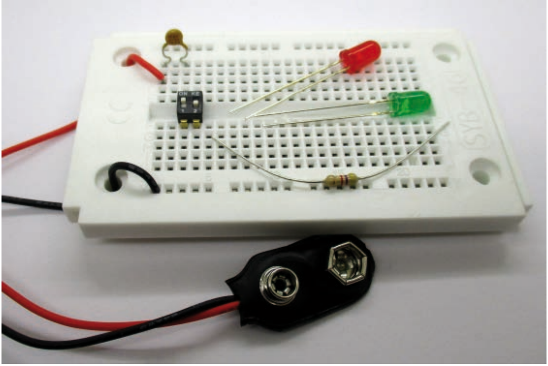
MAKER FACTORY

Content

1 Preparations

At the heart of this study package are light-emitting diodes and transistors, which make even complex applications possible. We have also included the necessary information on how all of this works, for the curious among you.

The study package contains the following components for assembling and connecting the components: a breadboard to set up all the experiments; a 9V battery clip to connect the battery; a dual four-port switch; a two-wire fuse; and five cables for the breadboard.



The battery cable should be fitted as securely as possible, so that it won't come loose during the course of the many experiments that we will run. Ensure that the bare ends of the red and black wires are plugged into the proper contact holes on the breadboard. Use a needle to first pierce small holes into the protective film on the back of the board and then insert the wires from below. That way they are adequate secured. Switch and fuse should be positioned exactly as shown. We will use this set up in all of the coming experiments.

We also have six light emitting diodes (LEDs). Five LEDs come in the colors red, yellow, green, blue and pink, and there is a red flashing LED with a more transparent housing and inside you can see a tiny chip.

Attention: Never connect LEDs directly to a 9 V battery! You still have to use a resistor, which is used to reduce the electrical current. We have nine resistors with different color rings.

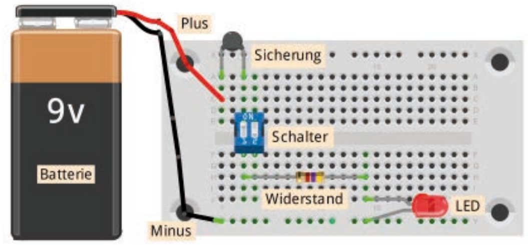
The experiments where we are using the other electronic components are particularly interesting. Important are the two transistors with the type designation BC547B. They come with three terminals, which you should not mix up. Then there is also a 100 microfarad (100 µF) electrolytic capacitor and two small pushbuttons.

2 Simple LED lamp

For our first experiment we will need six components. In the next experiments we will use four of those over and over again: the breadboard, the battery clip, the switch and the fuse. But for the first experiment we will also need a resistor with 4,700 ohms (yellow, violet, red, 4.7 kΩ) and a red LED (LED).

The direction the LED is installed is very important. An LED has a shorter leg (cathode = negative pole) and a longer leg (anode = positive pole). Inside the LED you can make out a slightly larger holder at the minus side, which carries the actual LED crystal.

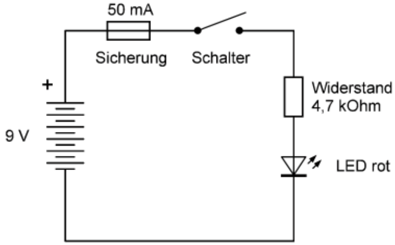
After everything is set up and double-checked, we need to connect the battery - and now you have got a red LED light with a switch. If you push the left switch to ON, the red LED goes on. If this doesn't work, check the setup again. The most common mistake is that the LED was installed the wrong way round. No worries, nothing gets broken should this happen. Just install the LED correctly, and it will work.



Circuit diagrams

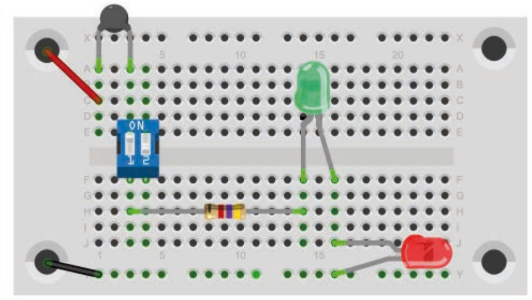
You don't necessarily need the diagrams in this manual in order to successfully set up the experiments. But they help you to better understand everything. A circuit diagram shows the wiring of components in a simplified way using switching icons for each component. Once you get familiar with the diagram, you will easily understand how everything works together.

The battery has six 1.5V battery cells. The longer dash indicates the positive pole. The fuse is drawn as a box with a wire. Right now, the switch shows an open connection. The resistance is shown as a box. And the LED has an arrow that points towards the direction of the current flow. Two small arrows represent the light produced. In this diagram, you can clearly see that all the components form a closed path, a circuit. There is but one point where the path is broken: at the currently open switch.



3 More colors: red and green

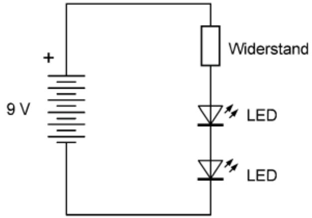
Here we are going to install a green LED in series with the red LED. Both LEDs will turn on together. You can turn both on and off together using the switch.



Series circuit

Two or more components connected in series carry the same current. This is a “branchless circuit” because the components are connected along one path. This means that the current is the same anywhere. You can easily test this by swapping both LEDs. The brightness remains exactly the same.

The 9 V battery voltage is distributed over three components. The red LED has a voltage drop of 1.8 V, the green 2.4 V, and the resistor 4.8 V. You get the total voltage by adding up all the sub-voltages: 1.8 V + 2.4 V + 4, 8V = 9.0V.

