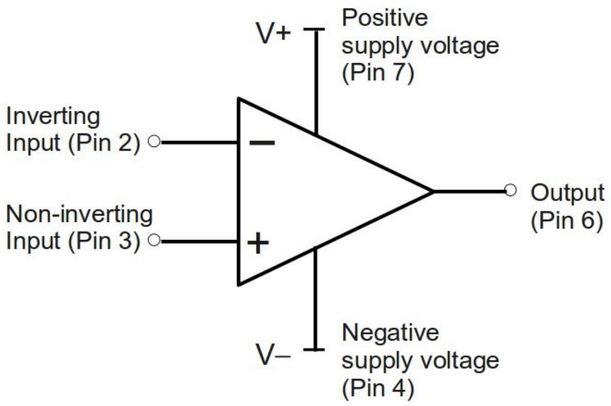
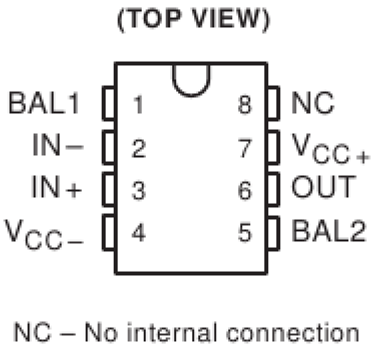
Lab 11: Relaxation oscillators (version 1.5)

WARNING: Use electrical test equipment with care! Always double-check connections before applying power. Look for short circuits, which can quickly destroy expensive equipment.

LM741 and LF411 operational amplifiers

This lab gives you the choice of using either the LM741 or LF411 operational amplifier. They have the same 8-pin diagram and can be directly substituted. Performance of the two devices will be noticeably different in the relaxation oscillator application. If an obvious notch is not visible on the plastic DIP package, look for a circular indent adjacent to pin 1.



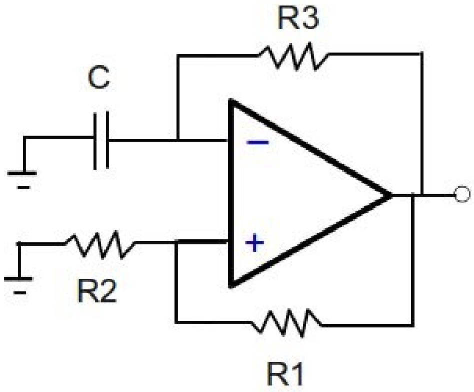


Op-Amp relaxation oscillator

For the relaxation oscillator, the op-amp is configured to run “open loop” in which no feedback is used to limit the gain. Because the amplifier is essentially unstable, it will move as quickly as possible to either its largest possible positive or negative output. These limits are set by the power supply voltage. The output can be automatically toggled between these two states by connecting the output to the inverting input with an RC time constant. This enables square wave oscillations.

Connect the ±15V positive and negative supply voltages on the lower left of the Elvis board to pins 7 and 4, respectively, of the op-amp. Setup a 1/2 voltage divider between the amplifier output pin 6 and the non-inverting input (pin 3) by selecting R1 = R2 = 47 kΩ (any resistor value > 10 kΩ will work). When R1 = R2, the oscillation frequency is determined by the components R3 and C according to the formula:

$$f = \frac{1}{2(\ln 3)R3C}$$



Select an assortment of resistor and capacitors to produce oscillations spanning four decades from 10 Hz – 100 kHz. Measure the component values with the Elvis DMM (avoid electrolytic capacitors) and get a minimum of one data point in each decade ($\geq$ 4 data points total). Measure the oscillator output frequency on pin 6 using a calibrated scope probe and the stand-alone oscilloscope (do not use the Elvis scope). Be sure to have the scope on DC coupling. Record the square wave oscillation frequency for the various R3C time constants. It is also instructive to use the scope/scope probe to observe the capacitor charging and discharging at the inverting input. Unstable behavior may occur if the resistor or capacitor become too small (< 1 kΩ or < 1 nF, respectively).

As the oscillation frequency increases, the output will begin to deviate from an ideal square wave. The waveform will look like a symmetric trapezoid and then a triangle wave at even higher frequencies. This is caused by the slew rate limitations of the op-amp (see Lab 9). The slew rate is measured by the slope of the rising or falling edge of the oscillator waveform. Record the slope in units of Volts/µsec for one of the oscillator configurations. Include the measured slew rate in your writeup. Plot the measured frequencies vs 1/(R3C) using a log-log graph. Compare this to theory by adding a curve depicting the above equation.

