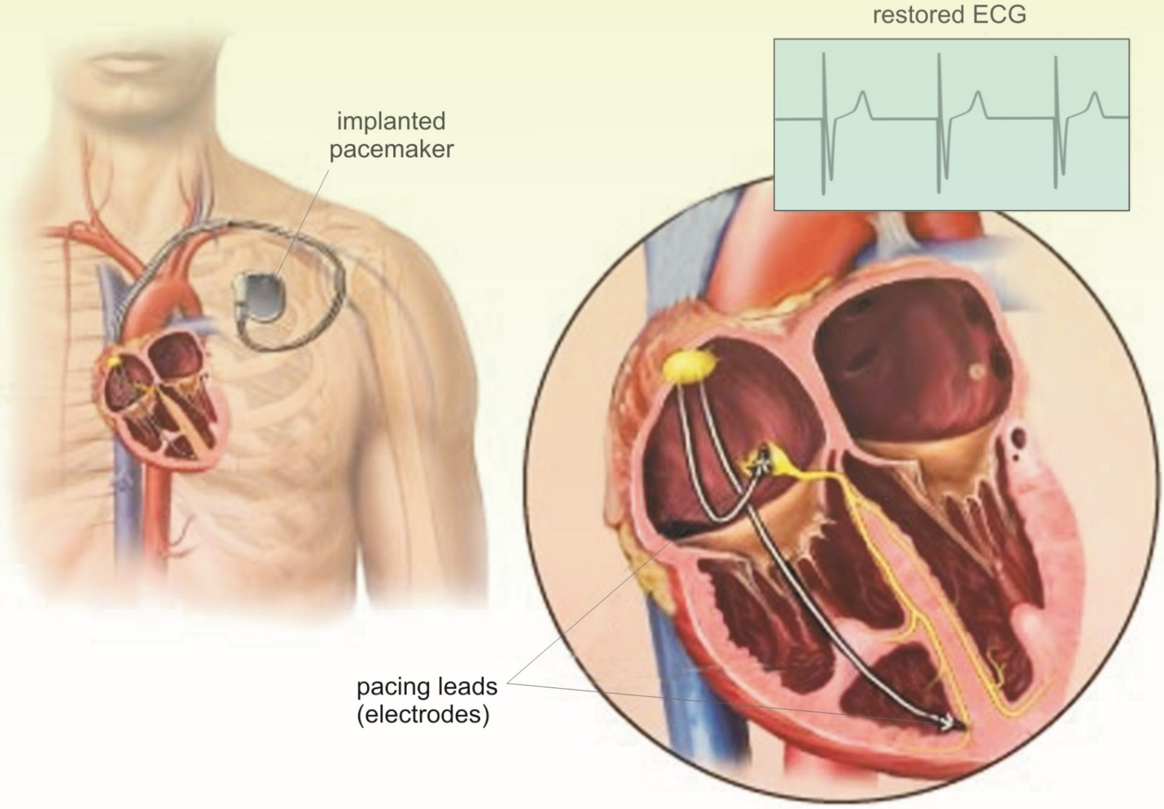
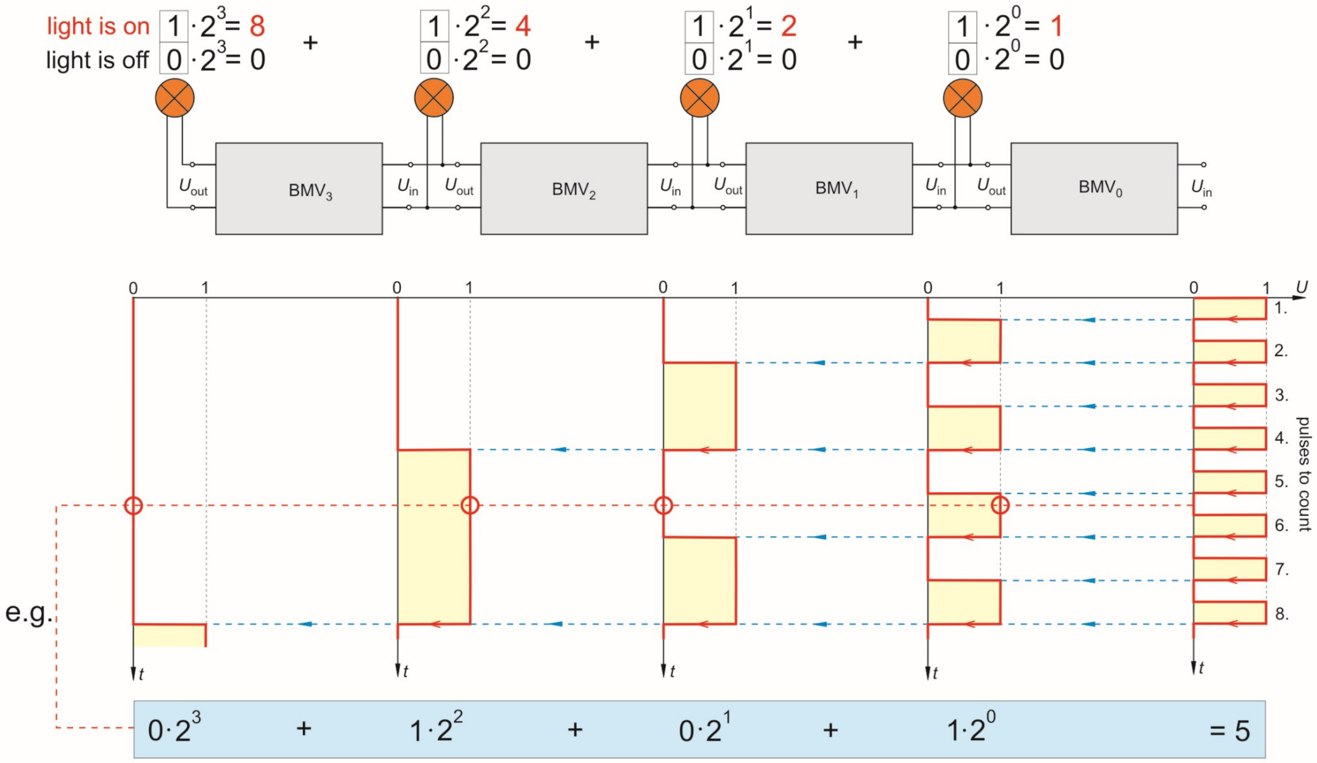
PULSE GENERATOR

