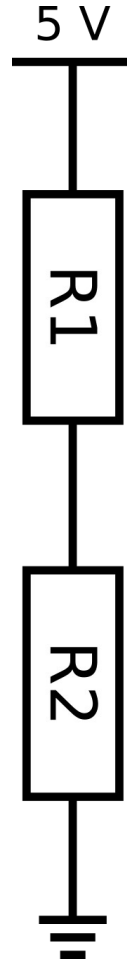


# Sketching with Hardware

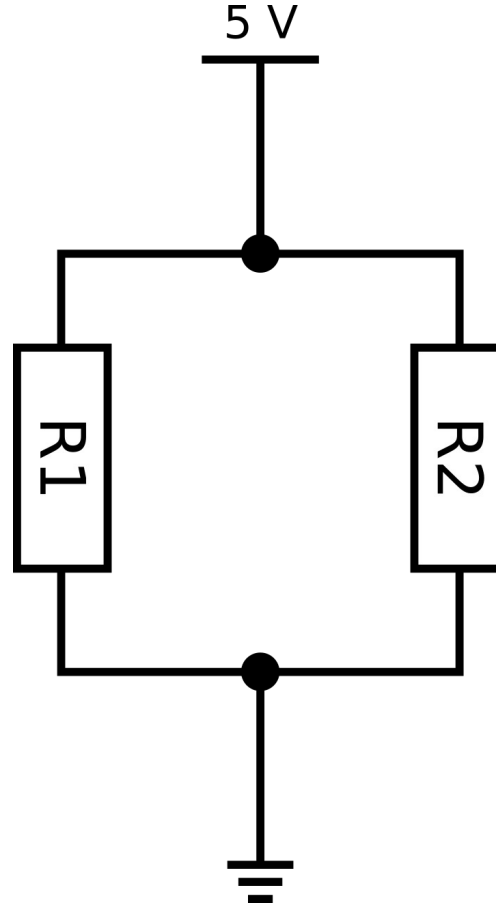
04: Electronics 02 + Digital Circuits

# Parallel- and Series Connection

Series Connection



Parallel Connection

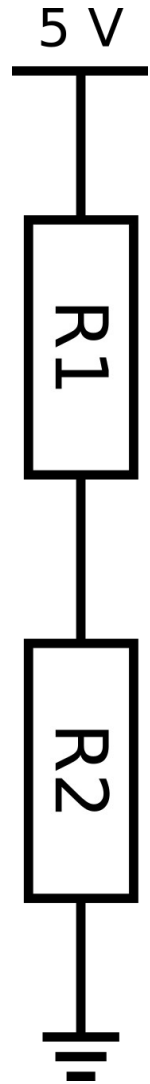


# Series Connection

- The total resistance  $R_{total}$  is the sum of all partial resistances in the series connection

$$R_{total} = R_1 + R_2 + \dots + R_n = \sum_{i=1}^n R_i$$

- The total voltage  $U_{total}$  is divided up into  $n$  partial voltages
- The current  $I$  is the same at every point in the series connection

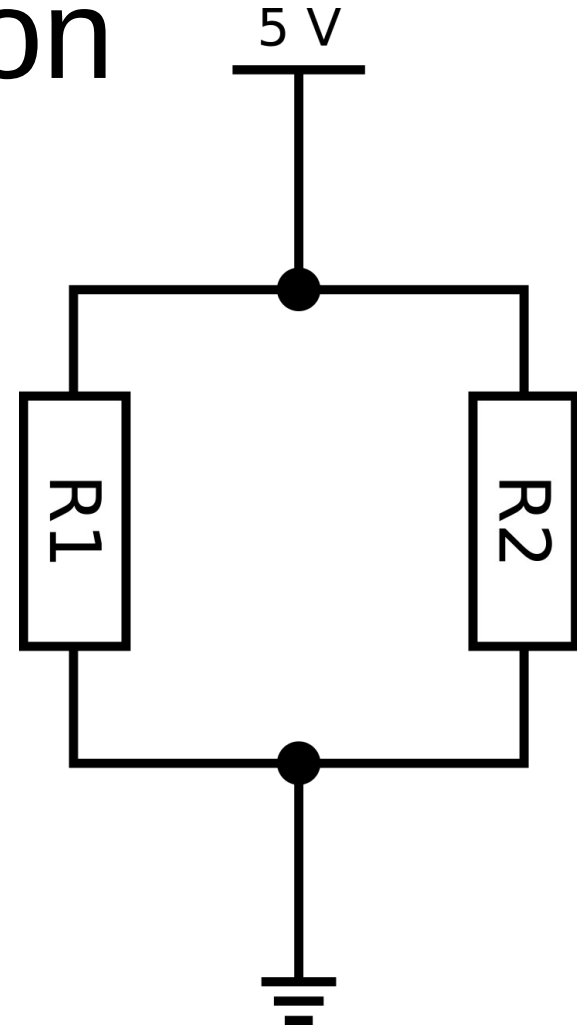


# Parallel Connection

- The reciprocal of the total resistance  $R_{total}$  is the sum of the reciprocals of all partial resistances in the parallel connection

