Multivibrators

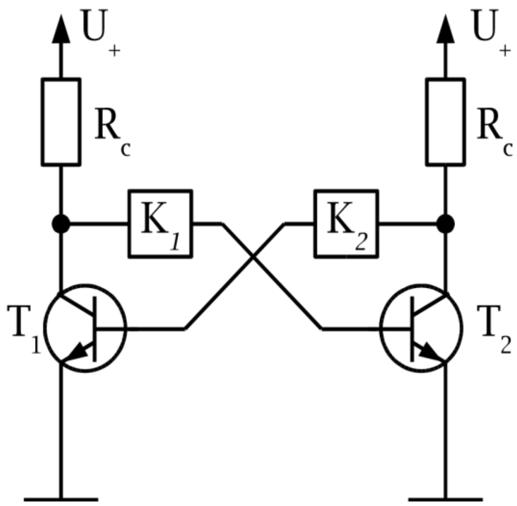
1. Introduction

Types of multivibrators

Multivibrator circuits are positive feedback universal digital circuits used to generate square waves. Their output voltage does not change continuously but can take on two discrete values. The flip can occur in several different ways. Accordingly, there are:

- bistable multivibrator --- both states are stable. The output signal level only changes when the switching process is triggered by an input signal.
- monostable multivibrator --- has one stable state. Its unstable state can be triggered by an input signal and lasts only for a period of time determined by the values of the components. After this time has elapsed, the circuit automatically returns to its stable state.
- astable multivibrator --- has no stable state. Without external control, it periodically changes its output voltage level, oscillating between its two states.

Oscillating circuits are generally shown in Figure 1. The type of oscillating circuit is determined by the feedback loop (K_1, K_2) (Table 1).



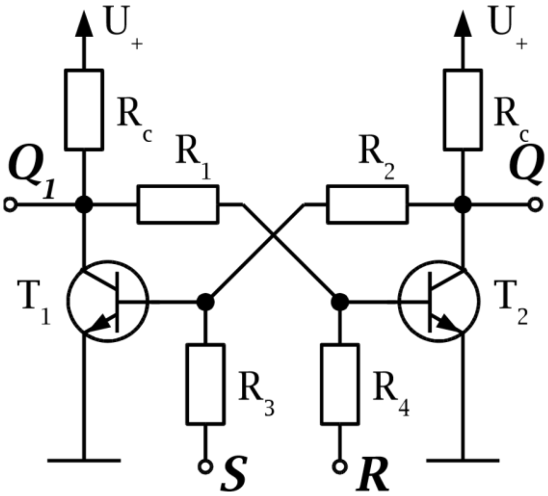
1. Figure–Block scheme of a multivibrators

Type	*K_1*	*K_2*
Bistable	R	R
Monostable	R	C
Astable	C	C

1. table–Feedback loops of multivibrators

2. Bistable multivibrator (flip-flop)

The circuit implementation of the bistable flip-flop is shown in Figure 2.



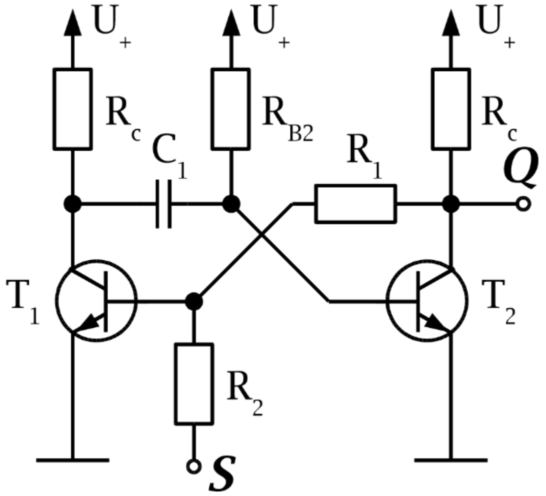
2. Figure–Bistable multivibrator

In the default state, no signal is applied to either the S or R input. In this case, the circuit is in one of the two stable states and remains there (either Q_1=0V and Q_2=U_+, or Q_1=U_+ and Q_2=0V, where U_+denotes the supply voltage). Let us assume that our circuit is in the latter state. If we apply supply voltage to the S input, the transistor opens due to the current flowing through the T_1 emitter-base diode, and the T_1 collector voltage decreases. As a result, the T_2base current decreases and the T_2 collector voltage increases. This increase feeds back through resistor R_2 to the base of T_1 and further increases its base current (positive feedback).
The circuit reaches a stable state when $T_1$is fully open. T_2 is then fully closed and keeps T_1 open via R_2. After this, we can disconnect the supply voltage from the S input, and the circuit remains in a stable state.