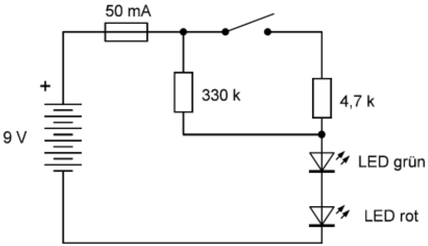


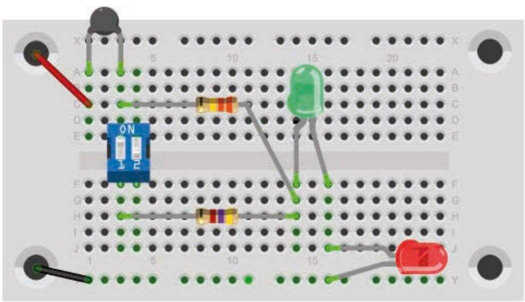
Simplified circuit diagram of
a series connection

4 Standby light for the night

Here we will install another resistor with 330 kΩ (330 kilo-ohms). The resistor has the color rings orange, orange, yellow and an extra golden ring. The greater the resistance the less current flows. Our first resistor had only 4.7 kΩ (yellow, purple, red) and the light was relatively bright. By using the larger resistor, the LEDs will only glow dimly.

The larger resistor used in this standby light ensures that you can find the lamp at any time, also in the dark. When you need to use the lamp, just turn on the higher brightness. The same mechanism is used in some light switches. A small glowing light helps you to find the switch easily.





Resistors and their color rings
The color rings on the resistors stand for numbers. They are read by starting with the ring that sits closer to the resistor edge. The first two rings stand for two numbers, the third for zeros. Together they represent the resistance in ohms. A fourth ring indicates the accuracy. All resistors have a golden ring.

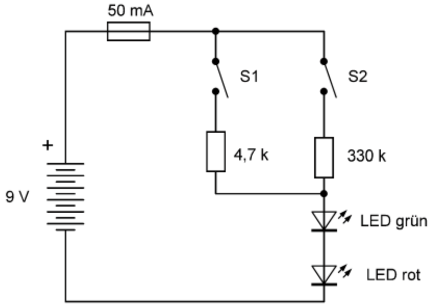
This means that the value indicated by the color rings could be 5% greater or smaller. Your first resistor is read as follows: yellow = 4, purple = 7, red = 00, together 4.700 ohms, or 4.7 kΩ.

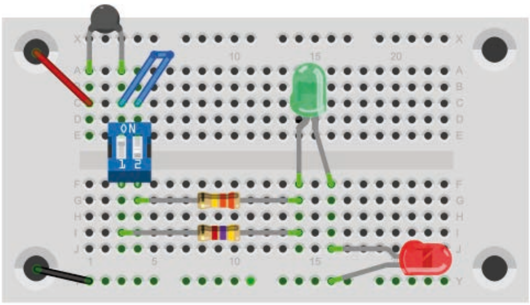
The resistor color code

Color	Ring 1 1st number	Ring 2 2nd number	Ring 3 Multiplicator	Ring 4 Tolerance
Black		0	1	
Brown	1	1	10	1 %
Red	2	2	100	2 %
Orange	3	3	1000	
Yellow	4	4	10000	
Green	5	5	100000	0.5 %
Blue	6	6	1000000	
Purple	7	7	10000000	
Grey	8	8		
White	9	9		
Gold			0.1	5 %
Silver			0.01	10 %

5 Adjustable brightness

We are going to rebuild the LED light so that the two parts of the dual switch control their own brightness. For this you need a cable with two plugs. You can toggle between three brightness levels: off, soft and bright light. Actually, there should be a fourth level, because current flows through both resistors when both switches are on. But the difference to the third level is so small you wouldn't even notice.





Voltage, resistance and current

We already know that electrical voltage is measured in volts (V). The battery has 9 V. Resistance is measured in ohms (Ω) or kilo ohms (1 kΩ = 1,000 Ω). But there is another very important measurement: electrical current is measured in amperes (A) or in milliamps (1 mA = 1/1000 A) in the case of low currents. All of these names are originally the names of famous researchers, who were researching electricity some 200 years ago: Alessandro Volta, Georg Simon Ohm and André-Marie Ampère.

You could use a meter to measure the current that is flowing through the LED. However, if you know the actual battery voltage and the voltage at the LED, you could calculate the current flow yourself. If the battery is new, it has a voltage of 9 V. The two LEDs together need about 4 V. We still have 5 V left for the resistor. Now you can calculate the greater brightness:

Current = voltage / resistance
Current = 5 V / 4700 Ω
Current = 0.0011 A = 1.1 mA

That's not much. The current flow is only 1.1 mA, while the LED tolerates a current of 20 mA. The battery will last a long time! The battery usually has a capacity of 500 milliamps (500 mAh) and could deliver 500 mA for one hour or 1 mA for 500 hours. Or, the lamp can glow for about 450 hours at 1.1 mA; that is almost three weeks.

The larger 330 kΩ resistor delivers a current of approximately 0.015 mA and will thus run four years on just one battery. Saving power pays!

6 Amplify current

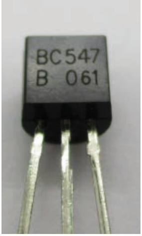
The most important component of this study package is the transistor. You should not mix up the three terminals. They are called emitter (E), base (B) and collector (C). The emitter connects to the negative terminal of the battery. Therefore, the transistor's flat side with the label should point to the left.

The experiment demonstrates the typical behavior of a transistor. When both switches are turned on, the green LED is dimly lit, but the red one is very bright. If you turn off the green LED with the right switch, the red LED will also go off. The transistor acts like a switch. A small amount current flowing through the base terminal causes a large current flow to the collector.

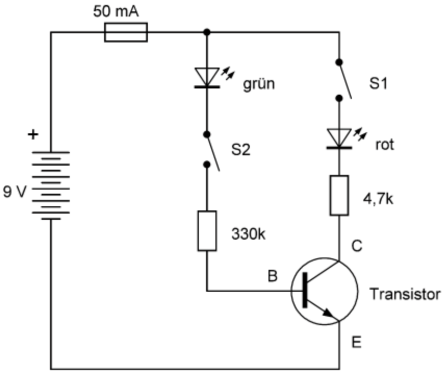
Transistors are essential components in all areas of electronics. They are used in radios and televisions and also in smartphones and computers –transistors are built-in everywhere. That's why it's important to understand exactly how a transistor works. The circuit diagram also shows an important basic element of a computer, namely the AND circuit. Only if switch 1 (S1) AND switch 2 (S2) are set to ON, the red LED will turn on. If one or both are set to off, then it will stay off. You can build machines, calculators or entire computers with such basic circuits.

