Understanding and using electronics
Burkhard Kainka

1. Step: Introduction

Since the transistor was invented, things have only gotten better with electronics. Today we are surrounded by devices whose integrated circuits contain many millions of transistors. But at the same time fewer and fewer know exactly how a (single!) transistor actually works. The gap between using and understanding electronics is constantly increasing. It is very simple: take a few transistors and do a few simple experiments – and an infinite number of possibilities open up. Many problems can be solved with simple transistor circuits. So get creative!

A transistor is a component with three connections and is for controlling the electric current. The amount of current that flows is influenced via a control connection (gate). There are essentially only two types of transistor. The bipolar transistors are made of layers with N and P semiconductor material. Depending on the sequence of layers, there are NPN transistors (e.g., BC547) and PNP transistors (e.g., BC557). By contrast, unipolar transistors consist of only one semiconductor channel whose conductivity is changed by an electric field. For this reason they are called *field effect transistors* (FET). A typical representative is N-channel MOSFET BS170.

This educational kit will make your start into electronics easier. First of all, the components are presented. The individual experiments are done on a breadboard. For each experiment there is a circuit diagram and a set-up photo. The photo is only meant as a suggestion. You can also arrange the components differently. The connection wires of the individual components were in some cases shortened for the photos to give a clearer view. But you should use the connection wires unshortened so that they can also be used for other experiments.

Patch panel
All experiments are set up on a laboratory experimental board. The patch panel with altogether 270 contacts in a 2.54 mm grid provides for secure connections of the components.

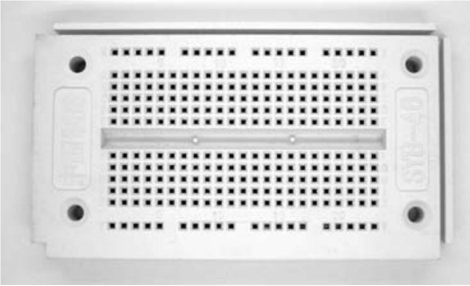


Fig. 1: The experimental board (B_Steckbrett.jpg)

The patch panel has 230 contacts in the middle area which are each electrically connected by vertical strips with five contacts. In addition, there are 40 contacts at the edge for the power supply, consisting of two horizontal contact spring strips with 20 contacts. The patch panel thus has two independent supply bars. Fig. 2 shows all internal connections. You can see the short contact rows in the middle area and the long supply bars at the edge.

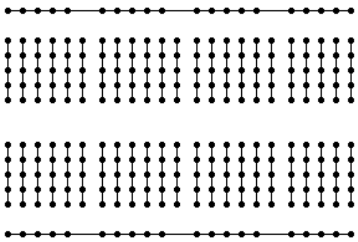


Fig. 2: The internal contact rows (Kontakte.gif)

Inserting components requires a fair amount of force. The connection wires easily snap. It is important that the wires are inserted exactly from above. A pair of tweezers or a small calliper helps. A wire is held as short as possible over the patch panel and pushed downward vertically. Sensitive connection wires such as the tinned ends of a battery clip can also be used.

For the experiments you need short and long pieces of wire which you have to cut to fit from the hook-up wire that is included. For stripping the wire ends, it is practical to cut the insulation all the way around with a sharp knife.

Battery

The following overview shows you the components as they really look and the schematic symbols as they are used in the circuit diagrams. A plug-in power supply unit, e.g., could be used instead of a battery.

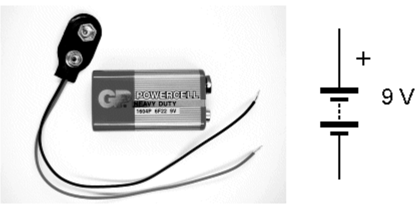
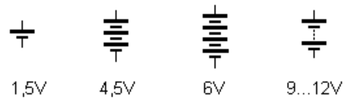


Fig. 3: The battery as it really looks and as schematic symbol (B_Batterie.gif)

Do not use alkaline batteries or rechargeable batteries, but only simple zinc-carbon batteries. The alkaline battery has a longer service life, but if there is a fault, e.g., a short circuit, it delivers (just like a rechargeable battery) very large currents up to more than 5 A. They can severely heat thin wires or even the battery itself. By contrast, the short circuit current of a zinc-carbon battery is usually smaller than 1 A. Thus sensitive components can already be destroyed, but there is no danger of fire.

The battery clip included has a connection cable with a flex. The cable ends are stripped and tinned. They are thus stiff enough that you can plug them into the contacts of the patch panel. But they can lose their shape through frequent plugging in. It is thus recommended that the battery connections are always left connected and that only the clip is removed from the battery.

A single zinc-carbon cell or alkaline cell has an electric voltage of 1.5 V. In a battery, several cells are connected in series. Accordingly, the schematic symbols show the number of cells in a battery. With higher voltages, it is customary to indicate the cells in the middle by a dotted line.

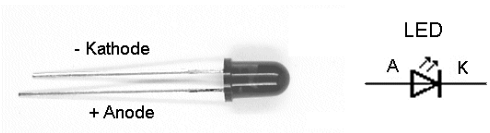


1.5 V 4.5 V 6 V 9... 12 V

Fig. 4: Schematic symbols for various batteries (Bat.gif)

Light-emitting diodes

The educational kit contains two red LEDs and a green and a yellow LED. With all LEDs, the polarity must always be attended to. The negative terminal is called the *cathode* and is on the shorter connection wire. The positive terminal is the *anode*. Inside the LED, you can see a cup-like holder for the LED crystal which is at the cathode. The anode terminal is connected to an extremely thin little wire with a contact on the top of the crystal. But in contrast to incandescent bulbs, LEDs must never be directly connected to a battery. A series resistor is always necessary.



- Cathode
+ Anode A C

Fig. 5: The LED (B_LED.gif)

Resistors

The resistors in the educational kit are carbon film resistors with tolerances of ±5%. The resistor material is attached to a ceramic bar and covered with a protective layer. Labelling is done in the form of coloured rings. Next to the resistance value, the accuracy class is also indicated.

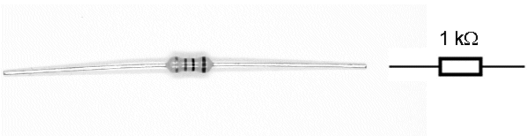


Fig. 6: A resistor (B_Widerstand.gif)

There are resistors with a tolerance of ±5% in the values of the E24 series, with each decade containing 24 values at an approximately uniform distance from the adjacent value.

Table 1: Resistance values according to the E24 series

1.0	1.1	1.2	1.3	1.5	1.6
1.8	2.0	2.2	2.4	2.7	3.0
3.3	3.6	3.9	4.3	4.7	5.1
5.6	6.2	6.8	7.5	8.2	9.1

The colour code is read based on the ring that is closer to the edge of the resistor. The first two rings stand for two digits, the third for a multiplier of the resistance value in ohms. A fourth ring indicates the tolerance.