We can cause the circuit to switch to another stable state by applying supply voltage to the R input. If power is applied to both inputs simultaneously, both transistors will open. This state is unstable. If we then remove the voltage from the inputs, the asymmetry of the circuit elements will determine which stable state the circuit will switch to. Since the final state cannot be clearly determined in this case, this input combination must be excluded. If we ensure this, then the two outputs (Q_1, Q_2) of the bistable multivibrator (flip-flop) are logically negated with respect to each other.

This circuit is a **memory element**, as it "remembers" the last state it was set to. It can be set with a signal applied to the S input (set) and reset with a signal applied to the R input (reset). Old static RAMs were composed of such elements.

3. Monostable multivibrator



3. Figure–Monostable multivibrator

The circuit solution for a monostable multivibrator can be based on a flip-flop circuit. One of the feedback resistors is replaced with a capacitor. The DC operating point of T_2 must be set with a resistor. This circuit is shown in Figure 3.

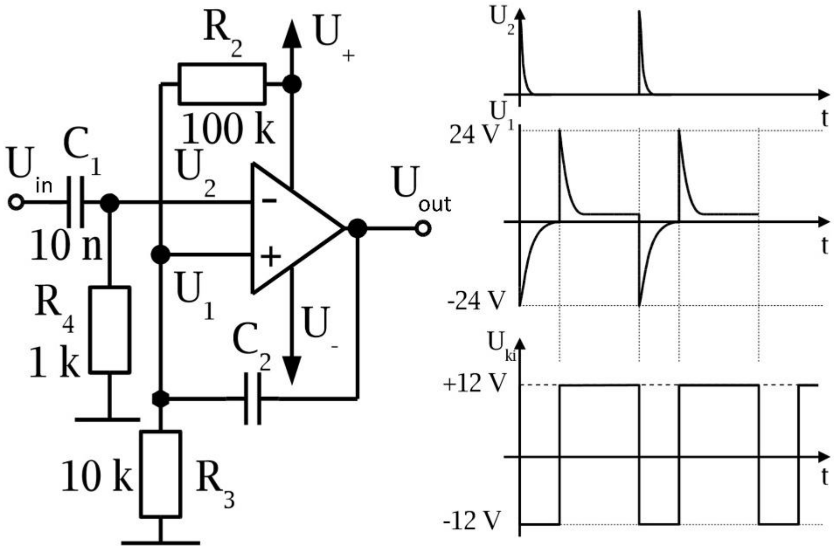
Let's assume that T_1 is in a closed state and the T_2 transistor is conducting (base current flows through R_{B2}). This is the stable state of the circuit. A short positive input pulse applied to S opens T_1, causing the collector voltage of T_1 to drop to nearly zero. This voltage jump is transferred by capacitor C_1 to the base of $T_{2,}$ causing T_2 to turn off and its collector voltage rise to the supply voltage. As a result, T_1 remains open via feedback resistor R_1 even if the signal on S has disappeared. This is not a stable state because the C_1 capacitor begins to charge through the R_{B2} resistor, causing the base voltage of T_2 to increase. After a time determined by the time constant of the $R_{B2}C_1$ element, T_2 opens and its collector voltage decreases. T_1 closes and the circuit returns to its stable state. The duration of the output pulse is determined by the time constant of the R_CC_1 element.

3.1. Monostable multivibrator with operational amplifier

The operational amplifier amplifies the difference between the two voltages applied to its inputs: $U_{out}=A(U_1-U_2)$.
Operational amplifiers typically have high gain, so they only operate linearly with small voltage differences (U_1-U_2). Larger voltage differences cause them to saturate (the positive or negative supply voltage appears at their output).

The ideal operational amplifier is characterized by the following parameters:

- their gain is infinite$A = \infty$
- their input resistance is infinite $R_{in}= \infty\Omega$
- their output resistance is zero$R_{out}= 0\ \Omega$



4. Figure – Monostable multivibrator with operational amplifier

If no signal is applied to the input of U_{in} in the circuit shown in Figure 4 (where U_+=12V and U_-=12V), the inverting input (-) of the amplifier is at ground potential (0V), and the non-inverting input (+) is at a voltage of 1.09V based on the R_2-R_3 voltage divider. The difference between the two inputs causes the amplifier to saturate, resulting in a stable output of +12V.

If we apply a (positive) voltage jump to the U_{in} input, the C_1 capacitor will allow the voltage change to pass through, causing $U_2$to also become positive. If the amplitude of this signal is greater than the potential of the non-inverting input (U_1=1.09V), the amplifier output level will drop to -12V.

