Crystal Clear Electronics

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08 - Astable Circuit

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In this chapter of the curriculum, you will learn about the simplest and most well-known LED flasher circuits.

What does astable mean? Maybe this was your first thought when you read the title. For now, let it remain a secret. Let's build the simplest astable circuit, and we will reveal the meaning of the phrase while understanding its operation.

Astable Circuit With Transistors

First, build a 5 V power supply with the previously known 7805 voltage regulator.

Then build the astable circuit on the breadboard based on the circuit diagram shown in Figure 1. You can see a possible layout in Figure 2.

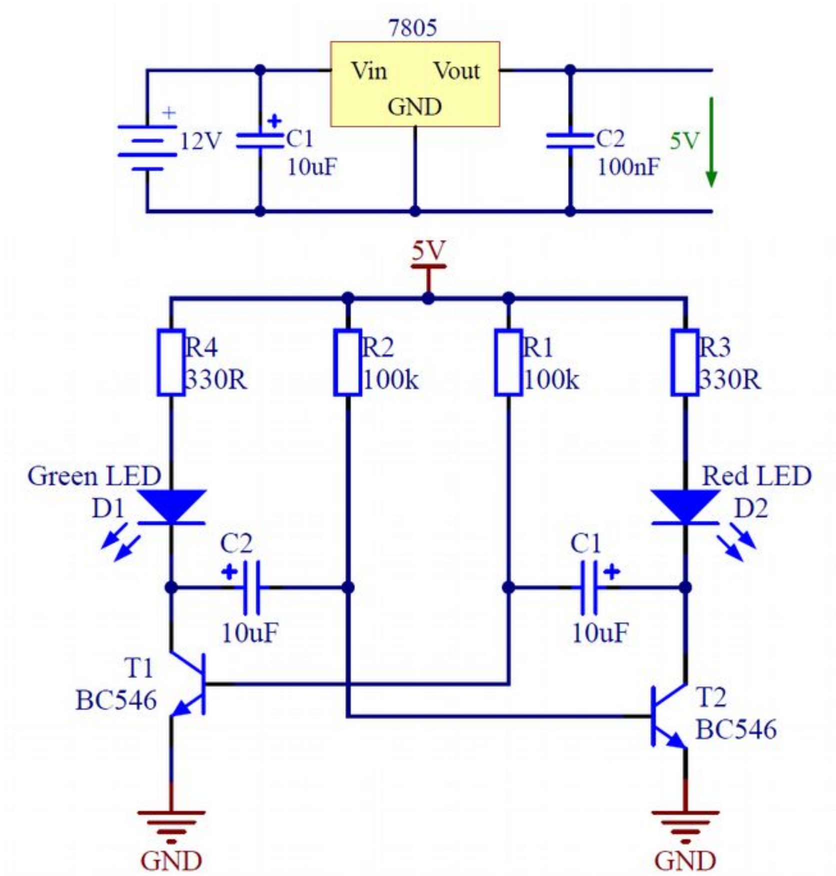

Figure 1 - 7805 voltage regulator and realization of astable circuit with transistors

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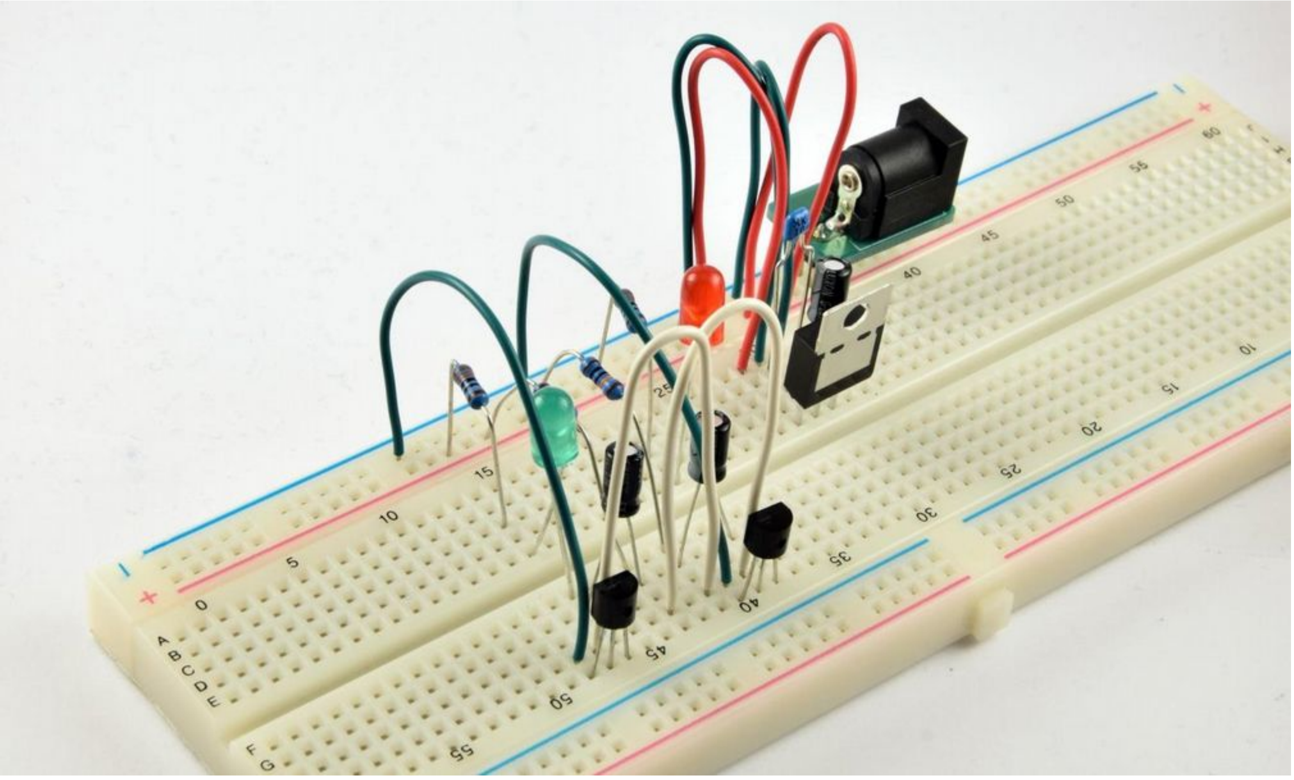