GENERATION OF ELECTRIC PULSES, COUNTING OF PULSES



BINARY COUNTER ARRAY



SUMMARY:

MONOSTABLE MULTIVIBRATOR (one-shot, monoflop): a pulse generator producing a single output pulse of defined length for every input pulse (trigger) above a threshold.

ASTABLE MULTIVIBRATOR (relaxation oscillator, free running multivibrator): a pulse generator producing a sequence of identical pulses. It can be constructed by connecting two monostable multivibrators in a ring.

BISTABLE MULTIVIBRATOR (flip-flop, biflop): a „pulse generator" that requires an input pulse (trigger) for the activation of either of the two stable states. By connecting several bistable multivibrators in an array a binary counter array may be constructed.

Further readings:
Damjanovich-Fidy-Szöllősi:
VII / 1. 7., IX / 4.

*Electric pulses are applied in **medical practice** both for diagnostic and therapeutic purposes. Different response to the electrical stimulation in the form of pulses of different length and amplitude indicates the normal function or malfunction of nerves and muscles. Electric pulses are often used for the stimulation of damaged skeletal muscles in order to restore lost function. They can be applied for the stimulation of the heart muscle as well. If the natural pacemaker cells of the heart are not working sufficiently or the electrical conduction system is damaged an artificial pacemaker can be implanted. Defibrillator is used to stop the deadly condition of ventricular fibrillation in which the heart beats very fast but too superficially for sufficient pumping of blood. In both of these applications electric pulses of different shapes are used. In the following we will discuss electric pulses of the simplest, square shape.*

THEORETICAL OVERVIEW

Ttwo-state (digital) systems — with fast transitions between the **resting and activated states** — produce pulses typically of **square** shape. They may exist in the resting or activated state only. As the system may not stay in between the two states (forbidden state), it will fall into either of the two permitted ones. The permitted states can be either stable or non-stable. The common names and symbols of the resting and activated states are:

activated state	active	excited	set	ON	High (H) level	B	1
resting state	passive	ground	reset	OFF	Low (L) level	A	0

The above-mentioned meaning can have any physical parameter (e.g., electric potential) or biological and physiological states (e.g., passive and active states of the nerve cell, blink of the eye, etc.). **Transition** between the two states is always **evoked by a signal**, which is a pulse that exceeds some threshold level (the falling edge of this pulse may also work). This is called a **trigger pulse** named after the trigger of the rifle (Fig.1).