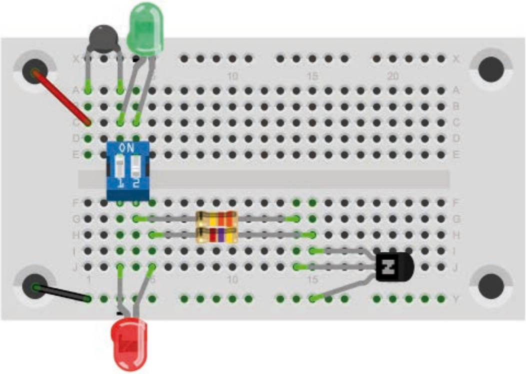
Transistors

A transistor contains a silicon crystal. Silicon (Si) is found in normal quartz sand in large quantities (quartz = silicon oxide). It belongs to the group of semiconductors; these substances neither conduct electric current as well as metals nor do they have the properties of insulating materials such as glass or rubber. In order to achieve a very specific conductivity, the smallest amounts of other substances are added to the pure silicon. Depending on the nature of these substances, N-silicon or P-silicon are obtained. Your transistor has three layers: NPN. Other types feature a different layer sequence, namely PNP. They work similarly, but the current direction differs.



Our transistor is a BC547B transistor. Using this type reference, you can select exactly the right type, which by the way is produced by a number of companies. Or you can search for the datasheet on the internet. The datasheet contains crucial properties and parameters. In a nutshell: This NPN transistor works with a voltage of 50 V and a current of 100 mA. Plus, it can amplify the current by 200 times at least.


50 mA
grün
S1
+
S2
rot
9 V
4,7k
330k
C
B
Transistor
E



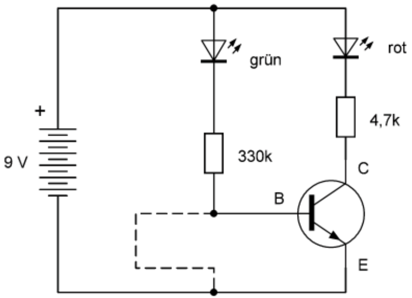
7 An alarm system

For this little alarm system, we will need a second cable. This is used as the connection between the base, which shuts off the collector current, and the emitter of the transistor. If you pull out the cable, an alarm is triggered, and the red LED goes on.

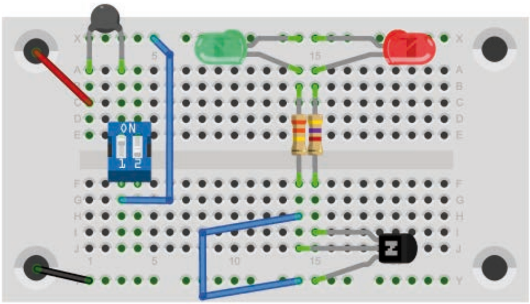
You could build an alarm system using a thin wire that breaks, if someone opens a window or door. If formed as an alarm loop, the wire could also secure several windows and doors. Should a burglar discover and simply cut the wire to turn off the alarm, then he will have a day of reckoning. In such a case, the alarm will go off, too.

When in the alarm state, a small amount of current flows through the green LED, the 330 kΩ resistor and through the base terminal of the transistor. The transistor thus turns on the collector current, and the red LED lights up. The alarm loop forms a short circuit between base and emitter. This turns off the base current. Without base current there is no collector current flow and the red LED stays turned off. But if you disconnect the alarm loop, the transistor will switch on.

A small current always flows, even without an alarm. The green LED is dimly lit and shows that the alarm is enabled. The battery will last for several years due to the very small amount current used in standby mode. But if an alarm is triggered, then more current will flow.



Attention: fuse and switch are not shown in the circuit diagram, they are however always part of it.

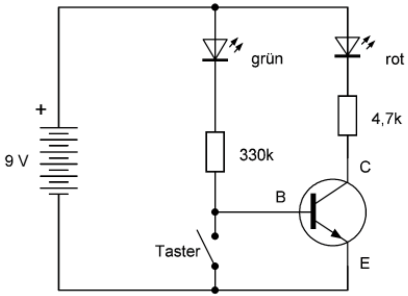


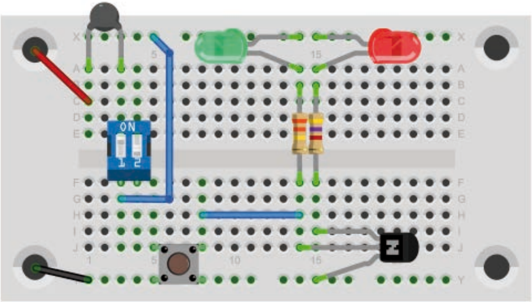
8 Off at the push of a button

We will use a push-button switch instead of the alarm loop of the last experiment. In the normal state, the switch is open. But when you press the button, the contact will close, and this will turn off the red LED.

The NOT circuit

Isn't it strange, we are closing a contact and switch on current, but by that another current is switched off. Switching on causes switching off, that is the exact opposite. However, this is another essential basic circuit in computer technology and it is called a NOT circuit. The other term for this is „Inverter". Like the AND circuit, the NOT circuit is a basic logic circuit. You can build an entire computer from a lot of AND NOT circuits.





9 Keep on the glow

The capacitor in this study package acts as a small energy storage. It is an electrolytic capacitor (short, e-cap). The important thing about this e-cap, you need to pay attention to polarity, just like with an LED. The negative pole is indicated by a thick white line and connects to minus.

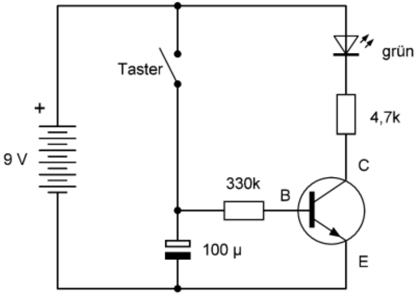
Attention! Do not install an electrolytic capacitor the wrong way round. If an e-cap's plus and minus are reversed, its insulation won't work. Current that flows will eventually ruin the component by time.

