RoboJackets Electrical Training – Information Sheet

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Electricity

Electricity is, as defined by Wikipedia:

> [A] set of physical phenomena associated with the **presence** and **motion** of **electric charge**

Electric Charge

Electric Charge is a physical property of particles, it can be either positive or negative. Charges carried by **electrons** are **negative** and **protons**/nuclei are **positive**. Particles with the **same charge repel** each other and particles of **opposite charges attract** each other.

Voltage

Voltage is the driving force for most, if not all, electrical applications. It is an **electric field potential difference**. Charged particles naturally move from higher potential to lower potential and it is measured in **Volts** (V). The value of voltage does not necessarily matter: current may flow from 5V to 3.3V and also from -5V to -12V. **Charged particles always move if there is a potential difference in place.**

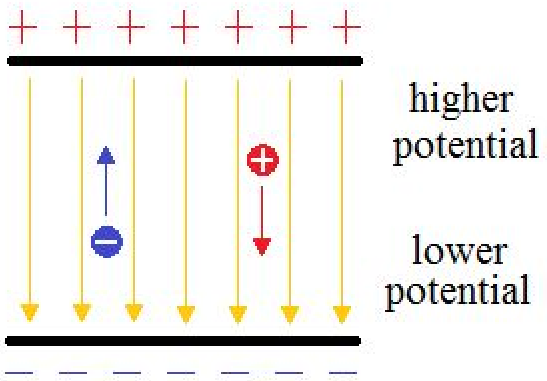


Figure 1. Visual of electric potential

Current

Net flow of charged particles is called **current** (*I*), measured in **Amperes** (A). By convention, the **current direction is opposite to the direction of the particles flow**. Current is usually induced by voltages and when there is no voltage, charged particles moves randomly so thus there exists no current.

Resistance

Resistance is a measure of the **difficulty for current to pass** through a component, it is measured in **Ohms** (Ω). The resistance can be calculated by dividing V by I.

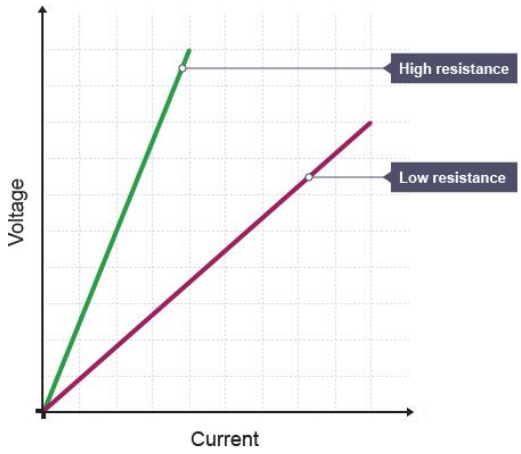


Figure 2. Voltage vs. current plot showing resistance

The current, voltage and resistance are linked by the formula $V = I \times R$, commonly referred to as **Ohm's Law**.

Water Analogy

If you are confused by current, voltage, and resistance, this is an analogy with water:

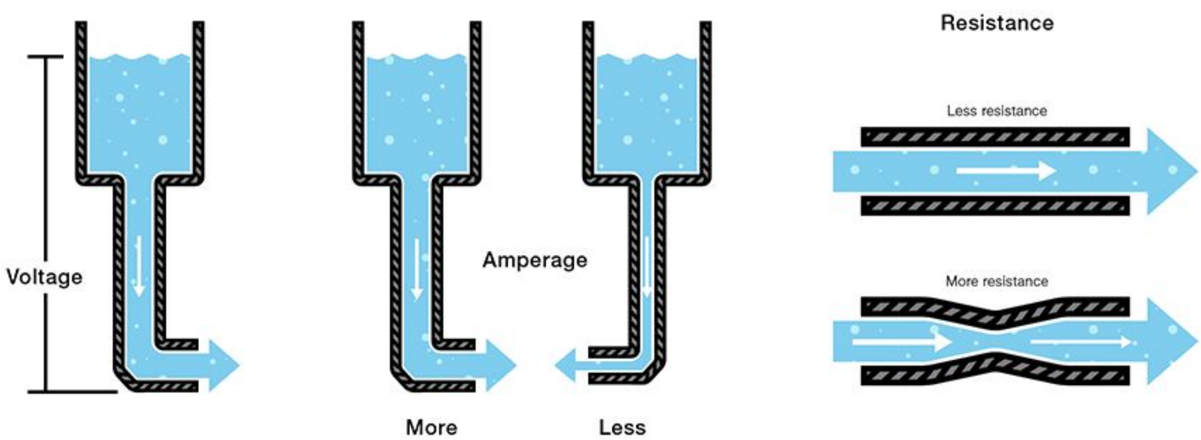


Figure 3. Water analogy for electricity

Imagine a pipe with water flowing. Electric charge is the water, voltage is the pressure of water through the pipe, and current is the flow of the water. Resistance would be the width of the tube at a specific point.

