Introduction to circuit technology

Practical exercise lecture

TAKE-HOME-LAB

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Table of Contents

1 Voltage/Circuit/Resistance/Measurement

1.1 Introduction

1.1.1 Circuit diagram

A circuit diagram is the graphical representation of an electrical circuit. Components are represented in simplified form by standardized symbols. A circuit diagram does not take into account the actual arrangement or size of the components. The components are usually designated with a component-specific letter followed by a number.

Conductive connections are represented by lines, where the conductivity of an electrical connection represented in this way is considered ideal. A conductive connection between two or more lines is represented by a point (node).

1.1.2 Pegboard

Experimental circuits can be constructed with a plug-in board (breadboard). Components can be plugged into holes which are conductively connected as shown below. Use the plug-in board only for low voltage (no 230V)! The contacts can only be loaded with low currents (typically 1A).

Use plug-in board only for low voltages and currents!

Be aware of creating shorts between contacts.

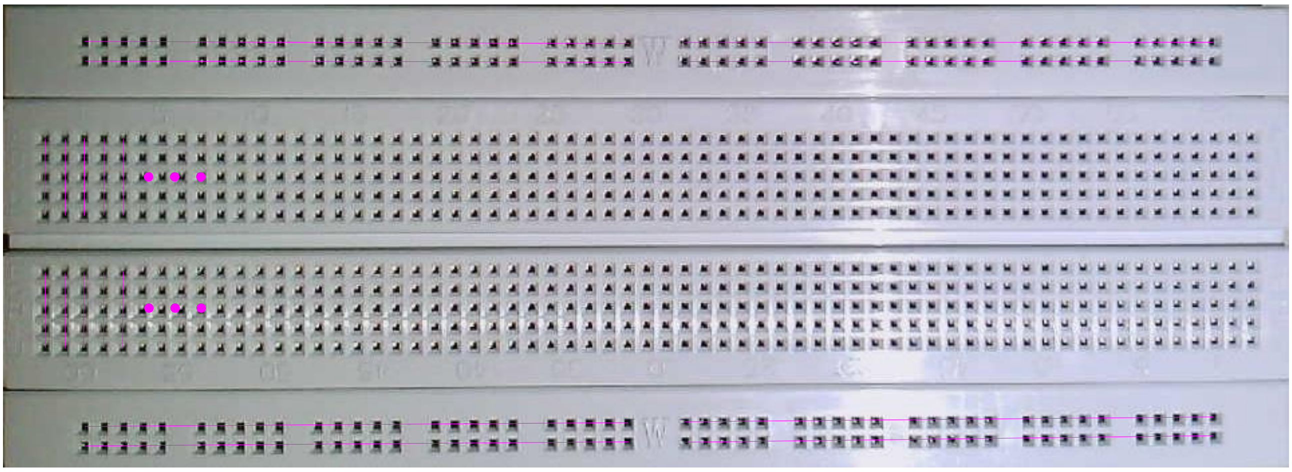


Fig. 1.1.2-1: Pegboard with conductive connections

1.1.3 Battery

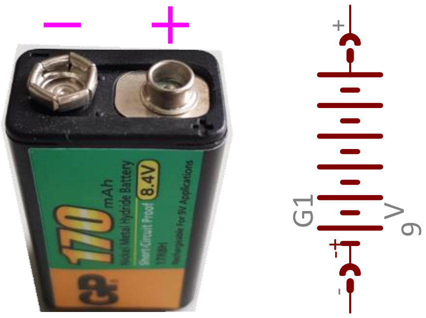


Fig. 1.1.3-1: Component and circuit symbol (EAGLE)

A battery provides a constant DC voltage, which means that the polarity of the voltage must be observed. Due to its very low internal resistance (a few ohms), a very large current flows in the event of a short circuit (poles directly connected), which can lead to the destruction of connected components and the battery. The battery used in the practical course is protected by a back-up fuse in the supply line, which blows in the event of a short circuit.

Never short-circuit batteries without fuses.

1.1.4 Resistors

Fig. 1.1.4-1: Component and circuit symbol (EAGLE)

A resistor is a two-pole component that opposes the current flow with a defined resistance. The greater the resistance, the less current can flow at the same voltage. The following relationship therefore applies:

$$R = \frac{U}{I}$$

The energy is converted into heat, and the following applies to the heat output:

$$P = U \cdot I$$

Thus, the power in the first equation is also:

$$P = \frac{U^2}{R}$$

The permissible power of the resistor must not be exceeded, otherwise it will fail and burn. The larger the component, the more power dissipation is permissible.

From the color coding, the resistance value can be read as follows:

Table 1.1.4-1: Color coding for resistors (4 rings)

Color		Resistor Value in Ω 1st Ring (tens)	 2nd Ring (ones)	Tolerance 3rd Ring (Multiplier)	 4th Ring
None		-	-	-	±20%
Silver		-	-	$1 \cdot 10^{-2}$	±10%
Gold		-	-	$1 \cdot 10^{-1}$	±5%
Black		-	0	1	-
Brown		1	1	$1 \cdot 10^{1}$	-
Red		2	2	$1 \cdot 10^{2}$	-
Orange		3	3	$1 \cdot 10^{3}$	-
Yellow		4	4	$1 \cdot 10^{4}$	-
Green		5	5	$1 \cdot 10^{5}$	-
Blue		6	6	$1 \cdot 10^{6}$	-
Purple		7	7	$1 \cdot 10^{7}$	-
Grey		8	8	$1 \cdot 10^{8}$	-
White		9	9	$1 \cdot 10^{9}$	-

Table 1.1.4-2: Color coding for resistors (5 or 6 rings)

Color		Widerstandswert in Ω 1st Ring (hundreds)	 2nd Ring (tens)	 3rd Ring (ones)	 4th Ring (Multiplier)	5th Ring (Tolerance)	6th Ring (Temp.-Coeff.)
Silver		-	-	-	$1 \cdot 10^{-2}$	-	-
Gold		-	-	-	$1 \cdot 10^{-1}$	-	-
Black		-	0	0	1	-	$200 \cdot 10^{-6}\,K^{-1}$
Brown		1	1	1	$1 \cdot 10^{1}$	±1%	$100 \cdot 10^{-6}\,K^{-1}$
Red		2	2	2	$1 \cdot 10^{2}$	±2%	$50 \cdot 10^{-6}\,K^{-1}$
Orange		3	3	3	$1 \cdot 10^{3}$	-	$15 \cdot 10^{-6}\,K^{-1}$
Yellow		4	4	4	$1 \cdot 10^{4}$	-	$25 \cdot 10^{-6}\,K^{-1}$
Green		5	5	5	$1 \cdot 10^{5}$	±0,5%	-
Blue		6	6	6	$1 \cdot 10^{6}$	±0,25%	$10 \cdot 10^{-6}\,K^{-1}$
Purple		7	7	7	-	±0,1%	$5 \cdot 10^{-6}\,K^{-1}$
Grey		8	8	8	-	±0,05%	-
White		9	9	9	-	-	-

When reading, the resistor must be held so that the rings are aligned to the left or the single ring can be seen on the right.

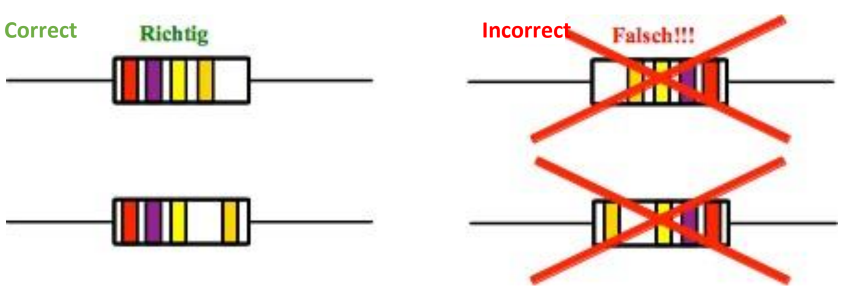


Fig. 1.1.4-2: Correct reading of the color rings [1].

The following example shows the reading of a resistor with 4 rings.

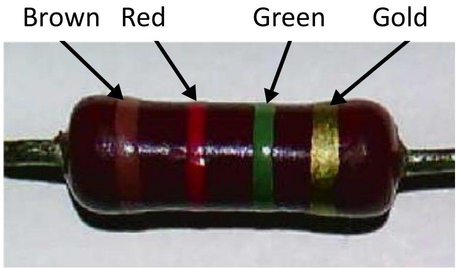


Fig. 1.1.4-3: Example Resistor

Thus, the resistance value is: R = (10 + 2) · $10^5\Omega$ = 1.2MΩ with a tolerance of 5%.

The resistors below are used in the practical course:

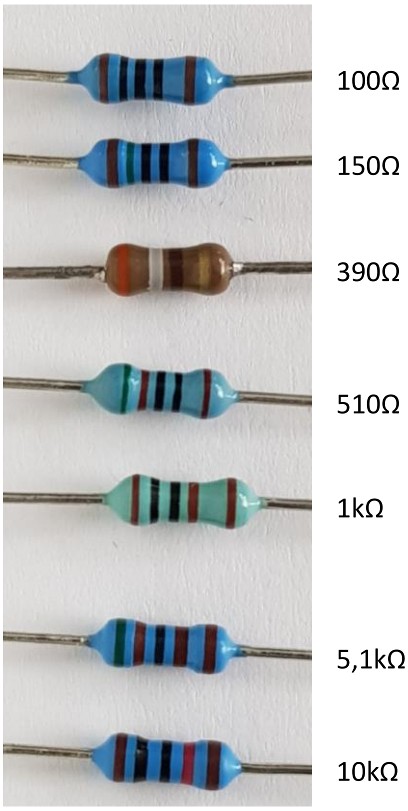


Fig. 1.1.4-4: The resistors to be used.

1.1.5 Light emitting diode (LED)

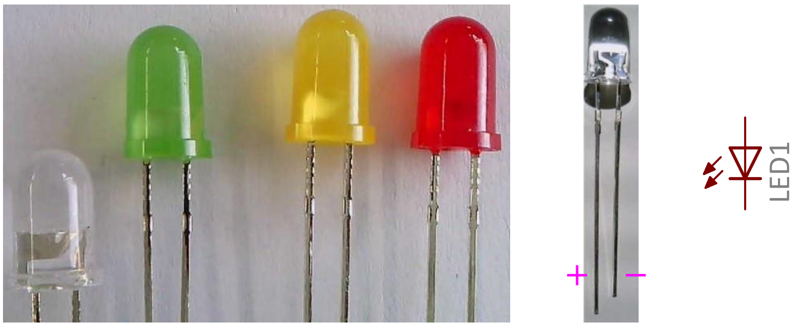


Fig. 1.1.5-1: Component and circuit symbol (EAGLE)

An LED is a semiconductor device that emits light in a specific color (wavelength) when current flows through it, depending on the semiconductor material. As a diode, it only allows current to pass in one direction and blocks it in the other. So, it is necessary to pay attention to the polarity of the component. The positive pole can be identified by its longer wire.

In reverse direction, the LED can only block a low voltage (a few volts) without being damaged. In forward direction it does not light up below a certain voltage (diffusion voltage, see data sheet) despite correct polarity. The current flow of an LED does not increase linearly with the voltage! The LED must never be operated without a series resistor.

Table 1.1.5-1: Series resistors to be used for the LEDs

Color	Series resistor (at 9V)	Series resistor (at 5V)
Red	390 Ω	151 Ω
Green	390 Ω	151 Ω
Yellow	390 Ω	151 Ω

LEDs should only be operated with series resistor!
Observe polarity!

1.1.6 Button

Fig. 1.1.6-1: Component and circuit symbol (EAGLE)

A pushbutton is an operating element that establishes a conductive connection and returns to its initial position when released, i.e. it does not latch.

Pushbuttons can be designed as normally closed or normally open contacts. A normally closed contact opens the circuit when actuated, a normally open contact closes it. In case of several connections, the wiring is to be taken from the data sheet. The permissible voltage and current must be observed. Pushbuttons are not suitable for switching short circuits, as they can be destroyed by this.

Observe the permissible voltage and current!
Do not switch short circuits.

1.1.7 Measuring device

A measuring device can be used to determine the value of a physical quantity (current, voltage, length...). Here it is electrical quantities.

Before starting the measurement, the correct **setting of the measuring range (via rotary switch)**, as well as the **connection of the test leads** must be observed. An incorrectly set measuring range or a faulty connection can lead to personal injury or destruction of the measuring device.

If the magnitude of the measurand is unknown, **first** use **the largest measuring range** and then reduce this step by step to the smallest possible measuring range.

For measurement, test leads are plugged into the appropriate sockets, the **black one always into the black COM socket** and the red one into V Ω mA or 10A, depending on the Measurand.

When measuring (U/I), a voltage on the red line must be higher than on the black line, otherwise the meter will display a negative value.

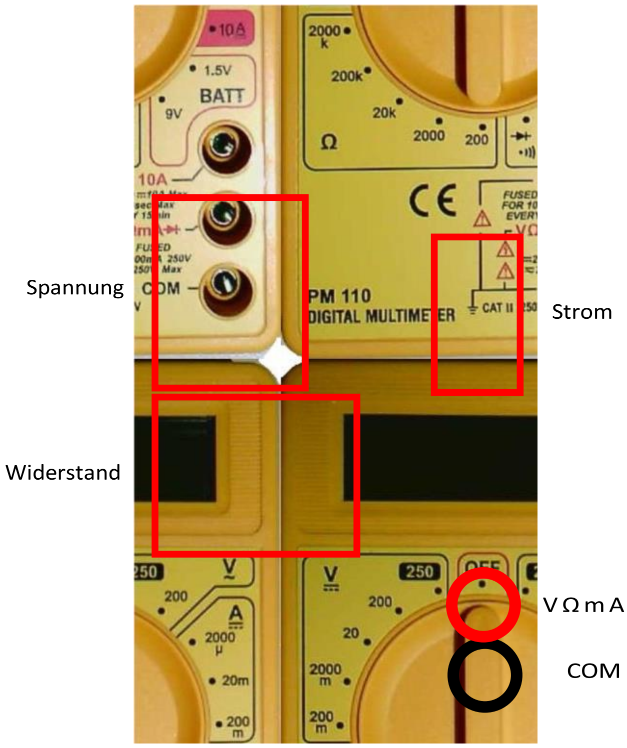


Fig. 1.1.7-1: Measuring Device

Observe measuring range and connection!

Observe polarity!

1.1.7.1 Voltage measurement

For voltage measurement, switch the instrument to the DC voltage measuring range (rotary switch) marked with V. Connect the meter in **parallel with the** voltage to be measured (here only the battery), observing the polarity. **Do not use the 10A measuring socket under any circumstances**, this will cause a short circuit and (in the case of stronger voltage sources, destruction of the meter).

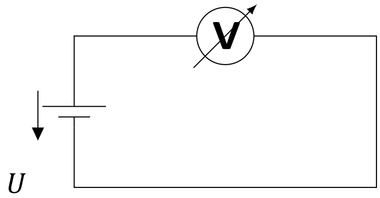


Fig. 1.1.7.1-1: Connection of a voltmeter.

Observe measuring range!
Do not use the current measurement socket under any circumstances!

Observe polarity!

1.1.7.2 Current measurement

The current measuring range (marked A) and the measuring socket marked above must be used. The meter is connected in **series in** the circuit. It should be noted that there is a sufficiently high-impedance consumer (resistor) in it. The low-impedance meter will cause a **short circuit if it is** connected in **parallel with a voltage source.**

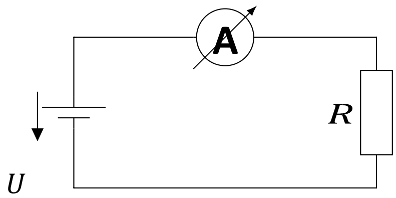


Fig. 1.1.7.2-1: Connection of a current measuring device.

Observe measuring range!
Do not connect in parallel to the voltage source!

Observe polarity!

1.1.7.3 Resistance measurement

The resistance measuring range (Ω) and the socket marked with it must be used. The meter sends a constant current through the resistor and records the falling voltage. It uses this to calculate the resistance value. Since the meter actively generates a current flow, under no circumstances should another voltage or current source be included in the measurement circuit. This could destroy the meter. When measuring high-impedance resistors, do **not** allow **both measuring tips to come into contact with each other,** otherwise the measurement result will be distorted.

There must be no current or voltage source in the measuring circuit!

Observe measuring range!
Keep your fingers away from a measuring tip, otherwise the result will be wrong!

1.2 Practical part

1.2.1 Circuit with consumer

The circuit shown below represents the simplest circuit. The voltage provided by the battery drops across the consumer $R1$.

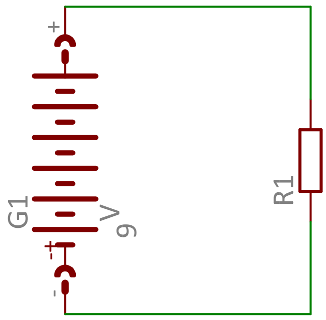


Fig. 1.2.1-1: Simple circuit with resistor as consumer.

Question 1: What happens to the current the smaller $R1$ becomes?
Question 2: What happens to the energy that comes from the battery?

1.2.2 Circuit with consumer and pushbutton

The following circuits show a simple circuit with consumer and pushbutton.

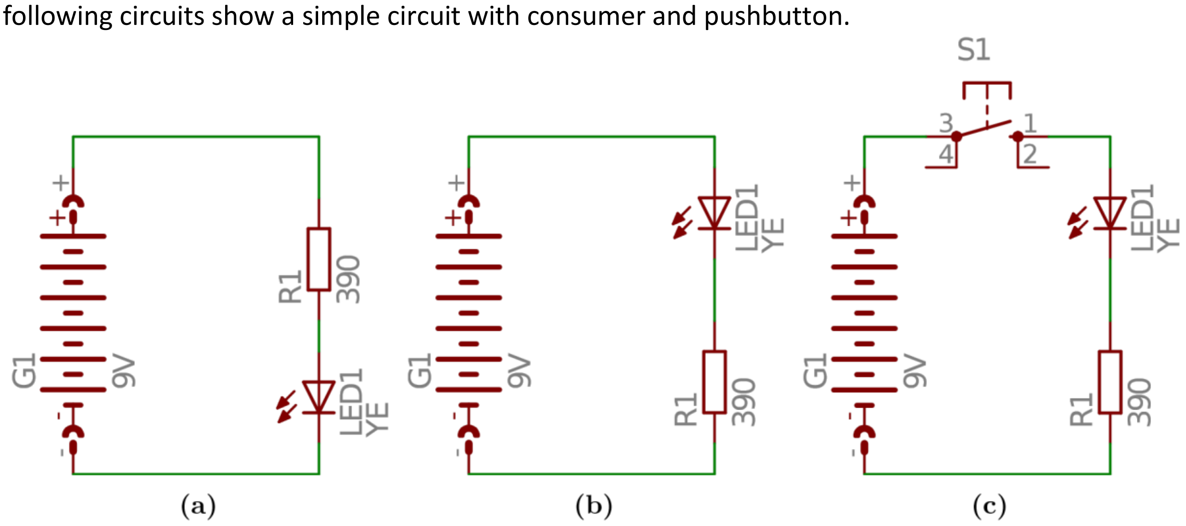


Fig 1.2.2-1: Simple circuits

Question 1: What happens if you operate the LED without a series resistor?
Question 2: What happens to the current through the LED compared to (a) if you place the series resistor of the LED behind the LED in (b)?