This causes a sudden 24V voltage drop on one plate of the C_2capacitor. C_2 passes the voltage change, so the 24V voltage drop also appears on its other plate. After the shift, the voltage U_1=-22.91V formed at the non-inverting (+) input of the amplifier is not stable, as the C_2 capacitor begins to charge and the voltage at the R_3-C_2 point begins to increase towards the equilibrium 1.09V set by the voltage divider.

When U_1 reaches the voltage level of U_2 (which will return to 0V after the spike appears on it), the circuit returns to its stable state. The return is aided by the capacitor as positive feedback.

According to Thevenin's theorem, the voltage divider can be replaced by a 1.09 V voltage generator with an internal resistance equal to the parallel sum of the resistances of the voltage divider (R_p). The current generated in this circuit charges the capacitor. The voltage measured across the capacitor during charging is:

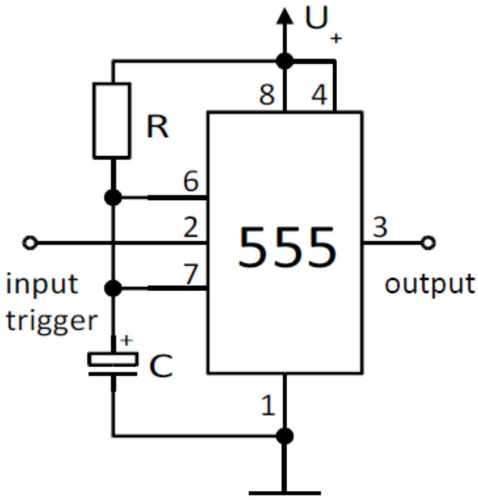
$$U_{C2}=1{,}09\cdot\left(1-e^{-\frac{t}{R_p\cdot C_2}}\right)-22{,}91\cdot e^{-\frac{t}{R_p\cdot C_2}}$$

Expressing the equation in terms of t and solving it, the time of tipping is:

$$t=R_p C_2\cdot\ln\left(\frac{24}{1{,}09}\right)$$

3.2. Monostable multivibrator circuit with universal timer 555

In practice, monostable multivibrators are often implemented using an integrated circuit (IC) designed specifically for this purpose: the 555 universal timer. This component can be used to implement timing functions ranging from µs to several hours.



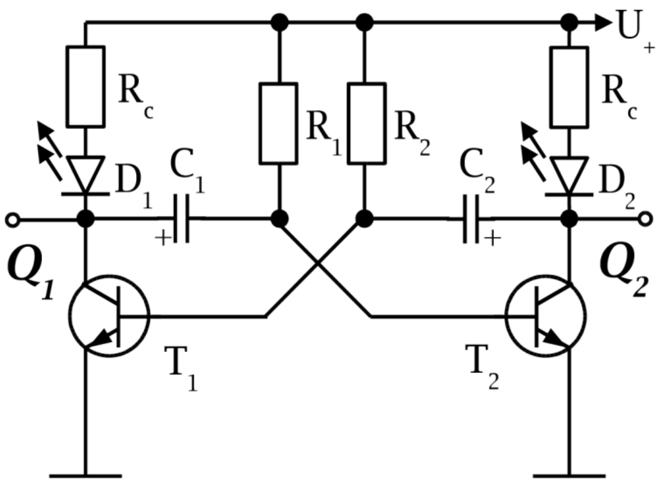
5. Figure - Monostable multivibrator circuit with universal timer 555

The period time of the IC monostable multivibrator (Figure 5) can be calculated using the following formula:

$$T = 1.1 \cdot R \cdot C [s]$$

4. Astable multivibrator

Multivibrators, as two-state electronic circuits, are suitable for generating square wave signals. A typical astable multivibrator circuit is shown in Figure 6. The role of the light-emitting diodes (LEDs) $D_1$and D_2 in the transistor collector circuit is to aid in the visual inspection of voltages.



6. Figure– Astable multivibrator with transistors

Let us assume that the two transistors and the other components form a symmetrical circuit. In this case, both transistors conduct when the circuit is in equilibrium. However, our circuit is not perfectly noise-free.
For example, the switching process causes significant transients. Due to positive feedback through the capacitors (since we feed the signal from Q, which is the output, to the base of the other transistor, which is the input), the circuit is not stable against noise.

Let's assume that due to interference, the collector current of transistor T_1 begins to increase, resulting in an increase in the voltage drop across the resistance T_1R_c. This voltage change passes through capacitor C_1, causing a decrease in the base voltage of T_2. The T_2transistor will therefore be less open, i.e., its collector current will decrease, and its collector voltage will increase. This voltage increase passes through the C_2 capacitor, opening the T_1 transistor more, and the process continues until T_2 closes completely. As a result, Q_1 is close to 0V, $Q_2 = U_+$, and the LED (D_1) lights up.