Resistor

A **resistor** is a **passive** (component that requires no energy to work) two-terminal component that **implements electrical resistance** between the two terminals. Resistors are used to reduce current flow, adjust signal levels, divide voltage, etc.

The **power** dissipated by a resistor is calculated by multiplying voltage and resistance, $P = V \times I$, this may further expand to $P = V^2/R$ and $P = I^2 \times R$. In fact, $P = V \times I$ applies to the power dissipation of nearly all electrical components.

The resistance of a wire is calculated with the formula $R = p \cdot l/A$ (p=resistivity of the material, l=length of the wire, A=cross sectional area of the wire).

Capacitors

A **capacitor** is a **passive** two-terminal component that **stores energy in an electric field**. The larger the capacitance (which is noted as C), the more energy a capacitor can store and the longer it takes to charge and discharge.

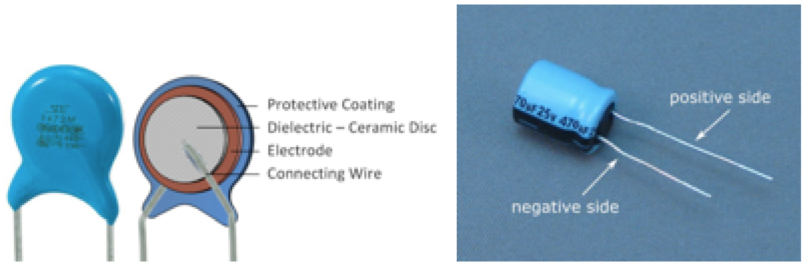


Figure 4. Ceramic (left) and electrolytic capacitor (right)

There are primarily two kinds of capacitors: ceramic and electrolytic. In our scope of application, we need to know that electrolytics easily obtain high capacitance values with low cost and electrolytic ones are usually much larger compared to ceramics, rendering most capacitors on Printed Circuit Board (PCBs) to be ceramic. Electrolytic capacitors have polarity or a direction they must be in, in circuits.

Capacitors act as energy sources when discharging, so they're often placed in parallel with voltage sources to maintain voltage levels during sudden load changes to prevent spikes. This application is known as "decoupling capacitance."

Inductor

An **inductor**, also known as a coil, is a **passive** two-terminal component that **stores energy in a magnetic field**. An inductor, which has inductance noted as L, can help smooth sudden current spikes in the circuit as it stores current temporarily. Thus, they are commonly placed in series with power supplies.

Inductors are also a primary component in electromechanical actuators such as relays (switches that use electromagnets), solenoids (values that use electromagnets), and motors (rotating devices that use electromagnets).

Diodes

A **diode** is a two-terminal **passive** component that **conducts current primarily in one direction**. It ideally has zero resistance in one direction and infinite resistance in the other.

A **Light Emitting Diode** (LED) is a **diode** that **emits light** when current passes through it. When designing an LED circuit, one must consider the maximum current the diode can handle.To implement an LED to a circuit, an additional resistor is needed as otherwise the LED will burn up from too much current. Below is an example of LED circuit.

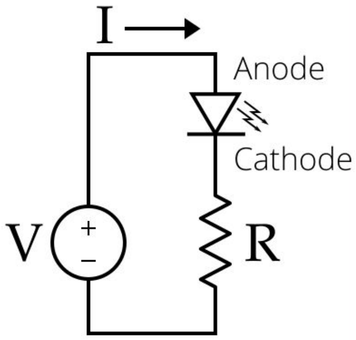


Figure 5. LED Circuit

Value of R depends on the voltage applied and the type of LED and can be found from Ohm’s Law.