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n} = \sum_{i=1}^n \frac{1}{R_i}$$

- The total current  $I_{total}$  is divided up into  $n$  partial currents
- The voltage over every resistor connected in parallel is the same



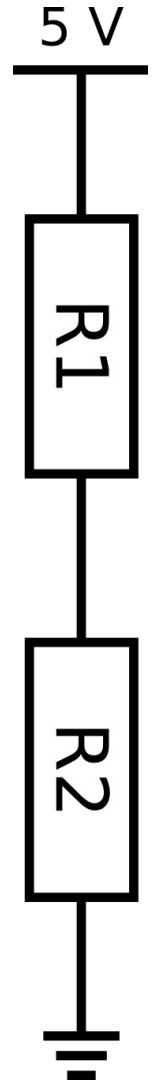
# Voltage Divider

- Series connection of resistors
- Divides the total voltage into several smaller partial voltages
- The ratio of the partial voltage over any resistor to the total voltage is proportional to the ratio of the partial resistance to the total resistance

$$U_{total} = U_1 + U_2 + \dots + U_n$$

$$\frac{U_i}{R_i} = \frac{U_{total}}{R_{total}}$$

- Exercise:  $R1 = 100\Omega$ ,  $R2 = 400\Omega \rightarrow$  calculate  $U1$



Any questions?

A red LED ( $\sim 2\text{ V}$ ) is supplied with power over a USB cable ( $5\text{ V}$ ). In order to protect the LED from overvoltage, it is connected in series with a dropping resistor ( $220\ \Omega$ ).

How can the circuit be changed to reduce the LED's brightness?

How can an electric motor (9 V) be supplied with power only using AA batteries (1.5 V)?

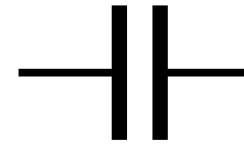


The motor from the last tasks works now but the batteries are draining too fast. What can be changed to fix this problem?

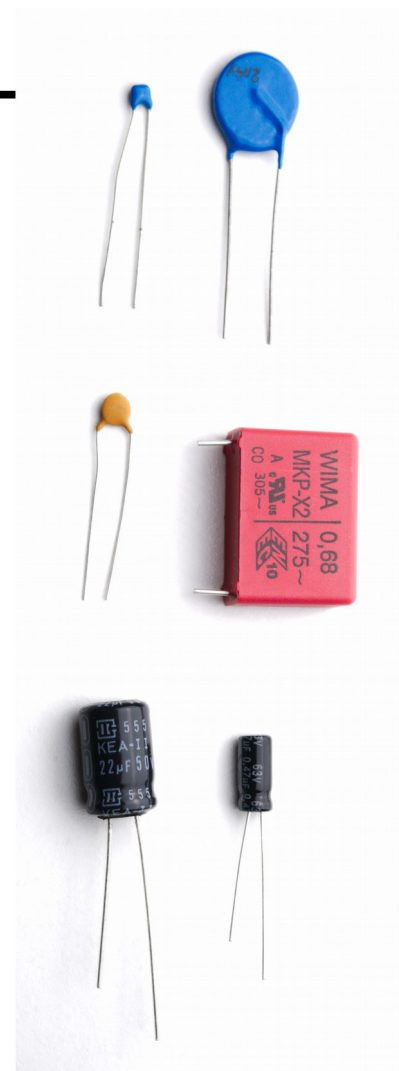
How can twelve red LEDs ( $\sim 2$  V) be supplied with power only using a power supply with 5 V?

The dropping resistor used in the last example gets very hot. How can the circuit be changed to avoid this?