Table 2: The resistor colour code

Colour	Ring 1 1st digit	Ring 2 2nd digit	Ring 3 multiplier	Ring 4 toleranc e
Black		0	1	
Brown	1	1	10	1%
Red	2	2	100	2%
Orange	3	3	1,000	
Yellow	4	4	10,000	
Green	5	5	100,000	0.5%
Blue	6	6	1,000,000	
Violet	7	7	10,000,000	
Grey	8	8		
White	9	9		
Gold			0.1	5%
Silver			0.01	10%

A resistor with the yellow, violet, brown and gold coloured rings has the value 470 Ω with a tolerance of 5%. In the educational kit there are two resistors with the following values:

470 Ω	yellow, violet, brown
1 kΩ	brown, black, red
22 kΩ	red, red, orange
470 kΩ	yellow, violet, yellow

NPN transistors
Transistors are components for amplifying small currents. The educational kit contains two silicon NPN transistors BC547B. The terminals of the transistor are called *emitter* (E), *base* (B) and *collector* (C). The base terminal is in the middle. The emitter lies to the right if you look at the labelling and the terminals point downward.
.

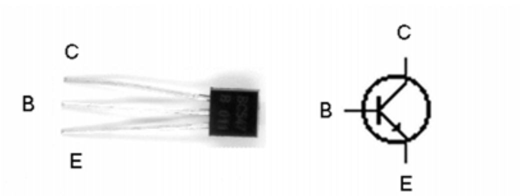


Fig. 7: The NPN transistor BC547 (B_NPN.jpg)

PNP transistors
The PNP transistor BC557B has the same terminal sequence and differs from an NPN transistor only in the polarity. In the schematic symbol the emitter arrow points inward.

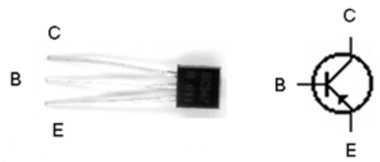


Fig. 8: The PNP transistor BC557 (B_PNP.jpg)

MOSFET
Even the field effect transistor (MOSFET) BS170 doesn't look outwardly different to a bipolar transistor. You can only identify it by the imprint. The terminals of the transistor are called *source* (S), *gate* (G) and *drain* (D). The source terminal lies to the right if you look at the labelling and the terminals point downward.

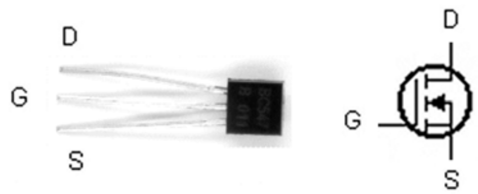


Fig. 9: The MOSFET transistor BS170 (B_FET.jpg)

Capacitors
The capacitor is an important component in electronics. It consists of two metal surfaces and an insulation layer. If you apply electric voltage, between the capacitor plates an electric force field forms in which energy is stored. A capacitor with a large plate surface and a small distance between the plates has a large capacitance and thus stores a lot of charge with a given voltage. The capacitance of a capacitor is measured in farads (f).

The insulation material (dielectric) increases the capacitance compared to air insulation. The ceramic disc capacitors use a special ceramic material with which large capacitances are achieved with a small design. The educational kit contains a ceramic disc capacitor with 10 nF (labelling: 103, 10,000 pF) and two with 100 nF (labelling: 104, 100,000 pF).

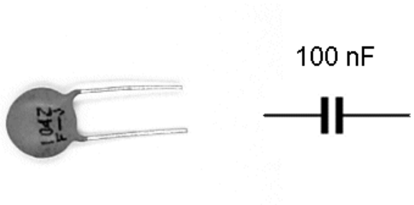


Fig. 10: A ceramic capacitor (B_Kondensator.gif)

Electrolytic capacitors
You get large capacitances with electrolytic capacitors. The insulation consists of a very thin layer of aluminium oxide. The electrolytic capacitor contains a liquid electrolyte and wrapped aluminium foil with a large surface. The voltage may only be applied in one direction. A leakage current flows in the wrong direction and gradually degrades the insulation layer, which leads to destruction of the component. The negative pole is designated by a white stripe and has a shorter connection wire.

Fig. 11: An electrolytic capacitor (B_Elko.gif)

2. Step: Current gain
The circuit in Fig. 12 shows the basic functioning of the NPN transistor. There are two circuits. A small base current flows in the control circuit; a larger collector current flows in the load circuit. Both currents together flow through the emitter. Since the emitter is at the common reference point of the circuit, this circuit is also called the *emitter circuit*. Once the base circuit is opened, no more load current flows. The base current is much smaller than the collector current. The small base current is thus amplified to a larger collector current. The base resistor is 470 times larger than the series resistor in the load circuit. The small base current can be identified by the low brightness of the green LED. The transistor BC548B amplifies the base current about 300-fold so that the red LED is substantially brighter than the green LED.

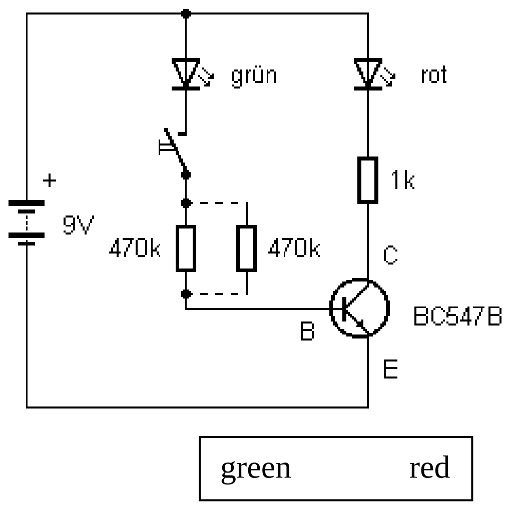


Fig. 12: An NPN transistor in the emitter circuit (Schaltung1.jpg)

Connect a second resistor of 470 kΩ parallel to the existing base resistor. The base current thus increases, and the collector current also becomes larger. The transistor is now fully interconnected, i.e., an even larger base current can no longer increase the collector current. If you connect a 22 kΩ resistor in parallel, the red LED does not become any brighter. The transistor now works like a switch. Between collector and emitter there is only a very small voltage drop of about 0.1 V. The collector current is already limited by the consumer and cannot increase anymore. Between base and emitter there is a voltage of about 0.6 V which changes only slightly with a change in current.

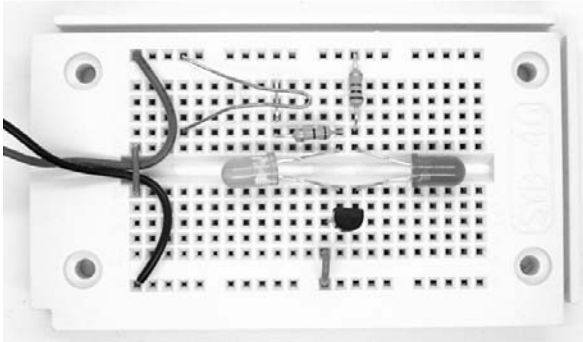


Fig. 13: Current gain (F_NPN1.jpg)

The LEDs are for indicating the currents. The red LED shines brightly, the green one barely. Only in a completely darkened room can the base current be seen as the weak shining of the green LED. The difference is an indication of the large current gain.

3. Step: Positive and negative reversed

A PNP transistor has exactly the same function as an NPN transistor, but with reversed polarity. The emitter is thus now at the positive pole of the battery.

