also apply power to a motor in this manner to control the speed or rotation. The key goal of this modulation process is to achieve a desired average value for some process. The range of possibilities is shown in the figure below where A has a high duty cycle and C a low duty cycle. We will now look at how a 555 timer can produce a range of average output voltages by adjusting the resistor and/or capacitor values used in the astable multivibrator circuit.

Returning to our initial astable multivibrator circuit shown on page 2, change the end time for the transient analysis to 20ms and then run it again. Display only the output voltage (pin 3) on your PROBE plot. Before printing it, we need to add something so we can see what happens to the average output voltage. Using the Trace Add feature, select the average function AVG() from the Functions or Macros menu. Insert the output voltage expression in the brackets of the average expression and then hit the OK button. This should add a trace of the time average of the output voltage. The average at any instant of time is the average of the voltage from time = 0 to the time of interest. Thus, you should see that the average asymptotically approaches a particular value. You can use the cursors to identify the average voltage at the largest time displayed. **Print this plot.** Now, using any cobination fo 3kΩ, 10kΩ or 30kΩ resistors for R1 and R2, find the combinaton of two resistors which results in the largest average voltage and the combination of two resistors which results in the smallest average voltage. **Print your plot for these two cases.** Verify in each case that the pulses produced by the multivibrator circuit obey the design rules. If the simulation does not work, the design rules are probably violated.



Part B Diodes and Light





In the circuits shown above, Q1 a phototransistor (or possibly a photodiode, depending on what is in your kit) is an infrared detector and the LED (Light Emitting Diode) is an infrared transmitter. We will address the phototransistor circuit first.

Photodetection

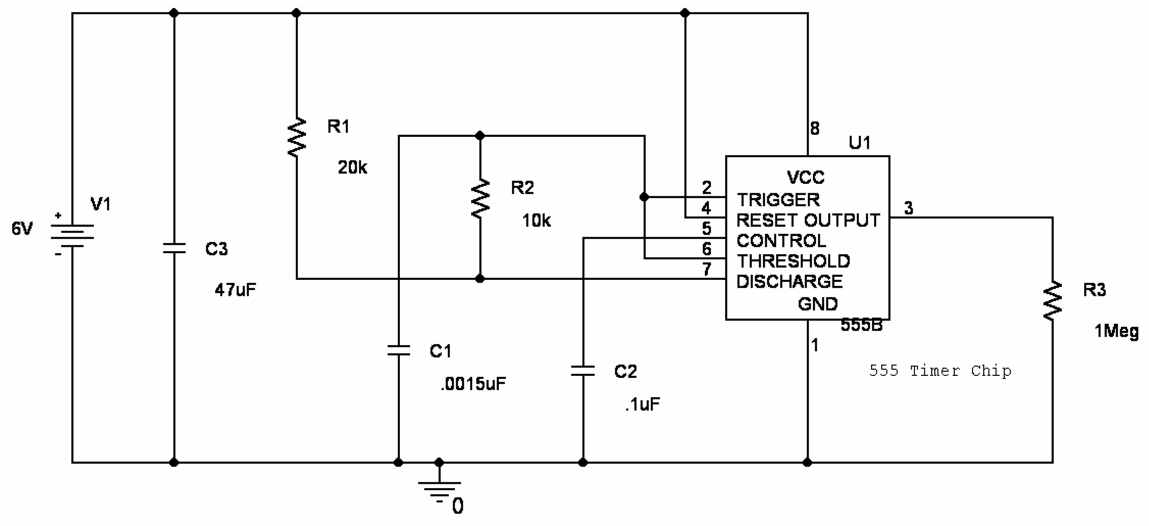
Build the circuit shown at the left. (The emitter of the phototransistor should face the resistor. Since diodes do not have reliable conventions, it is best to check the specs for your specific photodiode or test the photodiode in both directions. It will work in either direction, but when it has the correct polarity, the output will have a much greeater amplitude. Remember this fact for project 2 and test it in both directions then, as well.) Connect the output (the voltage across R1) to one channel of your scope. The signal you should be seeing is due to the lights in the classroom. Block the light going to the transistor and confirm that the signal at least becomes smaller. You may be also picking up some electrical noise related to the lights. Do not take this circuit apart at this time.

Light Emission from an LED

Assemble the circuit on the right on your protoboard. Use the function generator as the source. Adjust the function generator to produce a square wave with a frequency of 1 kHz. Aim the diode at the phototransistor so that the two rounded tips face one another. Raise the amplitude until you see a response in the detector circuit. Connect the output of the function generator to the other channel on your scope. The phototransistor circuit should still be connected. Observe the coupling between these two components. At 1kHz, find the minimum square wave amplitude that produces a signal in the phototransistor circuit. Again, you may be asked to use a different resistor in this circuit. **Record both the input and output signals on the scope and make a hard copy of what you see using Agilent Intuilink**. Raise the amplitude again until you can see a clear signal with little noise on it. Do not go too high in voltage, since you do not want to damage your LED. After obtaining a clear signal with this optical link, block the light by placing a piece of cardboard or something similar between the transmitter and receiver. Do you observe anything on the 'scope? Change the duty cycle of the square wave from 20% to 80%. Does the receiver do a good job of reproducing these signals?

Hardware Implementation (Optional, but needed for project 2. Build and save.)

If you have time, you should set up in hardware a variation of the 555 timer circuit that will be part of the next project. Once you get it working, show it to a TA or instructor. Monitor the output voltage. The 1 Meg resistor on the right is the ‘scope input. If you get it working, place an LED between pin 3 and pin 8 with the flat end of the LED toward pin 3. You should have a flashing diode when you do this. However, it will flash very fast, so it will look like it is on all of the time. There will be a demo version of a circuit like this on the center table, but the frequency will be very low, so you can see the flashing. How can you slow yours down?



Report and Conclusions:

The following should be included in your report. Everything should be labeled and easy to find. Partial credit will be deducted for poor labeling or unclear presentation.

Part A:

Include following plots:

1. PSpice plot for the astable circuit. (2 pts)
2. ‘Scope plots for the implemented astable circuit: Original setting and with 3kΩ, 10kΩ and/or 30kΩ resistors: largest and smallest duty cycles (3 plots total). (6 pts)

Answer following questions:

1. What is the minimum duty cycle that can be obtained from the astable multivibrator we modeled using PSpice? Can you show this mathematically using Duty Cycle = T1/(T1+T2)? (2 pts)
2. Show that the Mushroom Humidifier Timer mentioned in the helpful info section of the course webpage http://leda.lycaeum.org/Documents/Revised_Puerto_Method_Humidifier_Timer.10326.shtml (see figure 1) is indeed on for 20 seconds and off for 20 minutes. This result should contradict your answer to the previous question. The designer of this circuit is using the output to drive a relay, which the 555 timer chip cannot do directly. He has placed an additional transistor in between the relay and the 555 chip. This configuration inverts the output so that off becomes on and vice versa. (2 pts)
3. There are other ways to configure the 555-Timer into a circuit. The astable multivibrator , which generates a train of pulses, is just one. Name two others. (2 pts)

Part B:

Include following plot:

1. Plot of the input and output for the optical link. (2 pts)

Answer following questions:

1. What was the minimum amplitude square wave signal that you could detect with the phototransistor? (2pts)
2. Describe the differences between the input signal and the output signal. (Discuss all three of the duty cycles you considered and what you observed when you blocked the light signal.) Is what you see intuitively sensible? Why or why not? (3 pts)
3. What values of the two resistors gave the best performance? (2 pts)

Summarize key points (1 pt)

Discuss mistakes and problems (1/2 pts)

List member responsibilities (1/2 pts)