NAME 1:   SID:

NAME 2:   SID:

The 555 Timer IC

Inductors and capacitors add a host of new circuit possibilities that exploit the memory realized by the energy storage that is inherent to these components. In this laboratory we will use capacitors to build timer circuits. Timers have a many uses, from lights that turn off automatically after a prescribed period to blinking lights and synthesizers used in sirens or electronic organs. Timers are also used by other electronic circuits, for example as computer clocks. In fact, the 555 timer circuit used in this laboratory is one of the most successful ICs ever: Designed 1970 by Hans Camenzind at Signetics (later Philips and now NXP) and introduced 1971 (the same year Intel introduced its first—4-Bit!—microprocessor executing up to 60,000 instructions per second), sales are still strong with over 1 billion units sold each year! Can you think of other innovations with similar success and longevity? The first microprocessor has long been relegated to museums.

The notorious RC charging and discharging circuit that is at the basis of so many homework and exam problems is also at the center of many timer circuits (exams are practical, after all). For example, the time it takes to charge a capacitor can be used to delay turning on a device. Likewise, discharging sets the time to turn a device off. Combine these two circuits and you have a clock turning on and off at a rate set by a capacitor and resistors. Turing this simple idea into a complete electronic circuit calls for several functions in addition to the capacitor and charging and discharging resistors. Switches are used to alter between charging and discharging cycles. Comparators determine when a certain voltage level has been reached. Altogether quite a few components are needed to build that timer circuit. The 555 timer includes all these functions in an 8-pin package.

A timer circuit performs two functions: A mechanism for generating the delay, and a device to turn the timer state on and off, based on the delay. The first function is easily realized e.g. by the charging and discharging of a capacitor. The second involved comparing the resulting waveform to set thresholds. Fortunately the circuitry for this function is available as standard components. The most prevalent of these "timer ICs" (IC stands for integrated circuit, meaning a device that combines several electronic functions in a package) it the 555. For some reasons ICs typically have numeric "names" with little or no deeper meaning.

Figure 1 shows a simplified circuit diagram of the 555 timer. The box on the right with S and R inputs is a flip-flop and keeps track of the timer state. Its output Q is either V_{cc} or ground. Raising the S input to V_{cc} sets the flip-flop ($Q = V_{cc}$) which then remains in the set state until the R input is raised to V_{cc}. Raising both S and R results in a random state Q and must be avoided if deterministic circuit operation is desired. Two comparators generate the set and reset signals from inputs "trigger" and "threshold". The output of a comparator equals V_{cc} when the voltage at the plus terminal is greater than the voltage at the minus terminal, and $0\,\text{V}$ otherwise. The resistors R_1, R_2, and R_3 are equal and consequently $V_a = \frac{2}{3} V_{cc}$ and $V_b = \frac{1}{3} V_{cc}$.
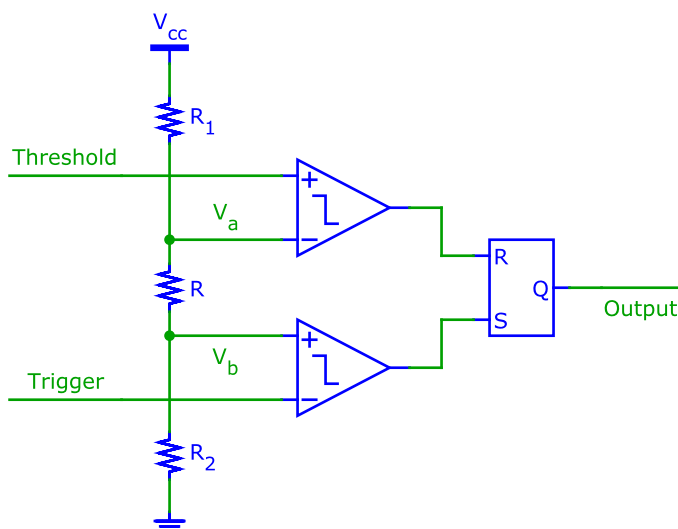