Diodes have many applications for reverse polarity protection (preventing current from flowing if the circuit is plugged in backwards) and voltage source protection (preventing current from flowing from one source to another). LEDs are used for indication and signaling of power levels, statuses, or faults.

Most diodes have a **maximum reverse voltage**: the breakdown voltage. Any higher than this voltage, and the diode will break down unless it is a **zener diode**, specifically designed to be reversible. This breakdown property is exploited in circuits which limit the voltage between two nodes by applying a zener diode of specified reverse voltage between them.

Field Effect Transistors (FETs)

Transistors are simple **electronic switches**. There are primarily two types of FETs: **Bipolar Junction Transistors** (BJTs) and **Metal Oxide-Semiconductor Field-Effect Transistors** (MOSFETs).

They typically have three terminals, the base being the ‘controller’, and the other two being the collector or source and emitter or drain. There exist two types of BJT: **NPN** and **PNP**. NPN is normally OFF and conducts current when there is positive voltage at its base. PNP works in the exact opposite way, it is normally ON and conducts when there is zero voltage at its base. nFET and pFET MOSFETS work in a similar fashion to NPN and PNP respectively. Transistors are used to switch on other parts of the circuit.

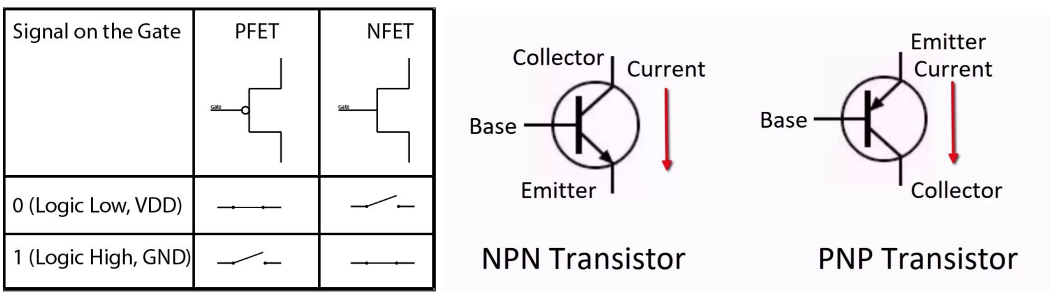


Figure 6. Sign and operation of MOSFETs and BJTs

VDD (Voltage Drain Drain) is the power source of the system, or the ON voltage. **GND** is “the reference point in an electrical circuit from which voltages are measured” or the OFF voltage. For our applications, 3.3V or 5V are usually the logical operating levels of printed circuit boards with 12V or 24V are usually the voltage level that power the robot.

Never directly connect 5V directly to 0V, as this is called a short circuit. This has the risk of not only breaking your circuit, but causing enough current flow to cause a fire. Transistors are

Circuit Analysis

A circuit with components in **series** has all of its components on the same “path” whereas a circuit with its components in **parallel** has all of its components on different “paths.”

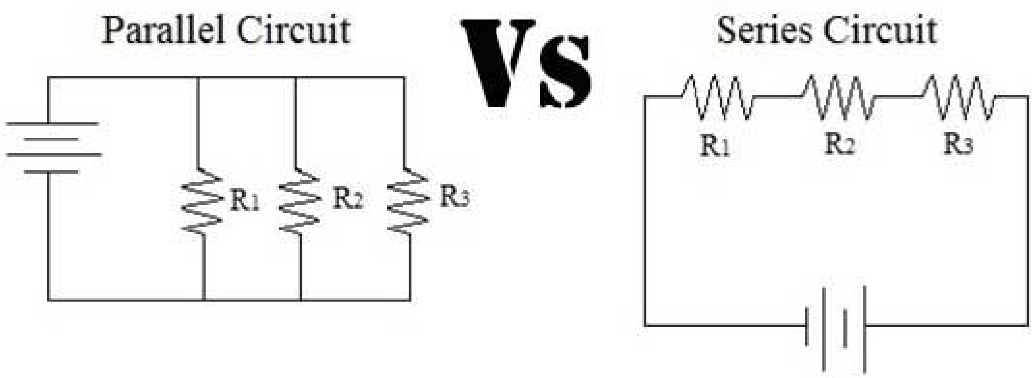


Figure 7. Example of components in parallel and in series

Series Circuit Components

$$R_{total} = \Sigma R_i$$
$$C_{total} = 1/(\Sigma(1/C_i))$$
$$L_{total} = \Sigma L_i$$

Parallel Circuit Components

$$R_{total} = 1/(\Sigma(1/R_i))$$
$$C_{total} = \Sigma C_i$$
$$L_{total} = 1/(\Sigma(1/L_i))$$

Kirchhoff’s Laws

Kirchhoff's Current Law is that the sum of current flowing into a node (or a junction) must be equal to the sum of current flowing out of it.
Kirchhoff’s Voltage Law is that the algebraic sum of the voltage (potential) differences in any closed circuit must equal zero.