# Capacitors

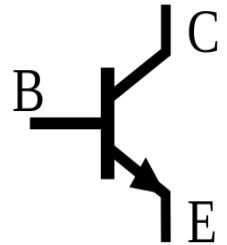
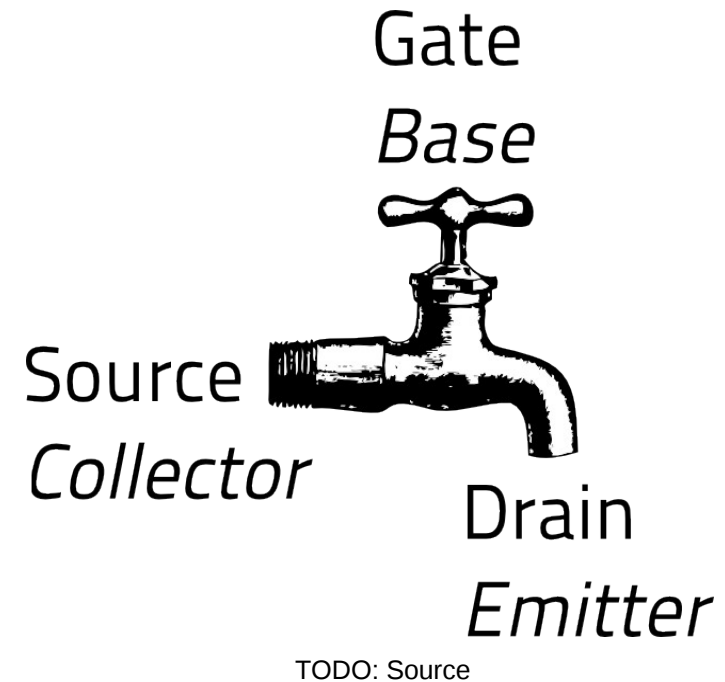


- Stores electrical charge (Q)
- Stored charge per Volt = Capacitance (C)
- Unit of capacitance: Farad (F)
  - $C = Q / U$
- Polarity is (sometimes) important!
- Usage:
  - Store charge
  - filter noise from signals
  - compensate peaks in voltage



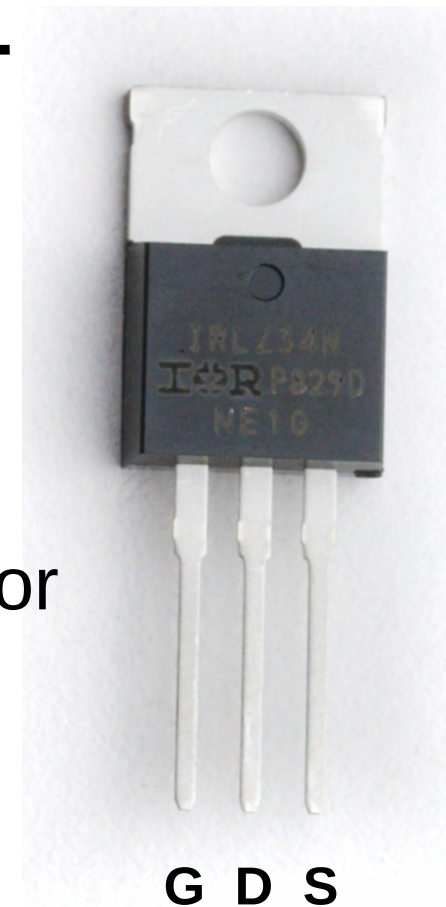
# Transistor

- Electronically controlled switch
- If there is a voltage on the **base**, current can flow from **collector** to **emitter**
- Application:
  - Switching large loads
  - Logic gates
  - Fundamental for digital circuits