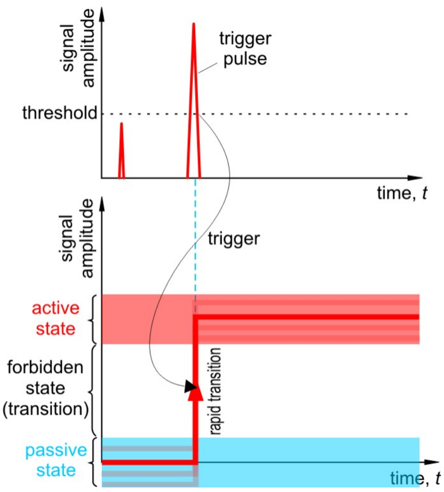


***Fig. 1.** Characteristic states of two-state system. Transition between the states is induced by a trigger pulse exceeding the threshold level.*

PULSE GENERATORS

There are three types of pulse generators: **monostable, astable and bistable multivibrator**, which are characterized by 1, 0 and 2 stable states, respectively.

MONOSTABLE MULTIVIBRATOR (E.G., DEFIBRILLATOR)

one-shot, monoflop
monostabiler Multivibrator, Monoflop
monostabil multivibrátor

Monostable multivibrator is also called one - shot or monoflop. **Triggered** by an input pulse it gives a **single output pulse** (usually square pulse) **of determined duration** (Fig. 2). The rising edge of the square pulse is induced by the trigger signal, but the system returns spontaneously without further triggering to its stable state (dropping edge) after the time given by the time delay (T). The system stays in the stable state until another trigger pulse arrives.
Examples:

- Every time the trigger is pulled, the pistol shoots one bullet (one-shot).
- Melody doorbell: when a button of the bell is pushed (trigger) the bell becomes activated and plays a tune of a given duration.
- The nerve cell responds to the transmembrane potential exceeding a threshold (trigger) by a short action potential.
- **Defibrillator**: the electrodes placed on the chest deliver the electric charge of the charged capacitor to the heart upon pressing the start button of the device (trigger).

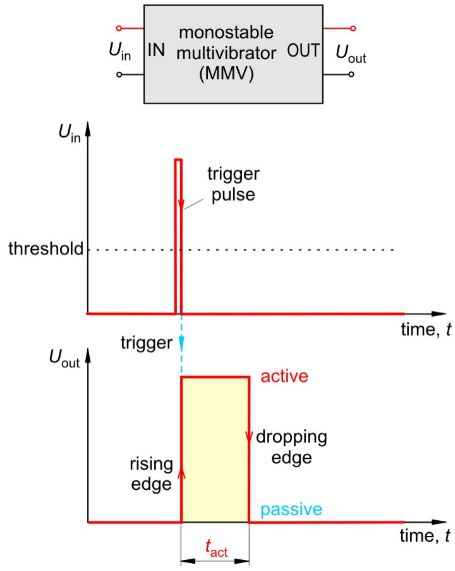


***Fig. 2.** The monostable multivibrator jumps to the activated state for a determined time following the trigger pulse.*

Let us take a closer look at the possibility of electronic timing (setting the delay time T) with regards to the defibrillator (Fig. 3). The resistance of the chest is R, at which the capacitor of capacitance C is discharged. Exponentially decreasing electric current I flows through the resistance R, and we encounter a voltage U decrease of similar shape. The **time constant** (lifetime, $T=\tau$) of the process is given by the time the voltage on the timing capacitor decreases to U_0/e value. The defined duration of this special "pulse", thus the time constant of the exponential process is given by the product of the resistance and the capacitance:

$$\tau = R \cdot C. \qquad (1)$$

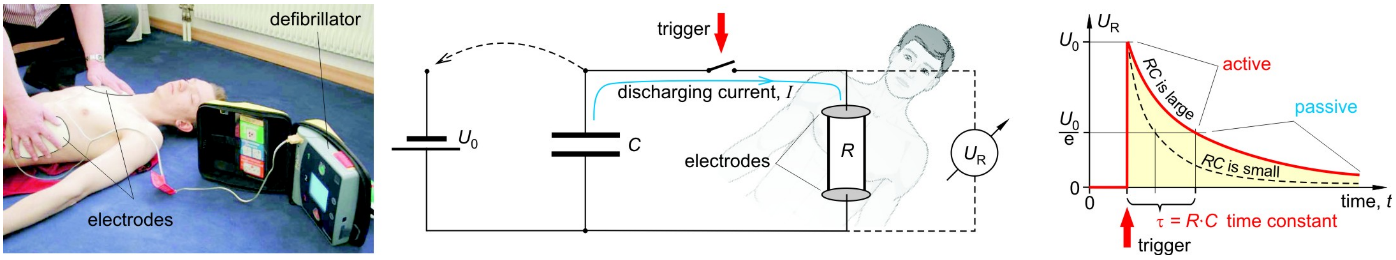


Fig. 3. Principle of operation of the defibrillator. The time constant of the pulse can be set by the R and C elements of the circuit.

Although we know from practice 24. SKIN IMPEDANCE that the skin and the human body can be modeled by R and C elements connected in parallel circuit, in the case of the defibrillator as the voltage change is relatively slow, the ohmic resistance (R) dominates. Only this is shown in Fig. 3.

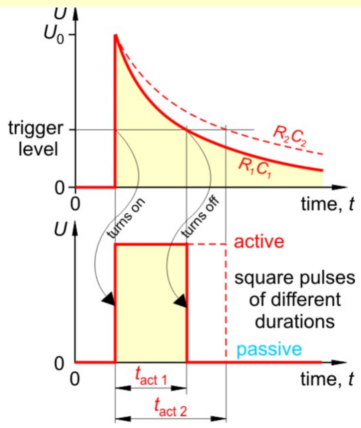


Fig. 4. Generation of a square pulse.

free running multivibrator, relaxation oscillator
astabiler Multivibrator, Rechteckgenerator
astabil multivibrátor

The pacemaker to be implanted produces pulses of $U = 5$ V amplitude and $T = 2$ ms length. The resistance of the tissues between the electrodes is $R = 2$ kΩ. The planned average heart rate is $f = 70$/min. Only 25 % of the total used energy is utilized in the form of pulses. What ampere-hour (Ah) lithium battery of 5.6 V is required to operate the pacemaker for 10 years?

The energy of one pulse is:

$$E_P = \frac{U^2}{R}\tau = \frac{(5\text{V})^2}{2\,\text{k}\Omega} 2\,\text{ms} = 25\,\mu\text{J}\ .$$

Number of generated pulses in 10 years is:

$N = 70\,/\,\text{min} \cdot 60\,\text{min}/\,\text{h} \cdot 24\,\text{h/d} \cdot 365\,\text{d/year} \cdot 10\,\text{years} =$
$= 3{,}68 \cdot 10^8$ pulses.

The total energy of the all pulses is:
$E_t = N \cdot E_P = 3{,}68 \cdot 10^8 \cdot 25\ \mu\text{J} = 9{,}2$ kJ.

The battery should provide four times more energy, thus:
$E_e = 4 \cdot E_t = 4 \cdot 9{,}2$ kJ $= 36{,}8$ kJ.

The charge Q that is needed to be produced by the battery of 5.6 V is:

$$Q = \frac{W}{U} = \frac{36{,}8\,\text{kJ}}{5{,}6\,\text{V}} = 6571\,\text{As}\ .$$

Thus the required "capacity" (amount of charge) of the battery in Ah units is:

$$\frac{6571\,\text{As}}{3600\text{s/h}} = 1{,}82\,\text{Ah} \approx 2000\,\text{mAh}$$

In electronics the **timing of a monostable multivibrator** is usually realized by an ***RC*-circuit** (Fig. 4) resembling that in Fig. 3. The exponentially decreasing voltage of a discharging capacitor controls a switching circuit which turns on and off according to the trigger voltage level, thus we obtain a square pulses of controlled durations, set by the values of R, C and/or the trigger level.

ASTABLE MULTIVIBRATOR (E.G. PACEMAKER)

By connecting two monostable multivibrators (MMV) in a ring (Fig. 5) we get the **astable multivibrator** (AMV), which is also called free running multivibrator or relaxation oscillator. The output of the first MMV (see Fig. 2, falling edge) triggers the second MMV, which triggers the first MMV and this process continues on and on. This way we get a periodic square pulse generator. Any of the connected in- and outputs can be used as the AMV output.