Figure 2 - A possible composition of the circuit on the breadboard

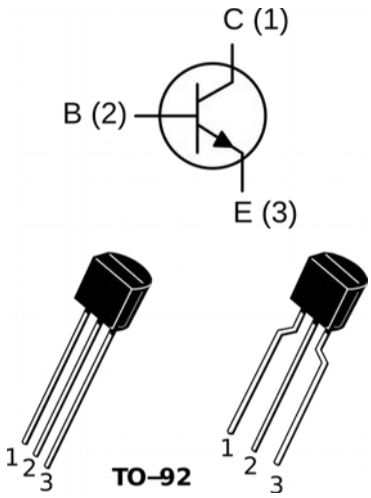

Figure 3 - BC546 transistor pin assignment

Connect 5V voltage to the circuit using the constructed power supply! You will notice that the two LEDs are blinking alternately approximately with a period of 0.5 to 1 second.

LET'S EXPERIMENT!

Don't forget: before changing a circuit on the breadboard, always turn off the power supply.

First, replace the R1 resistor with 33 kΩ. After the power is turned back on, the LEDs are blinking asymmetric, the D2 LED will light for a shorter time than the other. The same happens with LED D1 when

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you replace R2 (while R1 is 100 kΩ). If you replace both resistors with 33 kΩ, then the blinking will be symmetrical again, but it will be about three times as fast as it was with the 100 kΩ resistor. From this we can draw a conclusion that the blinking frequency is related to the value of R1 and R2.

Let's continue our experiments! Replace C1 with a 22 uF capacitor. Blinking is asymmetric again, now the D2 LED lights up for a longer time. You can experience the same with the D1 LED when you replace C2 with a 22 uF capacitor. If you replace both C1 and C2 with 22 uF, the blinking will be symmetrical and about half as fast as before. So the blinking frequency also depends on the capacity values.

If you try to replace R3 and R4 resistors, for example, with 1 kΩ, the blinking frequency will not change, but the brightness of the LEDs will be different (try strictly with higher values, because a lower value than 220 Ω can damage the transistor and the LED!).

In summary, you have found that the blinking frequency is defined by the values of R1, R2, C1 and C2. How does this circuit work?

Operation

Let's start with the case that the transistor T1 is in conducting state (**D1 is lighting**) and T2 is closed (**D2 is not lighting**). Then the voltage on the T1 collector is nearly zero.

In the first half of the entire cycle, C2 is charged via R2, the voltage measured on the capacitor slowly increases, and the voltage of the right arm (in the figure) reaches T2's forward voltage (about 0.7 V).