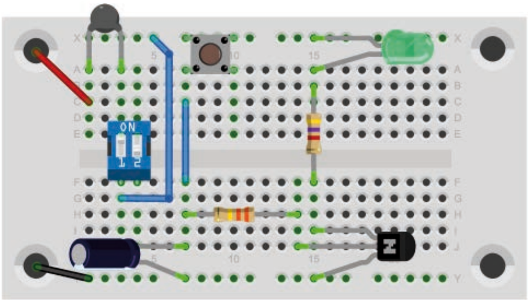
The LED turns on with a push on the button. The LED will not turn dark immediately when you release the button but stays lit for a minute or two and slowly dies away. This makes a perfect night lamp, because you can gradually adjust to the dark.

Capacitor
A capacitor has two metal plates or metal films that are isolated from each other and do not come in contact with each other. If connected to a battery, they become electrically charged and will store electrical energy.

The capacitance of a capacitor, that is the amount of electrical charge a capacitor can store at a given voltage, is measured in farad. The unit is named after the well-known researcher Michael Faraday. However, our capacitor only has 100 microfarads (100 µF). 1 µF is one millionth of a farad. The Greek letter µ (My) is the small m, and stands for “micros”, which is Greek, too, and means “small”. A capacitance of 100 µF is indeed very small. But with its large resistance of 330 kΩ, the capacitor only slowly discharges with a very small current. The transistor amplifies this small discharge current and this is why the LED is still glowing bright enough.

Without the transistor, the stored energy would just last long enough for a short flash of light. Test it yourself by removing the just charged capacitor from the board and holding it with the right direction to an LED. The LED will flash once briefly.





10 Red and green in sync

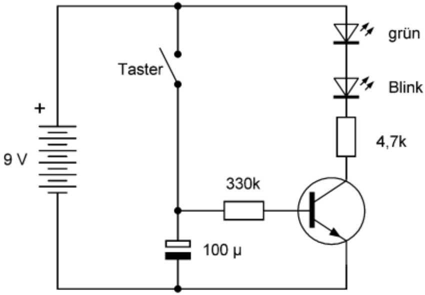
Besides the LED crystal, the red flashing LED has a circuit which switches the LED current on and off again and again.

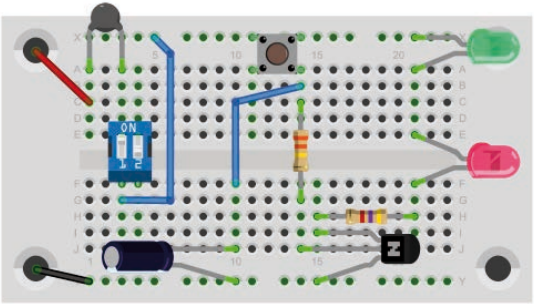
If you install the LED as laid out in the set-up plan, the green LED will also turn on and off. The result is a red and green flashing light that starts when you push the button switch and which then gradually fades away. If the LEDs don't flash, you have probably installed the normal red LED, which you can recognize by its somewhat matt colored housing.

The flashing LED

The flashing LED has an electronic switch that consists of a transistor. Nevertheless, other transistors and components are still needed. Together they will form a complex circuit and thus can control the exact timing. Together they are set on a small piece of silicon, which is then installed next to the LED crystal. An individual flash circuit will be built later on, so you can understand how it works.

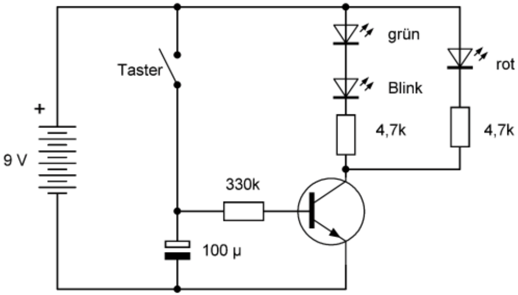
You can see that the green LED never goes fully dark between the flashing intervals but continues to glow dimly. The reason behind this is that despite no current flows through the red LED crystal, current flows still through the other parts of the circuit. Thus, we have small current flowing in the off state causing the green LED to glow dimly.

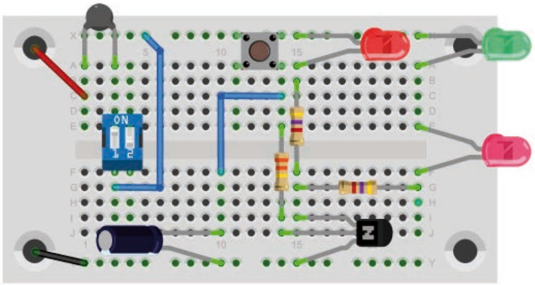




11 Three LEDs with turn-off delay

Now we are going to install a third LED together with another 4.7 kΩ resistor (yellow, purple, red). The second red LED will not flash because it is not in series with the flashing LED. It will slowly die away like the other LEDs. At the very end of the cycle, only the red LED continues to glow. The green LED and the flashing LED go fully dark, because together they have a greater voltage demand.

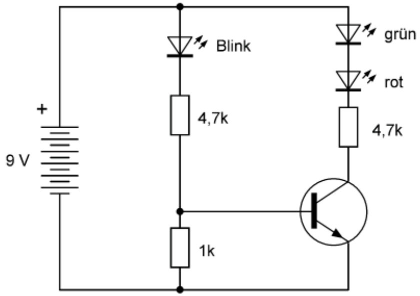


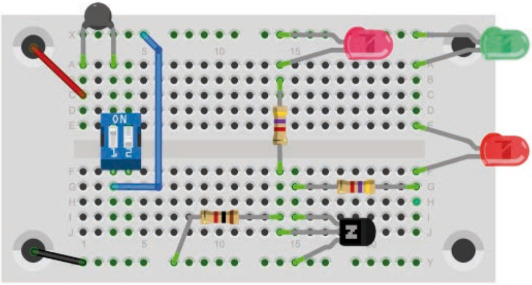


12 Flashlight trio in sync

We will arrange the circuit now in a way that all three LEDs will go fully dark in between the flashing cycles. We are going to use a 1 kΩ resistance (brown, black, red). The red flashing LED utilizes the transistor to turn the red and green LEDs on and off. As a result, all three LEDs are flashing.