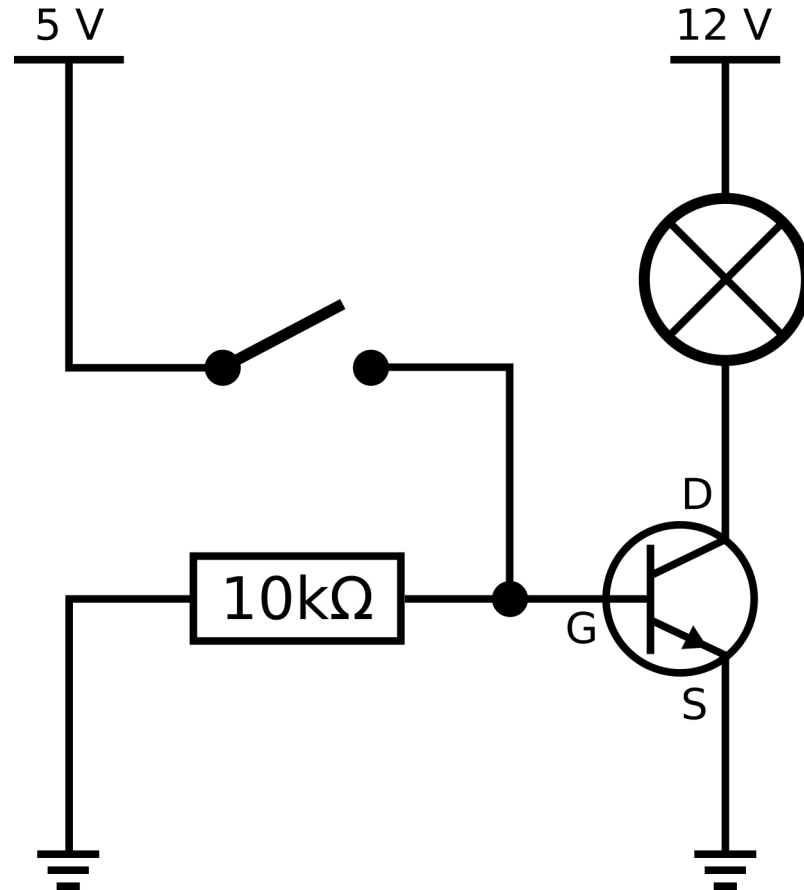


# Transistor: MOSFET

- Two types:
  - Normally open
  - Normally closed
- Can be used like a voltage controlled resistor
- Can switch large loads with a low voltage

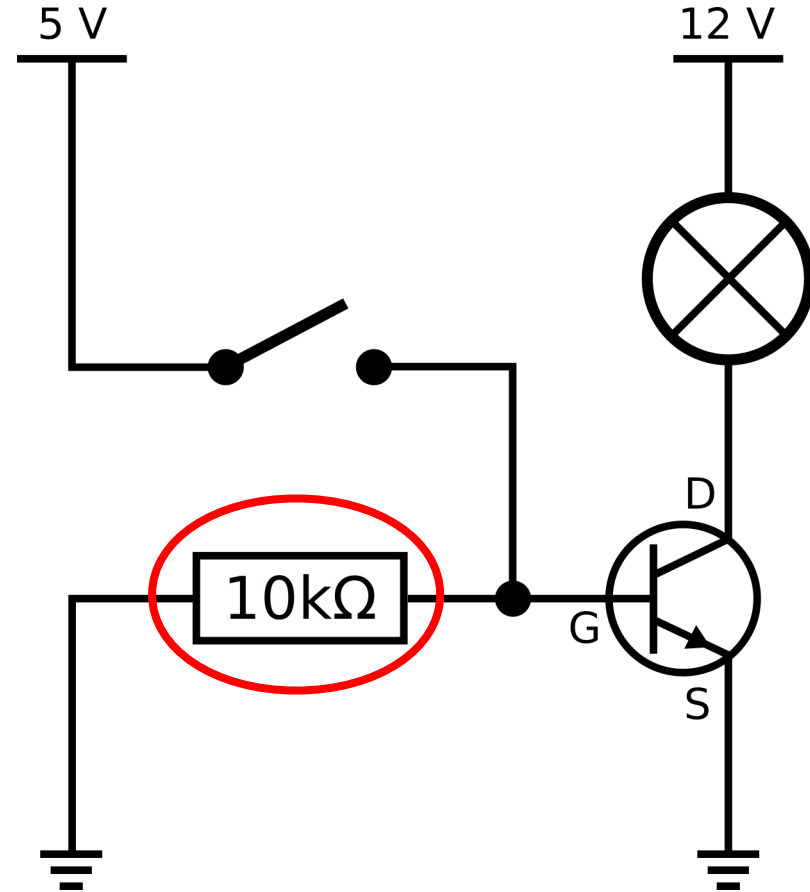


# Switching a load with a MOSFET



# Pull-Down Resistor

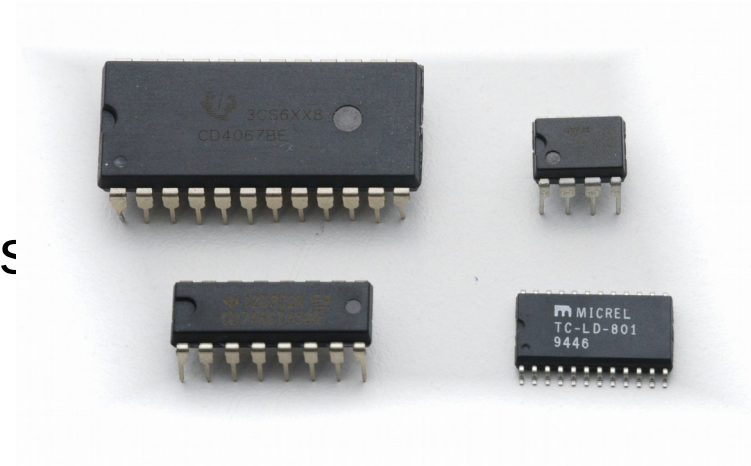
- When the switch is closed, voltage can flow from 5 V over *Gate* and *Source* to *GND*
- When the switch is opened again, there might still be potential between the switch and *GND*
  - Use a big resistor between *Gate* and *GND* so this voltage is **pulled down** to 0 V





