Introduction to Electrical Circuits w/ Flea-Scope

# Concepts -- Voltage, Current, and Resistance

Electricity behaves a lot like water running thru a household plumbing system, which you may be familiar with... Loosely speaking:

* electrical “voltage” can be thought of as being analogous to the water pressure (like pounds-per-square-inch) which pushes the water thru the pipes of the plumbing system,
* electrical “current” can be thought of as being analogous to the actual water “flow rate” (like gallons-per-minute) thru the pipes of the plumbing system, and
* electrical “resistance” can be thought of as being analogous to a restriction in a pipe that reduces the flow rate of pressurized water thru the pipes of the plumbing system.

Basically, just as a flow of water runs thru pipes of a household plumbing system, from higher to lower pressures, a flow of electricity runs thru the “conductors” of an electrical system, from higher to lower voltages!

# Electrical Circuits -- Introduction

An important difference between an electrical system and a typical household plumbing system is that in a plumbing system, eventually “used up” dirty unpressurized water just flows down the drain to the sewer, never to be seen again, while new clean pressurized water is always coming into the house from the water service main line!

In an electrical system, on the other hand, “used up” electricity always return to its source -- hence why we say it runs in a circle or “circuit”.

In our household plumbing system analogy, this “circuit” would be as if we took the water going down the drain of the house, cleaned it, repressurized it, and sent it back into the water service main line to be recycled into the house over and over -- we would no longer need the city water service main line or city sewer!

Please also note that while we talk about electricity as if it flows from more positive voltages (i.e., higher electrical pressures) to more negative voltages (i.e., lower electrical pressures), in reality, electrons actually flow on electrical conductors from more negative voltages to more positive voltages, because electrons have negative charges, and “like charges” repel each other, meaning negative voltages actually repel electrons, pushing them on their way towards positive voltages (that are actually attracting or pulling the electrons towards them)! As long as we are consistent in our nomenclature and reasoning, this fact is nothing more than a curiosity that has been with us for many hundreds of years.

# Measurements -- Voltage, Current, Resistance

Voltage is always measured as the difference of “electrical pressure” between two points in an electrical circuit. In our household plumbing system analogy, it would be the difference in water pressure measured between two points in the pipes. This difference (in electrical or water pressure) represents “potential energy” which might be turned into real energy or work if the conditions are right (and if the two points are somehow connected together so that a flow of electricity or water can occur between them).

Current, on the other hand, is measured as an “electricity flow rate” thru a single point in an electrical circuit. In our household plumbing system analogy, it is the water flow rate measured thru a point of a pipe. This flow rate (of electricity or water) is what does work in the actual system.

Note that in an isolated pipe -- where the amount of water flowing into one end must be equal to the amount of water flowing out of the other end -- it does not matter exactly where you measure the flow rate because you will always find the same value throughout the length of the pipe. Similarly, the measured current (i.e., electricity flow rate) thru an isolated conductor will also have the same value throughout the length of the conductor.

Unlike voltage and current, resistance (like a restriction in a pipe), is not something that can be measured directly, but instead can only be measured indirectly by its effect on a flow rate under pressure. Under the same pressure, a larger resistance (or a more severe restriction in a pipe) will allow less flow rate than a smaller resistance (or less severe restriction in a pipe).

In summary:

|  |  |  |  |
| --- | --- | --- | --- |
| what measured | units of measure | how measured | notes |
| voltage | volts (V) | the difference in electrical pressure between two points | higher voltage means more power |
| current | amps (A) | the flow rate of electricity thru a single point | higher current means more power |
| resistance | ohms (Ω) | measured indirectly by voltage difference across two points divided by current flow thru the points | higher resistance means less power, relatively speaking |

A “voltmeter” measures only voltage. An “amp meter” or “ammeter” measures only current. A “multimeter” can measure voltage and current, and using an internal battery to inject current into a circuit, can also measure resistance, capacitance, and possibly even inductance or other electrical properties as well.

# Calculations -- Power and Energy

We know from physics class that power is equal to force times velocity. We also know that pressure is force divided by area and flow rate is velocity times area! Therefore, power must also equal to pressure times flow rate! Using our analogy above, we can conclude (correctly) that:

power = pressure \* flow rate  
power = voltage \* current

We also know from physics class that energy (or work) is equal to power times time. So we can also conclude that:

energy = voltage \* current \* time

# Calculations -- Ohm’s Law

Finally, we will simply state the fundamental equation of electricity that we already implied above when qualitatively describing resistance measurements:

voltage = current \* resistance

This says that the voltage difference across two points in a circuit is equal to the current flow thru the points multiplied by the resistance between the two points.

From this and the equations above, we can also conclude:

power = current^2 \* resistance  
power = voltage^2 / resistance

# Electrical Circuits -- Reprise

So we are ready to look into more detail at the simplest possible electrical circuit. Remember, a “circuit” always provides a path for electricity to return to its source, so it looks loosely like a circle. For example:

3V

300Ω

Here we have a single-cell battery on the left, whose voltage is 3 volts, with the positive side of the battery indicated on top, and a resistor on the right, whose value is 300 ohms. Electrical current is shown with the curved arrows as leaving the top of the battery and progressing clockwise thru the resistor and returning to the bottom of the battery (these arrows are not typically seen in schematics).