1.2.3 Voltage measurement

The voltage of the battery U_{ges} *(germ. Gesamt = engl. total)* is the sum of the individual voltages at the series connection of $LED1$ and $R1$. Thus, the following equation is obtained:

$$U_{ges} = U_1 + U_2$$

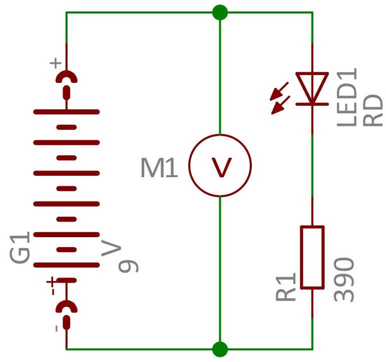
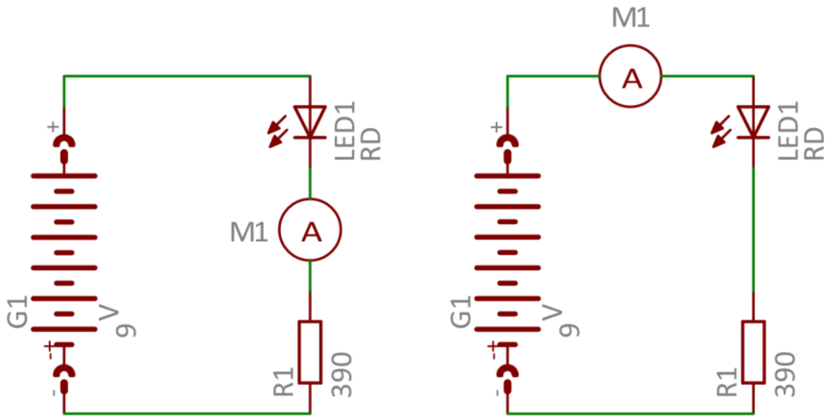


Fig. 1.2.3-1: Circuit for voltage measurement.

Question 1: What voltage does the meter $M1$ show when you disconnect the connection between the LED and $R1$?

1.2.4 Current measurement

Measure the current one after the other as shown. Install the measuring device **in the** circuit as shown.



(a) **(b)**

Fig. 1.2.4-1: Circuit for current measurement.

Question 1: What current does the meter show in the first current measurement compared to the second?

Question 2: What current does the meter show when you disconnect the connection between the LED and $R1$?

Question 3: What voltage is present at $R1$ when the connection between LED and $R1$ is disconnected?

2 Switches and relays

2.1 Introduction

2.1.1 Button

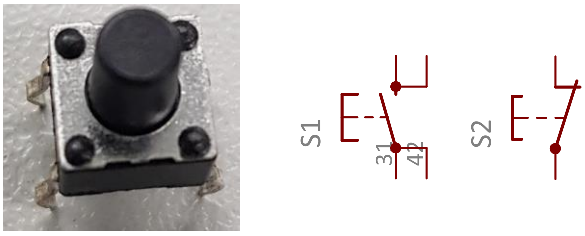


Fig. 2.1.1-1: Pushbutton (normally open, normally closed): component and switching symbol (EAGLE)

A **pushbutton** is a control element that establishes a conductive connection and, when released, reverts to its
The button returns to its initial position, i.e. it does not latch, as is the case with a **switch.** Pushbuttons can be designed as **normally closed** or **normally open contacts.** A normally closed contact opens the circuit when actuated, a normally open contact closes it.

2.1.2 Relay

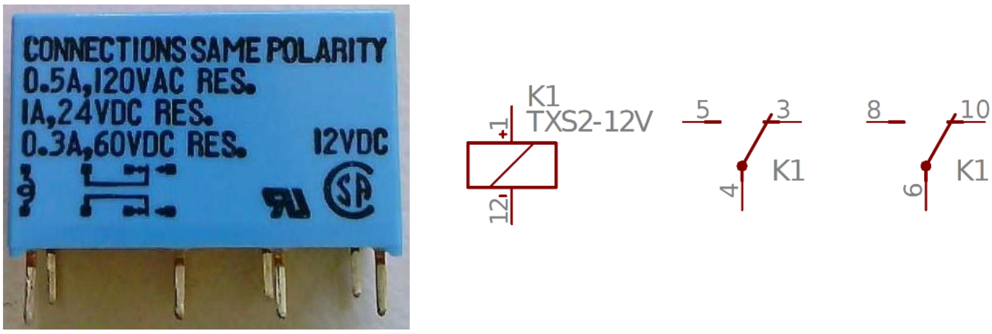


Fig. 2.1.2-1: Relay: component and circuit symbol (EAGLE)

A **relay** is an **electrically operated switch**. A weak current is applied to a coil in the **control circuit.** The coil's magnetic field then attracts an armature that can actuate one or more switching contacts. The contacts can open or close a **load circuit that** can carry **many times the current of the control circuit. The voltage** required for actuation, the ohmic **resistance of the coil,** as well as the **load capacity of the switching contacts can be** taken from the **data sheet.** The contact assignment is usually indicated on the Relay itself.

In **circuit diagrams, the coil** and the **contacts of** a relay are **shown separately.** An assignment is possible by the same designation of contacts and coil.

Relays for **switching high power** are called **contactors.** These are mostly used for Control of three-phase consumers, whereby the switching contacts then switch all 3 phases of the three-phase current simultaneously.

Since a **coil** is used to generate the magnetic field, there is an **increase in voltage (induction) in the control circuit** when it is **switched off,** which can destroy other components in the circuit and negatively affect components such as microcontrollers. To avoid this, so-called **free-wheeling diodes** (also known as recovery diodes) are used when controlling relays with DC voltage (see below).

2.2 Practical part

2.2.1 Pushbutton circuits

The following circuits illustrate the normally closed or normally open function of pushbuttons. Furthermore, simple logic operations are established.

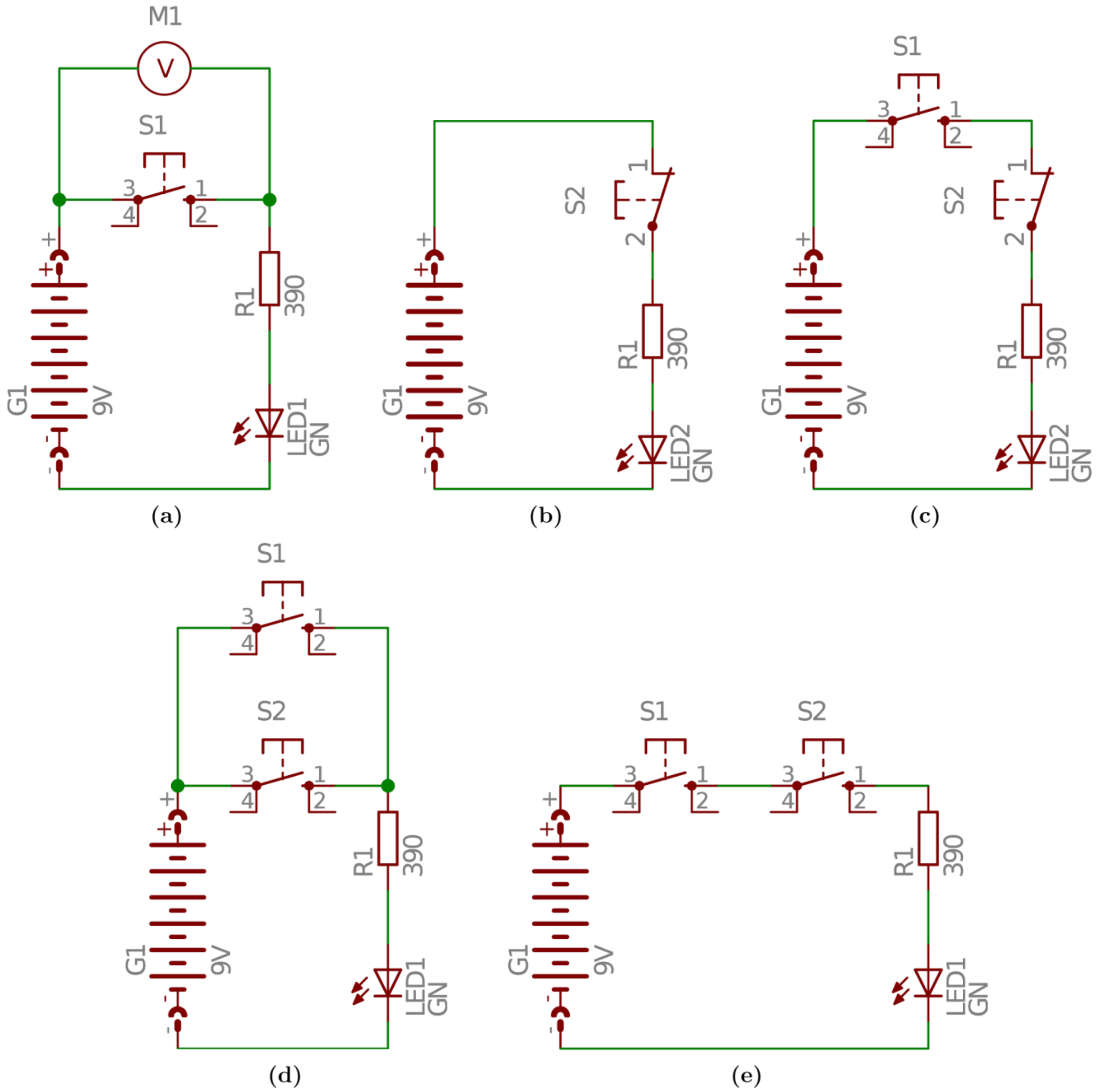


Fig 2.2.1-1: Logical operations with pushbuttons

Question 1: What voltage drops across the open pushbutton, and what voltage drops across the closed pushbutton?

Question 2: What are the logic operations of the buttons that are connected in parallel and those that are connected in series?

Question 3: What voltage drops across $S1$ and $S2$ when both are closed?

2.2.2 Relay as on switch

In the following, an LED is switched on with the help of a relay. When the pushbutton $S1$ is pressed, the contact belonging to the relay is switched over.

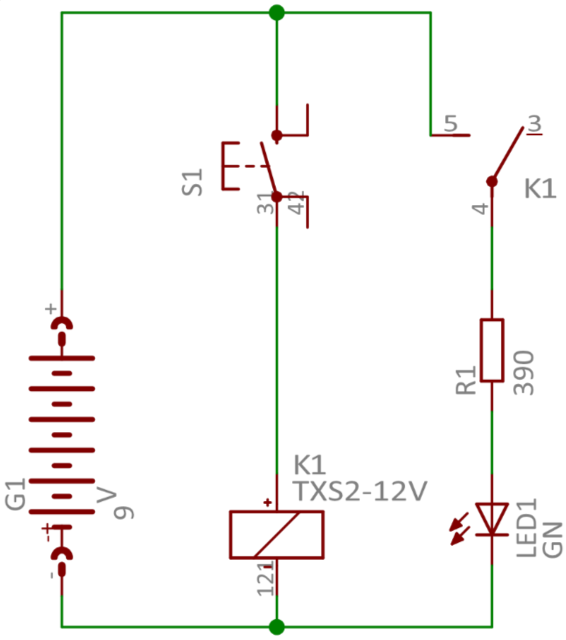


Fig. 2.2.2-1: LED switch on by means of relay.

Question 1: The LED could also be controlled directly with the pushbutton without the relay. With which type of consumer does it make sense to use a relay anyway?

Question 2: Which switching contacts of the load circuit are connected when the coil of the relay is energized?

2.2.3 Relay as circuit breaker

Here the LED is switched off using a relay. This shows that it is still possible to realize a normally closed function with a pushbutton designed as a normally open contact with the aid of a relay.

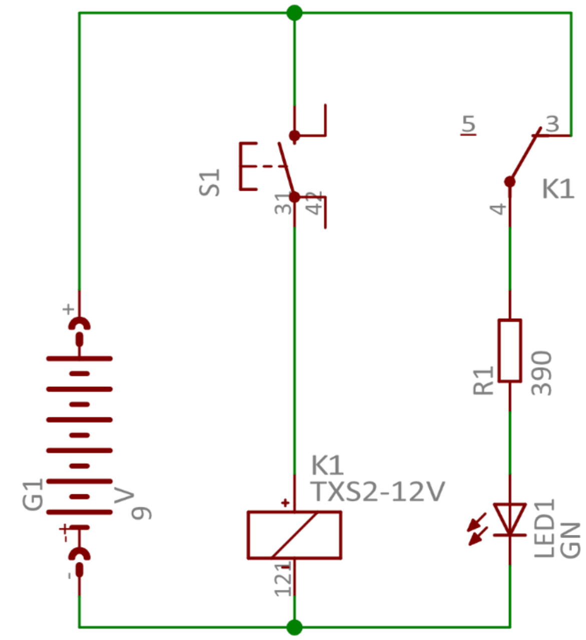


Fig. 2.2.3-1: Switch off by means of relay.

Question 1: What happens to the LED when $S1$ is turned on?

2.2.4 Relay as changeover contact

The relay allows switching between two loads in the load circuit.

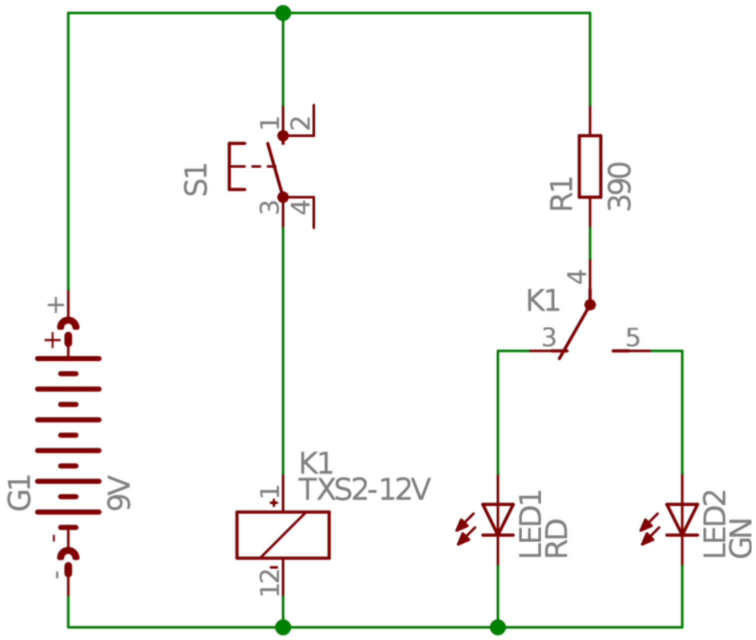


Abb. 2.2.4-1: Umschalten mittels Relais.

Question 1: Which LED lights up when S1 is off?

2.2.5 Reverse polarity relay

Here the relay **reverses the polarity of the** voltage when the button is pressed. If the button $S1$ is not actuated, $LED1$ lights up, otherwise $LED2$. This circuit can be used, for example, to **reverse the direction of rotation of a DC motor**.

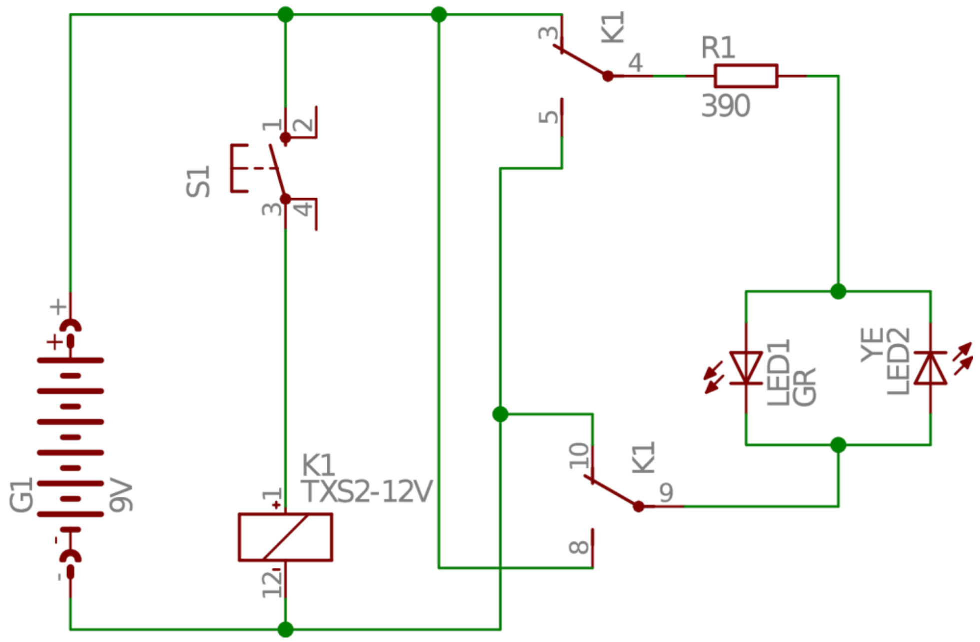


Fig. 2.2.5-1: Reversing the polarity of the supply voltage by means of a relay.

Question 1: Which LED lights up when $S1$ is off?
Question 2: What is the voltage from pin 4 to pin 9 of the relay when $S1$ is on?

2.2.6 Relay with latching

The following circuits show different possibilities to **realize a storing function** with a **relay**. In former times the **first computer memory modules** were realized with it! After the relay has picked up once, it bridges the pushbutton $S2$ and thus remains picked up. It remains in this state until it is switched off by an actuation of the **pushbutton.**

The first circuit is **often** used in **industry settings for switching plant components,** as this ensures that the **plant does not switch itself back on** after a failure of the supply voltage. **starts up again**. In addition, the **NC contact for** switching off provides **security against wire breakage**. In this case, it is switched off immediately.