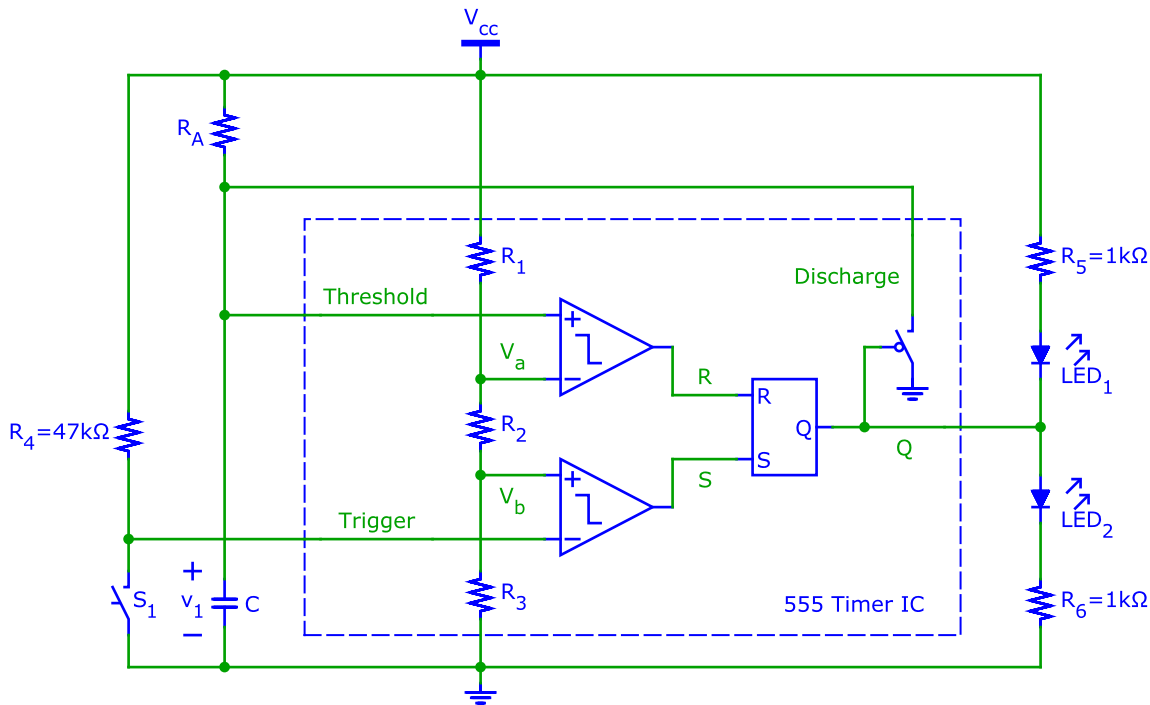**Figure 1**   Simplified diagram of the 555 timer IC.

Figure 2 Monostable timer circuit.

The datasheet for the 555 timer IC contains additional explanations and information. Download and study it, and bring it to the lab for reference.

On/Off Timer

Let's now use a 555 timer IC to design an off-timer, also called monostable timer. Figure 2 shows a possible circuit implementation using the 555. The output of the timer is connected to two light emitting diodes (LEDs) through current limiting resistors. Depending on the state of the timer output, one or the other LED is on.

Assume that initially the timer is off, i.e. $Q = 0\,\text{V}$. Then the "discharge" switch (which is part of the 555 timer IC) connected to the output is turned on, pulling the "threshold" signal low. As long as switch S_1 remains open, the "trigger" signal is high.

Determine the voltages at the inputs of the flip-flop and the resulting output.

R		1 pt.
		0
S		1 pt.
		1
Q		1 pt.
		2

Closing the momentary switch S_1 pulls the trigger voltage low. Consequently, the input to the bottom comparator is $V_b - 0\,\text{V} = \frac{1}{3}V_{cc} > 0\,\text{V}$ and its output, which controls the S input of the flip-flop goes high, setting $Q = V_{cc}$. The discharge switch opens, and capacitor C charges through R_a until the top comparator turns on and resets the flip-flop.