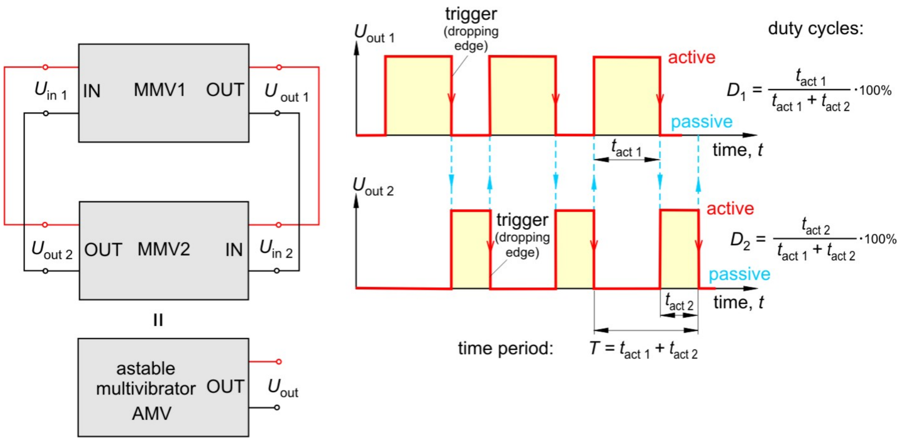


Fig. 5. Construction of the astable multivibrator from two monostable multivibrators.

The **time period** of the AMV is the sum of the individual active-state durations of the MMV_1 and MMV_2.

$$T_{AMV} = \tau_1 + \tau_2. \tag{2}$$

The pulse width of the two MMV-s can be adjusted individually by their RC elements; therefore, a square pulse train of any **duty cycle** can be produced. The duty cycle determines what portion (percentage) of the time period is occupied by the pulse itself, thus by the activated state. For the duty cycles of the output signals $U_{out\,2}$ (see Fig. 5) we obtain:

$$\text{duty cycle} = \frac{\tau_2}{\tau_1 + \tau_2} \cdot 100\% \tag{3}$$

The contractions of a healthy heart are controlled by electrical pulses similar to those produced by the AMV-s. There are several cells that create these stimuli as: sinoatrial node (SA node), atrioventricular node (AV node) and the cardiac muscle cells themselves. These are called pacemaker cells, and they directly control the heart rate. In case of the impaired function of the SA node the AV node takes over the pacemaker function, except with a somewhat slower rate. If this does not work either, or the conduction system is impaired, the ventricular cells will control the contraction but with even slower rate (bradycardia). In this condition an **artificial pacemaker** (called simply pacemaker) is implanted in order to restore the normal heart rate.

The pacemaker is such an AMV that has a resting state of 0.8 – 1 s (τ_1) and an activated state of 0.05 – 2 ms (τ_2). The output voltage of the active state (U_{out} that stimulates the cardiac muscle) is adjustable between 0.8 and 5 V. The pacemaker that is implanted under the skin has a long-lifetime battery or an accumulator that is rechargeable inductively from outside. The pacing leads are directed through one of the veins into the chambers of the heart and attached at the proper place to the heart muscle (see upper part of the title figure).

The pacemaker itself provides an artificial trigger function for a slow or irregular "biological astable multivibrator" (the heart) in order to induce contractions at the proper rate. Modern pacemakers carry out this job only if the heart's own pacemaker function is not sufficient (demand function).

Functions of a particular pacemaker can be read from the 4 or 5 character code-table (Table .1).

I.	II.	III.	IV.	V.
chamber(s) paced	chamber(s) sensed	response to sensing	rate modulation	multisite pacing
0 = None	0 = None	0 = None	0 = None	0 = None
A = Atrium	A = Atrium	I = Inhibitory	R = Rate modulation	A = Atrium
V = Ventricle	V = Ventricle	T = Triggered		V = Ventricle
D = Dual (A+V)	D = Dual (A+V)	D = Dual (I+T)		D = Dual (A+V)

Table 1. Code table as of 2019.

In some older unbits at the IV.th position the code „C" is also used: this indicates external communication (for progarmming, etc.). The newer devices have this as default, and is thus not indicated anymore as a feature.