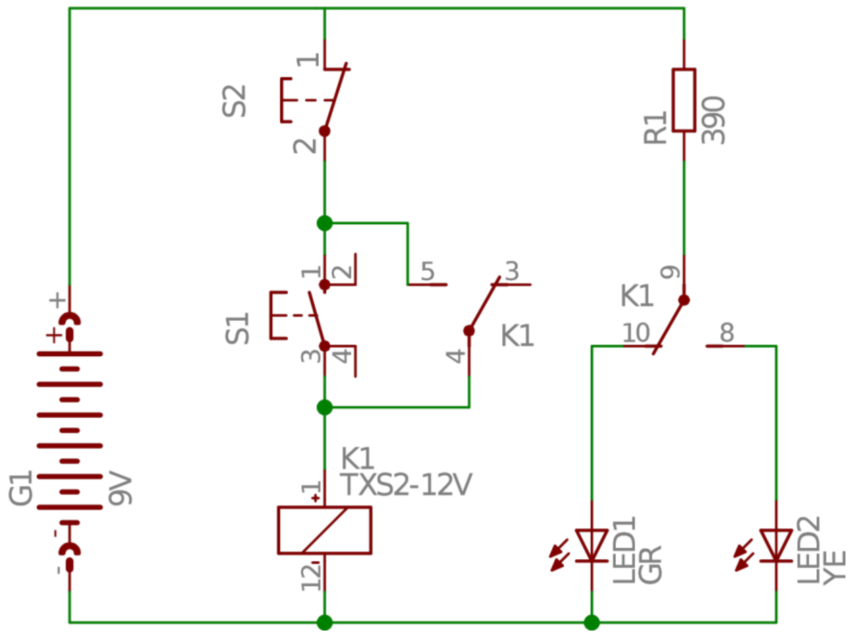


Fig. 2.2.6-1: Self-retaining using a pushbutton with normally closed function.

The following circuit is an "emergency solution" for the practical course, where instead of a normally closed contact a normally open contact can be used for switching off. It has some disadvantages and is **not suitable in practice**.

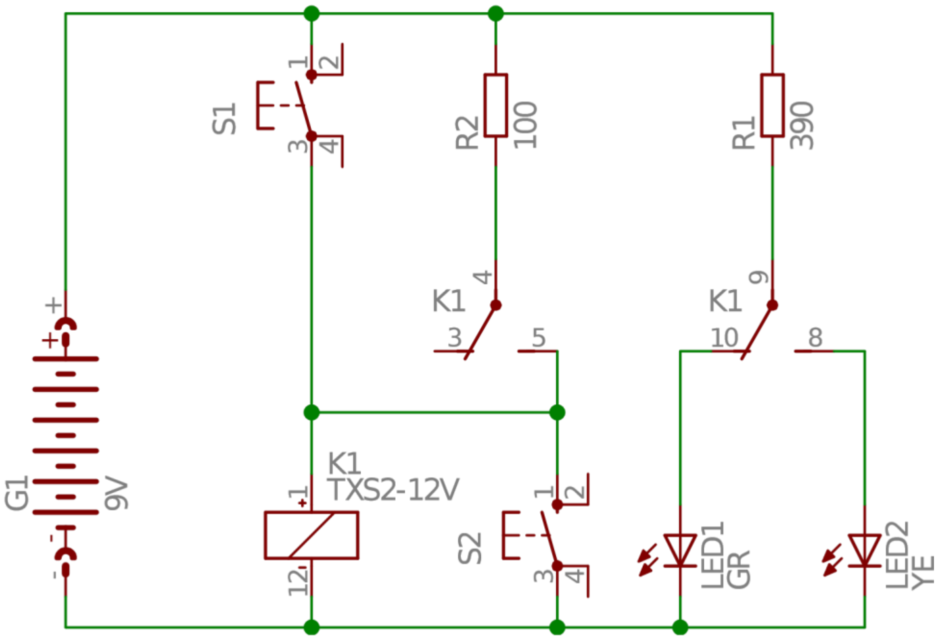


Fig 2.2.6-2: “Emergency Fix” for this practical exercise

Question 1: When $S1$ is pressed, what happens to the relay when $S1$ is released?
Question 2: The 2nd circuit works but cannot be used like this for "customers" in practice. Why not?

3 Resistors

3.1 Introduction

3.1.1 Resistors (repetition from P1)

Fig. 3.1.1-1: Component and circuit symbol (EAGLE)

A resistor is a two-pole component that opposes the current flow with a defined resistance. The greater the resistance, the less current can flow at the same voltage. The following relationship therefore applies:

$$R = \frac{U}{I}$$

The energy is converted into heat, and the following applies to the heat output:

$$P = U \cdot I$$

Thus, the power in the first equation is also:

$$P = \frac{U^2}{R}$$

The permissible power of the resistor must not be exceeded, otherwise it will fail and burn. The larger the component, the more power dissipation is permissible.

When reading, the resistor must be held so that the rings are aligned to the left or the single ring can be seen on the right.

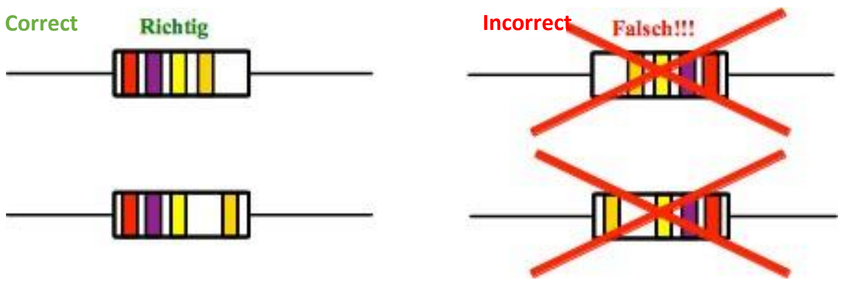


Fig. 1.1.4-2: Correct reading of the color rings [1]. The following example shows the reading of a resistor with 4 rings.

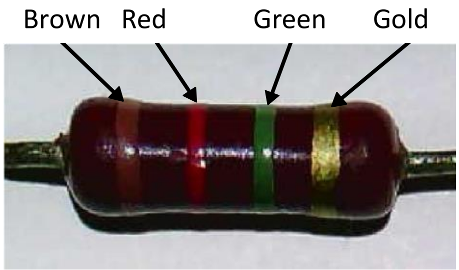


Fig. 1.1.4-3: Example Resistor

Thus, the resistance value is: $R = (10 + 2) \cdot 10^5 \Omega = 1.2 M\Omega$ with a tolerance of 5%.

3.1.2 Potentiometer

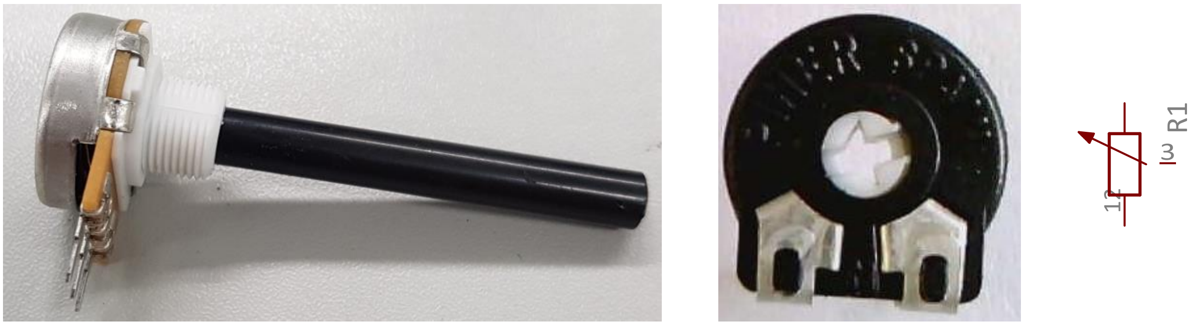


Fig. 3.1.2-1: Component and circuit symbol (EAGLE)

A **potentiometer** is a **mechanically variable resistor** that can be designed as a **rotary potentiometer** or **linear potentiometer** (e.g. on audio mixing consoles). It usually consists of a **carbon film track on** which a **sliding contact** slides. The actual length of the path from the beginning to the sliding contact determines the resistance. The two ends of the carbon layer track and the sliding contact are guided on contacts. The sliding contact is usually located in the middle.

3.2 Practical part

3.2.1 Voltage divider

If resistors are connected **in series** (i.e. one after the other), the total voltage U_{ges} at the individual resistors divides to U_i The total resistance $R_{ges}$is the sum of the individual resistances R_i. Only **one common current I** flows**, which is** the **same through all resistors.** How the voltage is divided (i.e., how large U_i is in each case) depends on the ratio of the resistors to the common current I. Thus, it holds true:

$$U_{ges} = \sum_{i=1}^{n} U_i$$

$$R_{ges} = \sum_{i=1}^{n} R_i$$

$$I = \frac{U_{ges}}{R_{ges}} = \frac{U_i}{R_i}; i = 1 \cdots n$$

The following circuits show first a single total resistance as consumer, then two voltage dividers, whose total resistance can be calculated by adding the individual resistances.

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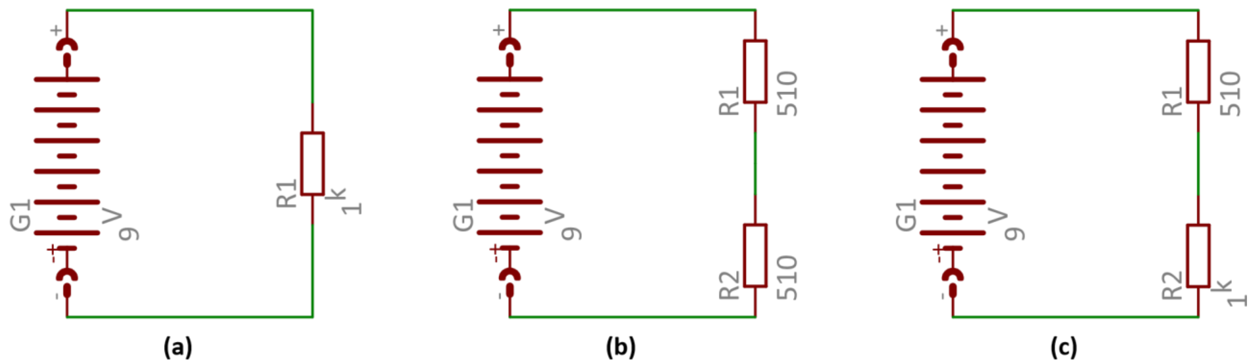
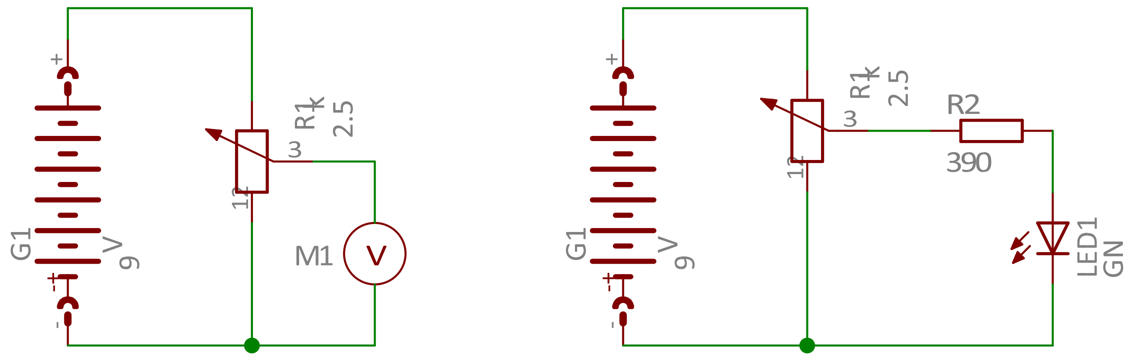


Fig. 3.2.1-1: Voltage divider in different versions.

Question 1: What is the total resistance of each of the 3 circuits? In which of the 3 circuits does the most current flow, in which the least?

Question 2: What current flows in the last circuit? What is the voltage that drops across $R1$ and $R2$ respectively?

At the next two voltage dividers the voltage is measured at the "lower" resistor, i.e. at the resistance of the contact path of the potentiometer up to the tap. First with a voltmeter, then by means of the brightness of an LED. By **measuring** the circuit it branches and it is **no longer a true series circuit**. Thus, the **measurement also falsifies the result**, because part of the current flows through the meter.



(a) (b)

Fig. 3.2.1-2: Voltage divider with potentiometer.

Question 1: What happens to the voltage from pin 3 to pin 1 of R1 when you disconnect the voltmeter? Does it increase, decrease, or stay the same?

Question 2: What is the resistance from pin 2 to pin 3 of R1 when the LED is at maximum brightness when turning the potentiometer? What is the voltage from pin 2 to pin 3 then?

3.2.2 Parallel connection

If the resistors are connected next to each other, i.e. in parallel, the following applies:

$$R_{ges} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

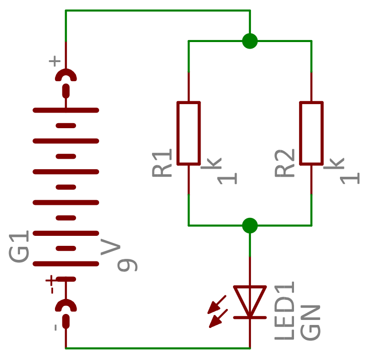
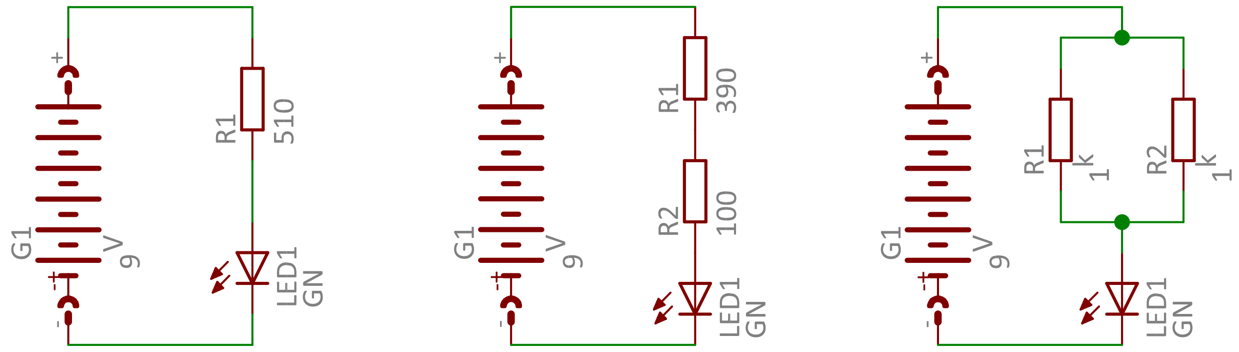


Fig. 3.2.2-1: Parallel connection of two resistors.

3.2.3 Series and parallel connection

The following circuits show the effects of series and parallel connection of resistors. The brightness of the LED is almost the same in all 3 circuits.



(a) (b) (c)

Fig. 3.2.3-1: Laws of series and parallel connection in connection with the current.

Question 1: What is the total resistance of each of the 3 circuits? In which of the 3 circuits does the most current flow, in which the least?

Question 2: Why does the LED shine almost the same brightness in all 3 circuits?

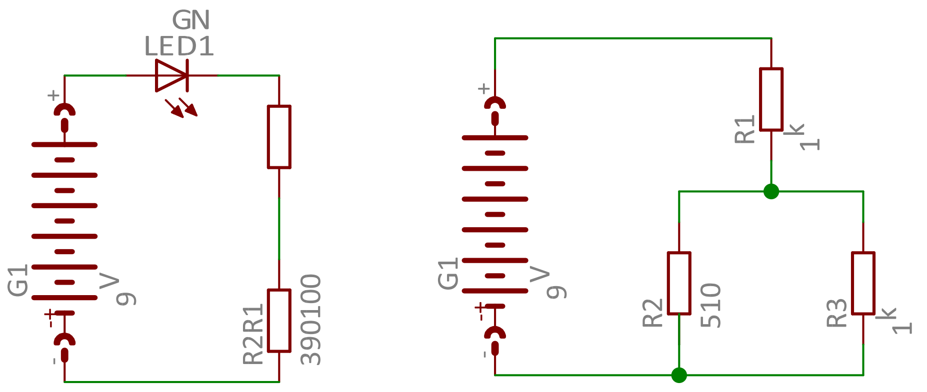
3.2.4 Mesh- and Junction Rule

In case of a complete **mesh loop, i.**e. if all **voltages** in a circuit are added together, the **sum of all voltages** is **0**. Here, however, the signs must be observed! The polarity of the voltage supply is reversed during the circulation.

$$\sum_{i=1}^{n} U_i = 0 \Rightarrow (a): U_{LED} + U_{R_1} + U_{R2} - U_{G1} = 0$$

In a **considering the junction rule,** the **current** that goes in must also come out in the same amount, so the **current sum** at a node **is 0.**

$$\sum_{i=1}^{n} I_i = 0 \Rightarrow (a): UI_{R_1} - I_{R2} - I_{R3} = 0$$



(a) (b)

Fig. 3.2.4-1: Schematics for the investigation of the mesh and node rule.

Question 1: What is the voltage that drops across the LED when 0.007A flows? Make a voltage circuit and calculate U_{LED} from U_{R1}, U_{R2} and 9V.

Question 2: In the circuit on the right, current I flows from the battery. Draw **I** in the circuit wherever **I** flows.

4 Capacitors

4.1 Introduction

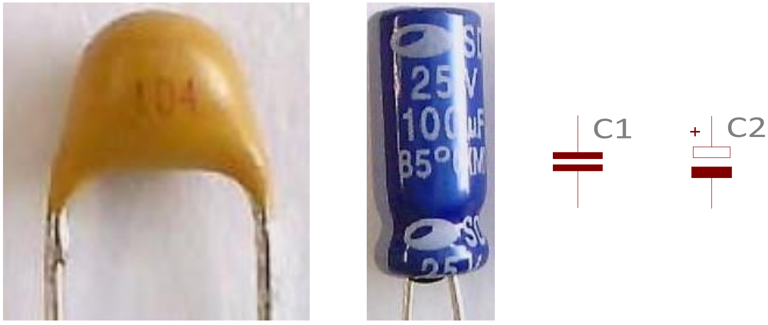


Fig. 4.1-1: Capacitor: component and circuit symbol (EAGLE).

A **capacitor** stores **electrical energy** in the form of an **electric field** between two **conductive plates or foils that are insulated from each other**. In the (blue) polarized capacitor shown in the figure on the right, the foils are rolled up. The insulating layer is called the **dielectric.** The "capacity" of the capacitor is the **electrical capacitance**:

$$C = \frac{Q}{U}$$

This depends on the size of the capacitor plates, their spacing and the dielectric used. The **unit** of capacitance is **farad**.

$$[C] = F$$

A capacitor can be compared to a compressed air. The charge is the air particles, the voltage is the air pressure, and the capacity is the size of the canister. At a certain size, you can "squeeze" more particles in with higher pressure. At first, a large stream of air flows into the canister, which then gets weaker and weaker until it stops altogether. When the air is let out, it is similar.

