Laboratory 7

Implementation and measurement of an audio oscillator; review

rev. 1e

Purpose: Experiments using an audio oscillator built on a breadboard. Measurement of the output signal using different devices. Review: measurement of amplitudes, frequencies and other parameters of signals using different methods. Implementation and measurement of a resistive divider.

Summary of theory

1. The integrated circuit 555

The circuit 555 (with different prefixes: NE555, LM555, etc) is a versatile integrated circuit (I.C.) used in different applications, of type *astable* (oscillator, rectangular signal generator) and *monostable* (generating an impulse of a given duration). The circuit has 8 pins, with the significance from fig. 1. Like for any integrated circuit, the numbering is done in counterclockwise sense, starting with pin 1 marked with a *notch* on the capsule.

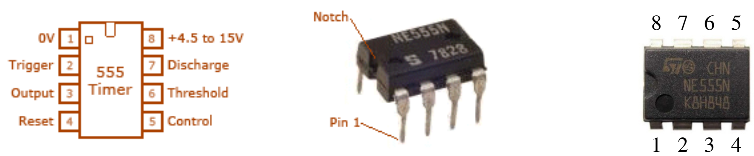

Figure 1: Circuit 555 – capsule, pin numbering

The connection schematic of the circuit in *astable* regime is given in figure 2. At the Vcc and ground terminals we apply the supply voltage from a DC voltage source.

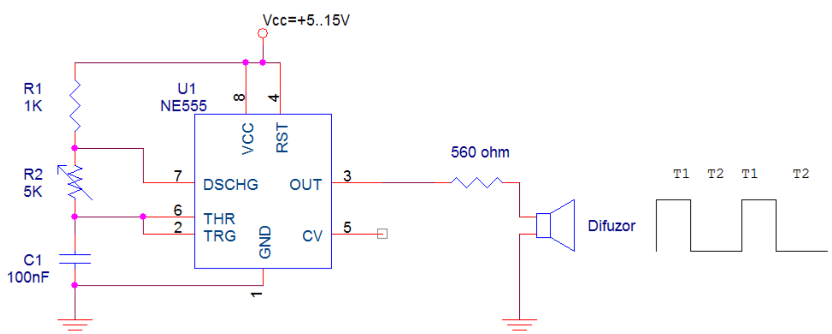

Figure 2: Circuit 555 – schematic for the astable configuration

At pin 3 of the I.C. a rectangular signal with durations T_1, T_2 is generated, having the values:

$$T_1 = 0.7(R_1 + R_2)C \qquad T_2 = 0.7R_2C \qquad (1)$$

Remark: like for most integrated circuits with dedicated functions, the connection of each pin, as well as the formulas which describe the functioning are given in the *datasheet* of the circuit, are based on its internal schematic and are not meant to be learned by heart.

From (1) it follows that the period and frequency of the signal are:

$$T = T_1 + T_2 = 0.7(R_1 + 2R_2)C \qquad f = \frac{1.44}{(R_1 + 2R_2)C} \qquad (2)$$

and the duty cycle is:

$$\eta = \frac{R_1 + R_2}{R_1 + 2R_2} \qquad (3)$$

The rectangular signal alternates between the 2 states „logic 0” and „logic 1”, of durations T_1 and T_2, none of the states being stable (a stable state is a state in which the circuit can stay for an unlimited time), this is why the obtained circuit is called *astable*. If the frequency of the produced signal (oscillation) is in the audible spectrum (tens of Hz... kHz), the circuit acts as an audio oscillator.

Measurements

1. Building the circuit on the breadboard

a) Measure using the DC voltmeter the voltage from the power supply, set on 6V (the value written is approximated – any value from 5... 15V will work).

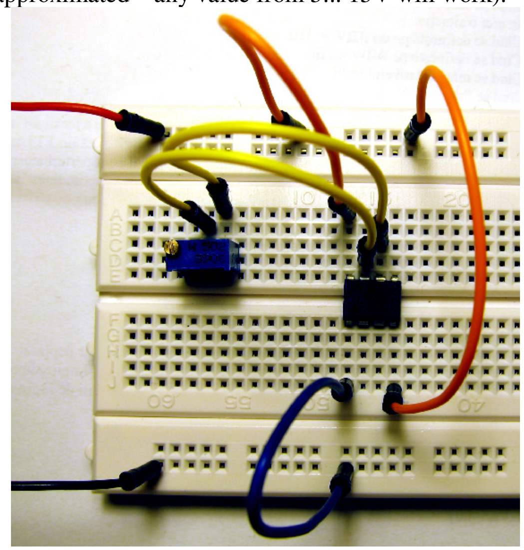

Figure 3: U1-555 and R2 on the breadboard

b) Identify the 1KΩ resistance and the 100nF capacitor and measure their exact values using either the digital multimeter or the LCR-meter.