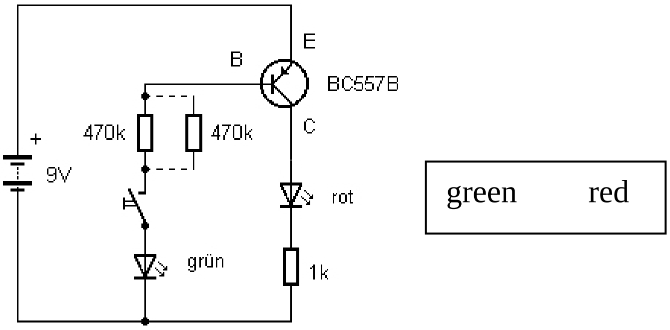


Fig. 14: A PNP transistor in the emitter circuit (Schaltung2.jpg)

Set up the circuit with the PNP transistor BC557 and examine the current gain here, too, with different base resistors. The BC557B likewise has about a 300-fold current gain.

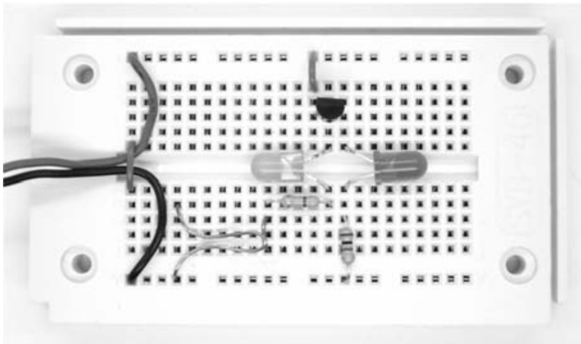


Fig. 15: Examining the current gain of the BC557 (Aufbau2.jpg)

4. Step: Follow-up control

The aim of this circuit is to make an LED electric torch with automatic afterglow. The interior lighting of automobiles often works according to this principle: after you leave the car, the light still shines for a certain time and then slowly goes out.

If you hold an electrolytic capacitor with the correct polarity to the battery, it takes an electric charge. After separation from the battery this charge remains for a long time. The electrolytic capacitor can then be connected to an LED. There is a brief flash of light. The electrolytic capacitor discharges in a brief moment.

The current gain of a transistor can be used to extend the discharging time of a capacitor. The circuit shown in Fig. 16 uses an electrolytic capacitor with 100 µF as the charging capacitor. After briefly pressing the key switch it is charged and now delivers the base current of the emitter circuit for a longer period.

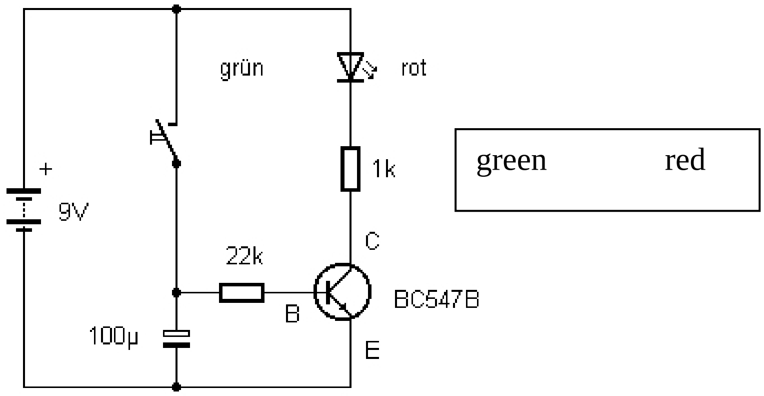


Fig. 16: Delayed switching-off (Schaltung3.jpg)
The discharging time is considerably extended by the large base resistor. After about two seconds the electrolytic capacitor is already mostly discharged. But after this time, the base current still suffices for a slight modulation of the transistor. The collector current decreases only gradually.

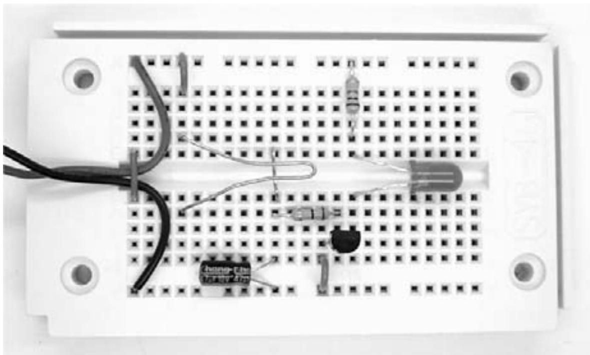


Fig. 17: The afterglow electric torch (F_NPN3.jpg)

The LED shines with full brightness as long as you keep the key switch pressed. But a brief press of the key switch suffices to turn the LED on. Afterward it remains fully switched on for about two seconds and after that shines more and more weakly. After about a minute a weak glow can still be seen. Actually, even after a longer period the LED does not go out completely. But the current drops to such small values that it no longer has any visible effect.

5. Step: Contact sensor

You can connect a lamp with a simple switch. However, a contact sensor can also be constructed with a suitable transistor circuit. Two wires or metal contacts do not directly touch, but instead you only have to touch them with your finger.

The current gain factors of two transistors can be multiplied if you amplify the amplified current of the first transistor once more as the base current of the second transistor. The circuit shown in Fig. 18 is also called a *Darlington circuit.*

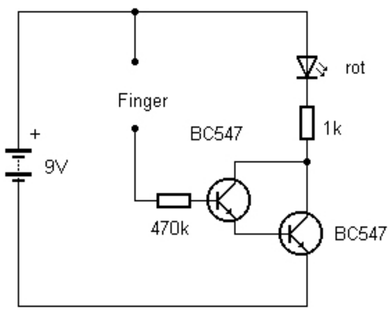


Fig. 18: The Darlington circuit (ng4.jpg)

If you assume a gain factor of 300 for each of the transistors, the Darlington circuit has a gain of 90,000. Now a base resistor of 10 MΩ already conducts sufficiently to switch the LED on. In a real experiment, you can use a physical contact instead of the extremely high-ohm resistor. Due to the large gain, a light touch with a dry finger is already sufficient. The additional protective resistor in the input lead to the battery protects the transistors in case the physical contacts are inadvertently directly connected.

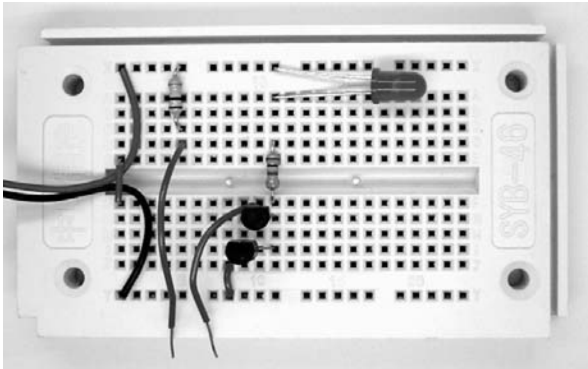


Fig. 19: The contact sensor (F_ Darlington1.jpg)

6. **Step: Motion detector**

This circuit has a sensor wire at the input of the first transistor. If someone moves in the vicinity of the wire, the LED lights up. Through motion on an insulating background, every person charges him-/herself electrically without noticing it. If you then move in the vicinity of conductive objects, the electrostatic forces lead to a shifting of electric charges, i.e., to a small current, which is highly amplified here. The Darlington circuit activates a PNP transistor so that the current gain once again becomes 300 times bigger. Now a few picoamperes already suffice to cause the red LED to visibly shine.

