Experiment 17: Metronome Circuit Using a 555 Timer Chip

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Objectives The objectives of this experiment are to determine the time required to charge and discharge a capacitor where these times are determined by two different resistor-capacitor networks in an astable multivibrator circuit and to measure the resulting frequency and duty cycle of the square wave output.

Estimated Time for Completion

Preparation Read the section describing RC time constants in your textbook. Also read Section 3.6 (Velleman Oscilloscope), Section 3.7 (Trim Potentiometers), Section 3.9 (Capacitors), and Section 3.13 (555 Timers) of this text.

Background Metronomes produce regular sounds, usually a single frequency tone, beat, or click, which instrument players and singers use to count the meter or tempo of a piece of music. The repetition rate of the sound from a metronome can be adjusted by the musician. The typical range is from 40 to 200 beats per minute (bpm), which translates to a frequency of 0.667 to 3.33Hz.

In this experiment, the square wave output of a 555 timer chip, configured as a astable multivibrator, will be used to drive a speaker to obtain the sound of the beat. The frequency of the astable multivibrator circuit, shown in Figure 1, is determined by the time required to charge a resistor-capacitor network composed of R_a, R_b, and C and to discharge a resistor-capacitor network of R_b and C. Internal to the 555 timer chip are two voltage comparators U1 and U2 (see Fig. 2). These two comparators are designed to keep the voltage across the capacitor V_C, which is also the voltage on pins 2 and 6 of the 555 timer chip, between 1.67 V and 3.33 V. When $V_C = 3.33\,V$, the output of comparator 1 resets the RS flip-flop (U2A) and causes a transistor is activated, which connects ground to pin 7 of the timer chip. This forces the node between $R_a$and R_b to be equal to 0 V. The capacitor will then discharge the stored charge on its plates through R_b to ground until the voltage on the capacitor decreases to 1.67 V. When $V_C = 1.67\,V$, the second comparator causes the transistor to be turned off, opening a switch between ground and pin 7. This allows a current to flow from V_{CC}through $R_a$and R_b to charge the capacitor. The output of the 555 timer (pin 3) is the output Q of the RS flip-flop whose state is set and reset by the output of voltage comparator U2 and U1, respectively. Thus, the output from a 555 timer is a logical “1” or close to 5V while the capacitor is charging and is a logical “0” or approximately equal to 0V while the capacitor is discharging.

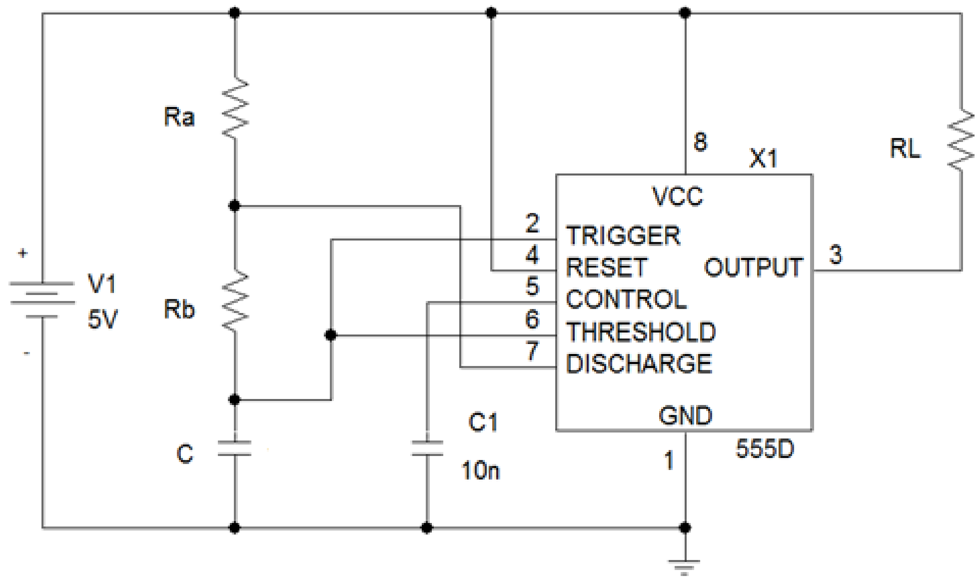

Fig. 1: Schematic for an astable multivibrator with output resistor R_L.