Now let’s use a voltmeter to measure the voltage across various points of the circuit. Remember, voltage is always measured across something, giving us one voltage (typically on the red lead of the voltmeter) relative to some other voltage (typically on the black lead of the voltmeter).

Typically (but not always) we put the red lead of the multimeter on the more positive voltage and the black lead of the multimeter on the more negative voltage, resulting in the voltmeter displaying a positive value for the voltage difference between the two leads. But if we do the opposite (putting the red lead of the voltmeter on the more negative voltage and the black lead of the voltmeter on the more positive voltage), then the voltmeter will display a negative value for the voltage difference between the two leads, as expected!

Taking four measurements with four virtual voltmeters in green on the circuit above might look like:

+3V

3V

300Ω

-3V

0V

0V

Measuring the voltage across the battery gives us positive (+) 3 volts, which is not a surprise. Measuring the voltage across the length of the top wire gives us 0 volts, because it’s just a wire -- the voltage does not change thru the length of the wire, any more than the water pressure would change across an unrestrictive pipe! Measuring the voltage across the resistor is curious -- it gives us negative (-) 3 volts! This is because we put the black lead of the voltmeter on the more positive side of the resistor (connected to the positive side of the battery), and the red lead of the voltmeter on the more negative side of the resistor (connected to the negative side of the battery). Finally, measuring the voltage across the length of the bottom wire also gives us the expected 0 volts.

From this we can learn a simple rule about electrical circuits:

*if we start at one point in a circuit and measure the voltage difference to a next point in the circuit, and keep going around the circuit (always being careful to keep the black and red leads of the voltmeter in the same orientation like we did above), then by the time we get back to our starting point, the sum of the voltages measured will always be 0 volts!*

Above, we saw: (+3 volts + 0 volts + -3 volts + 0 volts) = 0 volts! Note that the rule above is independent of where we start and end -- if we’d started in the top-right corner of the circuit (instead of the bottom-left), we’d still have found: (-3 volts + 0 volts + +3 volts + 0 volts) = 0 volts!

We can predict the current in the circuit (or specifically, thru the resistor in the circuit) using Ohm’s Law:

voltage = current \* resistance  
current = voltage / resistance

We know that there are 3 volts across the resistor and the resistance of the resistor is 100 ohms, so:

current = 3 volts / 300 ohms  
current = 0.01 amps = 10mA

Now let’s use our virtual multimeter to measure the current thru the circuit. Notice that when we measure current, we have to insert the meter into the circuit (so that all of the current from the circuit can flow thru the meter), rather than just touching the meter to the existing circuit (which was sufficient for measuring the voltage difference across or between two points).

Taking four current measurements with four virtual multimeters in green on the circuit above might look like:

10mA

3V

300Ω

10mA

10mA

10mA

Notice a second rule we can discover right here:

*the current measured thru the circuit is the same, regardless of where you measure it -- it all has to get back to where it started from! Furthermore, if we are careful to keep the black and red leads of the multimeter in the same orientation like we did above, the polarity will be measured the same as well!*

Of course, if we switched the red and black probes for one of the measurements above, we’d then get negative (-) 10mA instead of positive (+) 10mA as the current thru that point in the circuit, like we expect.

# Electrical Circuits -- Legend

wire

resistor

capacitor

buzzer

inductor

capacitor

diode

LED

PNP transistor

NPN transistor

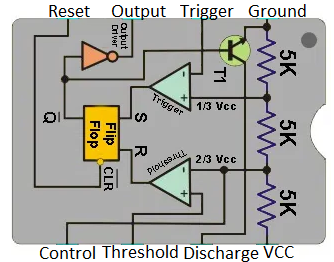
battery

NE555 IC

LM358 IC

gnd

vcc



# Concepts -- Capacitance and Inductance

Capacitance and inductance don’t have good analogies in the household plumbing system because we typically don’t have reversing pressures (i.e., like blowing and then sucking) in a household plumbing system, so we describe these only in terms of the electrical system.

Capacitance is where we can temporarily store a limited amount of electrical flow rather than immediately returning it back to its source.

Inductance is where

Volts, ohms, and amps.

multimeter

scope

What is a resistor?

What is a capacitor?

What is an inductor?

What is a diode?

What is a transistor?

What are oscillations?

Building a dc-to-dc using diode ladder

What is an operational amplifier?

What is a 555 Timer IC?

Condenser microphone

Can we record audio in deep-dive mode? Using ram at dim ram[8192] at address 0x80014000

Audio amplifier

Counters

Shift-registers

ALU

SPI, LED strips

I2C, displays, etc.

Microcontrollers (BASIC)

Microcontrollers (C)