The 555 timer chip

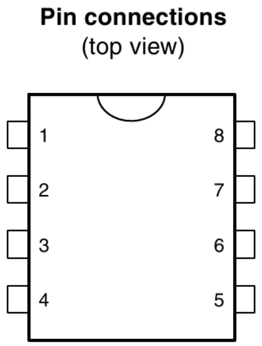
The 555 timer is a popular, versatile analog integrated circuit. Here it will be used to construct a relaxation oscillator. The oscillation frequency is given by:

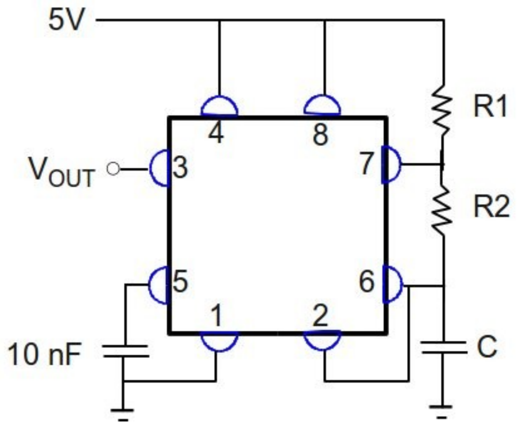
$$f = \frac{1.44}{(R1 + 2R2)C}$$

and the duty cycle is:

$$\text{Duty cycle: } \frac{R1 + R2}{R1 + 2R2}$$

Construct a 555 oscillator circuit using the following diagrams as a guide. A 5V power supply is available on the lower-left of the Elvis board. It will be convenient to run long jumper wires from pins 6 and 7 to an uncluttered area of the breadboard to allow easy component substitution.

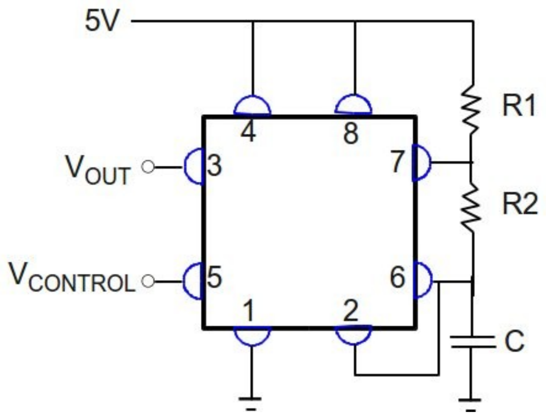




For the following measurements, fix the value of R1 = 1 kΩ and choose values of R2 at least an order of magnitude larger to keep the duty cycle close to 50%. Adjust values of R2 and C to produce oscillation frequencies over the a four decade span (10—100 kHz) as done above. As above, avoid making R2 and C too small. Observe the waveform at the output pin 3 using the scope (DC coupling) and scope probe. Only 1 data point per decade is needed. Graph the measured frequency vs 1/(R2C) and compare to a curve using the above frequency formula.

Next, fix R2 and C at any convenient values and increase R1 (> 1 kΩ) to change the duty cycle. Record the percentage duty cycle for several R1 values until >90% is reached. There may be a scope measurement function for this. Graph the duty cycle data as a function of R1 and compare to the model described by the above equation.

The voltage on pin 5 of the 555 can be adjusted to produce a voltage controlled oscillator. Remove the 10 nF capacitor and connect pin 5 to the Elvis board positive (+) variable power supply located on pins 48; be sure to also connect the circuit ground on pin 49.



Configure the variable power supply at the Elvis interface by clicking the button marked VPS. It may be easier to use the positive VPS in manual mode and adjust the output voltage using the knob located on the upper right of the Elvis board. If done this way, a method to monitor the control voltage is required. This can be accomplished with the second channel of the scope and a scope probe. Alternatively, wire the control voltage to one of the two Elvis board BNC connectors and connect to the scope with BNC cable. There is plenty of flexibility in the choice of component values, but R1 = R2 = 47 kΩ and C = 10 nF will produce an excellent range of oscillation frequencies.

Vary the control voltage in 0.5V steps from 1.0 to 4.5 V and record the oscillation frequency and duty cycle. Graph both as a function of control voltage. The oscillator produces a positive output for a time:

$$T_p = (R1 + R2)C \ln \frac{5V - 0.5V_c}{5V - V_c}$$

where V_c is the control voltage. One oscillation period is:

$$T = T_p + (\ln 2)R2C$$

so that the duty cycle is D = T_p/T and frequency is $f = 1/T$.

Note: The VCO may need some manual assistance to start. With the power supply on, disconnect and re-connect the control voltage wire from pin 5. Once it is running, adjust the control voltage and observe the oscillation waveform changing on the scope.

Writeup

1) Produce a graph (experiment and model) showing the oscillation frequency vs 1/(R3C) for the op-amp relaxation oscillator. Report the measured slew rate.

2) Plot the oscillation frequency (experiment and model) vs 1/(R2C) with a fixed value of R1 = 1 kΩ for the 555 timer oscillator. Plot the duty cycle (experiment and model) as a function of R1 for fixed R2 and C.