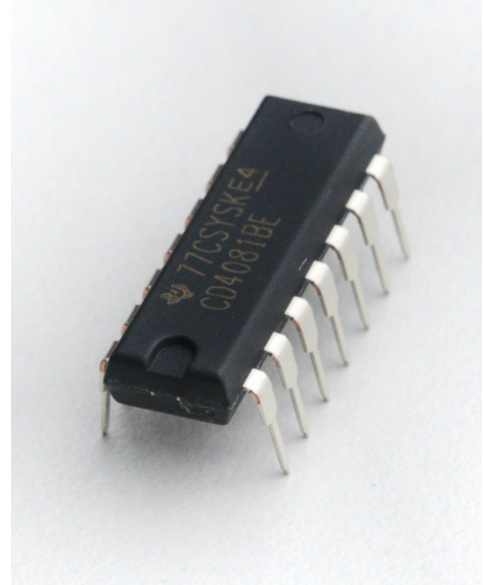
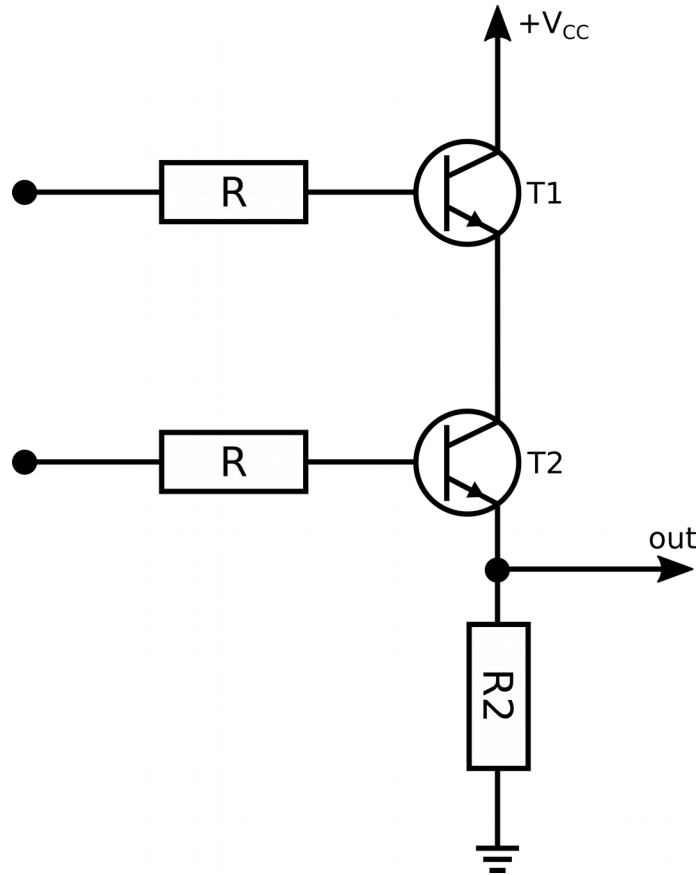
# Integrated Circuits

- Dedicated component that contains a certain circuit manufactured at a very small scale
- May contain millions of transistors, capacitors and resistors
- Used as a “black box”
- Examples:
  - Logic gates, amplifiers, timers, registers
  - memory, sensors, ...