c) Build the circuit on the breadboard, according to the schematic in fig. 2. The supply of the I.C. is between pins 8 (Vcc – the positive terminal of the DC power supply) and 1 (ground). It can be noticed that pin 4 must be also connected to Vcc. In fig. 3 you have a suggestion on how to begin the circuit, in which the supply cables from the power supply (Vcc and ground) will be connected to the superior and inforior horizontal rows of the breadboard, respectively.

In the figure, only pins 1,4 and 8 were connected to GND and Vcc, the trimmer R2 was connected to pins 6,7 (reminder: 2 of the 3 pins of the trimmer will be connected). Connect the rest of the components according to the schematic!

Remark: the notch in the middle of the board is dimensioned especially for integrated circuits; in this way, each pin of the I.C. comes connected to a vertical group of 5 holes, from which 4 holes remain free to connect other components to each pin;

d) in order to verify the functioning, connect a loudspeaker (buzzer) in series with a resistance of 400.. 800Ω between pin 3 and ground, according to the schematic in fig. 2; by varying with the screwdriver the trimmer R2, the frequency (pitch) of the sound that you hear must vary. By connecting the oscilloscope to pin 3, read the frequency of the trigger signal on the screen (bottom right part of the screen, according to annex A). Set R2 such that the frequency is around 1500-2000Hz (the audible signal at maximum intensity in the loudspeaker). If the frequency cannot be read in a stable way, use Trigger -> SET TO 50% or manually rotate the TRIGGER LEVEL button until the trigger level is approximately in the middle of the screen.

Remark: a rectangular signal of frequency *f* contains the fundamental on frequency *f* and the *harmonics* on frequencies that are multiples of *f*, which is why the sound that you hear will be „higher” that in the case when a sinusoidal signal of frequency *f* (with no harmonics) would be applied. Also, the actual signal is distorted due to the inductive and capacitive effects of the speaker, and differs from the ideal rectangular signal.
The human ear has maximum sensitivity around 1kHz... a few kHz, the exact value depends on the person and the age; additionally, the loudspeaker that was used favors some frequencies over others.

Next, ***disconnect the loudspeaker and the 560 ohm resistor from the output***, leaving just the oscilloscope connected. In the presence of the loudspeaker, the amplitude visualised on pin 3 will decrease, due to the nonzero internal resistance.

2. Measuring the signals produced by the oscillator with 555

a) Set C_X in order to see on the screen between 2 and 4 periods. Measure with the oscilloscope the period T of the signal from pin 3, as well as T_1 and T_2 (see fig. 2), using 3 methods:

- reading on the screen (using the divisions)
- using the time cursors of the oscilloscope

- using the MEASURE menu (only for the period T)

b) Measure using the MEASURE menu of the scope the frequency $\mathbf{f_{meas}}$ of the signal from pin 3. Calculate the frequency $\mathbf{f_{calc}}$ based on the period from point a (measured using the time cursors). By disconnecting R2, measure the value to which it was set by using the ohmmeter from the digital multimeter. Calculate using relation (2) the frequency $\mathbf{f_{theoretical}}$ using the measured values of the components.

Indication: when measuring the trimmer, **do not remove it from the board!** connect 2 fires to the corresponding holes in the board, and to the alligator clips of the ohmeter. However, during the measurement, no other compinent must be in paralell with the trimmer!
Also, note which of its pins (1 and 2 *or* 2 and 3) were used in the circuit, in order to correctly measure the resistance between the respective pair.

Determine the relative errors $\mathbf{f_{meas}}$, $\mathbf{f_{calc}}$ with respect to $\mathbf{f_{theoretical}}$, in percentage.

c) Set the trimmer R_2 such that the duty cycle η of the signal from pin 3 is 66% (by reading the values T_1 and T_2 on the screen of the oscilloscope). Notice that for this circuit you cannot modify η without also modifying the frequency. Compare to the situation from the signal generator, where η and f are different settings, independent (for this, more complex schematics are used).

