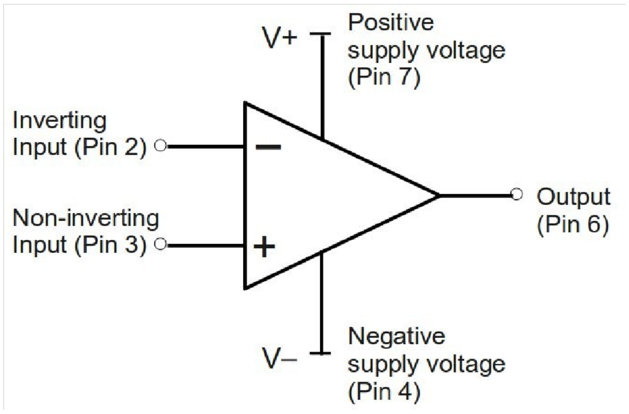
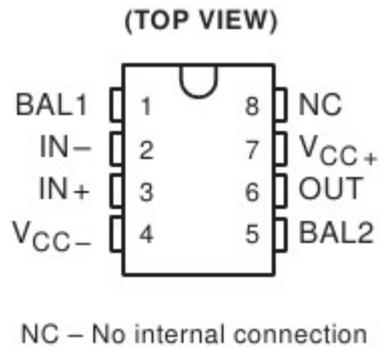
Lab 11: Relaxation oscillators (version 1.6)

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

LF411 operational amplifier

This lab uses the LF411 operational amplifier to build a relaxation oscillator application. Then it uses a 555 timer chip to build a more versatile relaxation oscillator and a VCO.



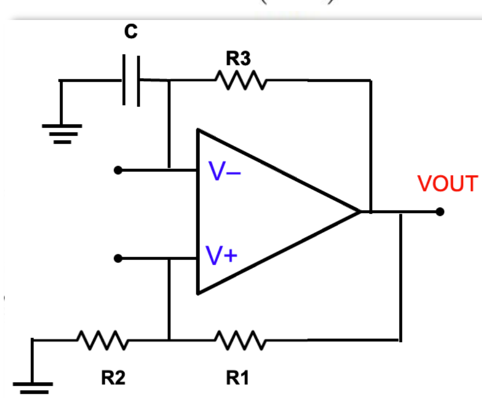


Op-Amp relaxation oscillator

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 at the output.

Build the circuit below corresponding to a relaxation oscillator. Use ±15V (or alternatively ±12V) supply voltages for the op-amp, and R1 = R2 ~50 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 and get a minimum of one data point in each decade (≥

4 data points total). Observe and characterize the oscillator output in the oscilloscope. Record the square wave oscillation frequency for the various R3C time constants. Also investigate the capacitor charging and discharging at the inverting input and their relation to the output. Note: Unstable behavior may occur if the resistor or capacitor become too small (< 1 kΩ or < 1 nF, respectively).

Note: 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 opamp (see Lab 9). The slew rate is measured in units of Volts/µsec. Include the measured slew rate in your lab notebook. 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

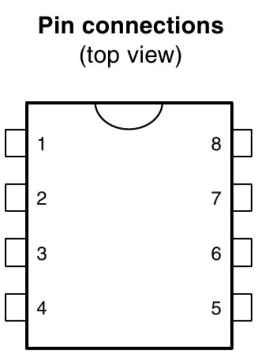
The 555 timer is a popular, versatile analog integrated circuit. Here it will be used to construct a relaxation oscillator. The oscillation frequency is given by:

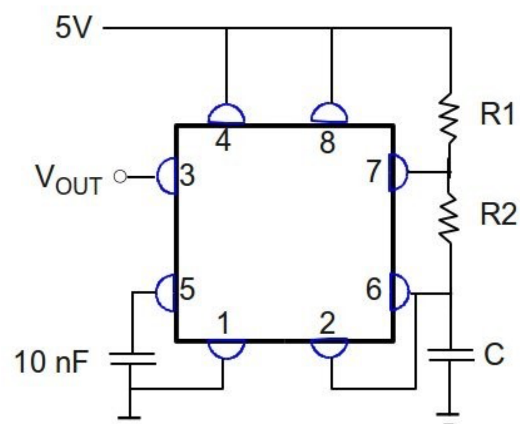
$$f = \frac{1.44}{(R1 + 2R2)C}$$

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.

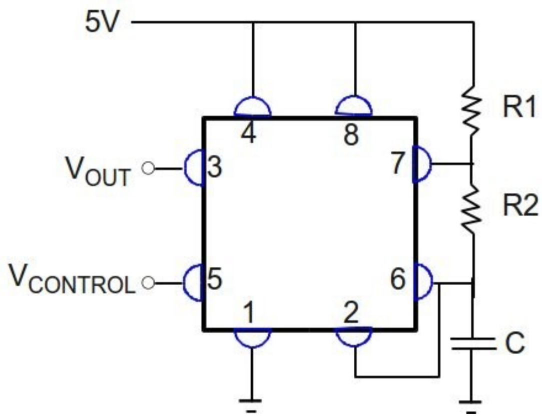




For the following measurements, fix the value of R1 ≈ 1-5 kΩ and choose values of R2 at least an order of magnitude larger to keep the duty cycle close to 50%. Adjust values of R2 and C to produce oscillation frequencies over a four-decade span (10—100 kHz) as done above. As above, avoid making R2 and C too small. Use a scope (DC coupling) and scope probe to measure 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 (> 1-5 kΩ) to change the duty cycle. Record the percentage duty cycle for several R1 values until >90% is reached. Graph the duty cycle data as a function of R1 and compare to the model described by the above equation.

Voltage Controlled Oscillator with the 555 timer



The voltage on pin 5 of the 555 ($V_{CONTROL}$) can be adjusted to produce a voltage-controlled oscillator (VCO). R1 = R2 ≈ 30-80 kΩ and C ≈ 5-20 nF will produce an excellent range of oscillation frequencies.

Vary $V_{CONTROL}$ in 0.5V steps from 0.5 to 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 with frequency $f = 1/T$

For your analysis

1) Produce a graphs (experiment and model) showing the oscillation frequency vs 1/(R3C) for the op-amp relaxation oscillator. Report the measured slew rate. Analyze relation with V- voltage.

2) Plot the oscillation frequency (experiment and model) vs 1/(R2C) with a fixed value of R1 ≈1-5 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.

For all the analysis, discuss your results and comparisons with the models.