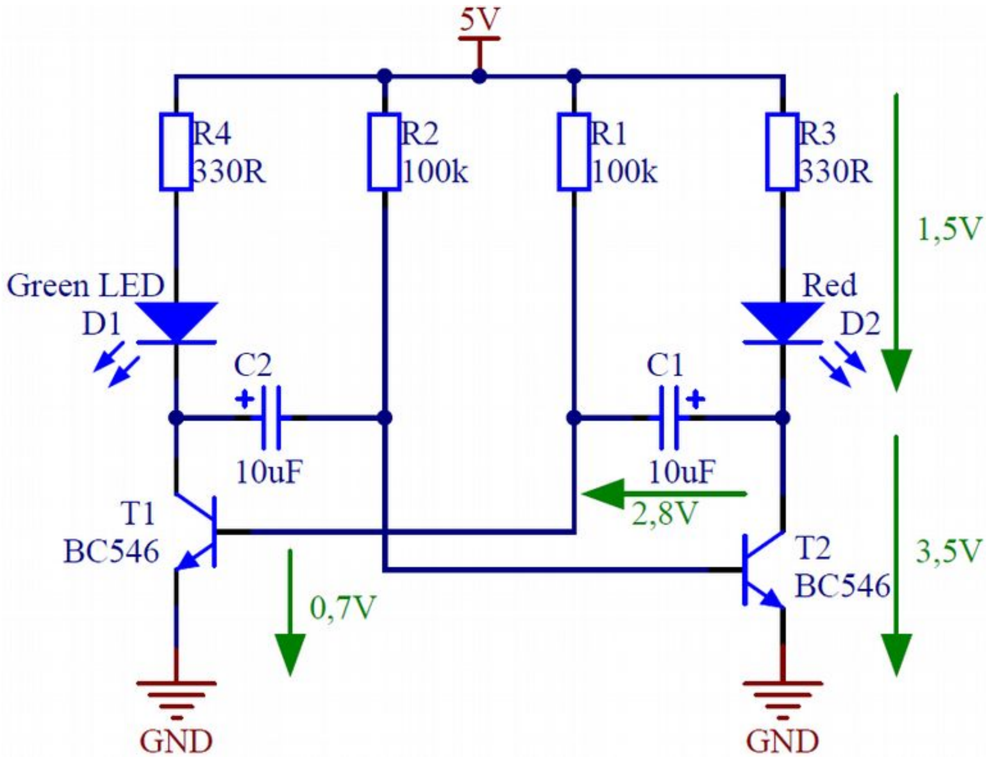

Figure 4 - Voltages, when T1 is open, and T2 is closed

At this moment, T2 transistor opens, its collector voltage will be zero, so **D2 lights up**. Practically **at the same time D1 turns off**, but why?

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To understand, you first need to know that the voltage between the capacitor's arms cannot change instantaneously. Therefore, at the moment of switching, the voltage before switching can be measured on capacitor C1.

How high was this voltage? Figure 4 shows the voltages before the switching happened. At the right side of C1, the voltage is the supply voltage minus the LED forward voltage, and on the left arm has 0.7 V, because T1 is open. The voltage measured on the capacitor should be the difference of these two voltages

$$U_{BE1} + U_{C1} - U_{CE2} = 0$$

that is, 2.8 V (in the marked direction).

At the moment of switching T2, the voltage of the capacitor remains the same, but the collector voltage of T2 decreases to zero.

Based on Kirchhoff's voltage law,

$$U_{BE1} + U_{C1} - U_{CE2} = 0$$

the base-emitter voltage of transistor T1 is -2.8 V, which is less than its forward voltage. For this reason, T1 turns off, and no more current flows through D1. That's why D1 turned off when D2 lit up.

So right now, D2 is on, while D1 is not.

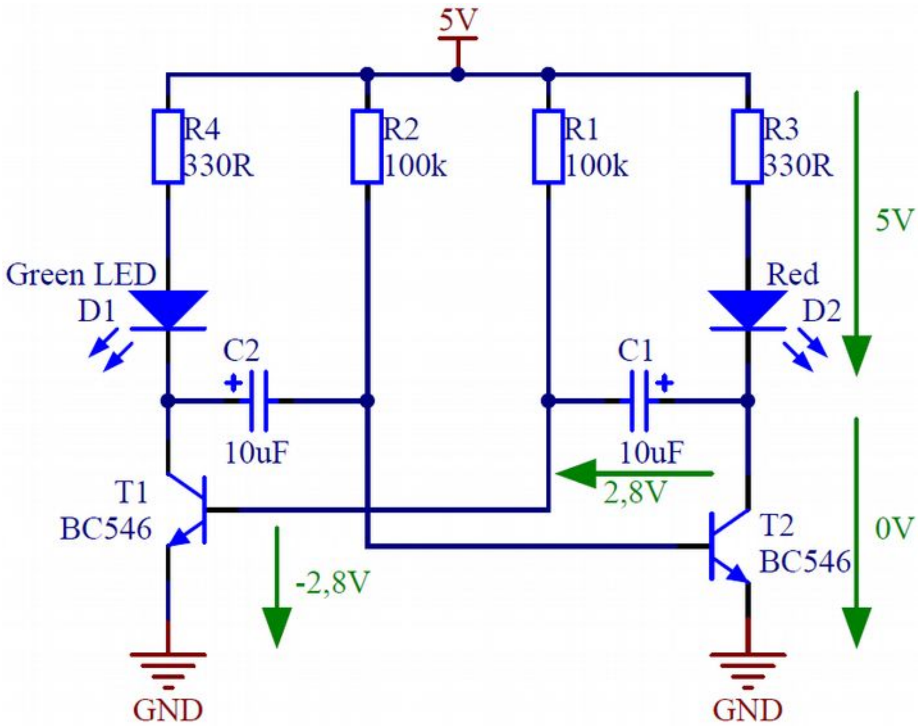

Figure 5 - Voltages immediately after opening T2

In the second half of the entire cycle, R1 will charge C1, which means that the voltage of the base-emitter of T1 will increase up to 0.7 V. At this point, the T1 transistor conducts (**D1 is on**), the capacitor C2 retains its pre-change voltage, which results that the base-emitter voltage of T2 will be -2.8 V. This will turn off T2 (**D2 is off**). From there, the process is repeated.