Pacemakers always have the available functions printed ont he housing with the standardized codes. The sample device on fig.6. shows VVIR/AAIR as the codes, which means the device can operate in two modes.

***Figure 6.** Sample device shown with the printed codes. This particular device can operate in two different*

Different types of electrodes can be applied as a mode of connection, this is also indicated in the housing (unipolar/bipolar). The unipolar electrode uses the housing as the positive pole, while the end of the cable serves as the negative pole. The bipolar cable has an additional metal ring approximately 1cm from the end, which serves as the positive pole instead of the housing.

I. Ihis code tells the site of pacing (excitation). In this case it is V or A, so this device can pace in either the ventricle or in the atrium.

II. The second code tells the site of sensing (where the device senses if there is a normal operation, or any signal from the heart). In this device it is alsoV/A.

III. The third code tells the response of the pacemaker if the sensing chamber supplies a signal to the device. The I: inhibitory mode blocks (inhibits) the pacing, if the device detects normal heart function. It will only pace if a pulse is missing. The T: Triggered mode can be used in the pacing and sensing chambers are different, such as in AV-block condition. The device in fig.6. is in inhibitory mode.

IV. The fourth code inidicates if the device can adapt to the frequency of the heart. R: rate modulation, in this mode the device adapts to the sensed pulse rate as the load of the patient requires. The devices can also gather information from additional sensors (such as saturation) and set the frequency accordingly. This device in fog.6. is capable of rate modulation.

V. The fifth code indicates if the pacemaker device is capable of multi-site pacing. If yes, then multiple electrodes can be installed to delicer pacing to sveral parts of the heart. The device in fig.6. does not have this function, this place is empty. (the 0 is often not printed ont he end of the codes)

BISTABLE MULTIVIBRATOR (E.G., MEMORY UNIT)

biflop, flip-flop
bistabiler Multivibrator, Flipflop
bistabil multivibrátor

The trigger pulse induces a **change of the state of the bistable multivibrator** (Fig. 6). If it was in the state A before, it is flipped to state B; and if it was in state B then it is flipped into the state A, and will remain in either state indefinitely, unless triggered again. This circuit has two equivalent, stable states, as the name "bistable" indicates.

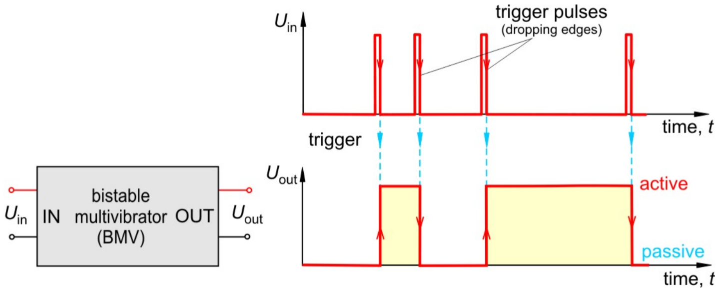


Fig. 7. *The state of the bistable multivibrator is changed by the trigger.*

Examples and comments:

- ON/OFF (toggle) switches: switching is the trigger that changes the state of the device (ON, OFF, ON… etc.)
- memory unit: writing and erasing (trigger) changes the content of the memory unit (0→1, or 1→0), and because both states remain indefinitely, it is memorized. The memories of the digital computers are made of BMV-s.
- Let us see Fig. 6: notice that number of output pulses is always half of the number of input pulses, thus the BMV can be used as a frequency divider.
- connecting several BMV-s in series we get a binary counter array (see the title page). The arithmetical units of the digital computers are made of BMV-s.

PLAN OF THE EXPERIMENT

DEMONSTRATION:

1. Demonstration of the pulses of the pacemaker on the oscilloscope.
2. Demonstration of the pulse shapes of the MINISTIM electrotherapeutical generator on the oscilloscope.

TASKS:

There are two identical monostable multivibrators (MMV) built in the prepared panels that students use for the individual measurement (Fig. 7). The value of resistance *R* in its *RC* circuit is adjustable continuously between 1 and 10 kΩ.; two different capacitors can be connected ($C_1 \cong 100$ μF, $C_2 \cong 1$ μF) into the circuit. MMV-s can be triggered either from the output of the other MMV or by releasing the start button ("START"). There is a counter array as well on the panel, which contains four pieces of bistable multivibrators (BMV-s).

