NAME (PRINT) | STUDENT ID | LAB DATE | GRADE

Experiment 4

Oscillators and clock circuits

One does not always have the convenience of a frequency generator. From simple oscillator circuits that provide buzzing tones, to security system's delay circuits, to the crystal-based clocks that provide the heartbeat of every modern computer, a variety of methods exists to generate oscillating signals. In this lab we shall explore some of them.

4.1 555 timer IC as a square wave generator

Additional components required

- one 555 timer IC chip
- miscellaneous capacitors and resistors

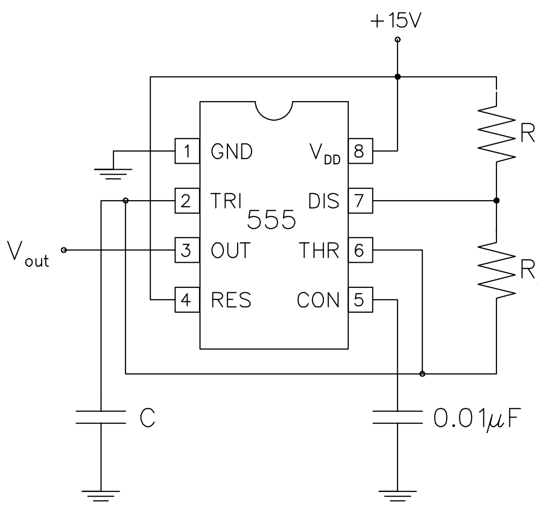

Figure 4.1: 555 Oscillator

The data sheet for this part describes the various modes of operation, connection diagrams and resulting waveforms. This timer has a monostable, or one-shot, mode where a high to low transition on the trigger input initiates a single pulse of a specific duration at the output.

The circuit can also be configured as a self-triggering (astable) pulse generator (Figure 4.1). You should pay particular attention to the charging and discharging equations for the astable configuration of the 555 timer, as they determine the duty cycle of the output pulse. The duty cycle of a digital (on/off) waveform refers to the proportion of the time that the signal is on relative to the overall period of the signal.

(!) Construct the 555 oscillator circuit shown in Figure 4.1. Refer to the internal schematic diagram shown in Figure 4.2 to understand its operation.

(!) Choose R_1, R_2, and C for an output of 1 kHz with as close to 50% duty cycle as you can. Verify that the circuit works and note the values you have chosen. Use the digital oscilloscope to monitor the output signal as well as the voltage at the capacitor and record these waveforms.

- $\boxed{?}$ What is the range in the duty cycle of the 555 output? Consider the changes/additions that you might make to the circuit to produce output pulses of a relatively small duration, for example, a 10% duty cycle.