We will design our timer so that pressing S_1 will turn the output on for 3.7 s. For $C = 100\,\mu\text{F}$, what is the correct value of R_a? To make our life easier, we first redraw the circuit diagram, including only the relevant elements as shown in Figure 3 on the following page.
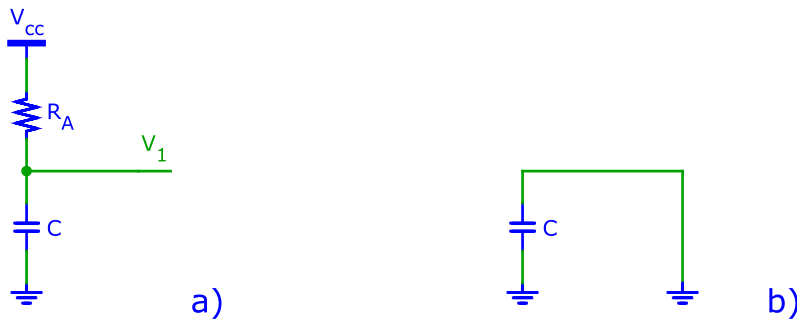
a)

b)

Figure 3 Partial timer diagram for (a) output high and (b) output low.
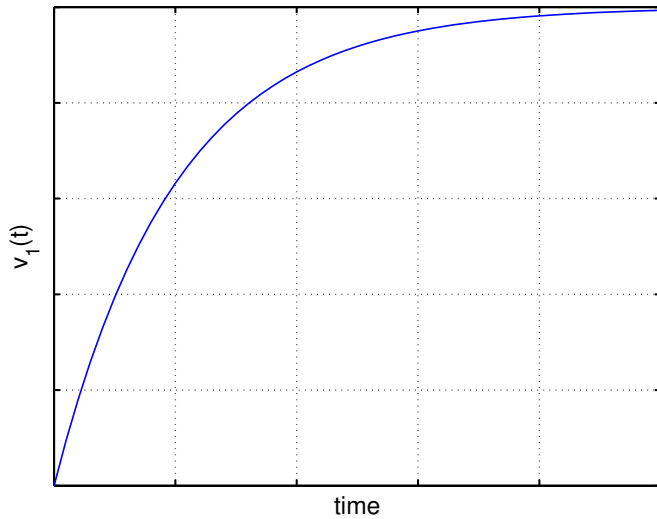

time

Figure 4 Capacitor voltage.

Part (a) depicts the situation during the charging phase. Straightforward analysis yields

$$v_1(t) = V_{cc}\left(1 - e^{-t/\tau}\right) \tag{1}$$

with $\tau = R_A C$. Mark the time T and voltage of the tripping point of the timer in Figure 4. Solve for the value of R_A for $V_{cc} = 5\,\text{V}$ and $V_{cc} = 10\,\text{V}$.

$V_{cc} = 5\,\text{V}$	$R_A =$	
$V_{cc} = 10\,\text{V}$	$R_A =$	

1 pt. 3
1 pt. 4

The design is now complete and ready for testing. The manufacturer makes the following recommendation in the datasheet: 1) Connect the unused reset pin to V_{cc}. 2) Connect a 10 nF capacitor between threshold and ground.

Often circuits operate even if such recommendations are not followed. Unfortunately, however, such shortcuts frequently lead to sporadic malfunction that is difficult to debug. For example, a circuit may operate correctly at room temperature but fail at elevated temperatures. Potentially even more vexing and damaging to a designer's reputation are situations where the malfunction occurs only in some circuits or occurs gradually over time. While infrequent, all these situations occur, often resulting in lawsuits or large payments of damages. It is cheap insurance to follow manufacturers recommendations unless you have good reason and insight for not doing so!

This circuit is mildly complex and a single and simple error such as an incorrect connection would result in it not working properly. Since such situations can be very time consuming to investigate in the laboratory, we first verify circuit operation with simulation (SPICE). All devices can readily be simulated with the exception of the momentary switch S_1, which is not a standard component in SPICE. A simple workaround is to use a pulsed or piecewise linear voltage source to simulate its effect. Program to source initially to V_{cc}, dropping to 0 V after 1 s for 500 ms and then returning to V_{cc}.

Hand in the following with your lab report (5 points for correct results, no credit for labs without SPICE):

- Printout of the SPICE circuit schematic.

- A plot of the result of a transient analysis showing the following signals: trigger voltage, $v_1(t)$, $Q(t)$, and the current through R_5. Use a voltage source with $V = 0$ in series with R_5 as an ammeter. Mark the time T and verify that it corresponds to the design value.

Verify your circuit in the lab. Unlike resistors, capacitors are not marked with a universally valid code. Instead, values are marked using a variety of different and ambiguous notations. Ask your lab assistant for help. As always, observe the polarity markings on all components. For LEDs the longer wire indicates the positive terminal (where current enters). If a momentary switch is not available you can emulate it by making momentary contact with a wire (an admittedly lousy lab technique). Verify the voltage at the timer output with the DVM and check polarity if the LEDs won't turn on and off as expected.