There are **polarized capacitors** where the insulation in the form of a thin oxide layer is chemically applied to one of the foils. This layer degrades if **the polarity** is **incorrect,** which can lead to **short circuits and explosion** of the capacitor. The max. voltage specified on the capacitor must also be observed, otherwise similar things can happen due to breakdown.

Observe polarity and dielectric strength.

In addition, it should be noted that a voltage can still be present at a capacitor long after the power supply has been switched off. Depending on the level of the voltage, this can pose a danger to humans or electronic components. If a discharged capacitor is connected to a voltage source U_0 via a resistor R at a time $t = t_0$, the current and voltage curve for $t \geq t_0$ follows the following equations:

$$u_c(t) = U_0\left(1 - e^{-\frac{t-t_0}{R \cdot C}}\right)$$

$$i_c(t) = \frac{U_0}{R} \cdot e^{-\frac{t-t_0}{R \cdot C}}$$

A **capacitor** therefore represents **a short circuit** at the **moment of switching on.**

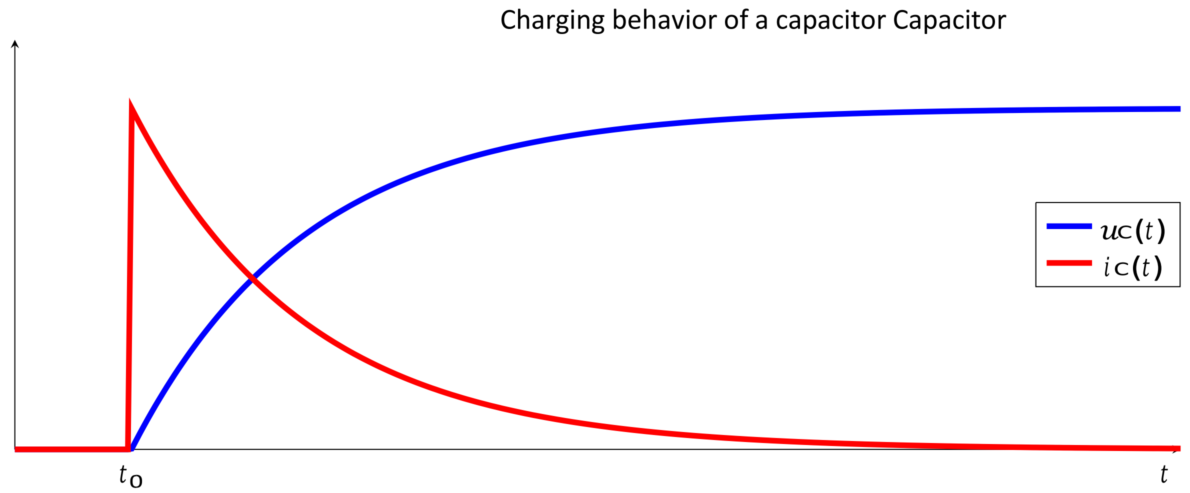


Fig. 4.1-2: Charge curves of a capacitor.

For the discharge behavior of a capacitor with initial voltage U_0 which is discharged at time t_0 through a resistor R, $t \geq t_0$ the following holds:

$$u_c(t) = U_0 \cdot e^{-\frac{t-t_0}{RC}}$$

$$i_c(t) = -\frac{U_0}{R} \cdot e^{-\frac{t-t_0}{RC}}$$

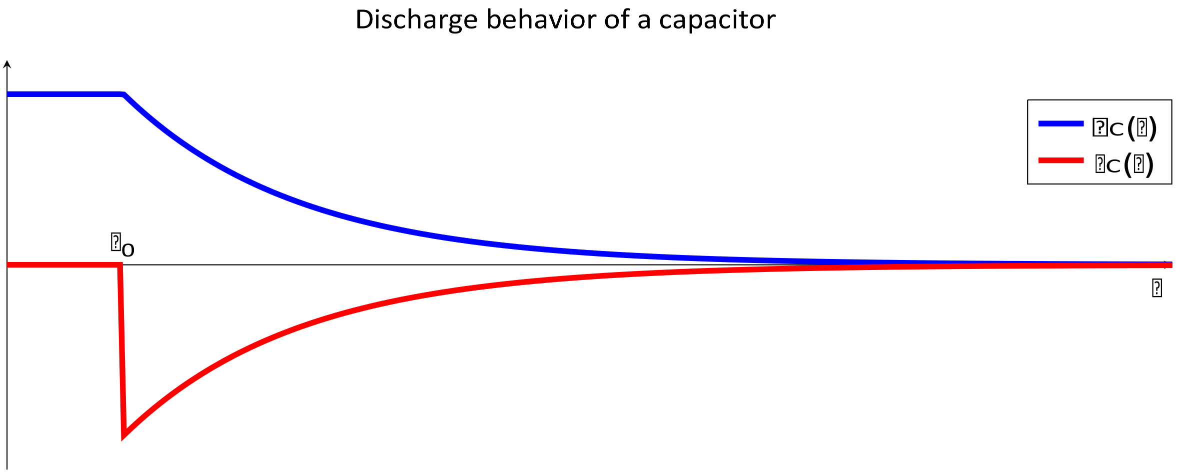


Fig. 4.1-3: Discharge curves of a capacitor

If a **capacitor** is connected to **AC voltage,** it is charged or discharged depending on the sign of the voltage. As a result, **a current flows quasi permanently**. A capacitor **therefore allows an alternating voltage to pass through it**. The amount of current flow also **depends on the frequency**.

4.2 Practical part

4.2.1 Charging and discharging behavior of a capacitor.

When the pushbutton S1 is closed, the capacitor is charged, and the current is limited by $R1$ and LED1. LED1 initially lights up and becomes increasingly dimmer as the current decreases. When the charging process is completed, LED1 goes out. The energy stored in $C1$ now causes a decreasing current flow through LED2 with S2 closed until the discharge process is complete.

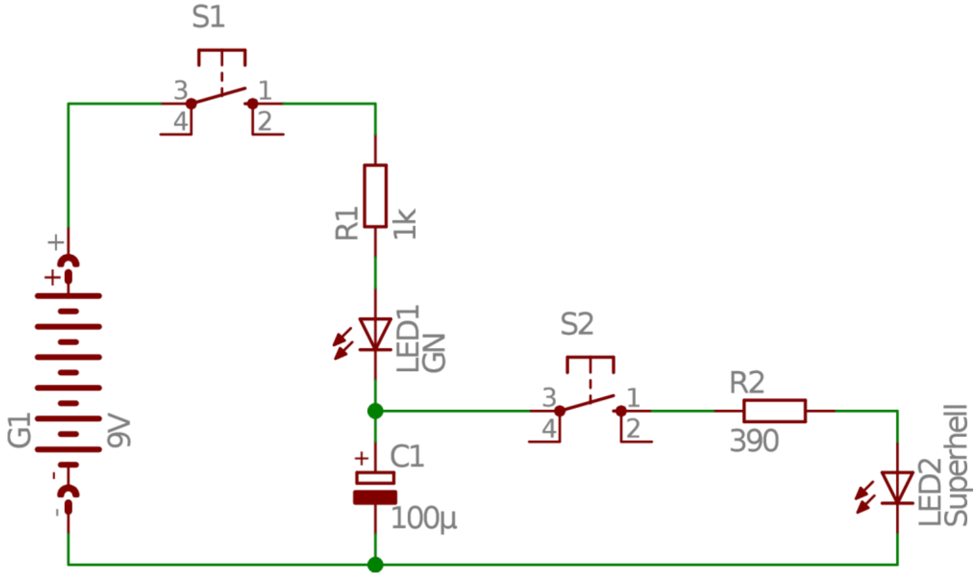


Fig. 4.2.1-1: Investigation of the charging and discharging behavior of a capacitor.

Question 1: What would be the current flow through S1 at the moment of switch-on if LED1 and R1 were bridged and the battery and C1 were ideal, i.e. had no ohmic resistance?
Question 2: What is the current flow through S1 when the switch is on for a very long time?
Question 3: What happens if switch S2 is closed when the capacitor is charged and S1 is open? Why?

4.2.2 AC voltage behavior of a capacitor

A capacitor allows an alternating voltage to pass. This is generated by quickly actuating S1. When the switch is open, almost 9V are applied to C1 via $R1$, and 0V when it is closed. The fact that the alternating voltage can pass the capacitor is shown by the alternating short flashing of the LEDs.

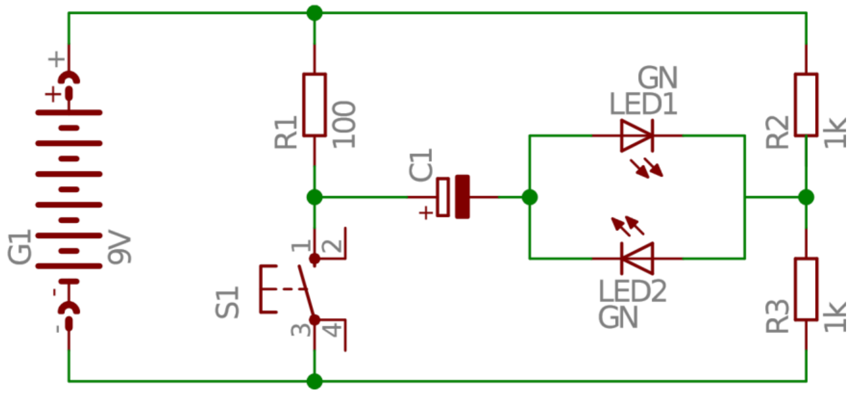


Fig. 4.2.2-1: Investigation of the AC voltage behavior of a capacitor.

Question 1: Assume that C1 is removed. What would be the voltage drop across S1 in the open state? What would it be in the closed state?

Question 2: Given the previous question, what would be the voltage dropped across R3?

Question 3: Given the previous question, what would be the voltage drop from the connection point R1-S1 to the connection point R2-R3 with S1 open and with S1 closed?

Question 4: Why do the LEDs only light up briefly?

Question 5: How would you have to change the circuit so that the LEDs light up permanently when opening and closing S1 respectively?

5 Coils

5.1 Introduction

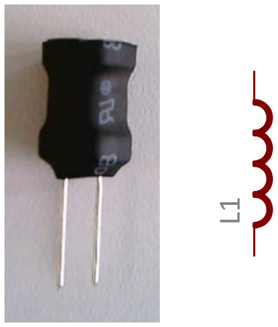


Fig. 5.1-1: Coil: Component and circuit symbol (EAGLE).

In the simplest case, a **coil** consists of a **wound, insulated wire**. A **current flow** through the coil generates a **magnetic field**, the strength of which depends on the current strength, as well as the number of turns, length, and diameter of the coil. **Energy is stored in** this **magnetic field**. When the current is turned on, there is no energy in the coil. Because the current transports energy into the coil, the coil first "brakes" the current until the maximum energy in the coil is reached. Then the current flows unimpeded through the coil, assuming an ideal coil, with no ohmic resistance of the coil wire.

Inductance describes the **relationship between the rate of change of current** through the coil and the applied **voltage**. The voltage is proportional to the rate of change of the current, where the **inductance** L is the **proportionality factor** for this change**.** It holds:

$$u_L(t) = L\frac{d_i(t)}{dt}$$

The unit of inductance is Henry:

$$[L] = H$$

A coil could be compared to a heavy "mill wheel" in a small stream where the water current could not pass. In order to send a current through the stream (cf. current through coil), the water level in front of the wheel must be higher than behind the wheel (=pressure difference, cf. applying voltage). However, the current then only starts to flow slowly, because it first has to get the wheel going (energy goes into the rotating wheel). Only when the wheel is fully in motion, the current runs unhindered. If you now want to stop the water flow abruptly (e.g. with a gate valve behind the wheel, cf. open switch in the circuit), the rotating wheel would still "shovel" the water and build up a large pressure against the shutoff (cf. high induction voltage of a coil, see below).

This example demonstrates a **problem** when using a coil: If the current flow of a coil is stopped too abruptly by the circuit, e.g. by **opening the** circuit, this leads to a **very high voltage at the coil**, which can **destroy surrounding components.**
However, this effect is also used, for example, by electric fences or electric shockers.
To allow the current to continue to flow, a so-called **free-wheeling diode is** connected in parallel with the coil (see practical part).

If a **coil** with inductance L, and an ohmic resistance R (DC resistance of the coil wire) is **connected to** a voltage source with voltage U_0 at time $t = t_0$, the following holds true for the current and voltage when $t \geq t_0$:

$$u_L(t) = U_0 \cdot e^{-(t-t_0)\frac{R}{L}}$$

$$i_L(t) = \frac{U_0}{R}\left(1 - e^{-(t-t_0)\frac{R}{L}}\right)$$

Switch-on process for a coil

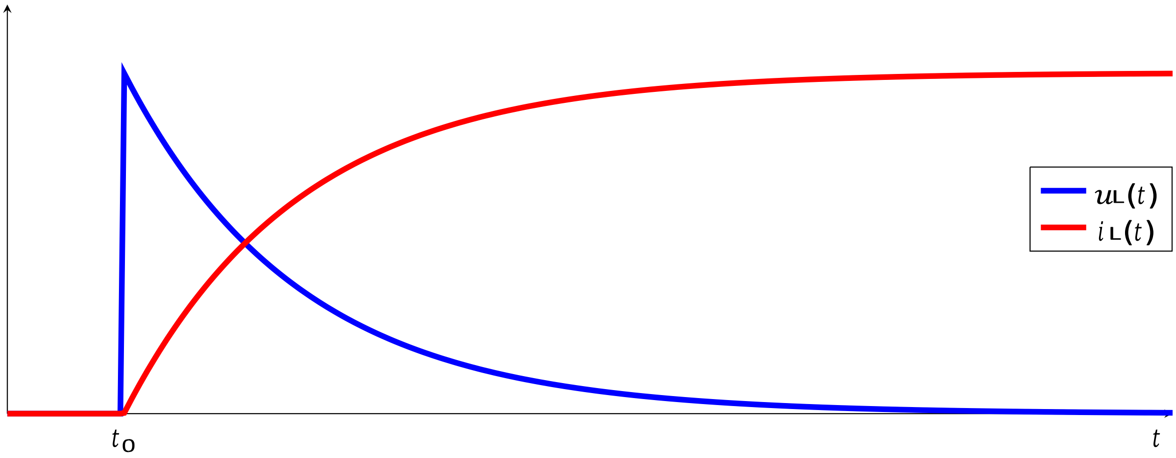


Fig. 5.1-2: Switch-on process for a coil.

For the **switching-off process at the coil** and current flow across its ohmic resistance R **with an ideal freewheeling diode installed,** $t = t_0$:

$$u_L(t) = -U_0 e^{-(t-t_0)\frac{R}{L}}$$

$$i_L(t) = \frac{U_0}{R} e^{-(t-t_0)\frac{R}{L}}$$

Switching-off process of a coil

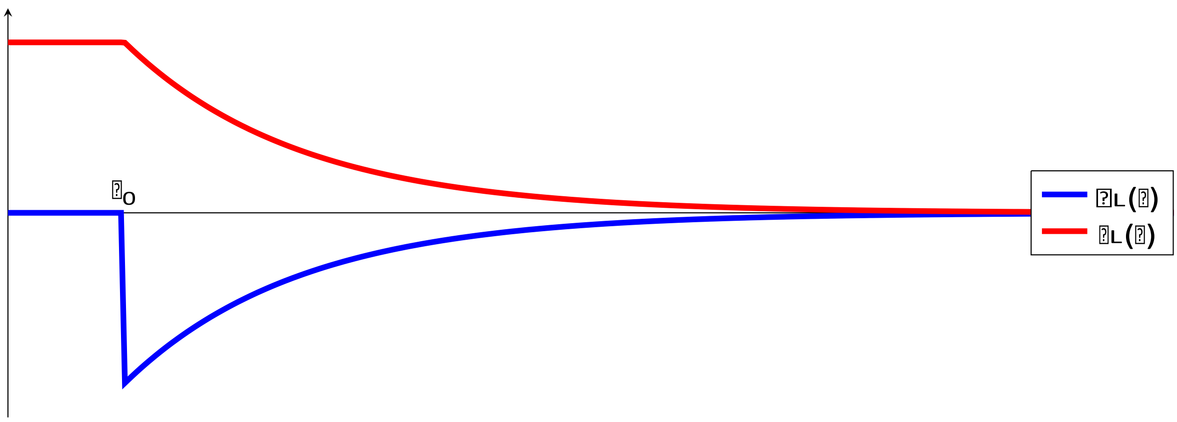


Fig. 5.1-3: Switching-off process of a coil

Be aware of the inductive voltage!

5.2 Practical part

5.2.1 Switching on and off behavior of the current at a coil

After closing pushbutton S1, LED1 lights up briefly because the coil initially has a "high resistance", i.e. it does not allow a sudden current flow. The current flows entirely through LED1. Over time, the current in the coil increases (the "resistance" of the coil decreases towards its ohmic resistance and thus to near zero). This short-circuits LED1, causing it to go out.

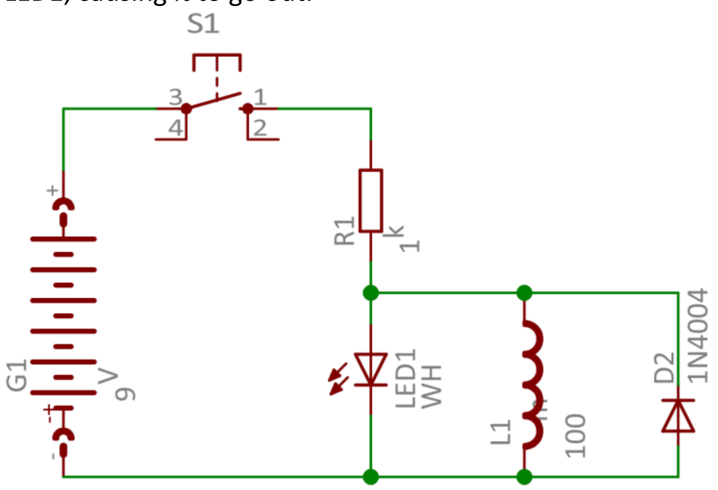


Fig. 5.2.1-1: Investigation of the switch-on behavior of a coil.

Question 1: What is the resistance of the coil at the moment of switch-on and through which components does the current flow?