After a rapid transition due to positive feedback, the capacitors (C_1-C_2) begin to charge. The point connected to the collector of C_1 is close to 0V, but the other point is connected to U_+via resistor R_1. Therefore, capacitor C_1 begins to charge at a rate determined by the R_1C_1 time constant. Due to the charging, the voltage at the base of transistor T_2will reach the opening voltage of the base-emitter diode, and T_2 will begin to open. At this point, a process very similar to the previous one begins, only now on transistor T_2. Thus, the system switches to its other state, with T_2 open and T_1 closed. At this point, Q_2 is close to 0V, while Q_1=$U_+$and D_1 is not lit.

From the above, the duration of the transitions between the two states is proportional to the charging and discharging times of the capacitors. This time can be controlled by the resistors $R_1$and $R_2$and the capacitors C_1 and C_2. τ_1= $R_1C_1$and τ_2= R_2C_2. If τ_1=τ_2, we obtain a symmetrical square wave. If this is not the case, the two states of the multivibrator have different time constants and the output square wave will also be asymmetrical.

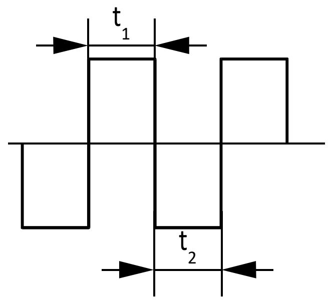
4.1. Astable multivibrator with universal timer 555

This circuit can also be implemented (Figure 7) with a 555 universal timer IC.
The frequency of the square wave can be calculated using the following formula:

$$f = \frac{1}{t_1 + t_2} = \frac{1}{0.693 * C\ (R_1 + 2R_2)}$$

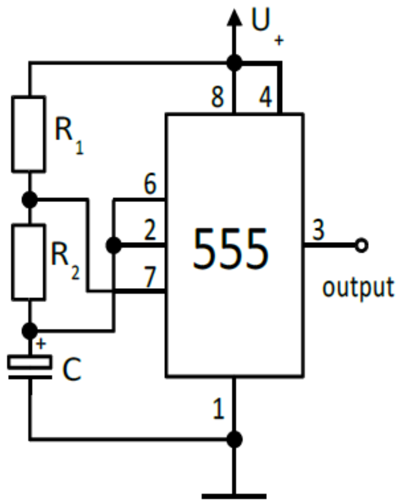
$$t_1 = 0.693 * C * (R_1 + R_2)$$

$$t_2 = 0.693 * R_2 * C \qquad D = \frac{t_1}{t_1 + t_2} = \frac{R_1 + R_2}{R_1 + 2R_2}$$



7. Figure–Rectangular wave with t_1 and t_2 time periods

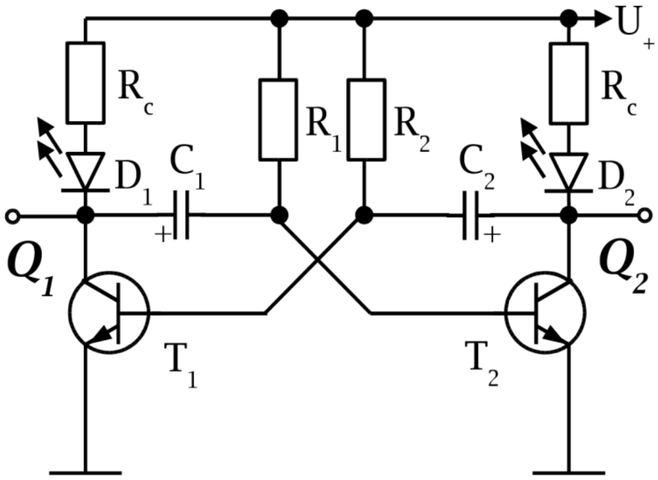
$t_1$and $t_2$are the lengths of the periods, D is the fill factor (the ratio of positive to negative periods).