Remove the 1 kΩ resistor out of the circuit and you will see that only the flashing LED will flash, the other two LEDs are steady lit. The transistor amplification is large enough to keep the remaining LEDs lit just by the small residual current of the flashing LED. The 1 kΩ resistance is thus used to dissipate this small current, so that the transistor conducts current only if the flashing LED is in the on state. Together the three LEDs flash much brighter than the flashing LED on its own. You just observed how the transistor works as an amplifier.





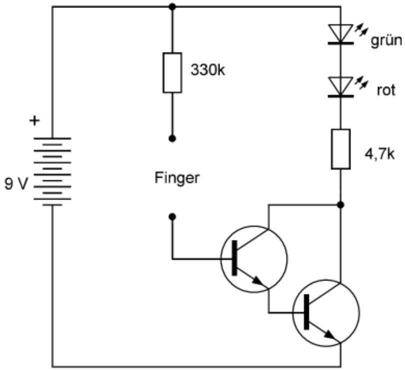
13 Touch switch

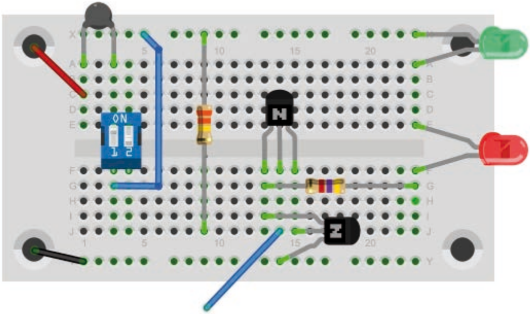
We add another transistor to the first to increase amplification even more. Both collector terminals are interconnected; the emitter of the first transistor goes to the base of the second. This circuit is called Darlington circuit. We will use this to build a touch switch. When you touch the free end of the wire and the 330 kΩ resistor at the same time with your fingers, a very small current, too small for you to feel, will flow through your finger and amplify to the point that both LEDs are turned on.

Until now we left our first transistor in its initial position. Today we have to install it differently, so that both transistors fit properly. The new input is the base of the left transistor.

The Darlington circuit

Connecting two transistors the way we see in the diagram is called Darlington circuit. The amplification of two transistors is greater than using just one. This holds especially true for this circuit, where the already amplified current is amplified even more by a second transistor. The inventor Sidney Darlington, who came up with this idea in 1952 gave the circuit its name. Both collectors are interconnected, and the emitter of the first transistor flows to the base of the second. The Darlington circuit behaves like a single transistor with huge power amplification.





14 LED light sensor

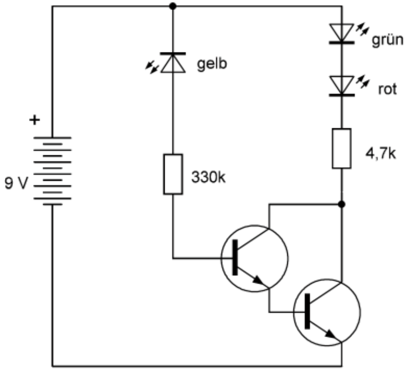
In this experiment, we are going to use a yellow LED as a light sensor. It is installed the other way round unlike we usual do and in consequence, it actually does not conduct electricity. But a small current flows as soon as light falls on the LED, very similar to a photodiode. This is then amplified by the two transistors and will cause the other two LEDs to light up. Try this with a flashlight. The more you illuminate the yellow LED, the brighter the two other LEDs will glow.

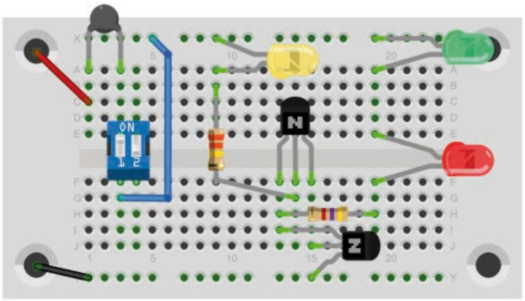
Photodiode
Each diode consists of a semiconductor with a P-N junction. Current will flow readily in one direction but not in the other, where current is blocked from flowing through.

Besides light-emitting diodes, there are rectifier diodes and photodiodes made from silicon, the very same material that is used in the transistors. A photodiode has a particularly large surface to have as much light as possible enter into the boundary from the outside. There, the light ensures that the isolating effect of the boundary layer is lifted in part and current flows. An LED is similar in structure, but its surface is very small. Thus, the light-dependent current is also very small. However, for this experiment it will be sufficient thanks to amplification by the two transistors.

Another test

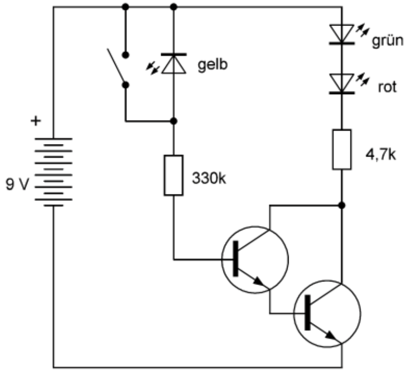
Both, the red and green LED, can also function as a photodiode. You could check out which LED is the best photodiode.