3) Graph the oscillation frequency and duty cycle (experiment and model) for the 555 VCO.

Be sure to include all the measured component values. Send to the instructor as a single .pdf file before the next class meeting.

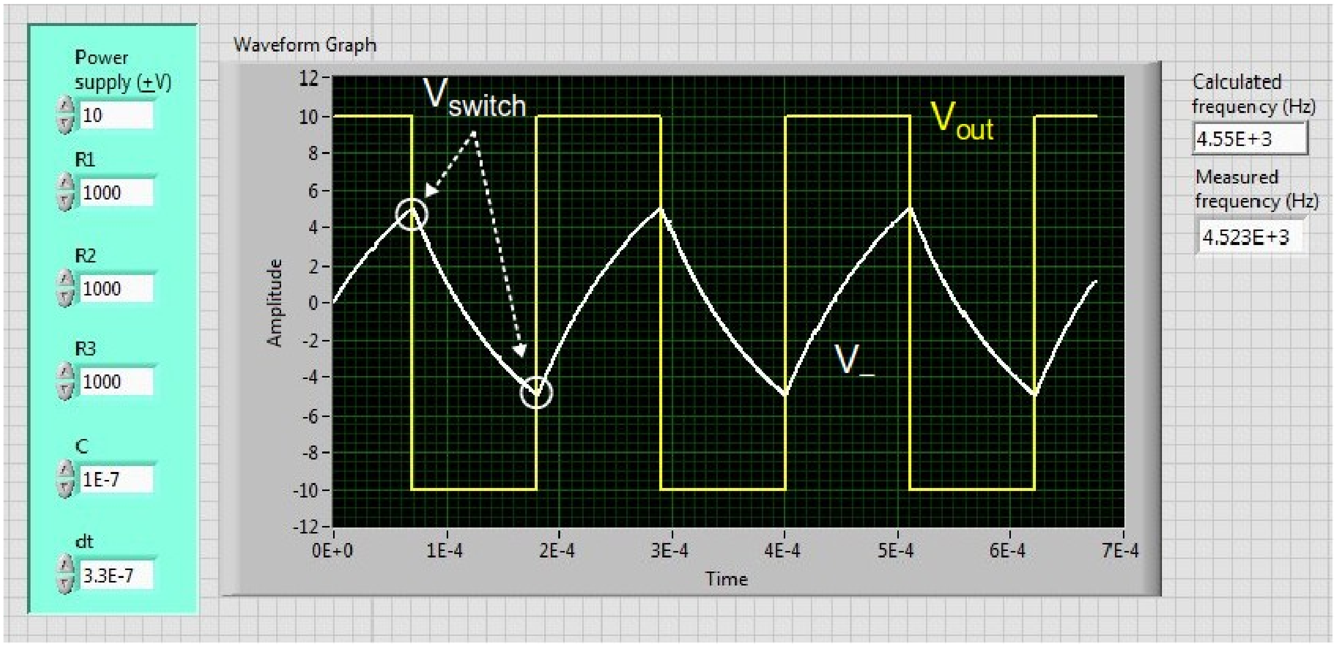
Optional Extra Credit: Model the Op-Amp Relaxation Oscillator

The following LabView project can be used to makeup/replace one of the weekly quizzes. Think of it as an optional take-home quiz, but students are required to work independently, i.e. no collaboration is allowed. You can use other resources for guidance provided you work alone. No new LabView techniques that haven't already been used on previous assignments are needed.

Model the op-amp relaxation oscillator drawn on the top of page 2. Use a FOR Loop and specify R1=R2, R3, C, Δt, and $\pm$ V for the power supply. Ignore slewing: Assume that when $V_- > V_+$ the output goes instantly to the positive power supply voltage; when $V_- < V_+$ the output goes instantly to the negative power supply voltage. The capacitor voltage is given by:

$$V_-(t) = (V_{\text{out}} - V_{\text{switch}})(1 - e^{-t/R3C}) + V_{\text{switch}}$$

where the switching voltage V_{switch} is shown in the Waveform Graph below:



Power supply (±V) 10

R1 1000

R2 1000

R3 1000

C 1E-7

dt 3.3E-7

Calculated frequency (Hz) 4.55E+3

Measured frequency (Hz) 4.523E+3

The time (t) in the above equation must be reset to 0 every time the circuit switches. Plot the oscillator output and V_- on the same Waveform Graph. Note that the VI does not loop; you should generate a pair of waveforms that illustrate oscillator behavior. Measure the frequency of the oscillator output. One option is to use Waveform: Analog Waveform: Measurements: Pulse measurement. Get the period and take its reciprocal.

Arrange to meet in my office to review this optional assignment *before* the next class meeting. It won't be checked during the next lab session.