Question 2: What is the resistance of an ideal coil (ohmic resistance = 0) after some time of a switched on S1 and through which components does the current flow then?

Question 3: Through which components does current flow shortly after S1 is switched off? Why?

5.2.2 Self-induction voltage on a coil

If pushbutton S1 is pressed, no LED is lit at first, since the coil represents a high resistance. This decreases over time until LED2 has reached almost full brightness. If the pushbutton is now opened, LED2 goes out immediately. As the coil tries to keep the current flowing, it generates a high voltage with opposite sign, which causes LED1 to flash brightly for a short time.

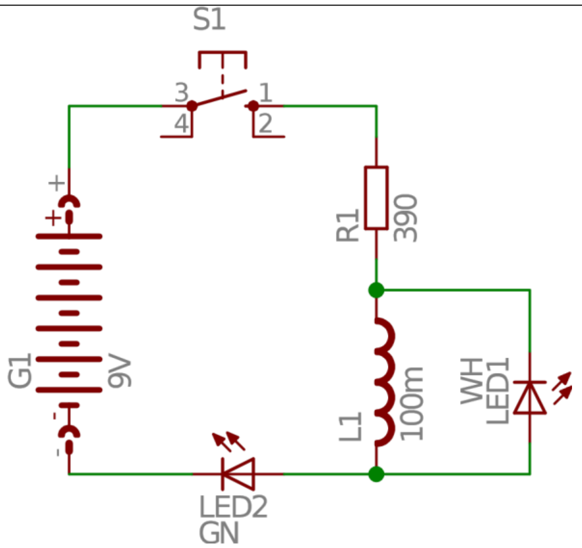


Fig. 5.2.2-1: Investigation of the self-induction of a coil.

Question 1: What is the resistance of the coil at the moment of switch-on and through which components does the current flow?

Question 2: What is the resistance of the ideal coil after some time of a switching on S1 and through which components does the current flow then?

Question 3: Through which components does current flow shortly after S1 is switched off?

6 Diodes

6.1 Introduction

Fig. 6.1-1: Diode and Z-diode : components and circuit symbol (EAGLE).

The **diode** is a component that allows **current** to pass in **only one direction**, from **anode (+)** to **cathode** (-**)**. The **cathode** is **marked with** a **ring**. A minimum **threshold voltage** (approx. 0.7V) must be applied in the forward direction for current to flow at all. This voltage then always drops across the diode. In reverse direction the diode blocks but starts to conduct from a **breakdown voltage of** -50V to -1000V (depending on the diode).

This breakdown voltage is used for so-called **Z-diodes.** Through corresponding setup, the voltage can be fixed to a certain value (e.g. -5.1V). The Z-diode can then be used as a **voltage limiter by** absorbing higher voltage peaks. To do this, the **Z-diode** must be **placed in the reverse direction**. (see practical part).

You can imagine the diode like a valve on a bicycle tire. If one overcomes a small pressure (cf. threshold voltage), air can flow through the valve (current). In the opposite direction, the Valve.

6.2 Practical part

6.2.1 Reverse and forward direction of a diode

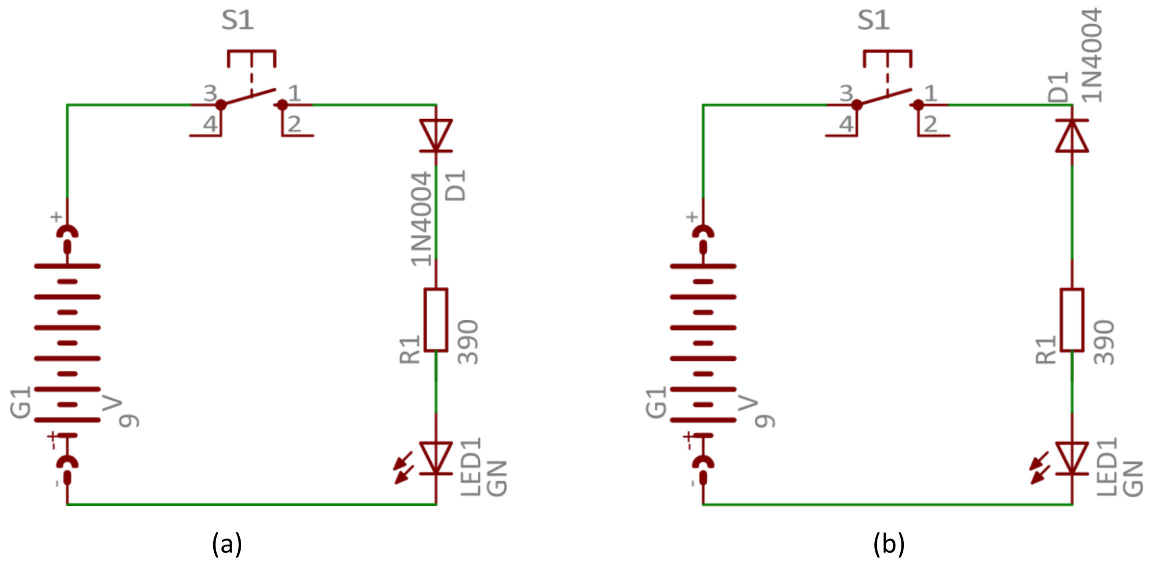


Fig. 6.2.1-1: Diode in forward and reverse direction.

Question 1: For which circuit is LED1 lit?

Question 2: What is the voltage drop across $D1$ in the 1st figure with S1 closed?

Question 3: What is the voltage drop across $R1$ and LED1 together?

Question 4: What is the voltage drop across $D1$ in the 2nd figure with S1 closed? What is the current through R1?

Question 5: What voltage do you measure at $D1$ in the 2nd figure with S1 closed and why is it different than it theoretically should be?

6.2.2 Bridge rectifier circuit

With **4 diodes** you can **rectify** an **AC voltage** (voltage without mean value, which changes its polarity), so that at the output of the rectifier the voltage is only positive. In the experiment, the LED continues to light up even if the battery is connected the other way round.

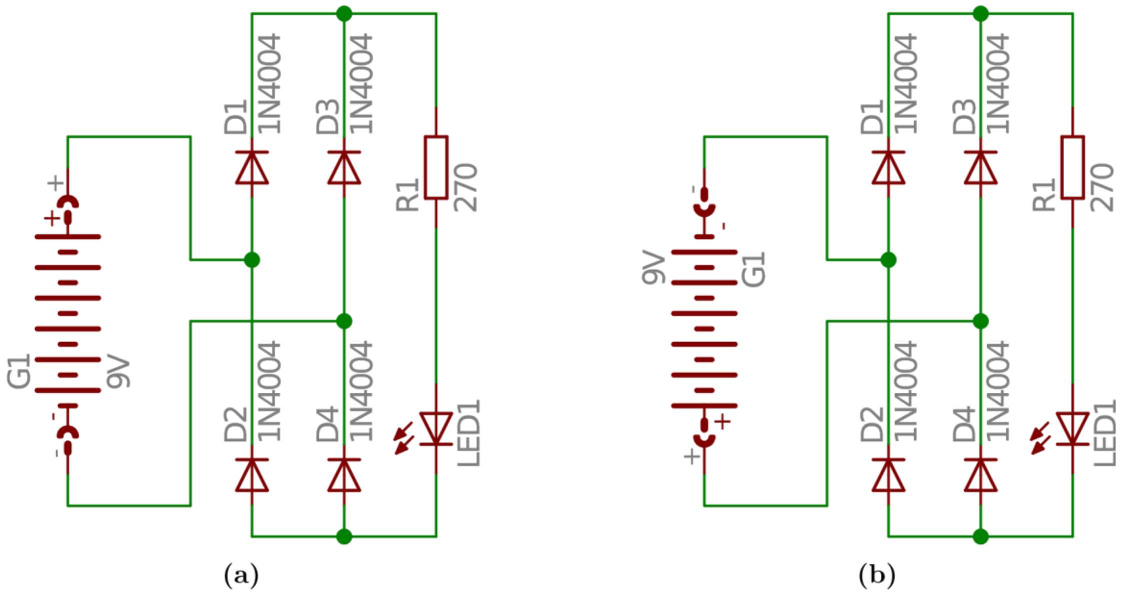


Fig.6.2.2-1: Bridge rectifier circuit

Question 1: For which circuit is LED1 lit?
Question 2: What is the voltage at the output of the rectifier, i.e. at $R1$ and LED1 together in circuit (a)?
Question 3: Through which diodes does current flow when the battery is polarized the right way round (top +)? Through which when it is reversed (Fig. b)?
Question 4: What happens if you connect a single diode the other way around as shown?

6.2.3 Free-wheeling diodes

The high **induction voltage at the coil of a relay** can be **avoided** with a **diode (freewheeling diode).** The **current** can **continue to flow** through the diode after the coil is switched off. When switched on, it nevertheless does not cause a short circuit because it is **connected in the reverse direction.**

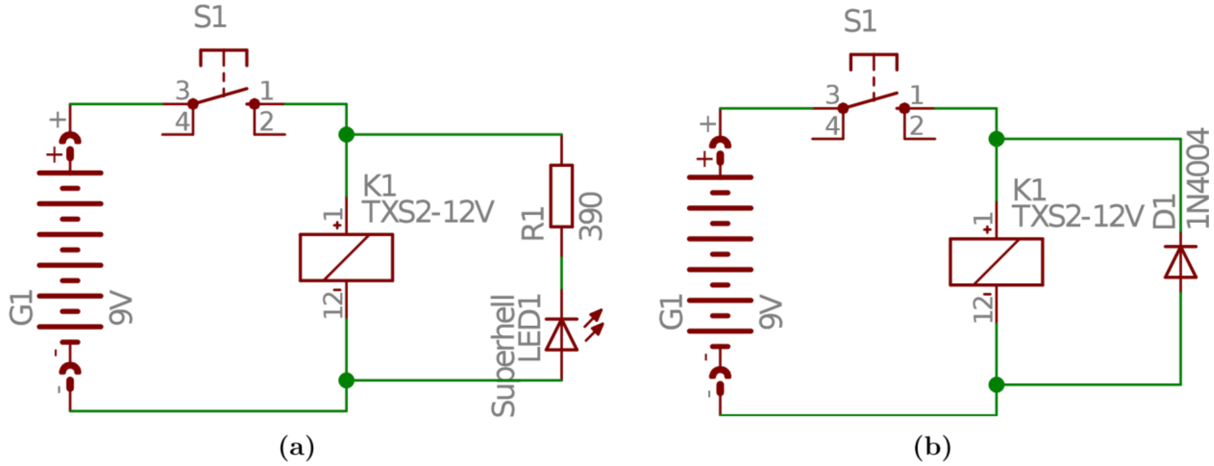


Fig.6.2.3-1: Relays with free-wheeling diodes

Question 1: When (in relation to S1) does LED1 light up?
Question 2: What happens if you connect the free-wheeling diode $D1$ the other way round?
Question 3: You switch S1 ON and OFF again. At what time does a current flow through $D1$?
Question 4: What happens if $D1$ is omitted?

6.2.4 Behavior of a Z-diode

The **Z-diode** used here has a fixed **breakdown voltage** of 5.1V. It is connected with $R1$ to a Voltage divider. In the voltage divider the voltages behave as the resistors do (see chapter 3).

When S1 is switched on, as long as $D2$ is still of exceedingly high impedance, 9V is present at $D2$. But since this voltage is > 5.1V, the breakdown at $D2$ occurs immediately and it starts to conduct so strongly that its resistance becomes smaller and smaller. This changes the division ratio at the voltage divider and the voltage that drops across $D2$ also drops until the 5.1V is reached. The voltage dropping across $D2$ is thus maintained at 5.1V.

In (a) the voltage is measured with a voltmeter. The "residual voltage" of the total 9V drops across the resistor $R1$. Even if the resistor R1 is changed (b), the voltage across $D2$ never exceeds 5.1V. The LED in (b) does not exceed a certain brightness.

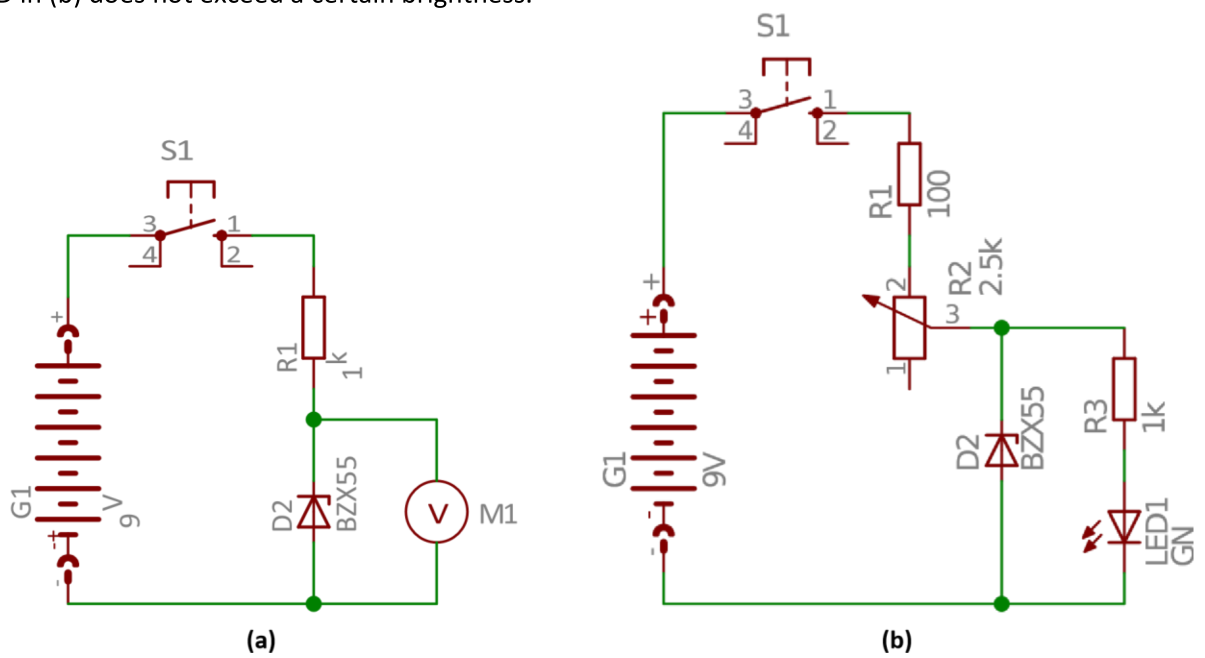


Fig. 6.2.4-1: Z-diode circuits

Question 1: What voltage does M1 measure when the Z-diode has a breakdown voltage of 5.1V?
Question 2: What voltage drops across $R1$?
Question 3: What would happen if you connected the Z-diode without $R1$?
Question 4: What would happen to the voltage at M1 if the Z-diode (with $R1$) were connected with the polarity reversed?
Question 5: Why does the LED1 in circuit (b) get darker at some point (despite the voltage stabilizing D2), if the potentiometer R2 is turned very far towards pin1?

7 Transistor

7.1 Introduction

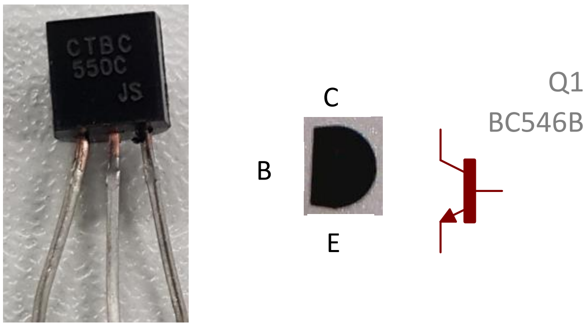


Fig. 7.1-1: NPN transistor: component and circuit symbol (EAGLE)

The **transistor** is an active electronic component that can be used to **control** a **large load current** by means of a **small control current,** i.e. in terms of effect it is like a kind of "controllable resistor".

The transistor has **3 terminals**: **collector (C), base (B) and emitter (E)**.

With the transistor type used here (NPN), the current to be controlled flows from the collector to the emitter and the control current from the base to the emitter. The emitter is then connected to the (-) pole and a voltage with a weak current is applied to the base, which is why a series resistor is required. A strong current can then flow from C to E.

The transistor can also be used as a **controlled switch** and thus forms the basic element of **digital technology**, i.e. **millions of transistors** are installed on **computer chips to** enable **logical operations and data storage.**

You can imagine the transistor like a faucet, which instead of a handwheel has a small water wheel, which could be opened with a small water jet. If one gives the small water stream (control current) to the water wheel (cf. base), the tap opens for the large current flow (cf. collector-emitter path).

7.2 Practical part

7.2.1 Transistor as switch without pull-down resistor

The transistor acts here as a switch. Via S1 a weak current is given into the base, which switches the CE path (collector-emitter) to low impedance, so that the LED lights up.

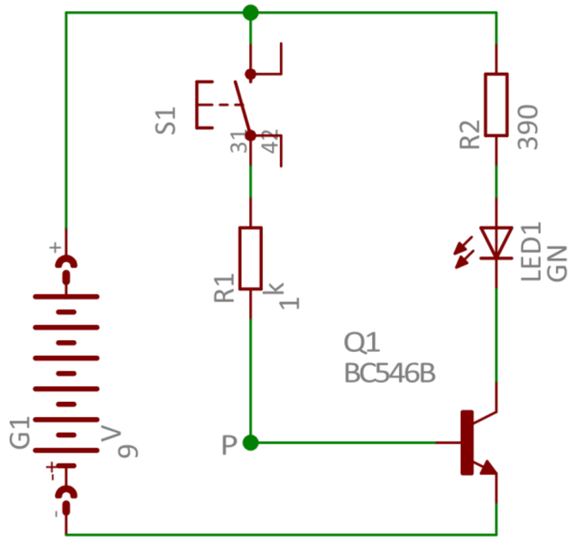


Fig. 7.2.1-1: Transistor circuit without pull-down resistor.

Question 1: Label base, collector and emitter.
Question 2: What is the ideal voltage drop across the path CE when the transistor is turned ON?
Question 3: What is the current from base to emitter when S1 is off? What does the transistor then do with its path CE?
Question 4: What happens when you touch point P with your hand? Why?

7.2.2 Transistor as switch with pull-down resistor

When S1 is opened, the base of the transistor must not hang "in the air", i.e. it must be "pulled" to a certain potential. Otherwise, a small unwanted interference or fault current can engage the transistor. Therefore, a pulldown or pullup resistor is used.