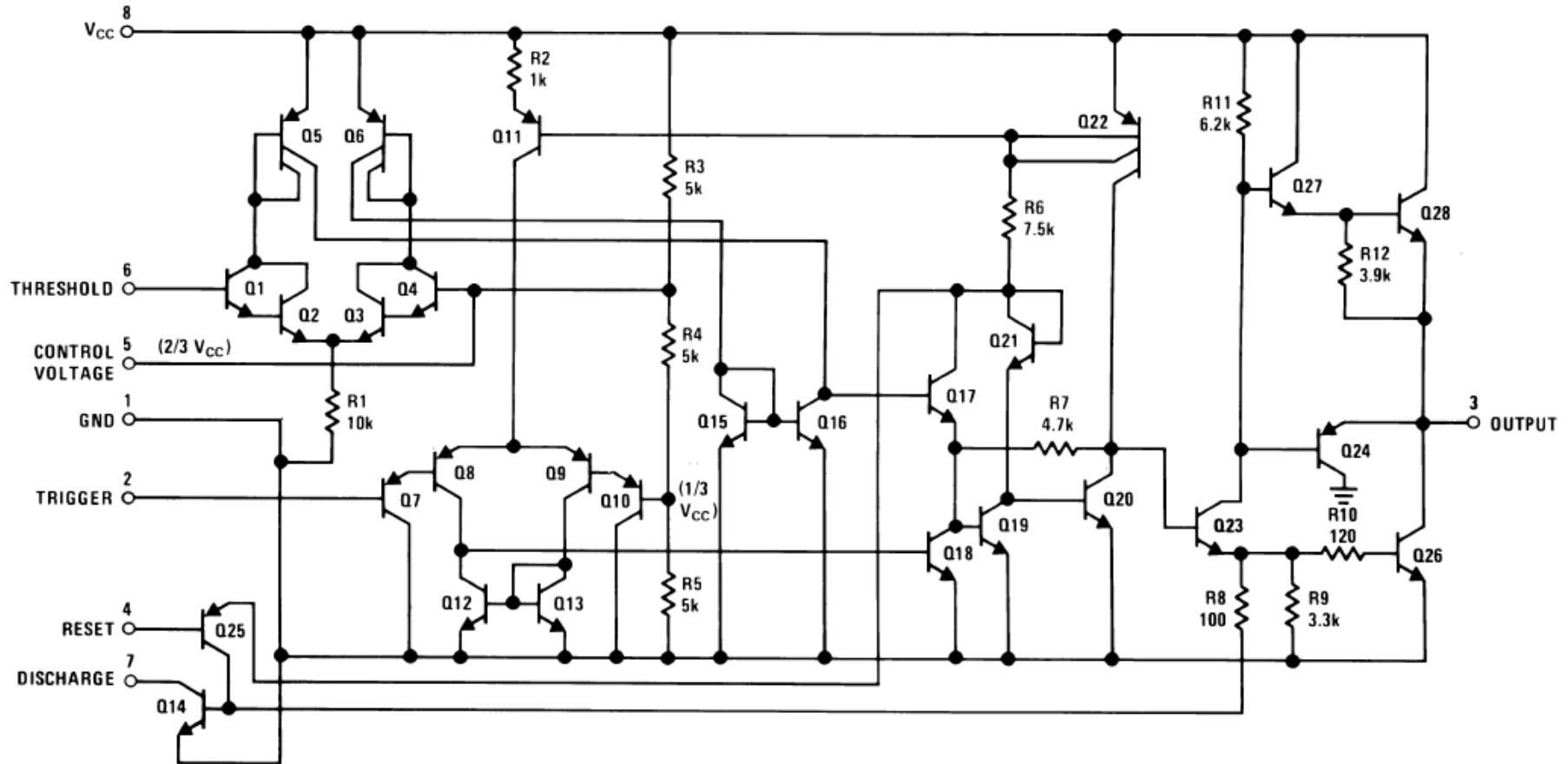


# Example: The AND Gate

```
and(a, b){  
  if (a == 1)  
    and (b == 1):  
      return 1  
  else:  
      return 0  
}
```