15 Extra switch for dark nights

We expand the light sensor by an additional switch. The second switch makes it possible to turn on the LEDs at night. We will install it parallel to the light sensor, where it will be able to deliver enough base current to turn the LED on when it is dark. Instead of the switch, you could also install two contacts for a touch sensor or simply touch the wires of the LED sensor.


grün
gelb
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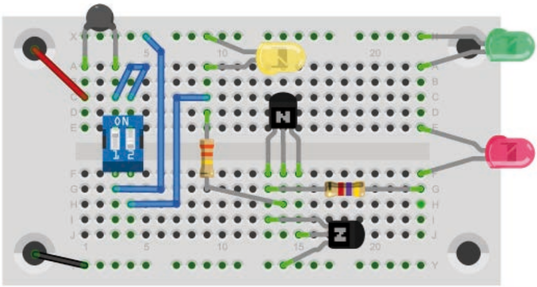
+
9 V
330k
4,7k



The PTC fuse

We are using fuses in all our experiments. Because if a short circuit happen, it could cause a wire to become burning hot. Or the battery could heat up and discharge quickly, or in the worst case, the battery could also explode. This is why we use a fuse to prevent such worst-case scenarios.

Most fuses simply blow in response to a short circuit. But this here is a special self-resetting fuse also known as PTC fuse. If in the event of a short circuit too much current is flowing, the PTC fuse becomes hot and restricts the current flow, so that only a small amount current passes through as its resistance sharply rises. PTC stands for "Positive Temperature Coefficient" which means that the resistance increases with temperature. In the event of a short circuit, the PTC fuse reaches approximately 60 degrees Celsius. Once you have turned off the power and eliminated the error, it cools down and works again like new.

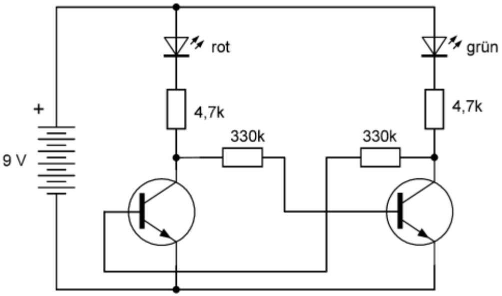
16 Transistor flip-flop: red or green

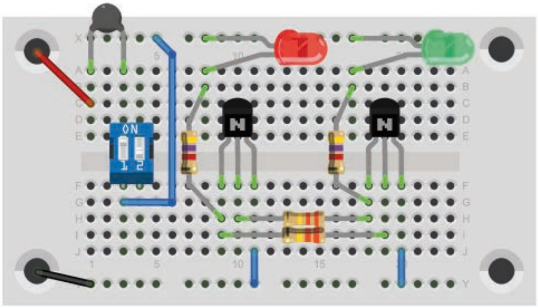
This circuit features two transistors that will switch each other on or off. A 330 kΩ large resistor is connected to each base. So, when a transistor turns on, it simultaneously shuts off the base current of the other transistor. In such a case either the red or the green LED will be on. The other LED, however, will be dimly lit due to the small base current still flowing though that other transistor.

It is impossible to predict the LED that will turn on. You can however switch the state by bringing a wire in contact with one of the base terminals, which will generate a short electrical pulse due to charges present at random. More often than not, it doesn't always work the first time. But you can do it safely by connecting the base to the emitter at the currently conducting transistor.

The flip-flop

A flip-flop is a circuit that knows two stable states. The existing state is stored for as long as you do not alter it on purpose. The flip-flop is therefore also an information memory. In our case, only one piece of information is stored. We could call it yes or no, but also one or zero, or in our case, we call it red or green. Many of those flip-flops together form the computer memory that stores large amounts of data.



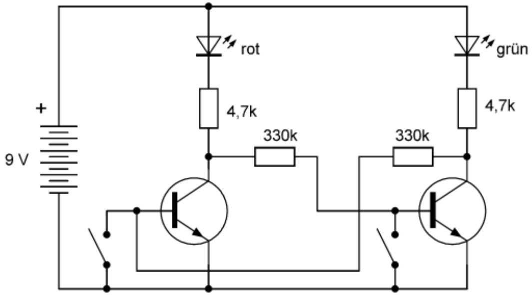


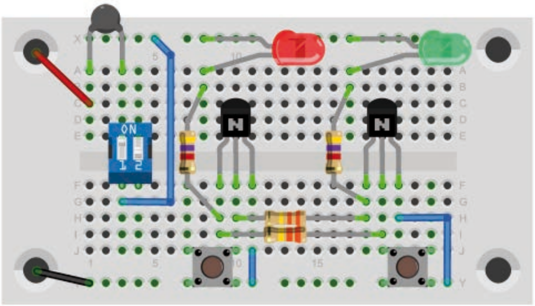
17 Reaction games

You can use two buttons to bring some system into the last flip-flop experiment and have it adopt the state you choose. You could use the experiment as a light signal where red means: Do not disturb! And green means: Communication allowed. At the same time, this experiment is also an electronic game.

Every switch can turn off the base current of its associated transistor, whereby also the connected LED goes off. Normally you would press only one button or one after the other. However, if you press both buttons at the same time, both LEDs will go dark. But when you release the buttons, only one LED will go on, and no one can foretell which is the one that turns on. It is almost impossible to release the switches at the very same time. One switch will open sooner than the other, even if the difference is just a micro-second, and turns on the LED at the side.

Here is how the game works for three people: Two will each press a switch, the third one will give the command to let go. Now you will see who reacted faster because only this LED will turn on. You can take turns and the winner could be established after several rounds.





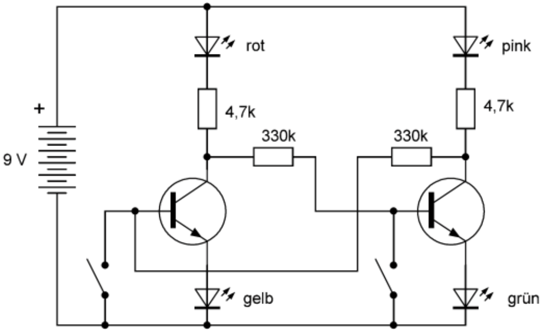
18 Four-color switch

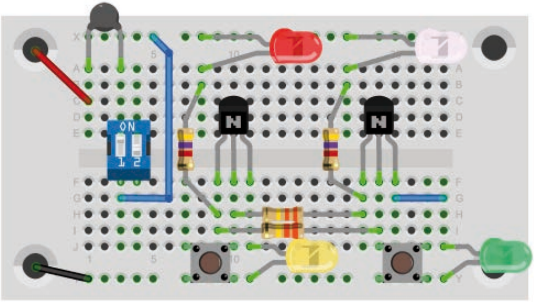
Today we are using the purple glowing LED for the first time. The housing is whitish, but in reality, the LED has a purple glow. We use the RS flip-flop of the last experiment and expand it by four LEDs. Just like before, each transistor has one LED in the collector line, but the other LED is installed into the emitter line. That way red and yellow will always glow in sync while at the other side we have purple and green.