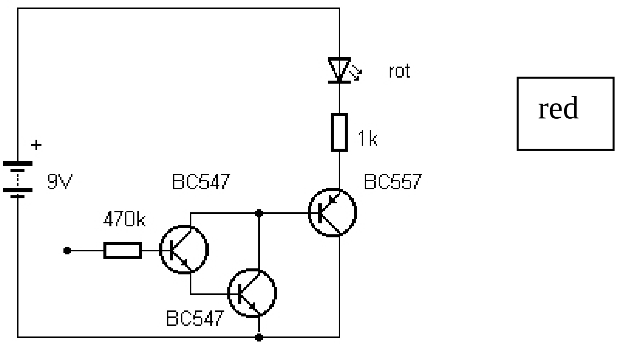


Fig. 20: Current gain with three transistors (Schaltung5.jpg)

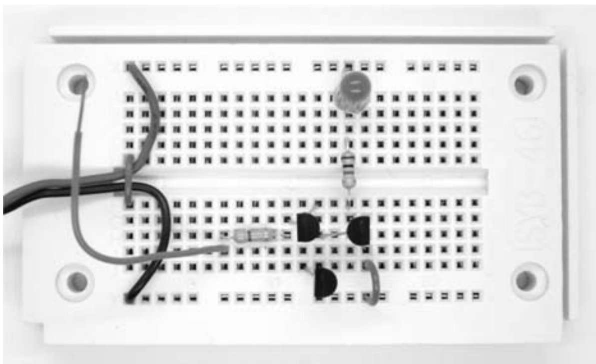


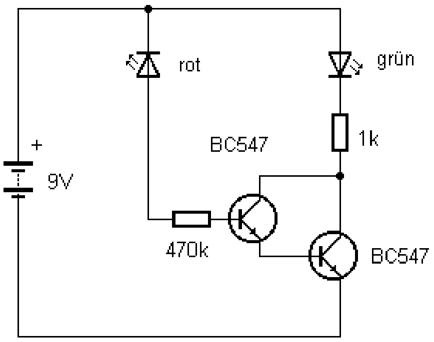
Fig. 21: Sensor amplifier for electric fields (Aufbau5.jpg)

For the first test of the circuit, a short 10 cm sensor wire is suitable. After some motion on an insulating floor, you normally have gathered sufficient electric charge. Then move your hand in the vicinity of the sensor wire. The brightness of the LED changes.

To increase the sensitivity of the circuit, a longer sensor wire can be connected. It can be a bare wire or an insulated cable. The sensor becomes even more effective if you additionally earth the negative pole of the battery. For this it is sufficient if a second person touches the circuit. Now it is already detected if someone walks by at a distance of half a meter. The flashing of the LED shows the individual steps. If there is direct contact with the bare wire end, you see a continuous shining. You can trace this back to the unavoidable 50 Hz alternating fields in the room. The LED actually doesn't shine constantly, but rather flashes at a frequency of 50 Hz.

7. Step: LED as light sensor

This light sensor controls the brightness of an LED. When light strikes the sensor, the LED goes on; in darkness it stays off. Actually, practically no current flows through a diode if it is put to a voltage in reverse direction. However, there is actually a very small reverse current, e.g., in the range of a few nanoamperes which normally can be disregarded. The high gain of the Darlington circuit, however, allows experiments with extremely small currents. Thus, e.g., the reverse current of an LED is itself dependent on the illumination. An LED is thus at the same time a photodiode. The extremely small photocurrent of the red LED is amplified with two transistors to such an extent that the green LED shines.



red green

Fig. 22: Gain of the LED reverse current (Schaltung6.jpg)
In a practical experiment, the right LED is already clearly switched on in normal ambient light. A shading of the sensor LED with the hand becomes visible in the brightness of the display LED.

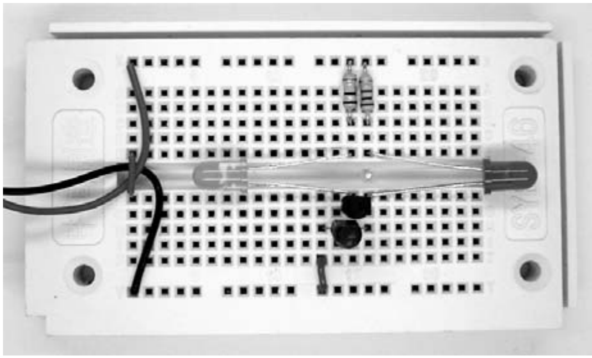
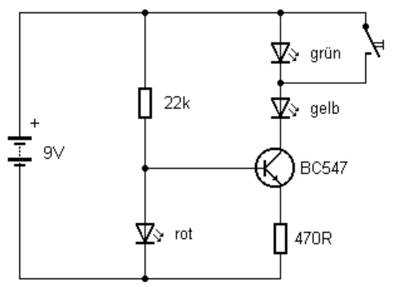


Fig. 23: The LED light sensor (F_Darlington3.jpg)

8. Step: Constant brightness

Sometimes you need a constant current which is as independent of voltage fluctuations as possible. An LED would thus shine with the same brightness even if the battery had lost some of its voltage. The circuit depicted in Fig. 24 shows a simple stabilisation circuit. A red LED at the input stabilises the base voltage to about 1.8 V. Since the base emitter voltage is always around 0.6 V, there is a voltage of about 1.2 V at the emitter resistor. The resistor therefore determines the emitter current and thus also the collector current of ca. 2.5 mA.

The LEDs in the collector circuit do not need a series resistor because the LED current is regulated by the transistor. The constant current source also works with different loads. Regardless of whether you use both LEDs in the collector circuit or short-circuit one of them – the collector circuit remains the same.



green
yellow
red

Fig. 24: A stabilised current source (Schaltung7.jpg)

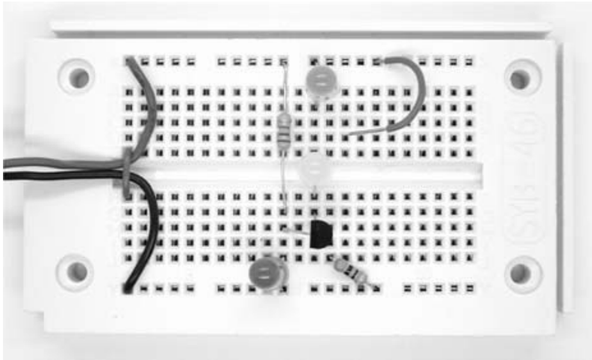
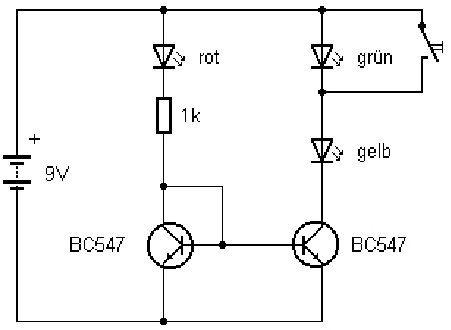


Fig. 25: Stabilisation of LED brightness (Aufbau7.jpg)

Check the results with a new battery and a heavily used one. As long as a certain residual voltage is present, the LED stays almost as bright. With only one LED, the battery voltage may be lower than with two LEDs, in which latter case at least about 6 V still have to be present.