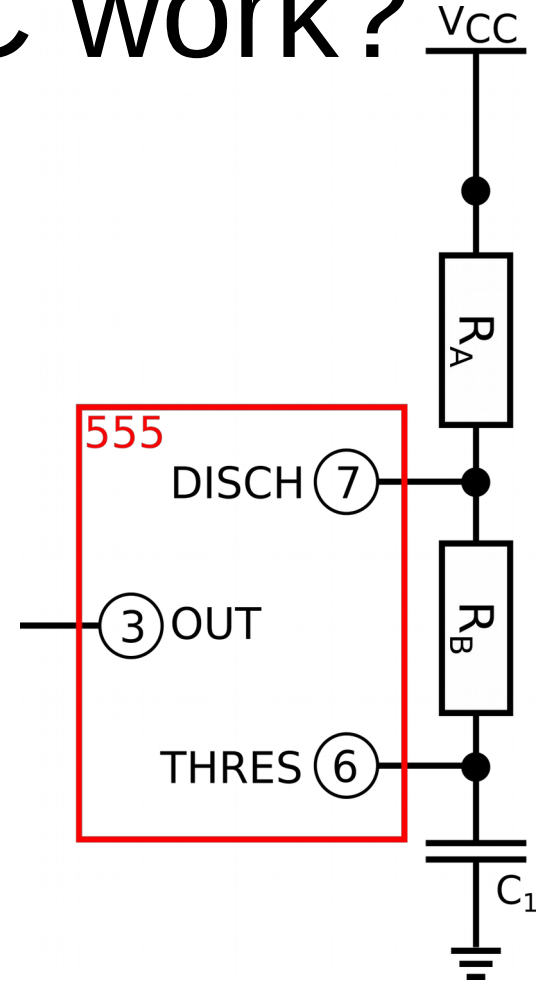
# Example: NE555



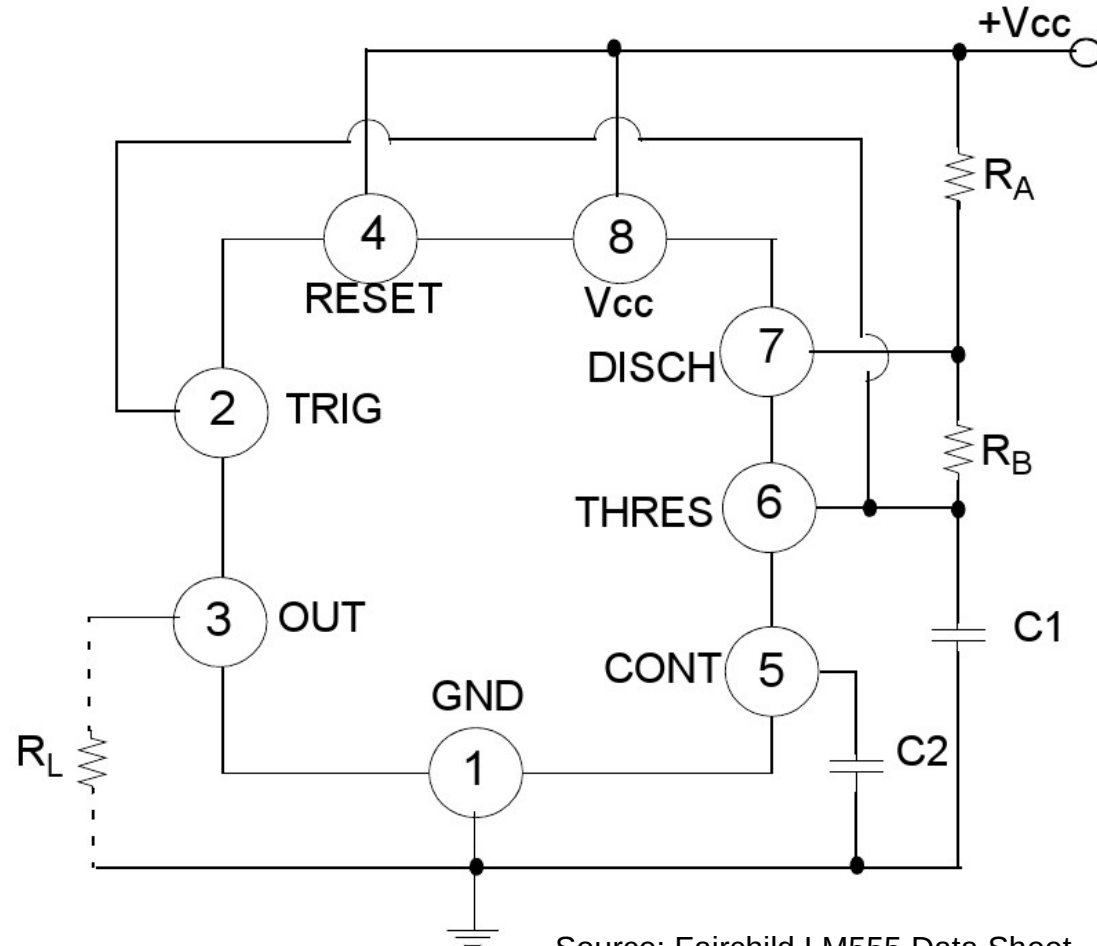
TODO: Source

# How does a 555 timer IC work?

- Different modes – depending on the circuit connection
- Basic principle: Charge a capacitor and do something when it's fully charged. Example: *astable multivibrator*:
  - 1)  $C_1$  is charged. *THRES* measures the voltage at  $C_1$ .
    - the voltage at *THRES* starts at 0 V as all of the voltage is used to charge  $C_1$ . As  $C_1$  gets charged, the voltage at *THRES* approaches  $V_{CC}$
  - 2) When the voltage at *THRES* reaches  $2/3$  of  $V_{CC}$ , *DISCH* is connected to *GND*. *OUT* is set to *high* ( $V_{CC}$ ).
    - $C_1$  gets discharged
  - 3) When the voltage at *THRES* reaches  $1/3$  of  $V_{CC}$ , *DISCH* is disconnected from *GND*. *OUT* is set to low (*GND*).
    - go to step 1




# 555: Astable Multivibrator



Source: Fairchild LM555 Data Sheet

# Reading Data Sheets



**LM555**  
**Single Timer**

**Features**

- High-Current Drive Capability: 200 mA
- Adjustable Duty Cycle
- Temperature Stability of 0.005%/°C
- Timing From  $\mu$ s to Hours
- Turn off Time Less Than 2  $\mu$ s

**Applications**

- Precision Timing
- Pulse Generation
- Delay Generation
- Sequential Timing


January 2013

**Description**


The LM555 is a highly stable controller capable of producing accurate timing pulses. With a monostable operation, the delay is controlled by one external resistor and one capacitor. With astable operation, the frequency and duty cycle are accurately controlled by two external resistors and one capacitor.