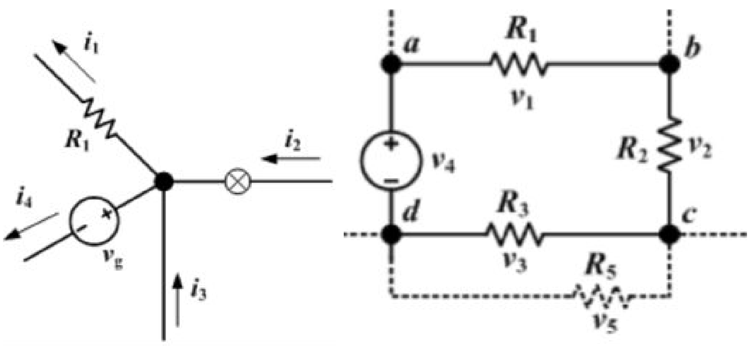


Figure 8. Kirchhoff’s Law graphic

As defined by Kirchhoff's law, in the left diagram $i_2 + i_3 = i_1 + i_4$; in the right figure, $v_1 + v_2 + v_3 + v_4 = 0$

Fuse

A **fuse** is a component that is **designed to fail when there is too much current** passing through it. When placed in series with your circuit, it is a safety device as it prevents over current.

Blown fuses alert you that there's excessive current, implying either:

1. A component is broken or operating in an unsafe region
2. The circuit must be redesigned taking into account maximum ratings

Breadboard

A **breadboard** is a device allowing you to **prototype circuits**. It offers the ability to let you connect circuits by directly plugging them into it, saving you the effort of making a PCB.

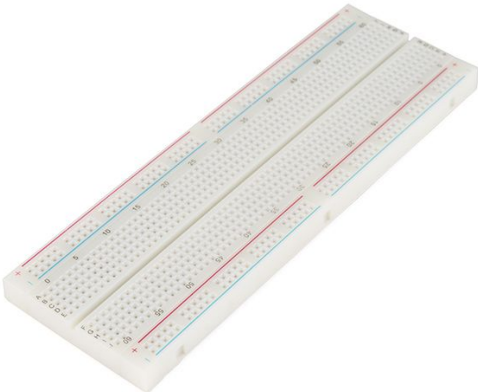


Figure 9. A breadboard

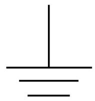
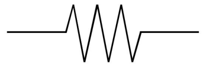
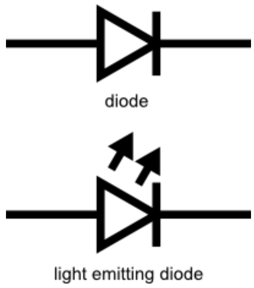
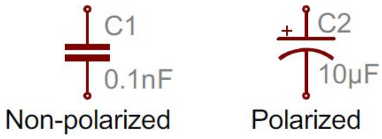
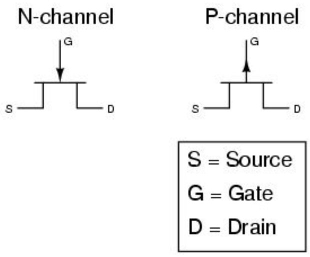
Basic Concepts Summary

Physical Quantity and Symbol	Units	Equations
Time (t)	Second	N/A
Charge (Q)	Coulomb (C)	$Q = It$
Current (I)	Ampere (A)	$I = Q/t$
Voltage (V)	Volt (V)	$V = E/Q$
Power (P)	Watt (W)	$P = E/t = V \cdot I$

A **cathode** is the terminal where current flows out of. An **anode** is the terminal where current flows in.

Basic Circuit Symbols Summary

Component Name	Schematic Symbol

GND or Ground	
Resistor	
Diode	
Capacitor	
FET	
Inductor	
VCC or Power Source