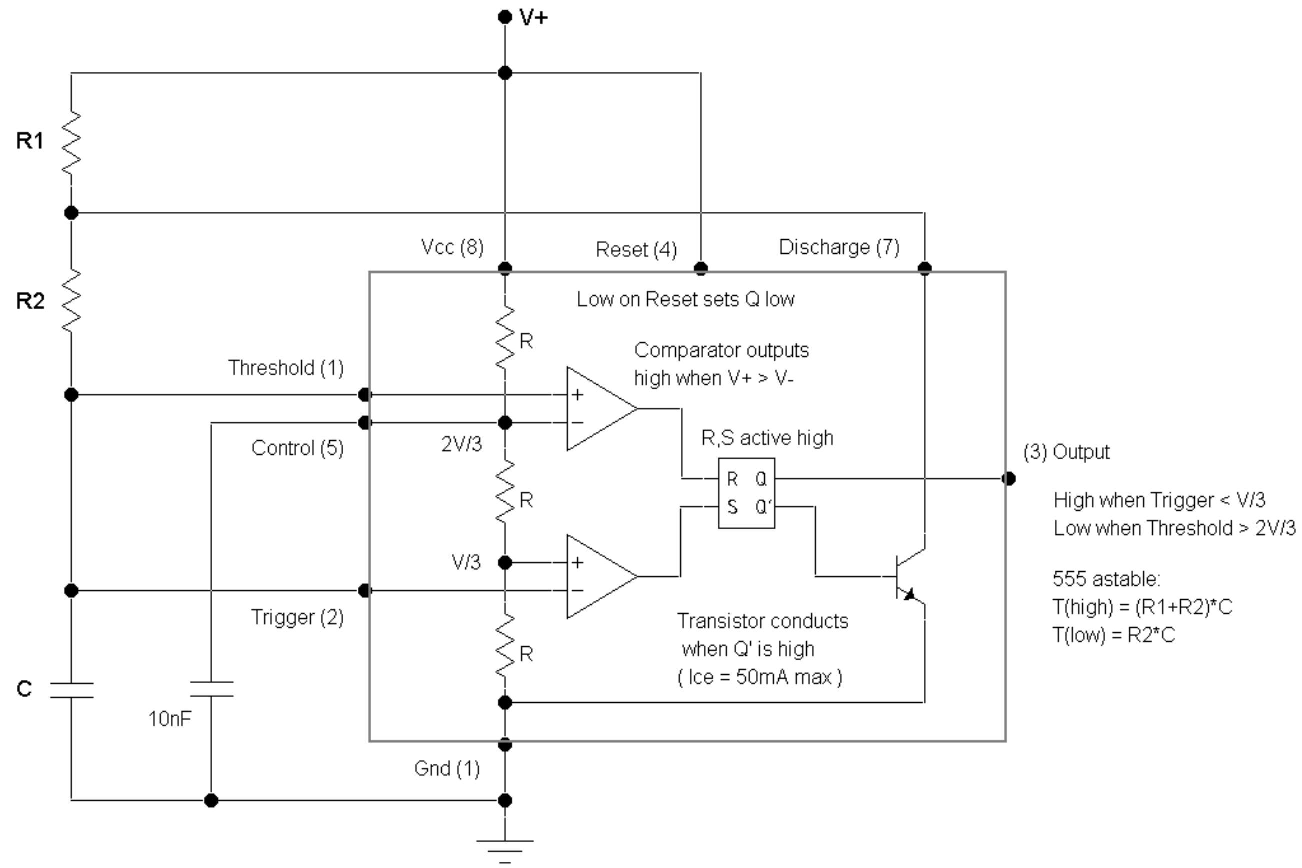

Figure 4.2: 555 bistable oscillator showing internal components

(!) Explore what happens if you disconnect the control voltage (CV) input pin 5 and instead connect it to a wiper of a 10-kΩ potentiometer that is connected between +15V and ground. This circuit is called a voltage-controlled oscillator.

$\boxed{?}$ Comment on the variation in duty cycle as you vary the control voltage. How does the off time vary with changes in CV? Explain your observation using the fact that the oscillation is based on the exponential discharging of a capacitor.

Review: operational amplifiers

The two triangle shaped devices internal to the 555 chip are operational amplifiers. The output of an Op-Amp is given by $V_o = A * (V_+ - V_-)$ where V_+ and V_- are the voltages present at the two inputs and A is the open-loop voltage gain of the Op-Amp. This gain is typically very large, i.e. $A \approx 10^5$, so that a tiny difference in the input voltages will cause V_o to swing between the limits set by the power supply voltages of th Op-Amp.

In the 555 timer chip, the Op-Amps are used in the open-loop configuration (no feedback) as voltage comparators. The output of a comparator is high when $V_+ > V_-$ and low when $V_+ < V_-$. When $V_+ \approx V_-$, circuit noise will cause the output to randomly swing between low and high states.