Thus, the time constants of two different resistor-capacitor networks determine the length of time the timer output, t_1 and t_2, is at 5V and 0V, respectively.

$$t_1 = 0.693(R_a + R_b)C \qquad (1)$$

And

$$t_2 = 0.693(R_b)C \qquad (2)$$

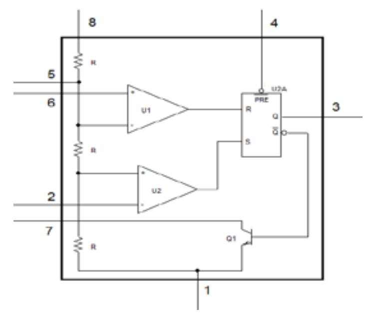

Fig. 2 Schematic of the 555 timer circuitry.

The frequency $f = \frac{1}{T}$, where $T = t_1 + t_2$, and duty cycle $D = \frac{t_2}{T}$ of square wave output of the 555 time is given by:

$$f = 1.44/[(R_a + 2R_b)C] \qquad (3)$$

and

$$D = R_b/(R_a + 2R_b) \qquad (4)$$

Note that the duty cycle of the square wave will always be less than 50%.

If R_b is held constant and the resistance of R_a is changed, t_1 will be fixed and t_2 will be a function of R_a. If a speaker or buzzer replaces R_L, which is connected between the output of the 555 timer (pin 3) and V_{CC}, then current will flow through the speaker or buzzer only and, hence, sound will only be produced from the metronome when the output of the 555 timer is 0V. The time between tones is determined by only t_2. Therefore, the beats per minute – the frequency of the square wave output from the 555 timer – will be varied by changing the value of R_a.

The resistance of most speakers and piezoelectric buzzers is very small. The resistance of the speaker in the Lab-in-a-Box parts kit is only 8Ω. If only the speaker replaced R_L in Fig. 1, the maximum current that would flow through the speaker, I = 5V/8Ω = 0.625 A, is larger than the 555 timer can supply and the power dissipated by the speaker, P = $(5V)^2$/8Ω = 3.125 W, would exceed the power rating of the speaker, which is 0.5 W. R_L should be replaced by the series combination of a speaker and a current limiting resistor (Fig. 3). In the circuit to be constructed, R_a is composed of trim pot and fixed resistor to prevent the case where $R_a = 0\ \Omega$.

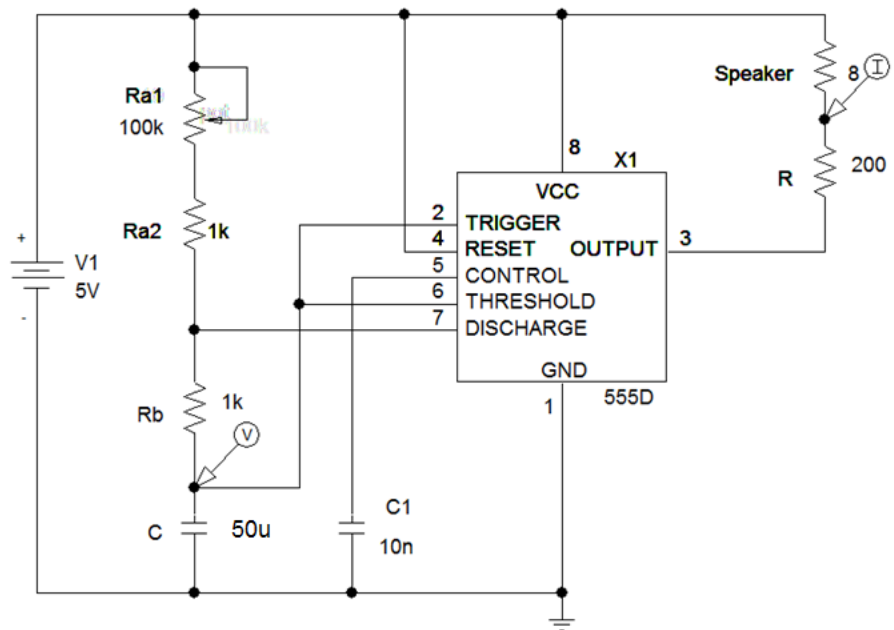

Fig. 3 Schematic of metronome circuit

Materials

The equipment and components required to perform this experiment are:

- ANDY board
- DMM
- oscilloscope
- 1 ea 200 Ω resistor
- 1 ea 1 kΩ resistor
- 1 ea 100 kΩ trim pot
- 1 ea 10 µF electrolytic capacitor
- 1 ea 10 nF capacitor
- 1 ea LM555 timer chip
- 1 ea speaker

Procedure

Analysis:

1. Calculate the maximum and minimum values for R_a that will produce a square wave output with a frequency between 0.667 and 3.33 Hz. Determine the duty cycle of the square wave when f = 0.667 Hz and f= 3.33 Hz.
2. Using MATLAB, plot the output frequency as a function of R_a where the value of R_a is allowed to range between the maximum and minimum resistances calculated in step 1.
3. Using MATLAB, plot the charge and discharge times, t_1 and t_2, as a function of R_a where the value of R_a is allowed to range from the maximum and minimum resistances calculated in step 1.
4. Determine the maximum current and power dissipated by the speaker.

Modeling

5. Plot the voltage across the capacitor *C* and the current through the speaker for 3-5 periods of the square wave outputted by the 555 timer when $R_{a1} + R_{a2}$ is equal to (a) the minimum resistance and (b) the maximum resistance found in step 1. Record the time required to charge and discharge capacitor *C*. [Note that the measurements should be made after the operation of the circuit has stabilized and the voltage across the capacitor varies between 1.67 V –3.33 V. Note that one terminal on the capacitor is always at a higher voltage than the other.

Measurements:

5. Measure the value of resistors R_{a2} and R_b and the value of capacitor *C* with your DMM.
6. Construct the circuit shown in Figure 3. Be sure to connect the electrolytic capacitor so that the polarity of the capacitor is correct (the positive terminal should be connected to R_b; see Section 3.9.).
7. Set the trim pot R_{a1} to its maximum resistance. Be sure that the unused terminal of the pot is tied to pin 2 as suggested in Section 3.11.
8. Using your oscilloscope, measure the frequency of operation and duty cycle of the output from the 555 timer. Adjust resistance of the trim pot to obtain a frequency of 0.667 Hz. Measure the maximum and minimum voltages across the capacitor *C* and the values of t_1 and t_2 using the other channel of the oscilloscope. Collect a screen shot of the oscilloscope traces. [Set the trigger on the oscilloscope to stabilize the image if needed.]
9. Remove the trim pot from the circuit. Measure its resistance using the DMM and record the value.
10. Calculate the percent deviation from the expected values of R_{a1}, the duty cycle *D*, and charging and discharging times of the capacitor t_1 and t_2.

$$\%\, deviation = \frac{Expected - Measured}{Expected}\ x\ 100\%$$

11. Insert the trim pot back into the circuit. Adjust the resistance of the trim pot such that the frequency of the 555 time output is 3.33 Hz. Measure the duty cycle of the output

from the 555 timer. Measure the maximum and minimum voltages across the capacitor *C* and the values of t_1 and t_2 using the other channel of the oscilloscope. Collect a screen shot of the oscilloscope traces. [Set the trigger on the oscilloscope to stabilize the image if needed.]

12. Calculate the percent deviation from the expected values of R_{a1}, the duty cycle *D*, and charging and discharging times of the capacitor t_1 and t_2.
13. Reinsert the trim pot into the circuit. Measure voltage across the speaker and calculate the current, assuming that the resistance of the speaker is 8Ω. Calculate the power dissipated by the speaker while the output of the 555 timer is 0V.
14. Calculate the percent deviation from the expected values of the current flowing through the speaker and the dissipated power.

Conclusions

15. Do the measured values of *D*, t_1 and t_2 differ from the expected values as would be expected from the measured values of R_{a1}, R_{a2}, R_b, and *C* when (a) f = 0.667 Hz and (b) f = 3.33 Hz. Why or why not?
16. Explain why the calculated values for the current through the speaker and dissipated power are differ from the expected values.
17. Explain why an electrolytic capacitor can be used for capacitor *C*.

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