- Write the definition formula of η as a function of T_1, T_2, determine the theoretical ratio between T_1 and T_2 (figure 2) in order to have η = 66%
- set R_2 while looking at the change of T_1 and T_2 on the screen (in divisions) until you obtain values that satisfy the desired ratio.
- measure R_2 using the ohmmeter (temporarily disconnect it from the circuit)
- calculate $\eta_{(3)}$ based on formula (3)

Compute $T=T_1+T_2$ and based on it, compute f.

d) Measure either the rise time or the fall time of the rectangular signal (at your choice – which one looks better on the scope), using the method from laboratory 2 (detail the image of a rising edge on the screen, by setting small values for C_x, measure the time in which the signal „rises” from 10% to 90% of the amplitude; because the amplitude cannot be modified, bring the signal on vertical between the desired limits of 0 and 100% using the setting **CH1 MENU → Volts/Div → FINE** instead of **Coarse**).

3. Measuring and changing the output voltage

a) Visualize and measure using the 2 channels of the oscilloscope the peak-to-peak values of the signal from pin 3 of the I.C. (rectangular signal) and pin 2 (the signal from the capacitor that is charging/discharging). The frequency remains the same as in the previous point. Set again **CH1 MENU → Volts/Div → Coarse**, in order to have calibrated values. Draw these signals, by setting C_X in order to observe between 2 and

4 periods and C_{y1}, C_{y2} such that the peak-to-peak values occupy between 2 and 3 divisions each.

Read the peak-to-peak values in divisions, then in V, for the signal from pins 3 and 2 of the I.C. The zero levels are placed s.t. the signals do not overlap and do not go out of the screen.

b) measure the DC component of the signal from pin 3, using 2 methods: by using the oscilloscope (switching from AC to DC) and by using the digital multimeter in DC voltmeter mode (DCV button).

c) make a resistive divider from 2 resistors, s.t. the peak-to-peak value from pin 3 of the I.C., applied at the input of the divider, is reduced between 2..4 times (between 50%... 25% of the value measured at point a).

- Choose 2 resistors R_A, R_B (of values between 1..12 KΩ) s.t. the dividing ratio K = U_{out}/U_{in} is between 1/2.. 1/4 (by choice, among the values available on the table)
- Measure the exact values of the 2 resistances and compute $K_{theoretical}$:

$$K_{theoretical}= R_B/(R_A+R_B)$$

- build the divider on the breadboard; draw the schematic.
- measure (using the voltage cursors of the scope) the peak-to-peak value of the signal from the input and output of the divider (U_i and U_o)
- based on the 2 values compute the real dividing ratio:

$$K_{meas}= U_o/U_i$$

- compute the error of K_{meas} with respect to $K_{theoretical}$ (in percentage)

When finishing the lab, remove all the components from the breadboard, *except the integrated circuit and the trimmer, which must be left on the board !*

Preparatory questions for the laboratory

1) What is the significance of an astable circuit ?

2) Compute R_2 s.t. the circuit 555 produces a rectangular signal with η=75%, knowing that R_1=1KΩ.

3) Calculate the necessary C_x in order to display exactly 2 periods of a signal with f=4.5KHz on the screen. Compute the closest calibrated C_x (the calibrated values have the form {1, 2.5, 5}•10^K sec/div). Draw the image for the chosen calibrated C_x.

4) Calculate the necessary C_y in order to display on the entire screen, on vertical, a signal of amplitude A=4.5V. Calculate the closest calibrated C_y (the calibrated values have the form {1, 2, 5}•10^K V/div) s.t. the signal does not go out of the screen. Draw the image for the chosen calibrated C_y.

5) Design a resistive divider with division factor K=1/7, by choosing the values for the resistances.

6) Calculate the relative error due to imprecise reading on the screen (knowing that a value can be read with a resolution of 0.2 div) of a voltage of $7V_{PP}$, knowing C_y = 2V/div, and of a period of 4.5ms, knowing C_x=1ms/div.

7) Calculate the DC component of a signal with peak-to-peak value $3V_{PP}$ knowing that, when switching from AC to DC, the signal moves on the screen upwards with 2/3 of the value of its amplitude.

8) Between which limits (on the vertical axis) is the rise time of a rectangular signal measured?

9) What is the audible frequencies spectrum for the human ear? At which frequencies is the ear sensitivity maximum?

10) (optional) Design an oscillator with 555 that generated a frequency of 20..25KHz, not audible by human, that can be used to eliminate the mosquitos or the aggressive dogs, knowing that they have an audible frequencies spectrum higher than the human beings.