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Let's Measure!

The principle of operation can also be checked by measurement. Replace R1 and R2 with 1 MΩ resistors, C1 and C2 for 22 uF capacitors, and then turn on the voltage on the circuit! The replacement of the components was necessary to keep the blinking speed much slower so you can follow the change of voltage on your meter.

Touch the COM wire of the multimeter to the ground of the circuit, the positive wire to the base of one of the transistors and observe how the base voltage changes! When the LED in the collector circle of the transistor extinguishes, the voltage will be negative (about the difference of the supply voltage and the LED opening voltage) and then slowly grows up to about 0.7 V, then the LED will light up. This complies exactly with the principle of operation of the circuit.

During the measurement, the period of blinking may change. This can occur if the so-called internal resistance of the multimeter you use is comparable to the size of the resistors used in the circuit. You don't have to worry about this phenomenon for the time being, so you can pay attention to the change in voltage.

What Is The Period of Blinking?

It can be seen that the turn-on time and switch-off time for T1 and T2 are set by the time required to charge the capacitors C1 and C2, which in this case are defined by the values of the components R1-C1 and R2-C2.

It can be deduced that the required charging time is:

$$t = 0.69 \cdot R \cdot C$$

Which in our case:

$$t = 0.69 \cdot 10\ [\mathrm{k}\Omega] \cdot 10[\mu\mathrm{F}] = 0.69 \cdot 100 \cdot 10^3 \cdot 10 \cdot 10^{-6} = 0.69\ [\mathrm{s}]$$

You also saw the LEDs blinking at a slightly smaller interval than a second. It is also clear from the formula that if you reduce the value of the resistance, the time when the transistor is on, will be reduced (this is the time when LED is on), which corresponds to your experience. It can also be read that if you increase the capacitor's capacity value, this time will increase, i.e. the blinking will slow down. You could also experience this when we replaced the capacitors.

Conclusion

During the experiment, before understanding the operation, you have already discovered how to change the blinking time. By understanding the operation, you can exactly "predict" how much blinking time is expected.

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WHAT DOES ASTABILITY MEAN?

The meaning of the word stability refers to permanency, constancy, and 'a' is an alpha privative, that is, the meaning of the word astable is 'not permanent', 'variable'. In this circuit, the state of the transistors was not constant, they were turning on and off.

The measurable voltage at the collectors was either 0 V or close to the supply voltage. The voltage, which is changing between these two values, is called a square wave.

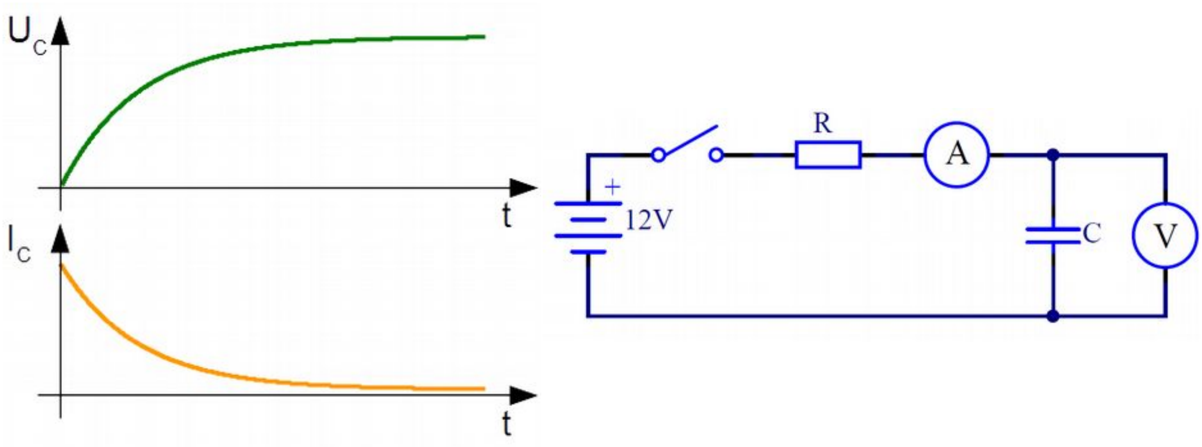

Figure 6 - Capacitor's voltage and current during charging

How does a capacitor's voltage change when charged through a resistor?