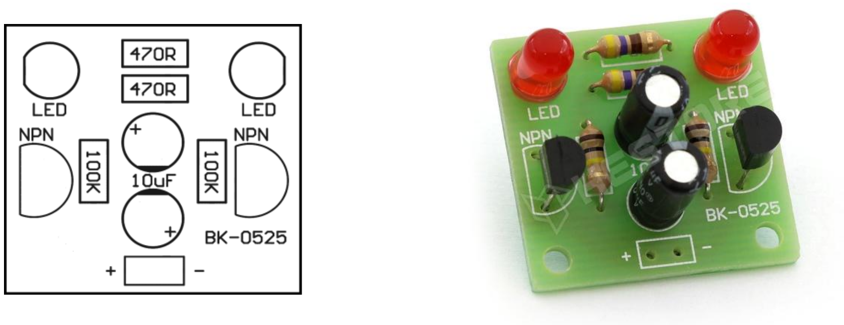
8. Figure - Astable multivibrator with universal timer 555

5. Measurement tasks

M1: Build an astable multivibrator on a predefined circuit board based on the connection shown in Figure 9!



9. Figure - Astable multivibrator with transistors

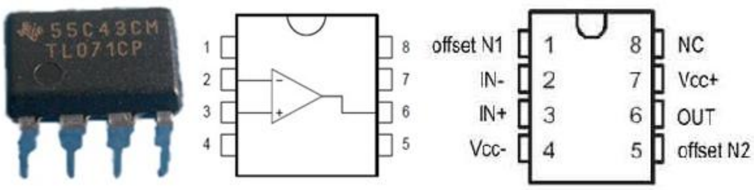


10. Figure–Astable multivibrator circuit diagram and finished circuit

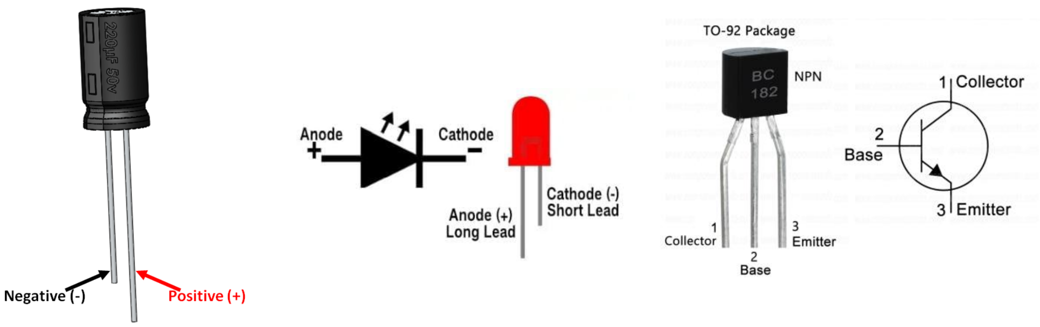
a) Measure the resistance values with a multimeter or read them from the color code. The values of C_1 and C_2 are 10 uF. Calculate the time constants (τ_1, τ_2).
b) Calculate the current of the LED (D_1, D_2) if the open circuit voltage is 1.8V, the supply voltage is 5V, and the series resistor value is R_C=470Ω.
c) Solder the astable multivibrator onto the pre-manufactured printed wiring board. Pay close attention when installing polarity-dependent components! (C_1, C_2, T_1, T_2, D_1, D_2). Solder 1-1 wire to the power supply connections on the board.
d) Connect the circuit to a DC power supply using banana plug crocodile clip wires and apply 5V DC to the panel with the correct polarity. Use an oscilloscope to measure the frequency at which the circuit output oscillates between the T1 collector and ground. Measure the values of τ_1 and τ_2 and compare them with the calculated values.
e) Take a photo of the circuit and the signal shape displayed on the oscilloscope and include it in the measurement report.

M2: Assemble a monostable multivibrator circuit based on the connection shown in Figure 4 on a breadboard. The duration of the switch (during which the output remains at a low level) should be 200 µs. The circuit requires a symmetrical supply voltage (±12V)! Use a µA741 or TL071 as the operational amplifier (Figure 11).

a) Connect the input signal from the function generator to the oscilloscope using a T-splitter and BNC cable. Apply the input signal (100 Hz square wave with a peak value of 5 V) to the circuit using the oscilloscope probe.
b) Change the frequency of the input signal first to 500 Hz, then to 1 kHz, and measure the switch time of the circuit.
c) In your measurement report, explain why the circuit does not maintain a settling time of nearly 200 µs above a certain frequency.
d) Take a photo of the circuit and the signal shape displayed on the oscilloscope and include it in your measurement report.



11. Figure–Pin assignment of TL071 andµA741



12. Figure – Electrolytic capacitor, LED and transistor connection, pin assignment

The measurement report shall list the measuring instruments, generators, cables, and components used, including their type, model number, quantity, and value, if these can be found on the devices.
The size of the photos should be such that the report does not exceed 10 MB.
The report should be in the following format: M5_lastname1_lastname2.pdf