9. Step: Temperature sensor

This circuit shows temperature differences via the LED brightness. It is enough to touch the temperature sensor with your finger. The circuit depicted in Fig. 26 shows a so-called current mirror. The current through the 1 kΩ resistor is mirrored in the two transistors and reappears in nearly the same magnitude as the collector current of the right transistor. Since in the case of the left transistor base and emitter being interconnected, a base-emitter voltage of about 0.6 V automatically appears which leads to the specified collector current. Theoretically, the second transistor should now show the same collector current with exactly the same data and with the same base-emitter voltage. In practice, however, usually slight differences result. The current mirror is at the same time a constant current source. The brightness of the yellow LED thus doesn't change if you bypass the green LED.



red	green yellow

Fig. 26: The current mirror (Schaltung8.jpg)

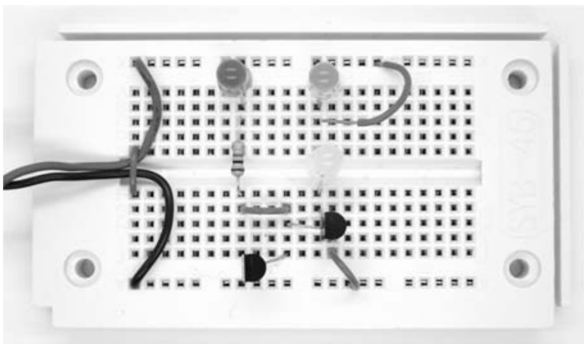


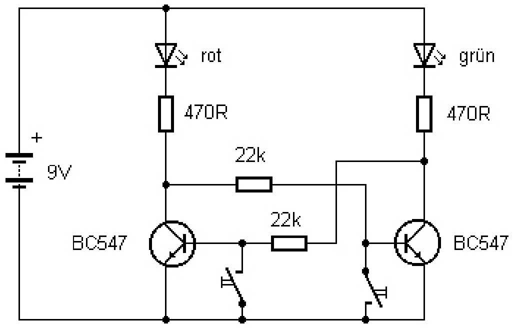
Fig. 27: Transistor as temperature sensor (Aufbau8.jpg)

The circuit is suitable as a sensitive temperature sensor. Touch one of the transistors with your finger. The heating that appears changes the output current and becomes visible in the LED's change in brightness. Depending on which of the two transistors you touch, you can increase or decrease the brightness of the right LEDs somewhat. Depending on ambient temperature, you can heat it up by up to 10 °C with your finger and which already becomes quite visible. The difference in brightness becomes even clearer if you carefully heat one of the transistors with a soldering rod.

10. Step: On and off

Now it goes digital: while more or less current flows in an analogue circuit, a digital circuit is either completely on or completely off. The states *On* and *Off* are also designated as *One* and *Zero*. The circuit depicted here can be seen as a basic module of computer technology.

A circuit with two stable states is called a *trigger circuit* or also a *flip-flop circuit*. An LED is either on or off, but never “half-on.” Fig. 28 shows the typical circuit of a simple flip-flop. In principle, the circuit consists of two coupled amplifier stages with closed feedback.



red	green

Fig. 28: A bistable flip-flop (Schaltung9.jpg)

The circuit flips into one of two possible states. If the right transistor conducts, the left is blocked and vice versa. The conductive transistor has a low collector voltage and thus switches the base current of the other transistor off. For that reason, once engaged a switching status remains stable until it is changed by one of the key switches.

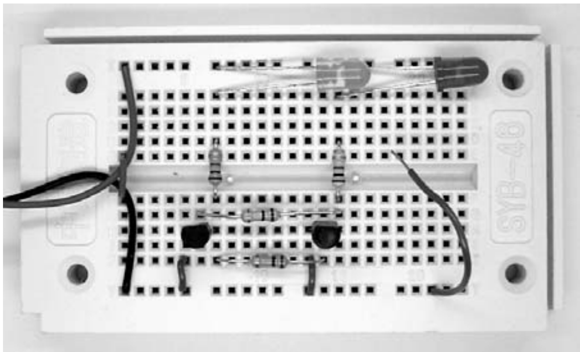


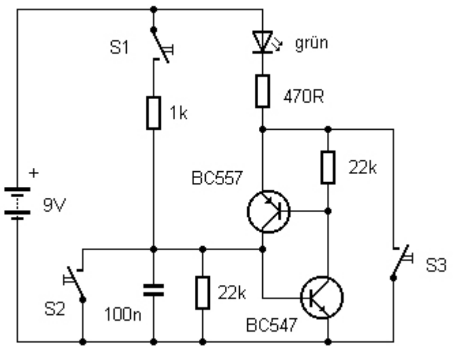
Fig. 29: The flip-flop (F_Flipflop1.jpg)

Switch the operating voltage on. You will discover that one of the two LEDs shines. But it cannot be predicted which side is switched on. Usually the unequal current gain of the transistors decides which side the circuit flips to.

Now use a jumper to block one of the two transistors. The engaged state remains after removal of the jumper. The two states are also designated as *Set* (*S*) and *Reset* (*R*), thus the name *RS flip-flop.*

11. Step: Firing and erasing

A bistable circuit can also be constructed with an NPN and a PNP transistor. The collector current of one transistor becomes at the same time the base current of the other transistor. Thus either both transistors are blocked or both are conductive. After being switched on, the circuit is at first in the blocking state. Brief activation of the switch at S1 switches over into the conductive state. This state is now stored and remains as long as the supply voltage is present. Only by switching the operating voltage off do the transistors return to the blocked state.



green

Fig. 30: Conducting and blocking (Schaltung10.jpg)

With a short connection S1, you fire the circuit so that the LED shines. With S2, by contrast, the conductive state can be erased. S3 switches the LED on, but at the same time erases the conductive state of the transistors. After opening S3 the LED is thus off.

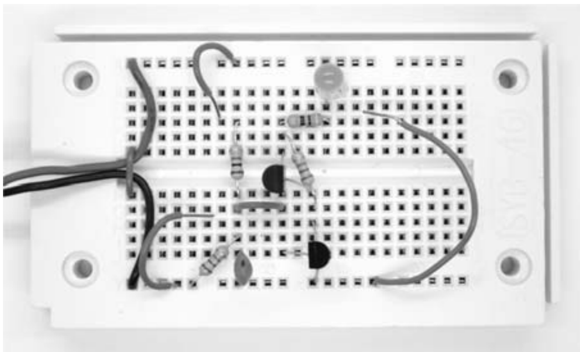
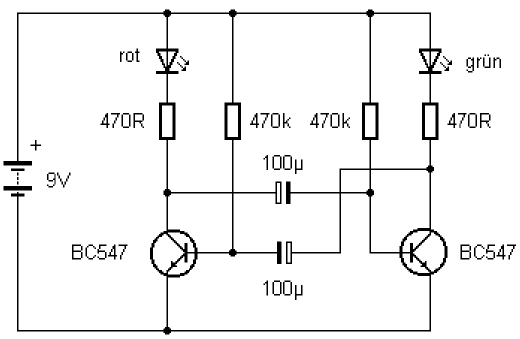


Fig. 31: On or off (Aufbau10.jpg)