**LM555 — Single Timer**

8-DIP



8-SOIC



**Ordering Information**

Part Number	Operating Temperature Range	Top Mark	Package	Packing Method
LM555CN	0 ~ +70°C	LM555CN	DIP 8L	Rail
LM555CM		SOIC 8L	Rail	
LM555CMX		SOIC 8L	Tape & Reel	

**Block Diagram**

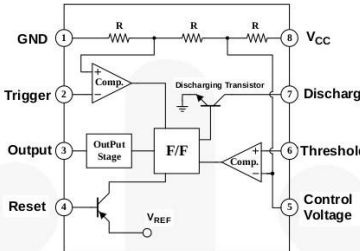


Figure 1. Block Diagram

**Absolute Maximum Ratings**

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operated above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at  $T_A = 25^\circ\text{C}$  unless otherwise noted.

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply Voltage	16	V
$T_{LEAD}$	Lead Temperature (Soldering 10s)	300	°C
$P_D$	Power Dissipation	600	mW
$T_{OPR}$	Operating Temperature Range	0 ~ +70	°C
$T_{STG}$	Storage Temperature Range	-65 ~ +150	°C

**Electrical Characteristics**

Values are at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 5 \sim 15\text{ V}$  unless otherwise specified.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply Voltage	$V_{CC}$		4.5		16.0	V
Supply Current (Low Stable) (1)	$I_{CC}$	$V_{CC} = 5\text{ V}, R_L = \infty$		3	6	mA
		$V_{CC} = 15\text{ V}, R_L = \infty$		7.5	15.0	mA
Timing Error (Monostable) Initial Accuracy (2)	ACCUR	$R_A = 1\text{ k}\Omega$ to 100 k $\Omega$ $C = 0.1\text{ }\mu\text{F}$		1.0	3.0	%
Drift with Temperature (3)	$\Delta t / \Delta T$			50		ppm / °C
Drift with Supply Voltage (3)	$\Delta t / \Delta V_{CC}$			0.1	0.5	% / V
Timing Error (Astable) Initial Accuracy (2)	ACCUR	$R_A = 1\text{ k}\Omega$ to 100k $\Omega$ $C = 0.1\text{ }\mu\text{F}$		2.25		%
Drift with Temperature (3)	$\Delta t / \Delta T$			150		ppm / °C
Drift with Supply Voltage (3)	$\Delta t / \Delta V_{CC}$			0.3		% / V
Control Voltage	$V_C$	$V_{CC} = 15\text{ V}$	9.0	10.0	11.0	V
		$V_{CC} = 5\text{ V}$	2.60	3.33	4.00	V
Threshold Voltage	$V_{TH}$	$V_{CC} = 15\text{ V}$		10.0		V
		$V_{CC} = 5\text{ V}$		3.33		V
Threshold Current (4)	$I_{TH}$			0.10	0.25	$\mu\text{A}$
Trigger Voltage	$V_{TR}$	$V_{CC} = 5\text{ V}$	1.10	1.67	2.20	V
		$V_{CC} = 15\text{ V}$	4.5	5.0	5.6	V
Trigger Current	$I_{TR}$	$V_{TR} = 0\text{ V}$		0.01	2.00	$\mu\text{A}$
Reset Voltage	$V_{RST}$		0.4	0.7	1.0	V
Reset Current	$I_{RST}$			0.1	0.4	mA
Low Output Voltage	$V_{OL}$	$V_{CC} = 15\text{ V}$ $I_{SNK} = 10\text{ mA}$		0.06	0.25	V
		$I_{SNK} = 50\text{ mA}$		0.30	0.75	V
		$V_{CC} = 5\text{ V}, I_{SNK} = 5\text{ mA}$		0.05	0.35	V
High Output Voltage	$V_{OH}$	$V_{CC} = 15\text{ V}$ $I_{SOURCE} = 200\text{ mA}$		12.5		V
		$I_{SOURCE} = 100\text{ mA}$	12.75	13.30		V
		$V_{CC} = 5\text{ V}, I_{SOURCE} = 100\text{ mA}$	2.75	3.30		V
Rise Time of Output (3)	$t_R$			100		ns
Fall Time of Output (3)	$t_F$			100		ns
Discharge Leakage Current	$I_{LKG}$			20	100	nA

**Notes:**

1. When the output is high, the supply current is typically 1 mA less than at  $V_{CC} = 5\text{ V}$ .
2. Tested at  $V_{CC} = 5.0\text{ V}$  and  $V_{CC} = 15\text{ V}$ .
3. These parameters, although guaranteed, are not 100% tested in production.
4. This determines the maximum value of  $R_A + R_B$  for 15 V operation, the maximum total  $R = 20\text{ M}\Omega$ , and for 5 V operation, the maximum total  $R = 6.7\text{ M}\Omega$ .

# Tutorial 03 – Electronics 02