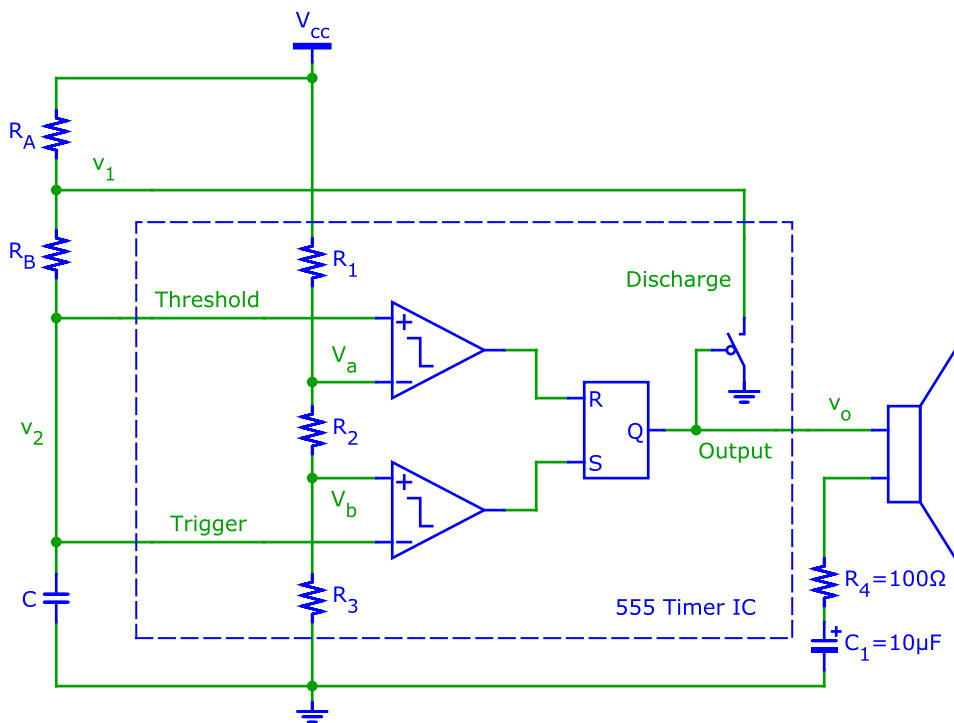Demonstrate your circuit to the laboratory assistant.

Figure 5 Circuit configuration for astable timer operation.

Electronic Synthesizer

Audio signals change periodically with time. For example, the music note A_4 corresponds to a waveform that repeats with a frequency of $440\,\text{Hz}$ or every $2.27\,\text{ms}$. We can use the 555 timer circuit to synthesize these signals. The configuration shown in Figure 5 shows the connections for astable operation of the timer, i.e. the capacitor C is periodically charged and discharged by the circuit.

Following the approach taken to design the on/off-timer, draw simplified circuit diagrams showing only the relevant components during the charging and discharging of C. Plot the waveforms at nodes v_1, v_2, and v_o as a function of time in the space below. Mark the voltage at the tripping points.

Now derive separate expressions for $v_2(t)$ during the charging and discharging phases of C. What values of R_A and R_B result in a $61\,\mu s$ charging and $24\,\mu s$ discharging time? What is the resulting repetition frequency f? Use $C = 1\,nF$.

$$R_A = \boxed{} \quad \text{1 pt.}\quad 5$$
$$R_B = \boxed{} \quad \text{1 pt.}\quad 6$$
$$f = \boxed{} \quad \text{1 pt.}\quad 7$$

We use the same timer IC to generate several different frequencies simply by replacing resistor R_A in Figure 5 on the previous page with the circuit shown in Figure 6. If all momentary switches are open, the value of $R_A = R_{A4}$. To play a tune, close only one switch at a time. For S_1 closed, $R_A = R_{A4} \parallel R_{B4}$, with S_2 closed, $R_A = R_{A4} \parallel R_{C5}$,
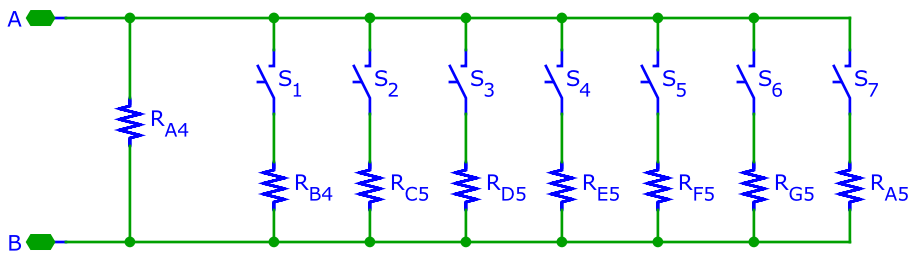