12. Step: Push-pull flasher

This electronic flasher works in push-pull action: two LEDs are automatically switched so that only one of them is on at any time. The symmetrical flasher circuit shown in Fig. 32 is also called a *multivibrator*. Feedback takes place via two capacitors. With the electrolytic capacitors, you have to pay attention to the polarity, since the voltage at the respective collector is higher on average than at the opposite base. The state of the circuit only remains stable as long as the charge reversal of the capacitors is still taking place. Afterward the circuit flips into the other state. With two 100 µF electrolytic capacitors a very slight flashing frequency results, with fewer than five complete alternations per minute.



red green

Fig. 32: The multivibrator (Schaltung11.jpg)

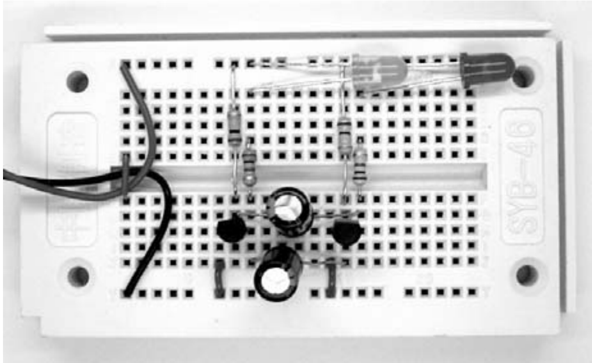


Fig. 33: A slow alternating flasher (F_Blinker1.jpg)

13. Step: Simple LED flasher

A flasher unit in a motor vehicle usually activates only one lamp. Another flip-flop is set up here that automatically switches back and forth. The circuit requires only one capacitor. Two transistors in an emitter circuit form an amplifier. The feedback from the output to the input passes via a capacitor that repeatedly charges and discharges itself.

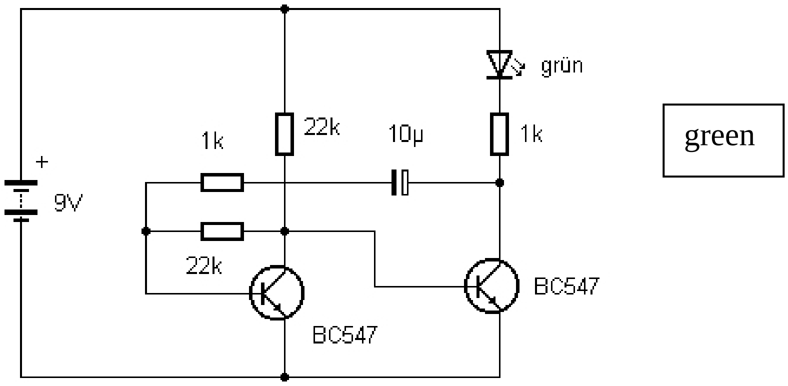


Fig. 34: The multivibrator (Schaltung12.jpg)

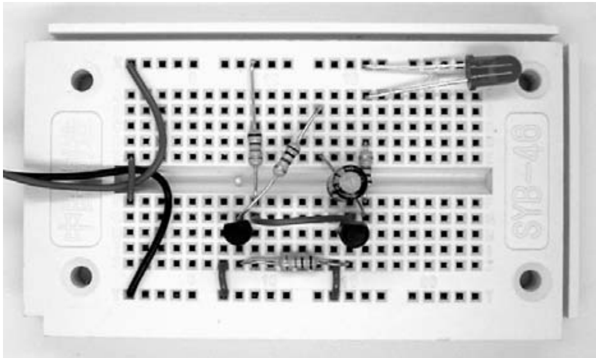
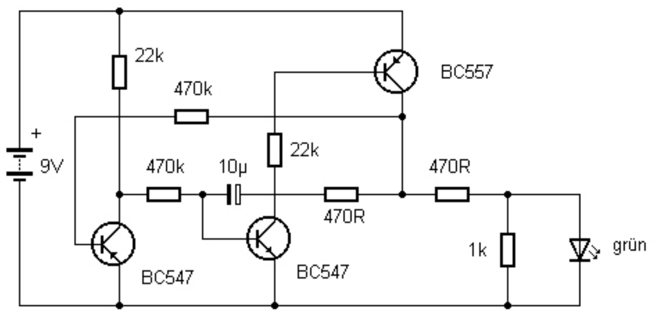


Fig. 35: The LED flasher (F_Blinker2.jpg)

14. Step: LED flashing light

This circuit produces regular short flashes of light. As long as the capacitor is still charged, all three transistors remain blocked. The voltage at the base of the middle transistor increases slowly. At about +0.6 V the middle transistor begins to conduct and delivers the base current for the PNP transistor. Its collector voltage increases and switches the LED on. At the same time, the electrolytic capacitor delivers a powerful and brief base pulsed current. The left transistor in the circuit is for securing the correct operating point of the circuit. About one flash of light per second is generated.



green

Fig. 36: The flashing light circuit (Schaltung13.jpg)

Remove from the circuit the 1 kΩ resistor that is parallel to the LED: the pause between flashes of light is considerably prolonged. The left transistor blocks only when the electrolytic capacitor is completely discharged. Only then does its collector voltage slowly increase so as to enable a new pulse.

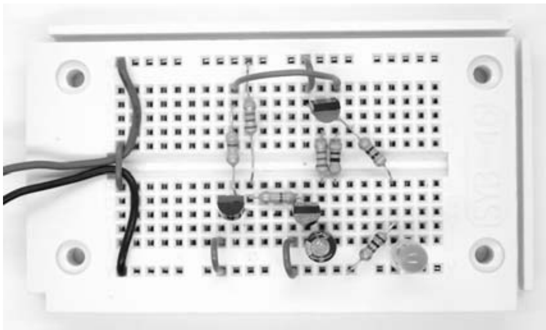


Fig. 37: LED flashing light (Aufbau13.jpg)

15. Step: MOSFET touch sensor

This circuit with the MOSFET BS170 (metal oxide semiconductor field effect transistor) controls an LED by means of two pairs of contacts which you can directly connect or touch with your finger. After a short connection of the contacts, the respective state is preserved for a longer period of time.

The NPN transistor was presented in the first experiment with a simple basic circuit. A base current has to flow so that a collector current is possible. A similar experiment with the MOSFET BS170 exhibits completely different behaviour. The MOSFET has three terminals: *gate* (G), *source* (S) and *drain* (D). This time, the controlled current does not depend on an input current, but rather on the voltage applied between G and S. If there is a positive voltage of about 2 V or more at the gate, the transistor conducts. The gate terminal is completely insulated and forms a small capacitor with about 20 pF. Once the gate is charged the gate voltage thus persists for a long time.

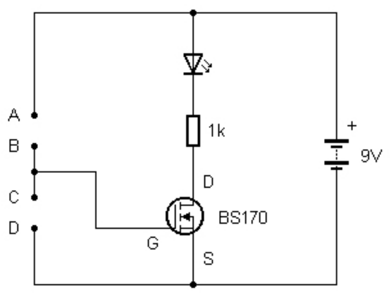


Fig. 38: Basic MOSFET circuit (Schaltung14.jpg)

Briefly connect the terminals A and B to charge the gate. The LED goes on and stays on. Connect the contacts C and D to discharge the gate and turn the LED off. Each of these two possible states persists for a relatively long time. The experiment thus demonstrates the basic functioning of a dynamic storage unit which also stores an electric charge so as to illustrate the one and zero states. At the same time the circuit is a simple touch switch, because when the contacts A and B or C and D touch it has the same effect as a direct contact.