Suppose there are no charges initially on the capacitor. Suddenly the power supply is connected to the resistor. At this moment, the charges start to flow to the capacitor, i.e. the current will flow, as large as if the condenser would be replaced by a wire, i.e. a short circuit, so the current will be I=U/R.

As the charges accumulate on the capacitor's arms, the voltage of the condenser is continuously increasing based on the U = Q / C relationship, resulting in less and less voltage on the resistor, thus reducing the current.

Measurements also confirm that the exponential functions shown in the above figure describe the capacitor voltage and current during charging.

The time function of voltage:

$$U(t) = (U_{end} - U_{start}) \cdot (1 - e^{\frac{t}{\tau}})$$

where τ is the so-called time constant:

$$\tau = R \cdot C$$

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Astable Circuit With 555 Integrated Circuit

Square wave is required for many applications, but the transistor solution occupies a large space on the one hand, and its frequency is also sensitive to heat and supply voltage on the other hand. Because of this, and in order to unify a wide range of functions, in 1971 the 555 IC was created, which is still very popular to this day.

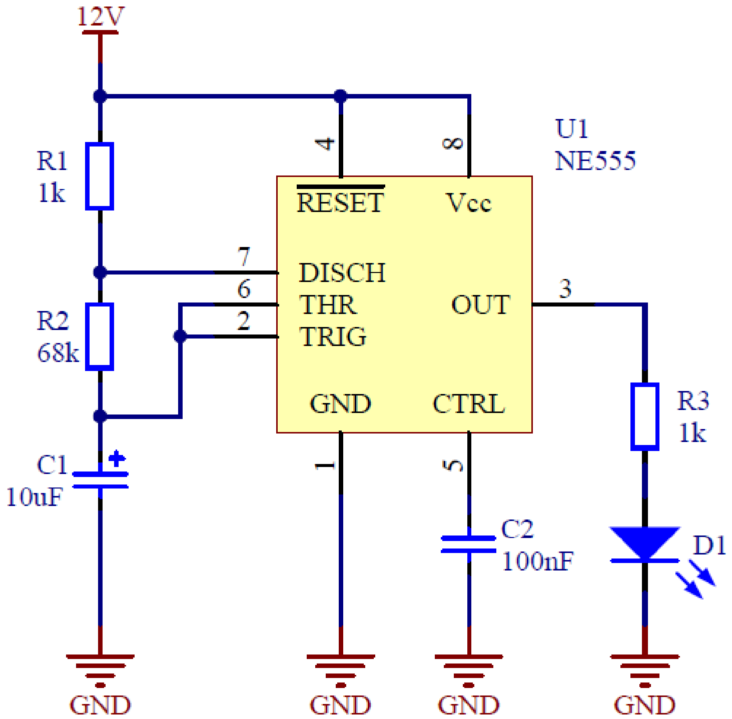

Figure 7 - Astable circuit with 555 IC

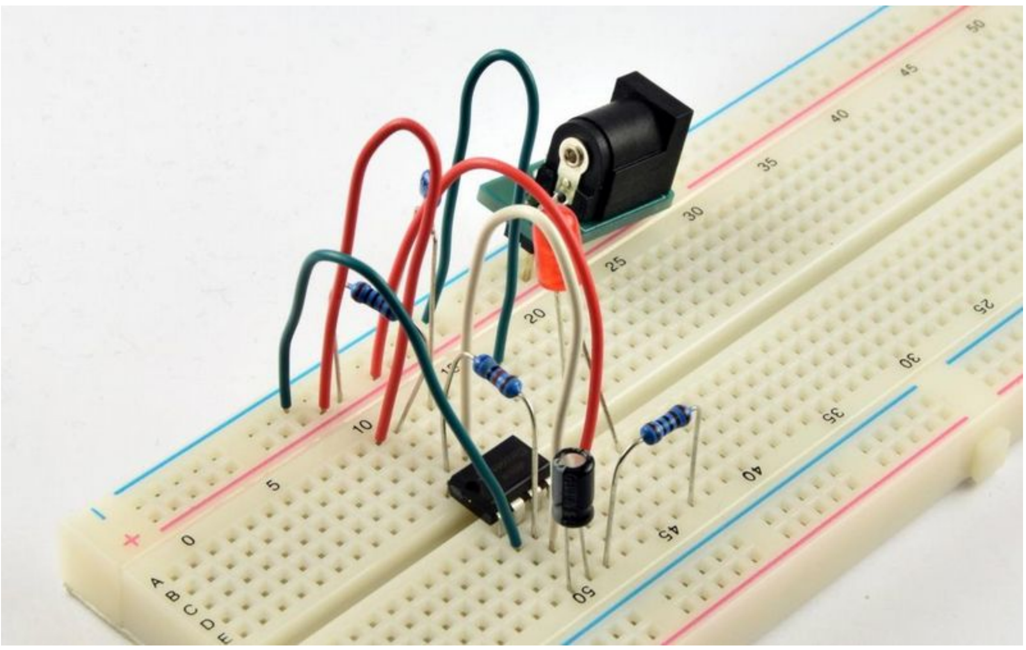

Figure 8 - Astable circuit with 555 IC on the breadboard

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Build the circuit shown in the figure on your breadboard, then add 12 V power to the circuit using a lab power or power plug. The LED on the output will blink, approximately once per second.