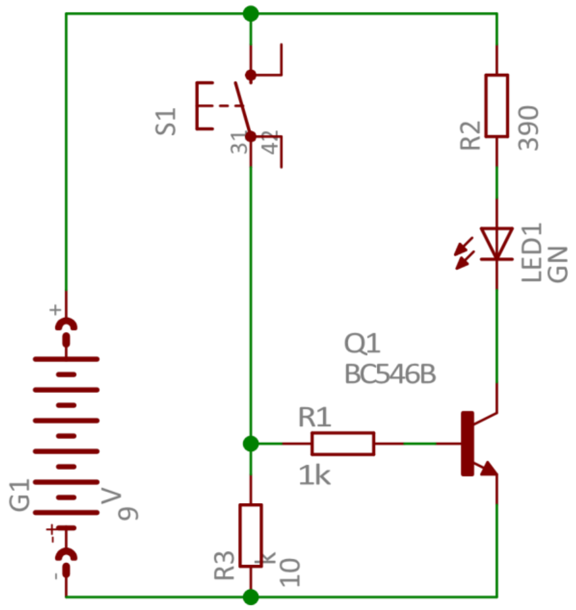


Fig. 7.2.2-1: Transistor circuit with pull-down resistor.

Question 1: What is the voltage between base and emitter when pushbutton S1 is open?
Question 2: Build a circuit with pull-up resistor, i.e. S1 and R3 swapped. Draw the circuit!
Question 3: In the circuit with pull-up resistor, how does the LED behave when S1 is closed and opened?
Question 4: What mathematical binary operation did you perform with it?

7.2.3 Switching a relay

The transistor as a switch can also control a relay. Such circuits are used on the output modules of industrial control systems, e.g. to control contactors. Instead of S1 a microcontroller switches the transistor. The free-wheeling diode is important here so that the transistor is not damaged.

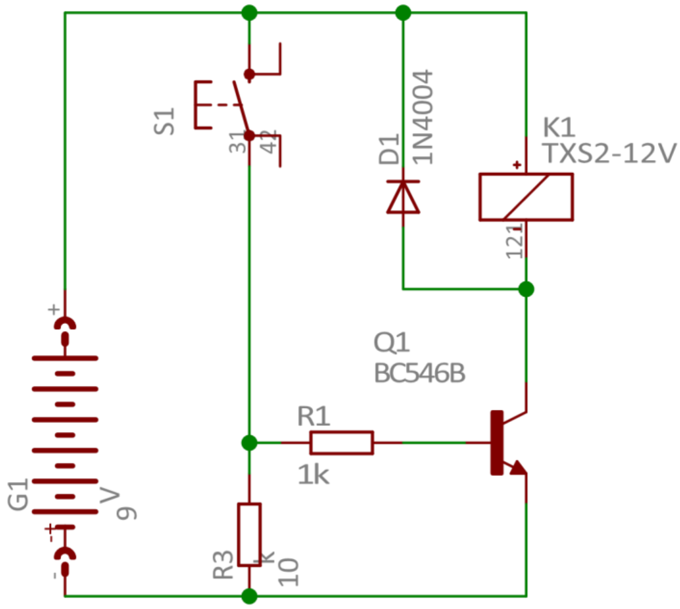


Fig. 7.2.3-1: Transistor for controlling a relay.

Question 1: What does D1 do?

Question 2: What can you say about the current through S1 compared to the current through K1? What advantage does this have for switch S1?

Question 3: What advantage could transistors offer as switches over relays in practice?

7.2.4 Amplifier

By means of a voltage divider (here LDR and R3), the voltage at the base is set so that the transistor just starts to pass current (0.3V - 0.7V , depending on the transistor type). From this so-called operating point, a very small change in resistance LDR will cause a large change in C-E current (through LED1). This can be used to amplify weak analog signals. Here it is a change in brightness that is converted by a photoresistor LDR into a variable resistor and thus into a variable current flow into the base of the transistor.

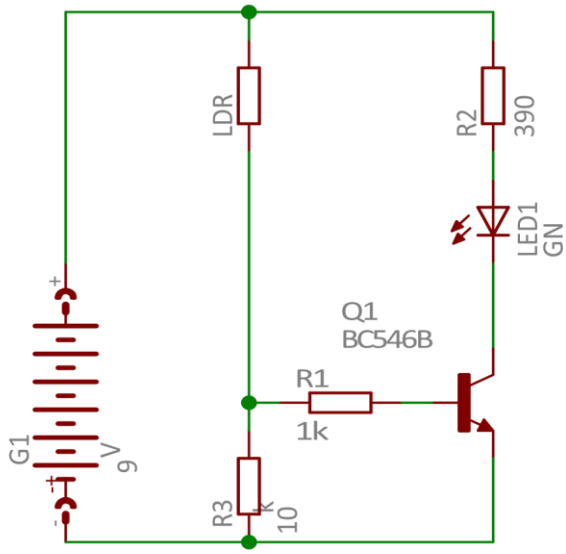


Fig. 7.2.4-1: Amplifier circuit

7.2.5 Timer Circuits

When S1 is closed, LED1 turns off, when S1 is opened, it takes some time until LED1 turns on.

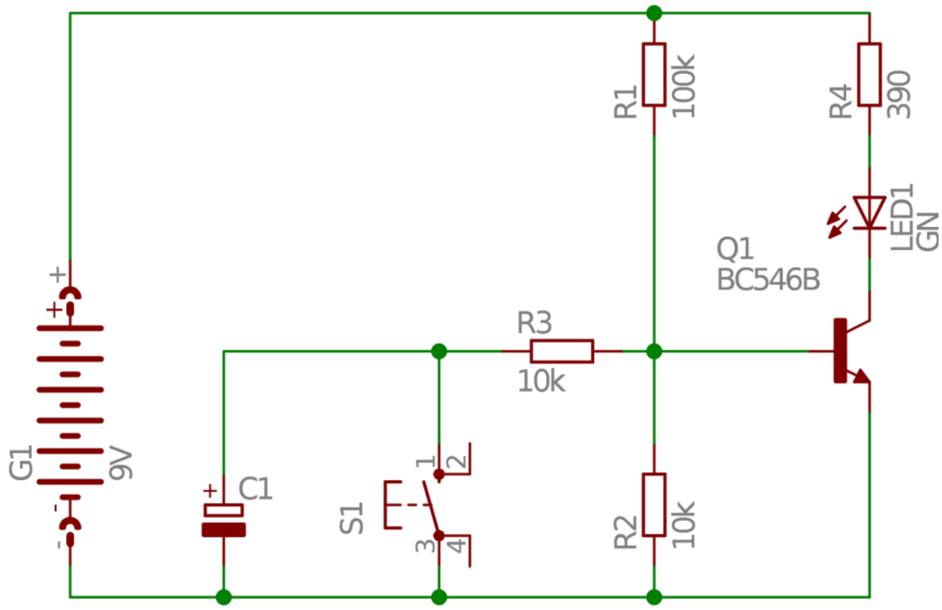


Fig.7.2.5-1: Transistor as timer

Question 1: With S1 closed, what voltage drops from B to E if the current into the base is assumed to be 0?

Question 2: From a voltage of 0.7 V between base and emitter the transistor opens. What is the state of the transistor when S1 is closed?

Question 3: What would be the voltage between collector and emitter with S1 open if C1 were not there? What would be the state of the transistor?

Question 4: What happens to C1 as soon as S1 is opened?

Question 5: What does the duration of the time delay depend on?

7.2.6 Flip-flop (Bistable tilt stage)

A **Flip Flop** is a circuit that can assume **two stable states** and thus **store** one **data bit**.

When **S1** is **actuated,** the base current becomes 0 and Q1 becomes highly resistive, so that the current flows through LED1 into Q2 and switches it on **=> LED2 lights up.** Thus Q1 remains off, because Q2 with R4 quasi replaces the switched on S1.

If **S2** is now **actuated**, Q2 goes off and the current via LED2 flows into the base Q1, causing Q1 to switch on and **LED1 to light up**. Q1 with R3 then replaces the switching function of S2, so that the state remains stable.

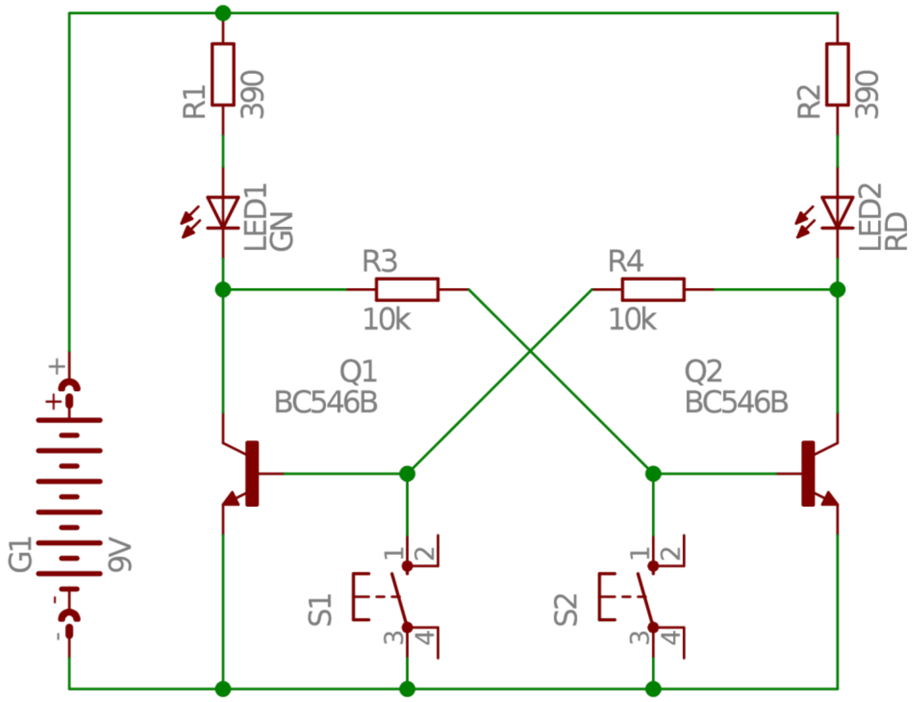


Fig.7.2.6-1: Flip-flop circuit

The bistable circuit **therefore "remembers" its state** as long as the voltage supply remains applied.

Question 1: What is the voltage from B to E of Q1 when S1 is on? What is the state of the transistor then?

Question 2: What would be the voltage of the path CE of Q1 if Q1 is OFF and the current in Q2 could be assumed to be 0?

Question 3: What does the voltage at CE of the switched off Q1 do for Q2?

Question 4: What happens if you press and hold both buttons S1 and S2?

7.3 Flashing circuit (Astable tilt stage)

The **Astable Tilt Stage constantly** tilts **back and forth** between its two states.

When **switching on,** a current flows into both transistors via R2 and R3 respectively into the base until one of the transistors switches through first. During this time C1 and C2 are positively charged.

Suppose it is **Q1 that** goes **ON first.** The + side of C1 is then suddenly pulled to almost 0V. Due to the (positive) voltage still present in C1 in the capacitor, the - side is thereby below 0V and Q2 blocks immediately. The - side of C1 is now slowly charged up again from the negative range via R2 until 0V is applied to the capacitor, and C1 is then charged even further "the wrong way round" until the voltage across C1 is -0.7V i.e. at the base of Q2 0.7V, so that **Q2 switches.**

With **Q2** LED2 turns on and the + side of C2 is pulled to almost 0V. Due to the (positive) voltage still present in C2, the - side is below 0V and Q1 blocks immediately. The - side of C2 is now slowly charged again from the negative range via R3 until -0.7V is reached and **Q1** switches **again.**

This starts the cycle all over again.

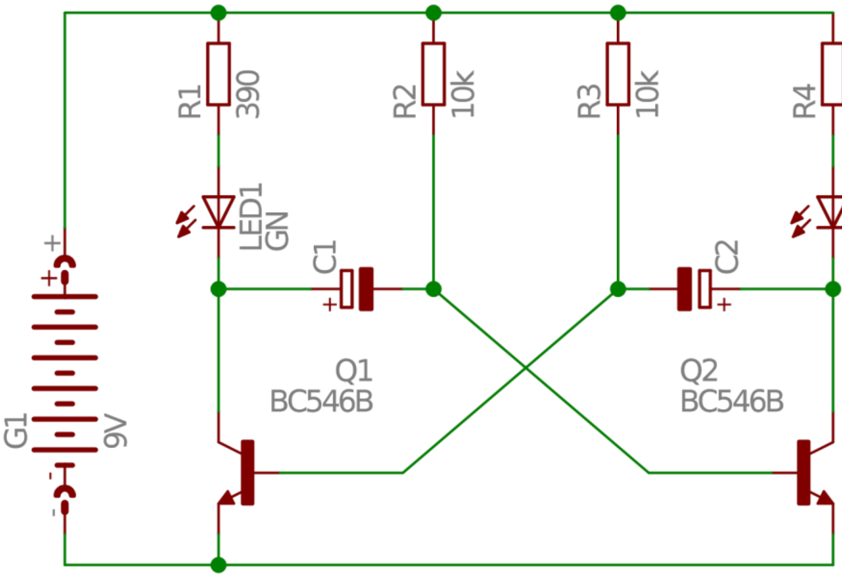


Abb. 7.3-1: Schaltung der Astabilen Kippstufe.

Question 1: Which charging process at C_x affects which transistor Q_x?
Question 2: What could the frequency of the blink circuit depend on?

7.3.1 AC voltage generator

The **AC voltage generator** is constructed like the flashing circuit, except that **smaller capacitors** are used. This increases the frequency of the "toggling back and forth" and you have an approximately rectangular voltage at one side of the circuit, which changes its value quickly back and forth between 0V and a U_{max} < 9V. It should also be noted that this is **not an AC voltage, but a mixed voltage** since an **AC voltage must have an average value of 0.** So, you would have to connect the measuring device with the - pole to $U_{max}/2$, so that the voltage at the measuring device can also become negative.

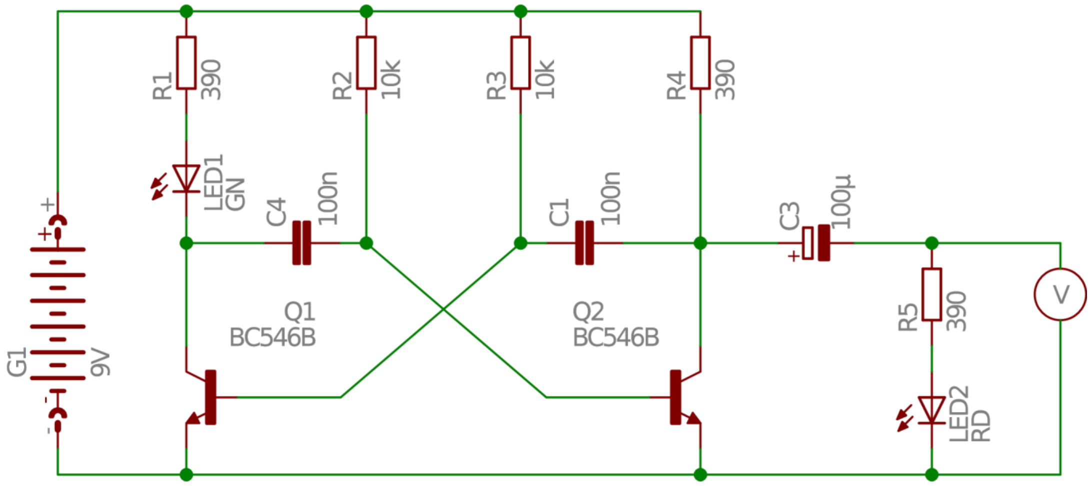


Fig. 7.3.1-1: The astable flip-flop as an AC voltage generator.

Question 1: What is the shape of the voltage at CE of Q2 coming from the generator, can you sketch it?
Question 2: Does the circuit also work with bridged C3? Which property of a capacitor can be shown with C3?
Question 3: How to adjust the meter to measure the AC voltage?

8 Logic circuits with ICs

8.1 Introduction

8.1.1 LM7805 voltage regulator

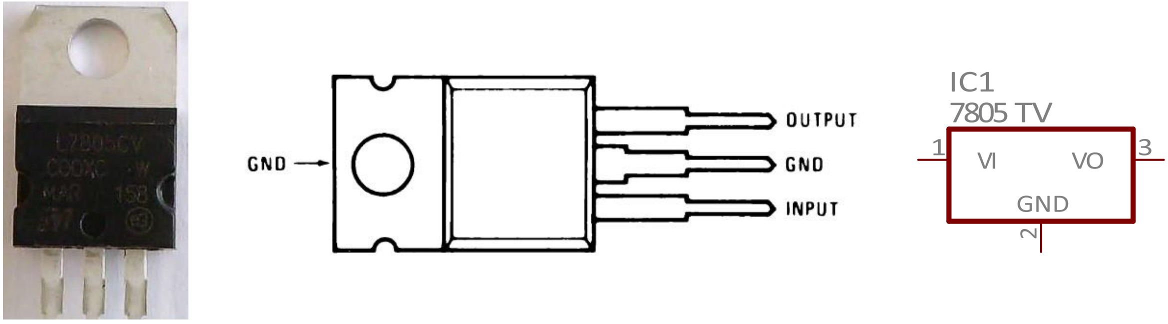


Fig. 8.1.1-1: Component, pinout[2] and circuit symbol (EAGLE)

The **fixed voltage regulators** shown here contain a **built-in small circuit** which provides a **fixed voltage VO** (e.g. 5V for the 7805) for the loads connected on the output side. In contrast to **a voltage divider** consisting of 2 resistors, this happens **independently of the load**.

Simplified, you can imagine this linear regulator as a voltage divider consisting of 2 resistors, whose "upper" resistor is the controlled transistor of the regulator and the "lower" resistor is the load circuit at the output. The "upper resistor" is then always adjusted so that the same voltage is always applied to the "load resistor" regardless of its size.

This also means that with this type of controller, **input current equals output current.** Inevitably, the greater the difference between VI and VO, the more **power is "burned" in the controller,** which is why it becomes **warm** and usually requires a **heat sink.**

The **input voltage VI** must be at least **1.5V-3V higher** than the desired **output voltage VO**. The controller must still be **connected to GND (Ground, 0V) to be** able to measure the voltage on the output side.

Depending on the type, **additional capacitors may be** specified in the data sheet, which must still be connected in parallel.

Note connection!
Incorrectly connected controllers or controllers short-circuited on the output side can become very hot!

8.1.2 AND module HCF4081

The **AND device** is an **IC (Integrated Circuit)** that has a circuit of transistors and other components. These are connected in such a way that certain **logical operations** result. Here they are **AND operations, i.**e. **both inputs** must be **ON for** the **output to** go **ON.**

The IC is connected with **5V** to VDD and 0V to VSS. The inputs can then be connected with **LO (0-bit, OFF)** i.e. **0-1.5V** or with **HI (1-bit, ON)** i.e. 3.5-5V can be connected, in order to set a LO (0V) or HI (5V) depending on the logical operation at the output. The special specifications in the **data sheet for** the **permissible voltages and currents must be** observed!