But be careful! A gate voltage of more than 20 V is not allowed and can lead to destruction of the transistor. Therefore you have to be careful with electrostatic charge. So always first touch a terminal of the operating voltage so as to divert any charges. There is particular danger for the transistor if two persons touch the same circuit. Since the two can be differently charged, a discharge via the transistor can result which destroys it.

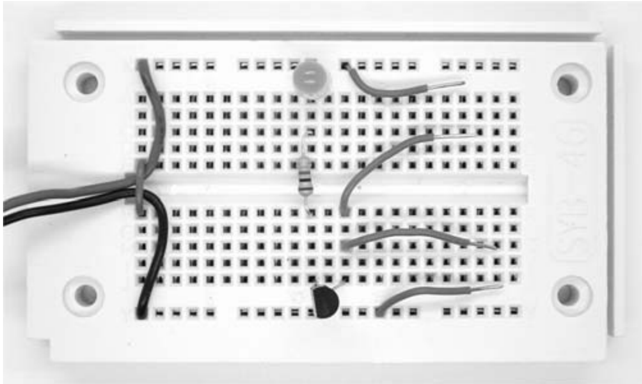


Fig. 39: Charging and discharging the gate (Aufbau14.jpg)

16. Step: Sensor-dimmer

With an additional capacitor between gate and drain, intermediate states between “completely on” and “completely off” are also preserved. If the voltage at the gate drops, the drain current becomes smaller and the voltage also drops at the LED and its series resistor. The drain voltage therefore increases. This is only possible if the capacitor is charged. Every change in the drain voltage counteracts a change in the gate voltage. Thus, with a small input current the LED brightness only changes slowly. If the contacts A and B touch, the LED gets brighter. By contrast, to make it darker C and D must touch. The time it takes for a reaction to touching differs in the two cases. Brightening takes place more quickly than darkening due to the higher charging voltage.

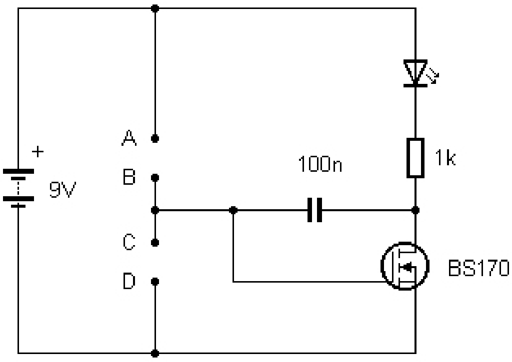


Fig. 40: The touch dimmer (Schaltung15.jpg)

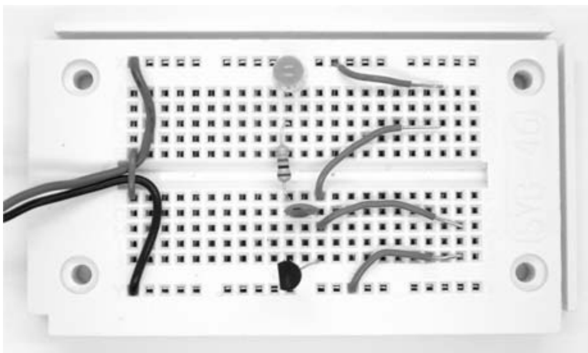


Fig. 41: Adjustable brightness (Aufbau15.jpg)

17. Step: Electrometer

An electrometer is a measuring device for detection of small electric charges. Electrically charged objects or persons carry an electric field with them which can charge insulated objects in the surrounding area through electrostatic induction. This also applies to the insulated gate of the BS170. An insulated wire is connected at the input of the circuit. Electric charges in the surrounding area then influence the LED brightness. You can, e.g., rub a plastic ruler on a cloth and hold it near the circuit. In doing so, maintain a safety distance of 10 cm so as to not damage the MOSFET.

The initial state after switching on is indeterminate; the transistor could thus be completely blocked or completely conductive. In both cases, small differences in the gate voltage have no effect. There is thus a start switch with which you briefly connect gate and drain. The gate voltage adapts to the middle range at around ca. 2 V.

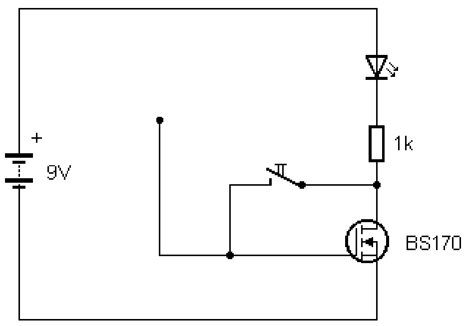


Fig. 42: The electrometer (Schaltung16.jpg)

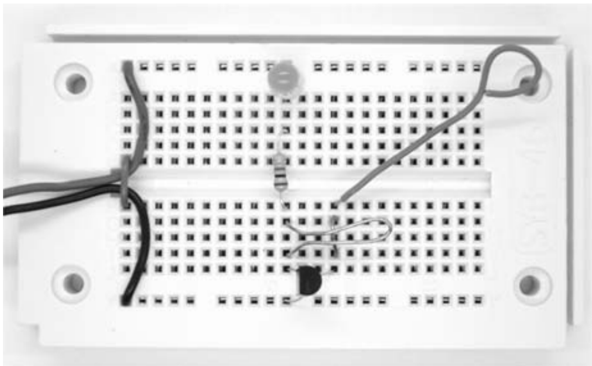


Fig. 43: Detection of electric charges (Aufbau16.jpg)

18. Step: LEDs as photovoltaic cells

This experiment shows another way to make a simple light sensor. This time you use a BS170. Two LEDs serve as light sensors. In Section 16, an LED was used as a light sensor with two NPN transistors in a Darlington circuit. Thanks to the almost infinitely large input resistance, a single MOSFET performs the same task alone. But now you need two LEDs as light sensors. The LEDs are used as photovoltaic cells that can deliver a voltage. The BS170 conducts starting at a gate voltage of 2 V. With sufficient illumination, two LEDs together can produce the required voltage. Even just a slight increase in brightness shows the effect. Also experiment with different LEDs. A green LED delivers somewhat more voltage than a red one.

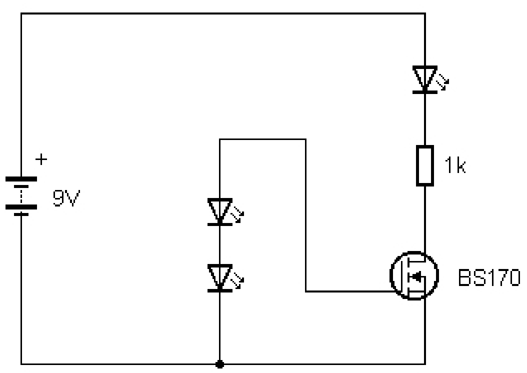


Fig. 44: LEDs as photovoltaic cells (Schaltung17.jpg)

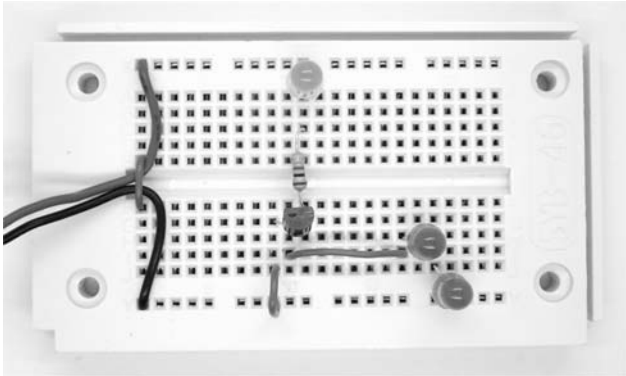


Fig. 45: The light sensor (Aufbau17.jpg)

19. Step: Capacitor temperature sensor

A ceramic capacitor with 100 nF can be used as a temperature sensor. Such a capacitor has a large temperature coefficient. The capacity is diminished with heating. In this experiment, the switch must initially be closed and then opened again. The gate voltage automatically adapts to the threshold voltage of approximately 2 V; the LED shines. There is a voltage of about 7 V at the 100 nF capacitor.