LET'S EXPERIMENT!

Try changing the blinking frequency again by replacing the components. You have to pay attention to make sure that R1 is not smaller than 1 kΩ, otherwise the IC may be damaged.

1. First replace resistor R1 to a value of 68 kΩ. You will notice that the LED is on for a longer period of time than it is off, and the blinking speed is slightly reduced.
2. Replace the 1 kΩ resistor in place of R1 and replace C1 with a capacitor of 22 uF. The blinking speed will then be halved while the LED is lit up for about the same length of time as not.
3. If you decrease the value of R2, the blinking will become faster and the time difference between the two states of the LED will increase.

We can conclude that the frequency of the LED blinking depends on the value of R1, R2 and C, the ratio of the times of the LED states depends on the value of R1 and R2.

WHAT'S INSIDE THE IC'S CASE?

Let's see what's in this integrated circuit!

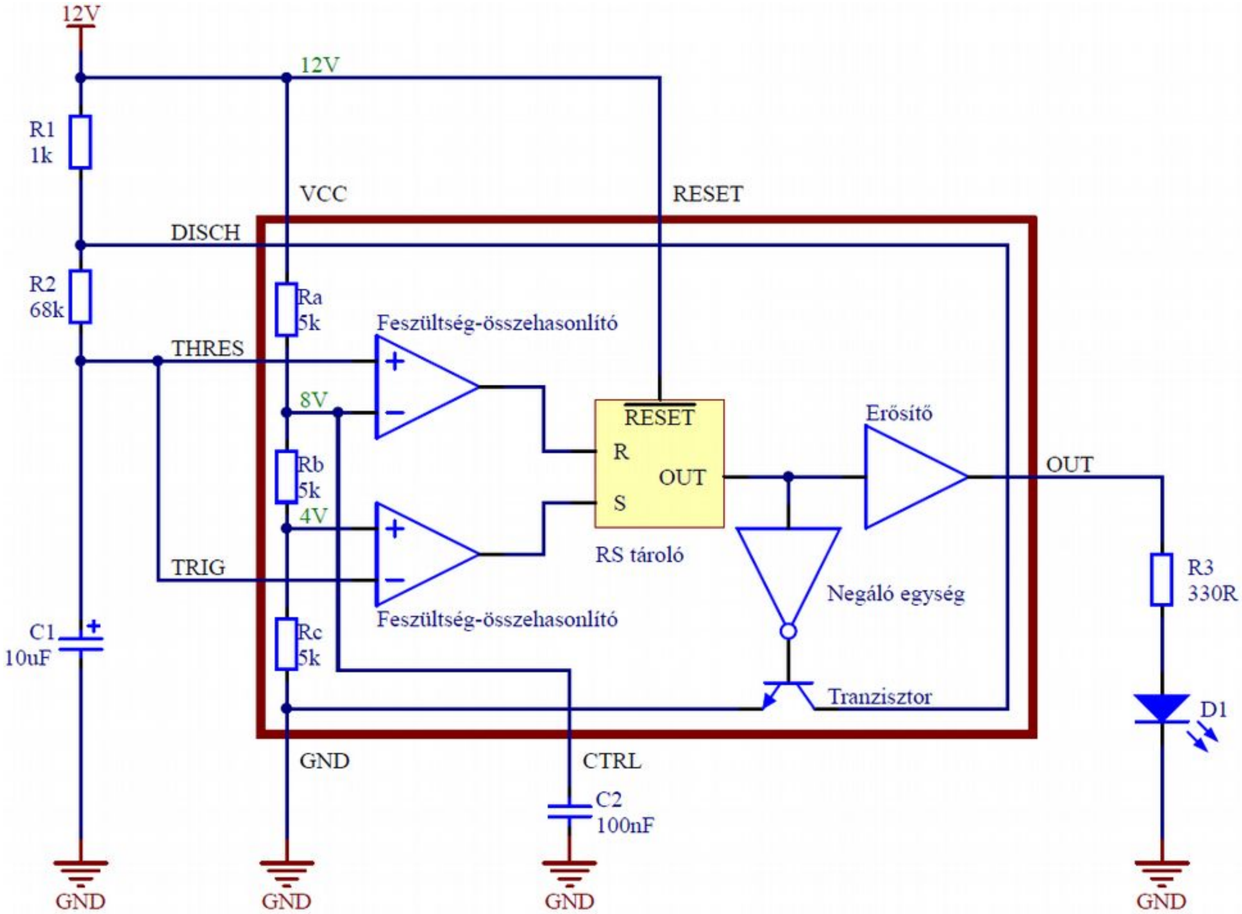

Figure 9 - Block diagram of the 555 IC in the astable circuit

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Inside, there is a voltage divider consisting of three resistors of equal value (Ra, Rb, Rc). In their connection points, the ⅔ of power supply voltage and ⅓ of power supply voltage can be measured from top to bottom, which in this case means 8 V and 4 V.