4.2 Crystal oscillator and ripple counter

Additional components required

- one 4.096-MHz crystal
- one 4060 ripple counter IC chip
- 1-kΩ and 1-MΩ resistors
- 10-pf and 39-pF capacitors

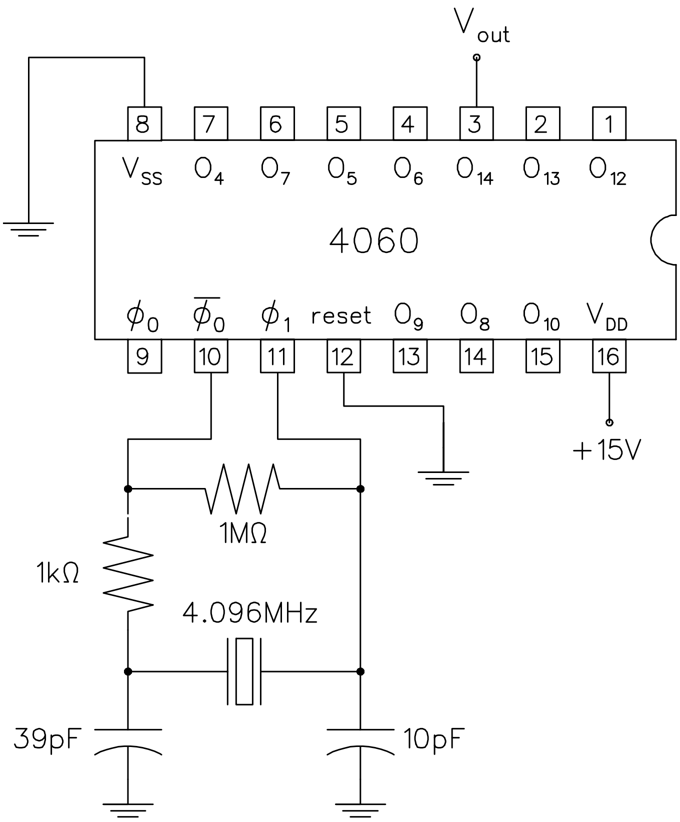

Figure 4.3: Crystal-based digital oscillator

Crystal oscillators are available in a variety of frequencies, which are determined by manufacturing them to exacting size and shape specifications. Often one encounters unusual values, such as the 4.096-MHz crystal provided for this lab. The reason for choosing such a strange value is to be able to generate oscillations of much lower frequencies by using multistage divide-by-two circuits. It just so happens that $4096 = 2^{12}$, and all we need is to build 12 divide-by-two counters in a row to get to 1 kHz, for example.

A convenient device is a 14-stage ripple carry binary counter, 4060. Depending on which output one chooses, one can obtain from a divide-by-2^9 to a divide-by-2^{14}. Thus with a single IC we can generate frequencies as low as 250 Hz, a convenient frequency if one wishes to build a small timer circuit with a time resolution of about ±0.002s.

Note how the suggested component values are selected to ensure a reliable 50%-duty-cycle oscillation, by keeping the crystal at the midpoint of the voltage divider formed by the 1 kΩ resistor and the 39 pF capacitor, *i.e.* how for $\omega = 2\pi \times 4.096$ MHz

$$|Z_{R=1\,k\Omega}| \approx |Z_{C=39\,pF}|\,.$$

Also note that since the oscillator components are not directly connected to the chip power supply, the oscillator frequency is not affected by variations in the power supply voltage.

(!) Download a copy of the 4060 data sheet and review the internal schematic. Implement the circuit shown in Fig. 4.3. Check other outputs as well. Which output stage provides the 1-kHz signal?

(!) Determine with the aid of a two-channel oscilloscope the propagation delay t_{pd} for one of the flip/flop stages of this ripple counter. Measure also the delay of several (N) stages. Does this delay represent an integer multiple N of the single stage delay t_{pd}? Should it? How does your result for t_{pd} compare with that stated in the data sheet? Explain any noted discrepancy.

(!) Use HP function generator to provide a 250-Hz trigger signal to the oscilloscope and monitor the output of your crystal oscillator. HP signal generators contain high-precision internal frequency standards with very low phase drift. Carefully adjust the function generator's frequency until your oscillator's signal appears completely stable, then wait a few minutes and observe if the frequency has drifted. See if cooling your circuit with a gentle air flow causes changes.

[?] Why would it be a bad idea to use a 555 circuit as the frequency source for your timer circuit?