Now touch the capacitor very lightly with your finger, which leads to an increase in temperature. The charge stored in the capacitor remains constant. But since the capacity diminishes, the capacitor voltage increases. This leads to a smaller gate voltage and thus to a smaller drain current. Even a light touch suffices to cause the LED to shine noticeably weaker. The circuit reacts to small changes in temperature more sensitively than the transistor circuit in Section 18. As soon as the sensor capacitor has cooled down again, the original LED brightness returns.

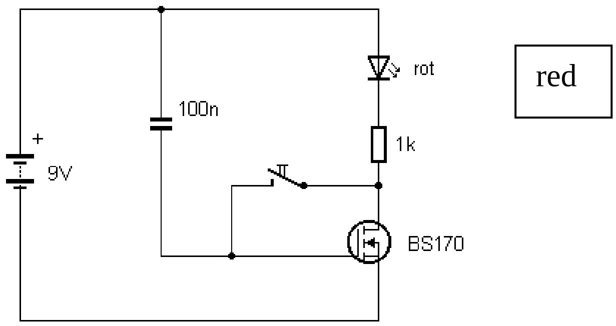


Fig. 46: Analysis of capacitor voltage (Schaltung18.jpg)

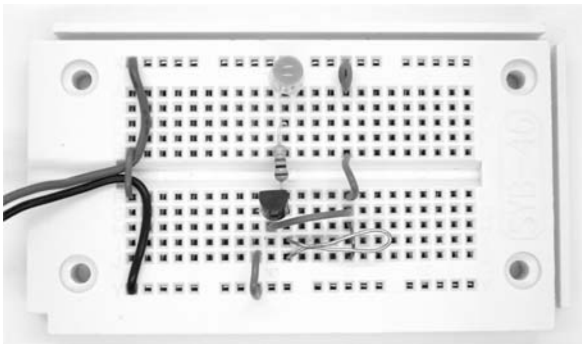
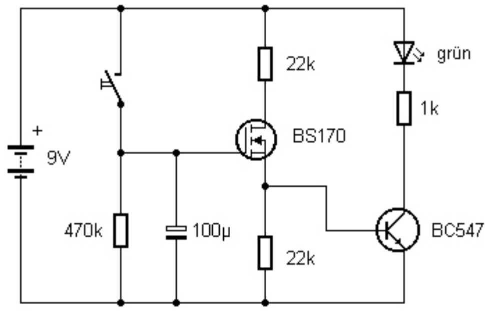


Fig. 47: The temperature sensor (Aufbau18.jpg)

20. Step: Minute light

The light is switched on by pressing the key switch and then remains on for about a minute. The transition between bright and dark is smooth but relatively fast. The electrolytic capacitor is charged to 9 V by pressing the key switch. It discharges via the 470 kΩ resistor. As long as the gate voltage is more than ca. 2.6 V, the FET conducts and delivers the base current for the NPN transistor and the LED switches on. If the input voltage drops, the FET conducts more weakly. Once the base voltage of the NPN transistor has dropped below ca. 0.6 V, no more noticeable collector current flows and therefore the LED goes out.



green

Fig. 48: Slow capacitor discharge (Schaltung19.jpg)

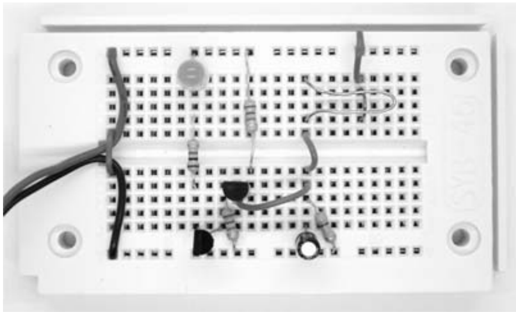
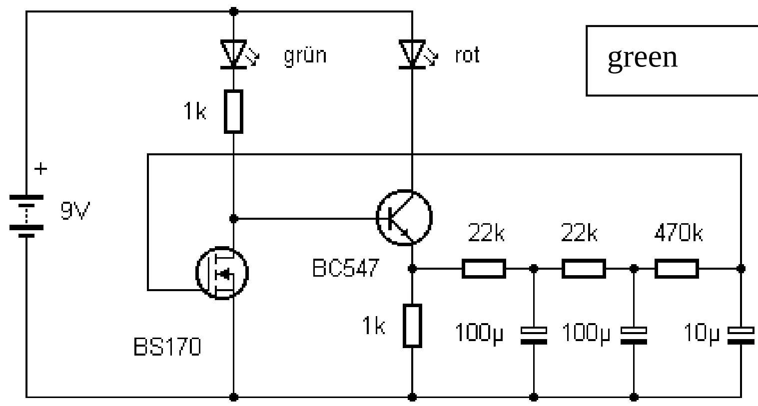


Fig. 49: The minute light (Aufbau19.jpg)

21. Step: Smooth flasher

An LED flasher with smoothly swelling and ebbing brightness can, with a suitable frequency, help the viewer relax. The brightness follows a sinus wave. This circuit activates two LEDs precisely in phase opposition. The light thus continuously changes with smooth transitions between red and green.



green red

Fig. 50: A phase shifter oscillator (Schaltung20.jpg)

At the start of the circuit, the electrolytic capacitors are still discharged. Therefore the BS170 blocks and the NPN transistor conducts. At first only the red LED shines. Then the circuit tries to swing onto a middle current, but constantly overshoots and produces a sinusoidal signal at which first the one transistor conducts and then the other one conducts.

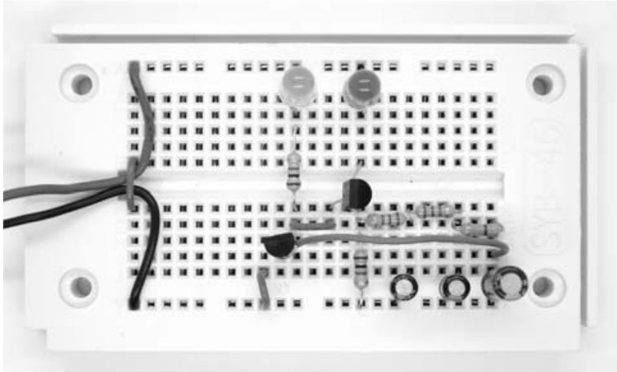


Fig. 51: The soft flasher (Aufbau20.jpg)