Then there are two voltage comparative modules that connect the supply voltage to their outputs (hereinafter referred to as logic 1 state) if their positive inputs have higher voltages than their negative inputs. In all other cases, 0 voltages can be measured at the outputs (hereinafter referred to as logic 0).

The IC THRES terminal (threshold) is connected to the positive input of one of these modules, and its negative input is connected to the resistor divider's ⅔ point. So this comparator will have an output of "1" if the voltage on the THRES pin is greater than ⅔ (in our case greater than 8 V).

The positive pin of the other module is connected to the ⅓ point of the divider, the negative pin is connected to the IC leg marked with the TRIG title, which means its output will be "1" if the voltage on TRIG (trigger) pin is less than ⅓ of the power supply (less than 4 V in our case).

The output of the two voltage comparative modules is connected to a so-called RS storage element. This element is capable of maintaining its output voltage ("0" or "1" state), the state change between states is determined by the voltages "0" and "1" on its inputs.

If S (set) is set to 1, then the output is set to "1". If you have "1" on the R (reset) input, the output is set to "0".

In the 555 IC, this means that the output of the RS container is set to "0", if the voltage on the IC THRES pin is higher than ⅔ of the voltage of the power supply, and it gets to "1" state, when the voltage on the TRIG pin drops below ⅓ of the supply voltage.

The IC output is connected via an amplifier to the output of the RS container to ensure that up to 200 mA current can be flown on the output of the IC (OUT leg).

The IC includes a transistor that switches on when the output of the RS flip-flop is in the "0" state (this negated operation is accomplished by a unit represented by a triangle and a small circle connected to the base of the transistor).

The IC DISCH (discharge) pin is connected by the transistor to the pin of the IC GND.

Operation of the Circuit

How does the IC work in the astable circuit?

Initially, the voltage of the capacitor C1 is 0 V. When the power supply is connected, the supply voltage can be measured on the IC output (**the LED is on**) since the voltage on the TRIG pin is lower than ⅓ of the supply voltage (hereinafter referred to as 4 V), and the S input of the flip-flop is "1".

The capacitor starts charging via resistors R1 and R2. As soon as the voltage reaches 4 V, the lower comparator output will be "0", but the R input of the flip-flop will still be "0", so the IC output will not change.

The process described so far takes place only when the circuit is turning on.

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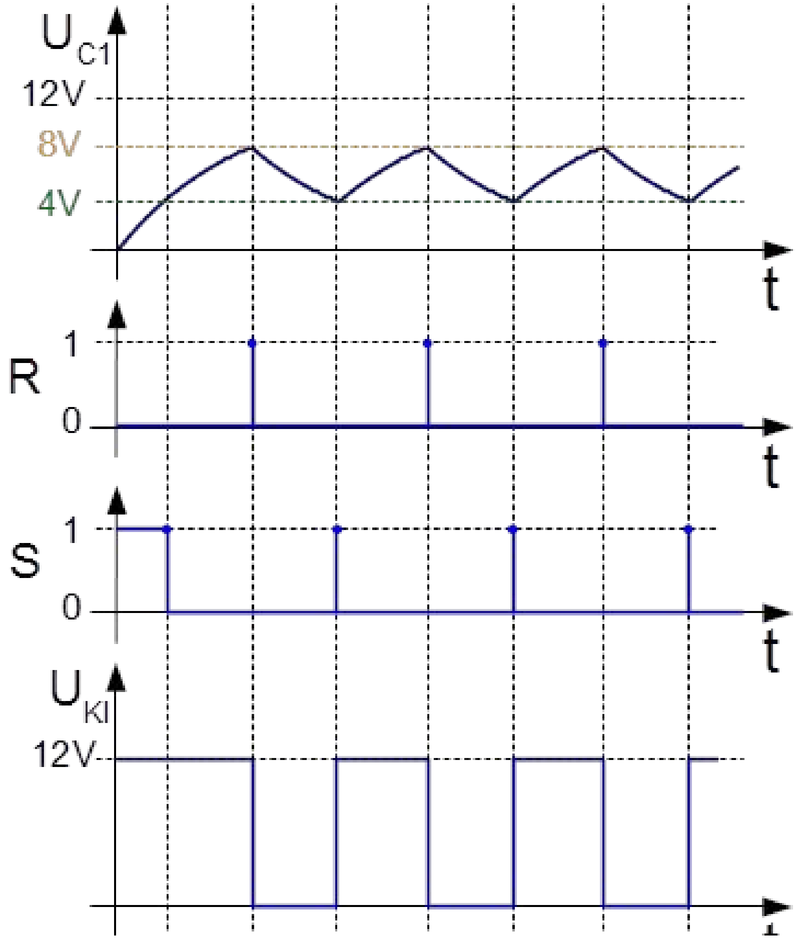

Figure 10 - Voltage measured on the capacitor C1 and the signals of the 555 IC

Further events will be repeated periodically.