It must also be noted that the inputs accept one of the two levels and do not "hang in the air" (see transistor)!

In the case of this particular IC, more than 5V would be allowed, but **for practice,** the circuit is to be built with a **fixed voltage regulator.**

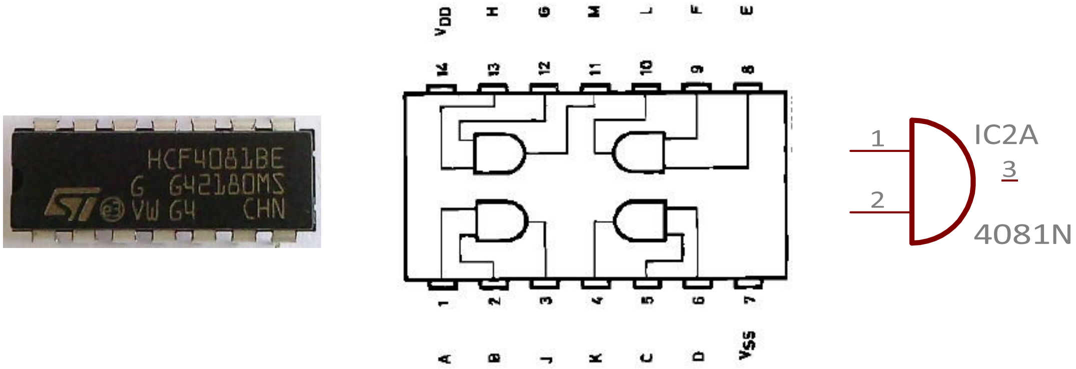


Fig. 8.1.2-1: Component, pinout[3] and circuit symbol (EAGLE)

Do not short-circuit outputs!

Observe the maximum permissible voltages at the input and supply according to the data sheet!

Observe the maximum current at the output according to the data sheet!

Do not leave inputs unconnected, i.e., undefined!

8.1.3 OR module HCF4071

The **OR device** is an IC whose logical operations result in an OR. So, it is enough if at **least 1 input** is **ON to switch the output**.

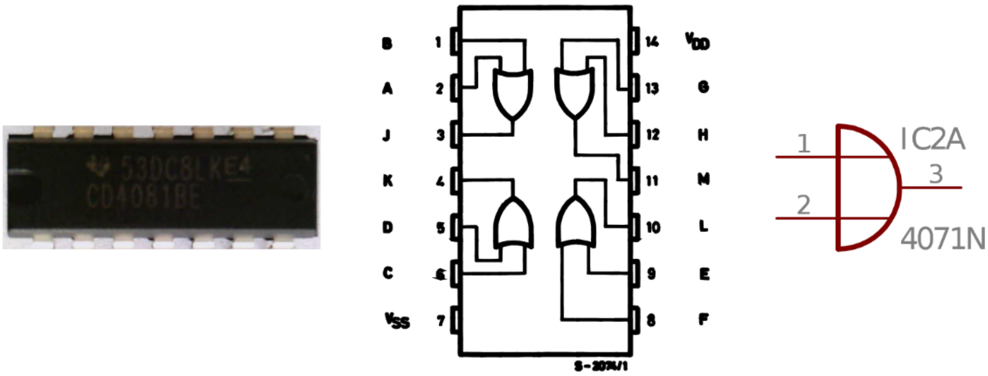


Fig. 8.1.3-1: Device, pinout [4] and circuit symbol (EAGLE)8.2 Practical part

8.2 Practical Part

8.2.1 AND and OR circuit with pushbuttons

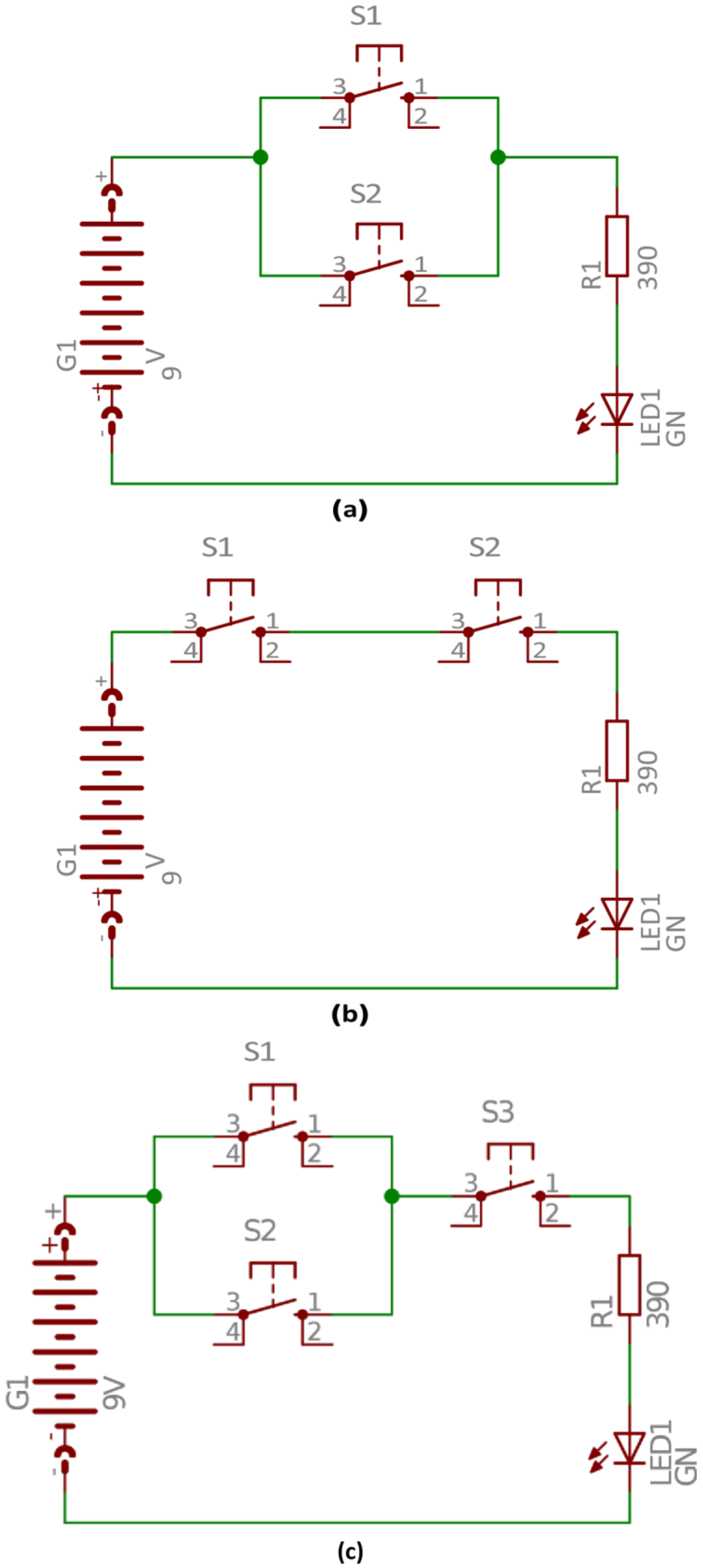


Fig. 8.2.1-1: Logical links with buttons.

Question 1: What logical operations are provided by circuits a and b?
Question 2: In c, what is the voltage that drops across S1 when and S2 and S3 are closed?

8.2.2 AND IC without driver circuit

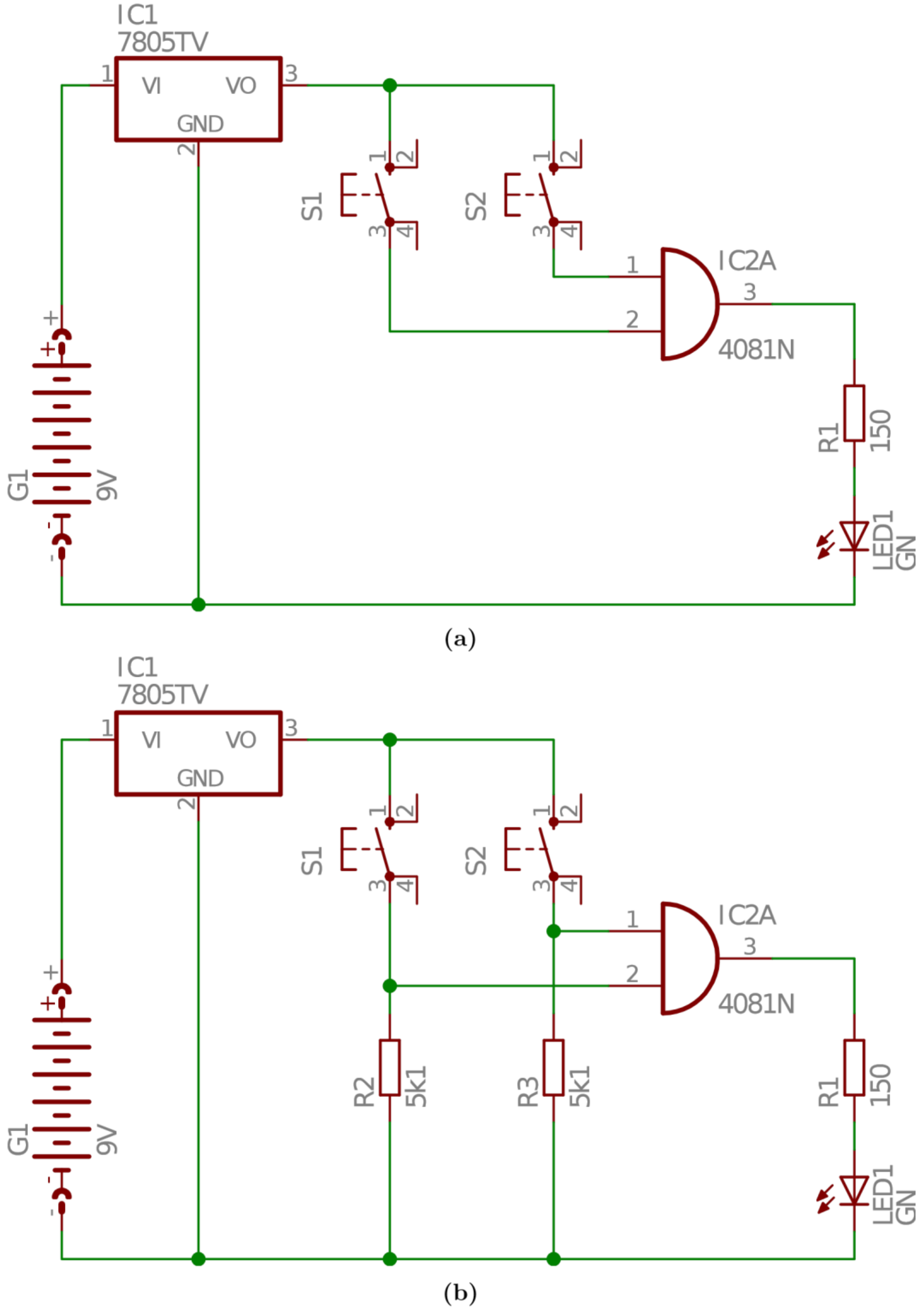
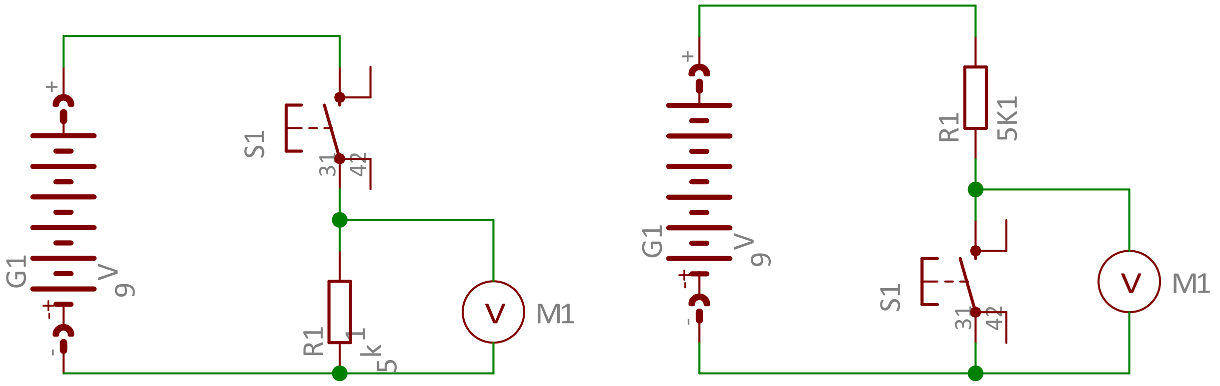


Abb. 8.2.2-1: Schaltungen mit UND-IC.

Question 1: What is the problem with circuit a?
Question 2: What are the resistors in circuit b for?
Question 3: What is the state of the output when switches S1 and S2 are open?

8.2.3 Pullup and pulldown resistors

The following circuits show again the principle of pullup and pulldown resistors.



(a) (b)

Fig. 8.2.3-1: Pull-up or pull-down circuit.

Question 1: Which circuit is "pulldown" related to the measuring device?
Question 2: What is the ideal voltage at b at M1 when S1 is open?

8.2.4 AND IC with driver circuit

Depending on the load, logic ICs and microcontrollers cannot drive the load directly, but require a transistor that "drives" a higher current with possibly higher voltage through the load. These drivers are also available as IC with many transistors (e.g. ULN 2003A)

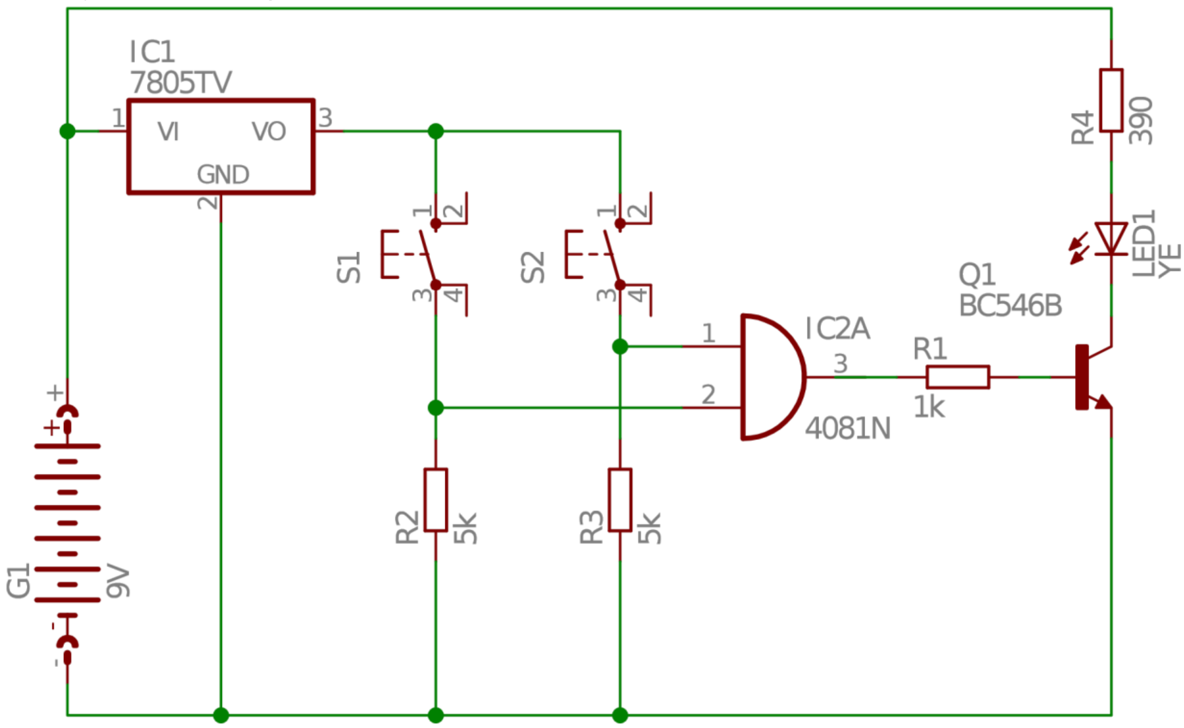
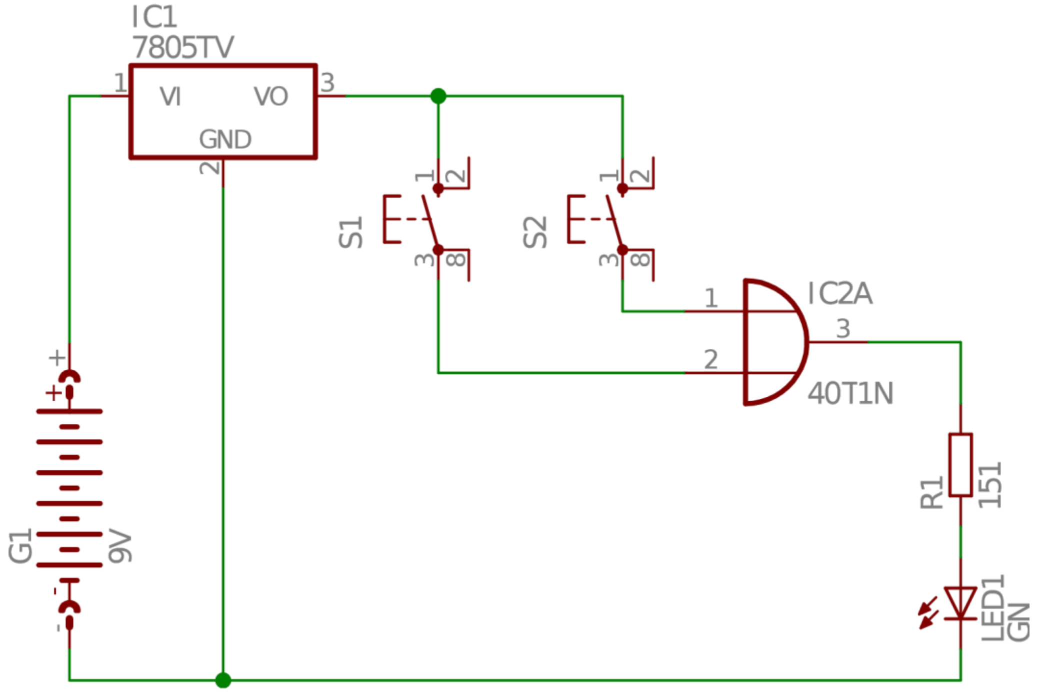


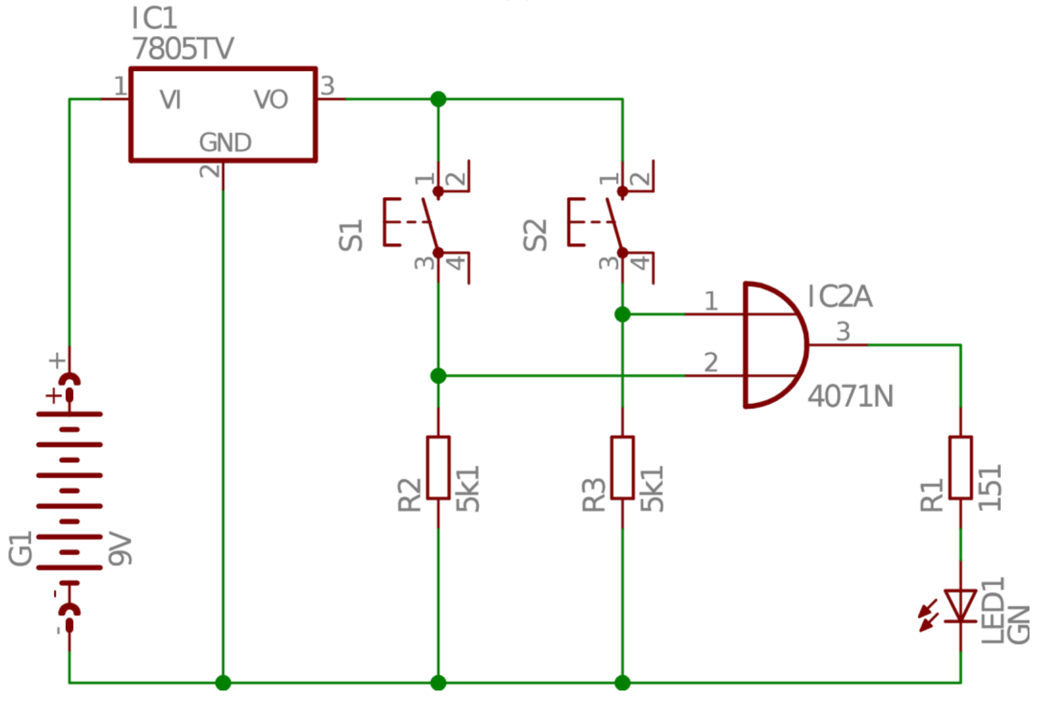
Fig. 8.2.4-1: AND-IC with supply via driver IC

Question 1: What is the transistor for?
Question 2: What happens if the series resistor is omitted?
Question 3: Draw the circuit with pullup resistors, how does the logic change?