Figure 6 Circuit for R_A to produce eight different tones.

etc. Calculate the resistors values needed for the tones in the table below (suggestion: use Matlab, Excel, or another program you are familiar with). These frequencies realize an equal tempered scale, the most commonly used scale in western music. Use $R_B = 1\,\text{k}\Omega$ and $C = 220\,\text{nF}$.

Tone	Frequency			
A_4	440 Hz	$R_A =$		1 pt. 8
		$R_{A4} =$		1 pt. 9
B_4	494 Hz	$R_A =$		1 pt. 10
		$R_{B4} =$		1 pt. 11
C_5	523 Hz	$R_A =$		1 pt. 12
		$R_{C5} =$		1 pt. 13
D_5	587 Hz	$R_A =$		1 pt. 14
		$R_{D5} =$		1 pt. 15
E_5	659 Hz	$R_A =$		1 pt. 16
		$R_{E5} =$		1 pt. 17
F_5	698 Hz	$R_A =$		1 pt. 18
		$R_{F5} =$		1 pt. 19
G_5	784 Hz	$R_A =$		1 pt. 20
		$R_{G5} =$		1 pt. 21
A_5	880 Hz	$R_A =$		1 pt. 22
		$R_{A5} =$		1 pt. 23

Simulate your circuit with SPICE before testing it in the laboratory (mandatory). Attach a printout of your SPICE schematic or netlist and plots of $v_1(t)$, $v_2(t)$, and $v_o(t)$. Mark the values of T_1 and T_2 in the plots. Model the speaker with an $8\,\Omega$ resistor. Note: simulate more than one period in SPICE to let startup transients decay. Verify the supply voltage or value of R_4 to adjust the audio volume. Summarize your results in the table below:

Tone	Frequency	Simulated [Hz]		Measured [Hz]	
A_4	440 Hz		1 pt. 24		2 pts. 24
B_4	494 Hz		1 pt. 24		2 pts. 24
F_5	698 Hz		1 pt. 24		2 pts. 24
A_5	880 Hz		1 pt. 24		2 pts. 24

Explain differences and ask the lab assistant to verify your circuit.

Obviously this synthesizer can be improved. The addition of more tones is straightforward. Two or more 555 timer ICs can be combined such that one sets the control voltage of the other to greatly expand the repertoire of tones that can be generated from siren like to the synthesis of the beat and imitation of different instruments. Good options for the class project.

PRELAB SUMMARY

LAB TIME:

NAME: SID:

Copy your results from the blue Prelab boxes in the rest of the lab onto this page and turn it in at the beginning of the lab section. Only the values on this page will count!

Blue box #	Value	Result	Points
0	R		__/ 1
1	S		__/ 1
2	Q		__/ 1
3	R_A (V_{cc}=5V)		__/ 1
4	R_A (V_{cc}=10V)		__/ 1
5	R_A		__/ 1
6	R_B		__/ 1
7	f		__/ 1
8	R_A (440 Hz)		__/ 1
9	R_{A4} (440 Hz)		__/ 1
10	R_A (494 Hz)		__/ 1
11	R_{B4} (494 Hz)		__/ 1
12	R_A (523 Hz)		__/ 1
13	R_{C5} (523 Hz)		__/ 1
14	R_A (587 Hz)		__/ 1
15	R_{D5} (587 Hz)		__/ 1
16	R_A (659 Hz)		__/ 1
17	R_{E5} (659 Hz)		__/ 1
18	R_A (698 Hz)		__/ 1
19	R_{F5} (698 Hz)		__/ 1
20	R_A (784 Hz)		__/ 1
21	R_{G5} (784 Hz)		__/ 1
22	R_A (880 Hz)		__/ 1
23	R_{A5} (880 Hz)		__/ 1