In this experiment the two LEDs on the negative terminal need to have similar voltages; that is only likely, if the colors are located close to each other. The LED voltages at the same current differ, whereby the order follows that of a rainbow: red, yellow, green, blue, purple. Yellow and green are also found close on the voltage scale. Try and change the places of the LEDs and see how the circuit responds.

Structure of the purple LED

Actually, the LED crystal of the purple LED emits blue light. But the crystal is covered with a fluorescent material that captures part of the blue light and emits it as red light. So in reality the purple LED emits two colors: red and blue and thereby creates the composite color purple.



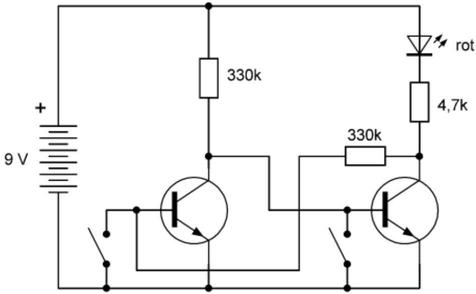


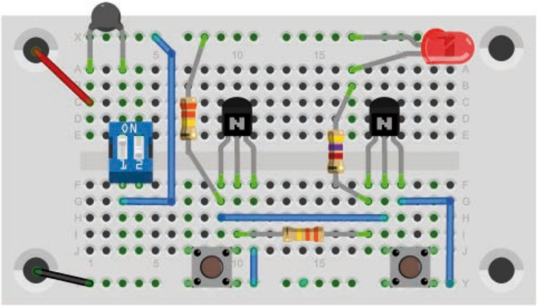
19 Simple RS flip-flop

A very basic flip-flop can be built with just one LED and three resistors. The two buttons are used to switch the LED on and off. Such a circuit is also called RS flip-flop. The abbreviation stands for Reset (reset = switch off) and Set (set = switch on). The RS flip-flop is an important element in digital electronics and computer technology.

The two-transistor circuit is again based on the fact that each transistor can turn off the base current to the other transistor. Because we are only using one LED, you may be interested in testing out the other colors too. You can remove an LED that is turned on and replace it with a different one. After the LED is replaced, the newly connected LED will go on first. Because when you remove an LED, you also switch off the base current for the left transistor. That is like you were switching the

LED on. You may also want to find out what happens when you install the flashing LED. Will flashing affect the state of the RS flip-flop?

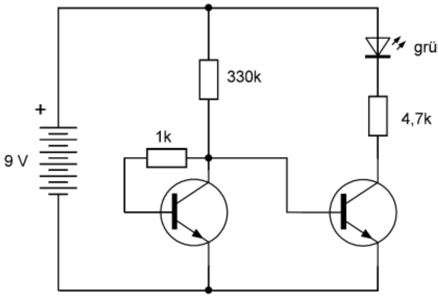


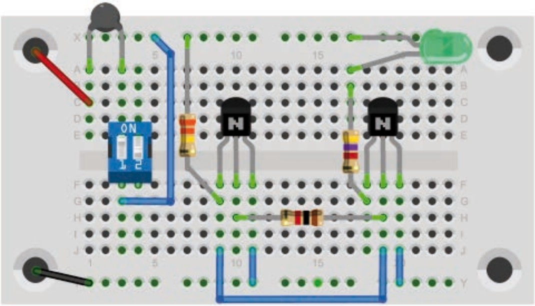


20 Temperature sensor

We will modify our last circuit just a little bit, but it will behave totally different and will respond to different temperatures. The 1 kΩ resistor (brown, black, red) delivers base current to the left transistor. The LED is neither fully on nor fully off, but glows steadily and very dimly.

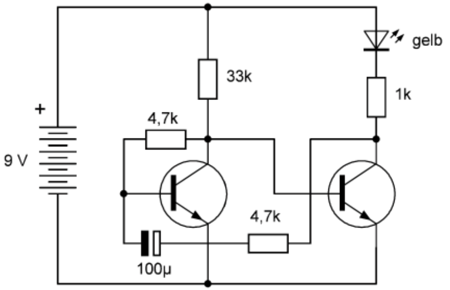
Now, if you touch the right transistor with two fingers, it warms up a bit. The LED will glow a bit brighter. Touch the left transistor and you will see that the opposite is happening; the LED is only dimly lit. The difference in brightness is not huge and depends on the actual temperature differences achieved. You will get better results by touching the left and the right transistor alternately at intervals of half a minute. For greater temperature differences, place some ice on a spoon, hold another spoon to the heater and then touch the transistors with the spoons.

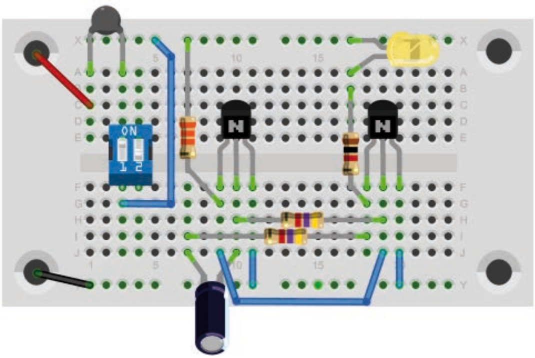




21 Slow flasher

Rather than using the red flashing LED with its built-in flasher we will build our own flasher. The circuit is a bit like the flip-flops of our previous experiments. The main difference is that this time we are going to install a capacitor. The base current flows through the capacitor for as long as the capacitor is charged or discharged. After that, the flip-flop automatically changes state. Flashing speed and the time the LED is lit or dark depends on the dimensioning of the components.