8.2.5 OR-IC



(a)



(b)

Fig. 8.2.5-1: Circuits with OR-IC without driver circuit.

Question 1: What is the problem with circuit a?
Question 2: What are the resistors in circuit b for?
Question 3: What is the state of the output when S1 is closed and S2 is open?

In the following circuit, a transistor is used again to relieve the IC from the load current.

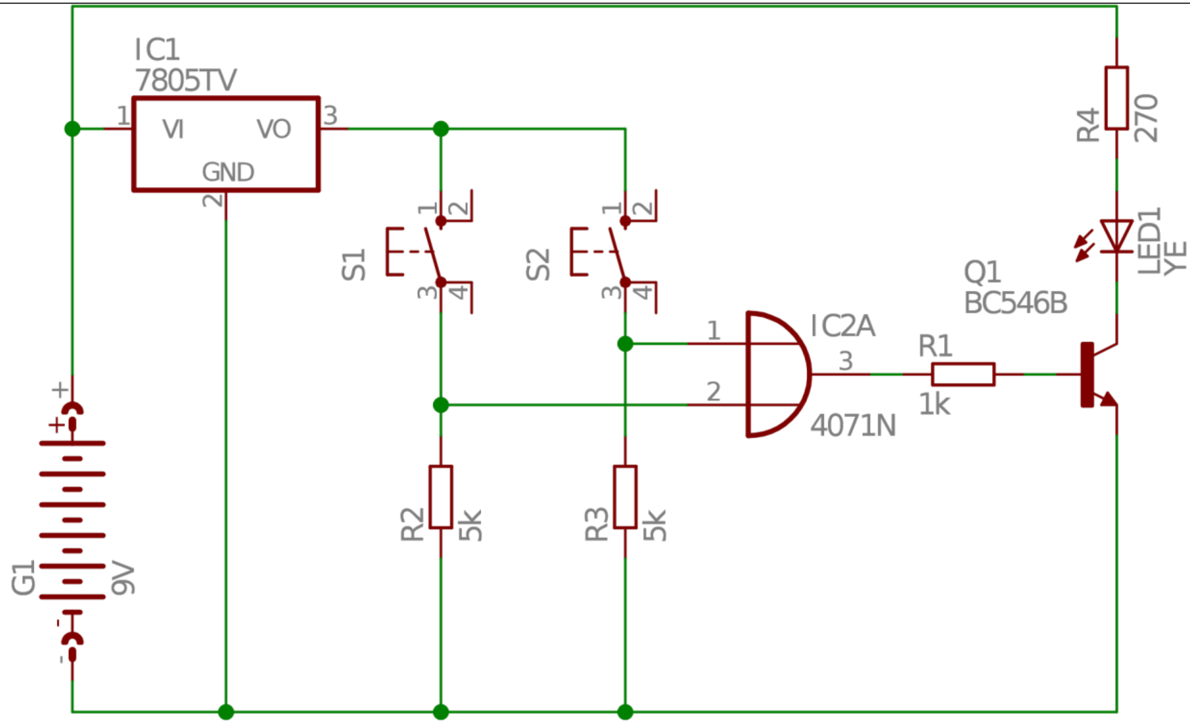


Abb. 8.2.5-2: ODER-IC mit Treiberschaltung.

Question 1: Draw the circuit with pullup resistors, how does the logic change?

8.2.6 Control of a relay with AND-IC

In the following circuit, the transistor is used because the coil of the relay has relatively low impedance, and the IC could not apply the current.

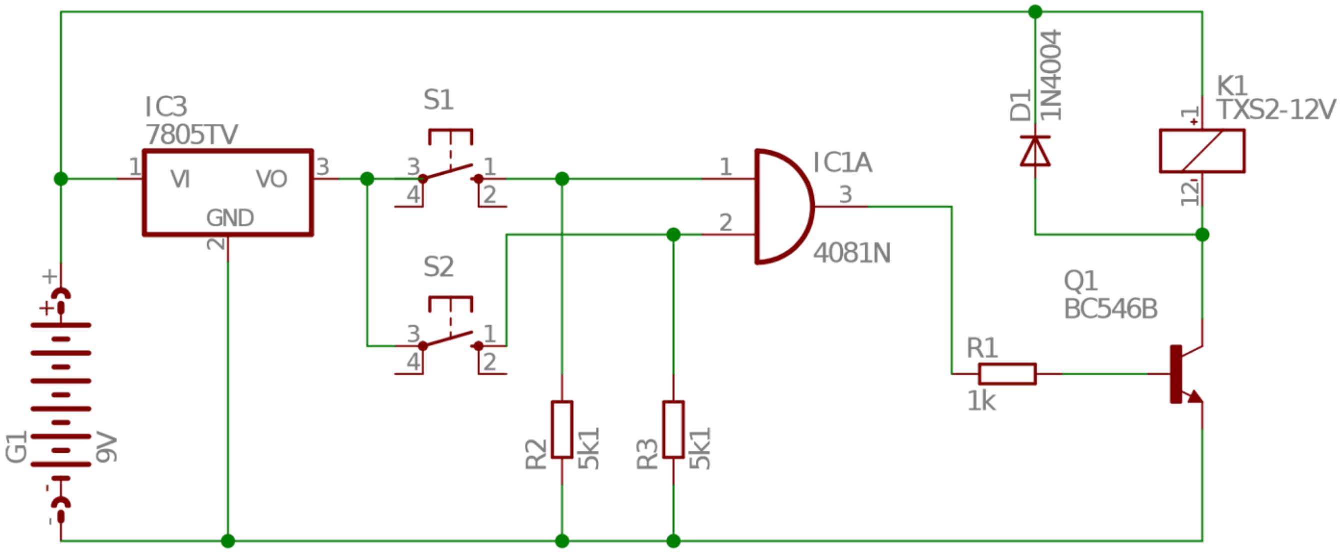


Abb. 8.2.6-1: Relais ansteuern mit UND-IC.

Question 1: What is the purpose of D1?
Question 2: What is the voltage at PIN1 of IC1 when S1 is on?
Question 3: What voltage drops across K1 when S1 and S2 are on?
Question 4: What is the voltage across K1 when S1 is on and S2 is off?
Question 5: Which two "wires" that would need to be plugged into the breadboard are not shown as green lines in this circuit?

9 Further circuits

9.1 Introduction

9.1.1 Counter module CD4017

Find out how the CD4017 works from the Internet using the data sheet (Datasheet).

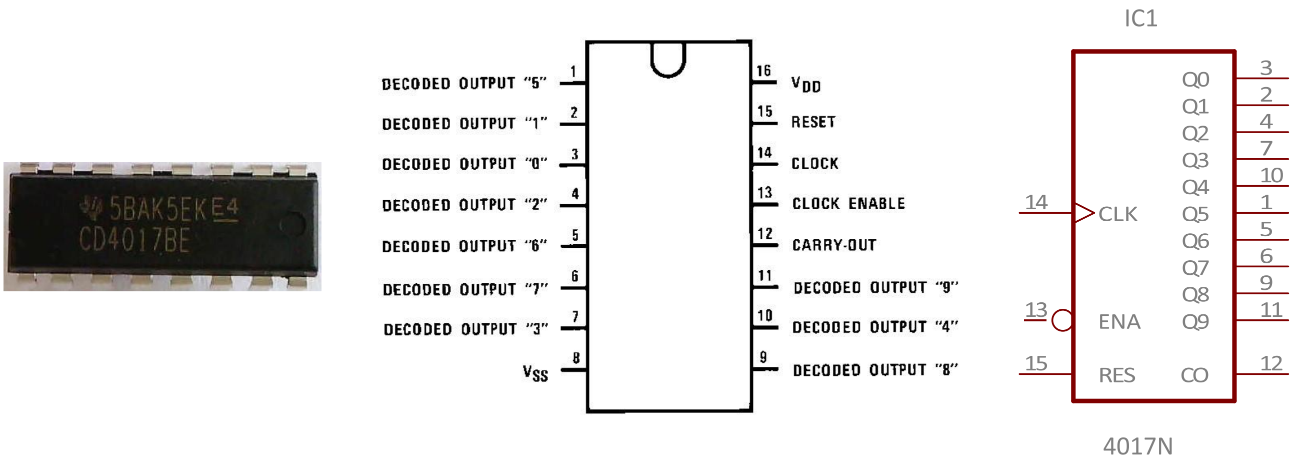


Fig. 9.1.1-1: Component, pinout [5] and circuit symbol (EAGLE)

9.1.2 Timer module NE555

Find out how the NE555 works from the Internet using the data sheet (Datasheet).

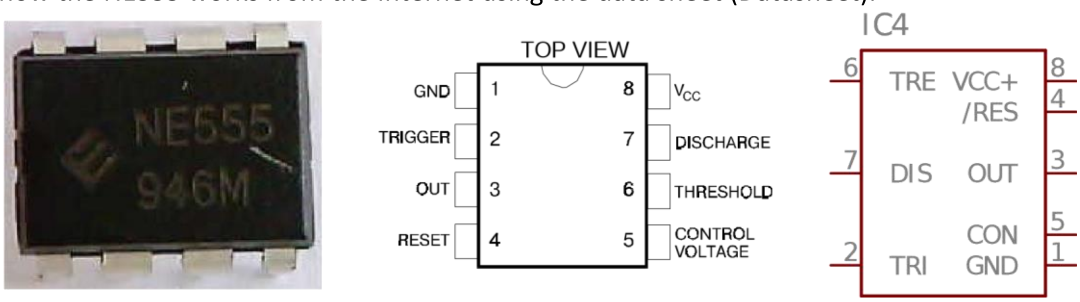


Fig. 9.1.2-1: Device, pinout [6] and circuit symbol (EAGLE)

9.2 Practical part

9.2.1 Time switching with the NE555

A flashing circuit can be set up with the NE555.

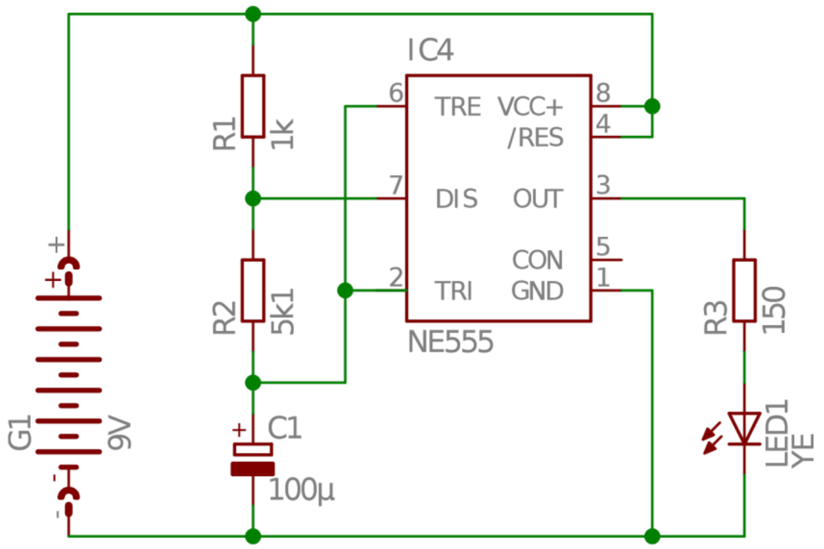


Fig. 9.2.1-1: NE555 as timer circuit

9.2.2 Use of a counter IC

The following circuit shows a running light with LEDs.

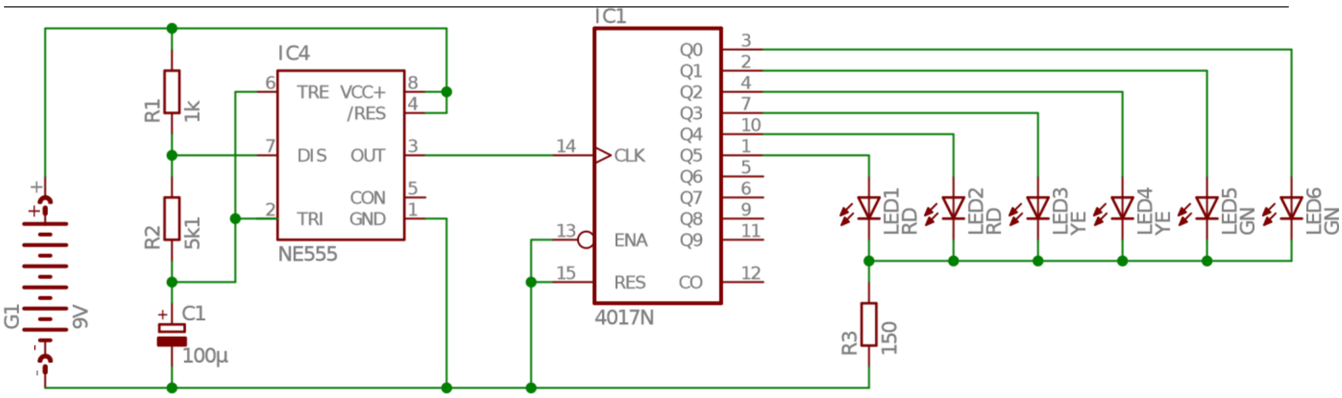


Fig. 9.2.2-1: Use of a counter IC.

9.2.3 Counter IC with reset

With this circuit, the running light always starts from the beginning.

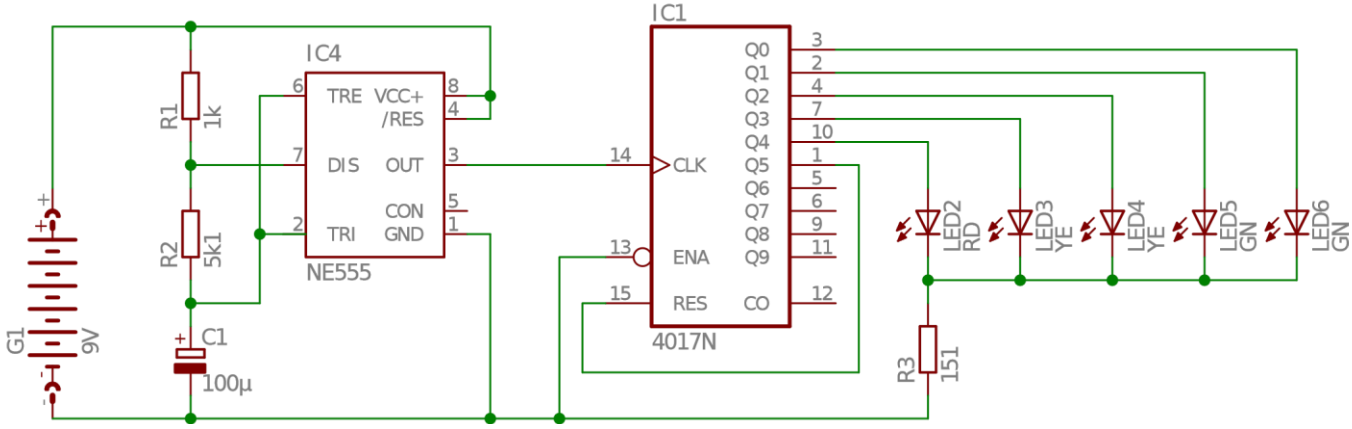


Fig. 9.2.3-1: Counter IC with reset.

Literature

[1] url: http://elektronik-kurs.net/elektrotechnik/farbcode-toleranzen-normreihenleistung/ (visited Sep. 14, 2017).

[2] url: http://cdn-reichelt.de/documents/datenblatt/A200/LM78XX-TI.pdf (visited on 30.09.2017).

[3] url: http://cdn-reichelt.de/documents/datenblatt/A240/MOS4081STM%23STM.pdf (visited Sept. 30, 2017).

[4] url: http://cdn-reichelt.de/documents/datenblatt/A200/MOS4071_STM.pdf (visited Sept. 30, 2017).

[5] url: http://cdn-reichelt.de/documents/datenblatt/A240/MOS4017_MOS4022%23FAI.pdf (visited Sept. 30, 2017).

[6] url: http://cdn-reichelt.de/documents/datenblatt/A200/555ESTEK.pdf (visited on 30.09.2017).