The capacitor's voltage will increase further up to the ⅔ of the supply voltage (hereinafter referred to as 8 V). At this moment, the output of the top comparator changes to "1", which makes the output of the RS flip-flop to "0", and zero output voltage can be measured at the IC output (**the LED is off**).

At the same time, the transistor is turned on and it connects the DISCH pin to the ground, which causes that current flows from the capacitor through R2, that is, it starts to discharge (that's the origin of the name of the discharge pin).

The capacitor's voltage drops down to 4 V, at that time the lower comparator output will change to "1", resulting that the output of the flip-flop will be set to "1". The internal transistor closes and the connection between of the DISCH pin and GND will be terminated. At the same time, the power supply can be measured on the IC output, so **the LED lights up**.

Let's Measure!

Replace R2 with 1 MΩ resistance! This will increase the time of change in output. Use your multimeter to measure the voltage at the terminals of the C capacitor. You will experience that while the LED is on, the

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voltage will increase from 4 V to 8 V, then the output will change and the voltage will decrease until it reaches 4 V and then the process starts from the beginning.

The two threshold voltages are exactly ⅔ and ⅓ of the supply voltage, i.e. the circuit operates as described above.

What Is The Period of Blinking?

The change in voltage at the IC output depends on the charge and discharge time of the capacitor. During charging, this time is determined by the values of R1 + R2 and C (at the output the supply voltage can be measured, the LED is on), only the values of R2 and C are authoritative during discharge (the output voltage is then 0, the LED is off).

This means that if the resistance of R1 is not much less than the resistance of R2, then the duration of the on and off states will not be equal.

You also experienced this, when R1 and R2 were 68 kΩ resistors. The ratio of the two periods:

$$\frac{\tau_{on}}{\tau_{off}} = \frac{(R_1 + R_2) \cdot C}{R_2 \cdot C} = \frac{68\ [\mathrm{k}\Omega] + 68\ [\mathrm{k}\Omega]}{68\ [\mathrm{k}\Omega]} = 2$$

that is, the LED lights up twice as long as not. If the value of R1 is much less than the value of R2, then the two periods will be approximately equal, the frequency of the output will be determined mainly by the value of C and R2.

Additional features of the IC

We haven't talked about the remaining two pins of the IC.

The RESET pin of the IC is visibly connected to the RS flip-flop. If this pin is set to "0", the output of the flip-flop will be set to "0" regardless of the inputs R and S, from which comes the name (reset). If we do not want to affect the operation of the flip-flop, then it must set to "1", i.e. connect it to the power supply.

The upper ⅔ point of the resistor divider is routed to the IC CTRL (control) pin. This is useful because if, for example, 5V is connected to this pin, then the comparative modules do not compare their inputs with ⅔ and ⅓ of the supply voltage, but with 5V and 2.5V, so we can shift the sensitivity voltage of the THRES and TRIG pin to any value.

In an astable connection, the CTRL pin is connected to the ground with a small capacitor. On the one hand so that the voltage generated by the internal resistance divider would be noiseless. On the other hand, when the circuit is turned on, the voltages, measured on the resistance divider connected to the voltage comparator modules, reach ⅔ and ⅓ of the supply voltage slower, because of the capacitor. This ensures that the IC output is stable when it is turned on.

I mentioned that the value of R1 should not be reduced too much because it endangers the integrated circuit itself. Why is that? When the DISCH leg is connected to the GND by the internal transistor practically R1 is connected between the power supply and GND. If the value of R1 is too small, then a high current will flow through it (I = U / R), which can destroy the transistor connected to the DISCH pin.

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The 555 IC is not only capable of implementing an astable circuit. For example, it can realize a monostable circuit that maintains a pulse arriving at its input for at least a predetermined time on its output. It can also produce a PWM signal, which we will be discussed later in the curriculum.

You can find some more interesting applications in the IC datasheet.

SUMMARY

In this chapter of the curriculum, you have learned about the two types of implementation of the astable circuit. Both solutions are based on the time required for a capacitor to charge or discharge through a resistor. You also learned that the time depends on the capacity and the resistance. In fact, we used this method to "measure time".

The voltage at the output of the astable circuit changed between two values, called logical “1” and “0” states. This also means that the output can be considered as a digital signal.

In the curriculum this was the first circuit that "did" something independently, in this case it produced a digital signal and flashed two LEDs!

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