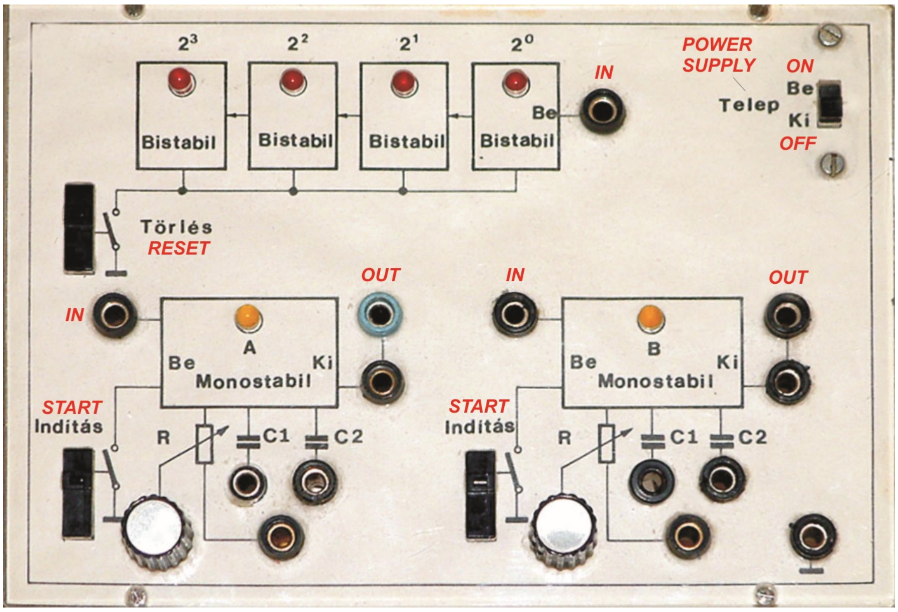


Fig. 8. *In the different setups of the panel students will study the function of the monostable, astable and bistable multivibrators.*

MONOSTABLE MULTIVIBRATOR

1. Select the capacitor of higher capacitance (C_1) and observe the length of the activated state (when the LED lights up) for different resistance (R) settings.

2. Repeat the task above so that the change of the voltage between the resting and activated state is monitored using the DC input of the oscilloscope (See Chapter 17. MEASUREMENT TECHNIQUES, recommended settings: X: 1 ms/DIV and Y: 1 V/DIV). Measure the difference between the two voltage levels and their difference (amplitude of the square pulse).

3. Connect the output of the MMV to the bistable counter array and follow the counting of the pulses. The number of counted pulses is given by the numbers above the LEDs that are lightened up.

4. Select the capacitor of higher capacitance (C_1) at the RC circuits of both MMV-s. Connect the output of the first MMV ("A") to the input of the second MMV ("B") and repeat the task 1 so that the first MMV ("A") is triggered.

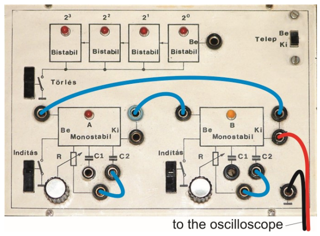


Fig. 8
Setup for the astable multivibrator.

ASTABLE MULTIVIBRATOR AND BISTABLE MULTIVIBRATOR ARRAY

5. Make an AMV by connecting the outputs of the both MMV-s to the inputs of the other MMV. Select the capacitor of higher capacitance (C_1) at the RC circuits of both MMV-s. After adjusting the different values of the resistances **observe the changes of the lights by eye**. After connecting the AMV output to the BMV array observe the counting of a slow pulse train.

SIMULATION OF THE PULSES OF THE PACEMAKER

6. Measure the active and passive times of the pulses of the pacemaker on the oscilloscope. Calculate the period time, the frequency and the duty cycle. Based on the codes on the device identify the functional modes of the pacemaker.

7. Select the resistance setting combination from the available ones from the previous task, for which the space factor of the pulse train most closely resembles that of the pacemaker. Measure the active and passive times, and calculate the frequency and the duty cycle. Compare the pulses you have generated to the pulses of the actual pacemaker. Calculate the energy of one pulse and the charge that would get through a tissue of resistance $R = 2000\ \Omega$.