gelb
33k
1k
+
4,7k
9 V
4,7k
100µ

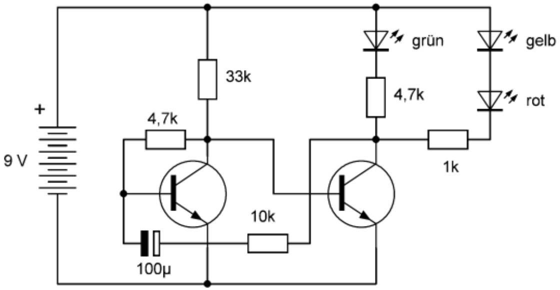


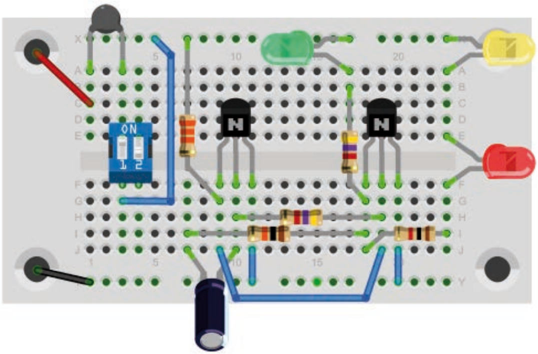
22 Transistor flasher in three colors

We will install an additional 10 kΩ resistor (brown, black, orange) in series with the capacitor into the flashing circuit of our last experiment. This will make the on-off ratio more balanced. Another change involves the LEDs. The right transistor can control more than just one LED. Here we have three of them flashing in sync.

The oscillator

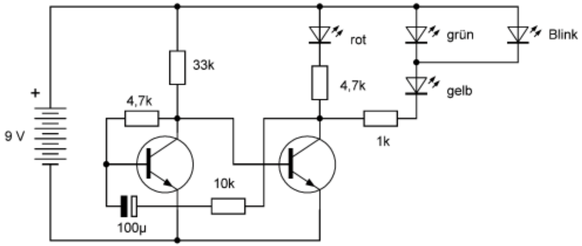
A circuit that automatically generates vibrations is called an oscillator. Oscillators are important circuits in electronics and computer technology. Many components used in a computer work in unison. This clock cycle is preset by an oscillator, but of course is working much faster than the flasher introduced here.

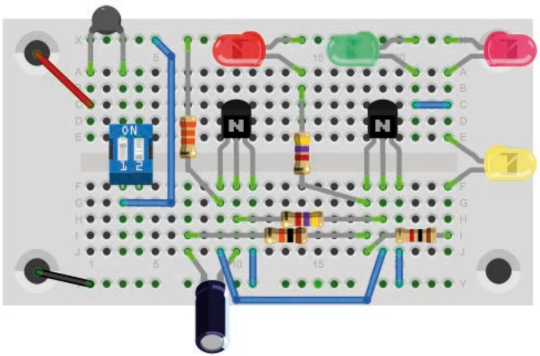




23 Intermittent flasher

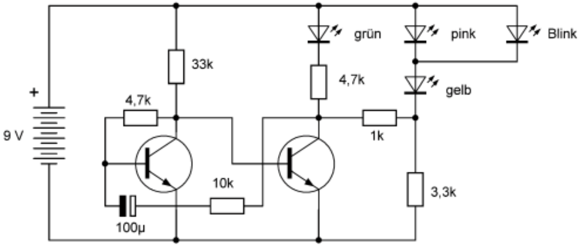
The flasher gets a fourth LED. This time we are also using the flashing LED, which we install parallel to the green LED. Thus, the red flashing LED and the green LED are always flashing alternately. Flashing is now faster compared to our self-made flashing circuit. You can see a series of flashing pulses, where the flashing LED is flashing about six times together with the green LED and then stops. The flashing pulses of the other LEDs are slower.

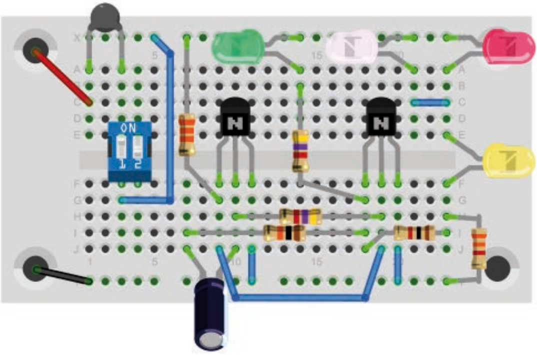




24 Flickering fire

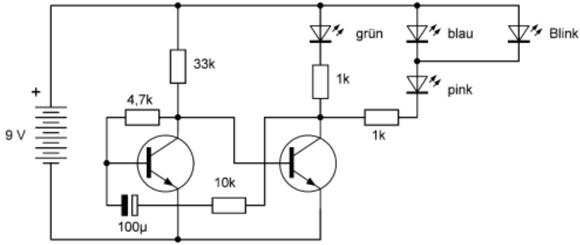
In this experiment we intend to create a soft flickering that simulates a campfire. We will add a third brightness level between on and off to our circuit. This time, the purple LED is installed parallel to the flashing LED and will go on whenever the flashing LED is off. This creates a complex flashing pattern reminiscent of the flickering of a fire.

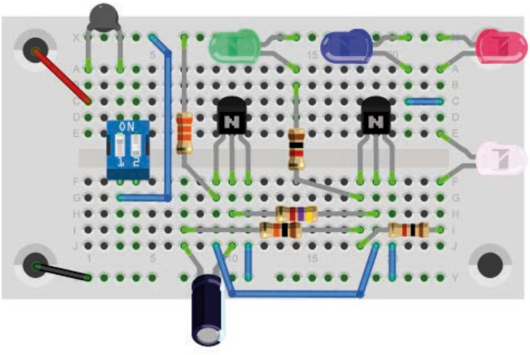




25 The special LED light

One color was missing up to now. So here, we are now installing the blue LED. The intermittent red and blue alternating flasher is particularly beautiful and attracts everyone's attention. And so many extensions with very different colors are possible. Yellow, red, green, blue? With or without flashing? Everything is feasible!





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