What is a Resistor?

Analog Electronics, 2026-01-16

Also, what is a battery!? In the lab, the very first thing we are going to do is power up our kits, using 6 AA batteries. I should say something about what a battery is!

Resistors and Conductors

In your kit are lots of parts. The most common and basic part in most circuits is the simple — even lowly — resistor. In this handout, we will cover the theory that relates to the resistor.

Actually, even more common than the resistor is the wire. A wire is a piece of metal, sometimes bare, but usually surrounded by an insulator made of brightly-colored PVC. The whole point of a wire is that charge can flow perfectly freely through it. Well, not perfectly. You have to have a superconducting wire for the charge to flow perfectly freely. But darned close to perfect because the metals we make wires out of — copper, silver, or aluminum, usually — are almost perfect conductors of current.

First, What is Current?

In the previous handout, it was claimed that there is something called charge, and that it can be combined, divided, and moved from place to place, but never created or destroyed.

Now *an interesting thing about circuits is that charge can never pile up anywhere!* That is because like charges strongly repel. So if a Coulomb of charge starts to pile up somewhere, and let's say a half-Coulomb of it somehow has piled up, the next half-Coulomb is going to very repelled by the first half. In fact, this repulsion is so extreme, I am going to show it to you in a quantitative example with two $\frac{1}{2}$ Coulomb charges separated by 3 mm from each other.

In 1687, Newton published *The Principia,* and it contained the Universal Theory of Gravitation:

$$F = -G\,\frac{Mm}{r^2}$$

where

G = Newton's constant, although Newton had no way of measuring it

$G = 6.67 \times 10^{-11}\ \frac{\mathrm{N\,m^2}}{\mathrm{kg^2}}$

In 1785, Coulomb published Coulomb's Law:

$$F = \frac{k q_1 q_2}{r^2}$$

where

k = Coulomb ' s constant

$k = 9 \text{ x} 10^9 \ \frac{\text{N m}^2}{\text{C}^2}$

To say how radical Coulomb's Law is, I have to first say that N stands for the Newton. You already know what m and C stand for.

The Newton happens to be the amount of force that a small apple, exerts downward on your palm, when holding it. Here is a tangerine whose mass is 102 grams:

Oh jeeeezzz. Yet another unit? Yes, I have to explain the gram, which is of course $\frac{1}{1000}$ of the unit that is fundamental in the mks system, the kilogram, and I need to appeal to your intuition of what this tangerine would feel in your palm on the Moon, where the force downward on your palm would only be about $\frac{1}{6}$ of a Newton, to illustrate that a gram is a unit of mass, not of force.

Anyway, here on Earth this tangerine exerts a downward force — because of the presence of the enormous mass of the Earth below you — of almost exactly 1 Newton. That's why I chose this particular tangerine whose mass is 102 grams.

Now you know what a Newton is, and you have all the ingredients you need to do the quantitative example with two $\frac{1}{2}$ Coulomb charges separated by 3 mm and find the number of Newtons that would require, and then it becomes obvious why charge can never pile up in a circuit.

I Still Haven't Said What Current Is!

I hope I just convinced you that charge can never pile up in a circuit. *There is a partial exception to this rule.* We will get to it. It is a specially designed circuit element called the capacitor whose entire function is to make it easier for charge to pile up by spreading it out. But even *the capacitor has to use a sneaky cheat to overcome the tremendous repulsion between like charges.*

For the moment, with only wires and resistors, charge simply cannot pile up!

That means if one Coulomb goes into one end of a wire, one Coulomb must come out the other. If the other end of the wire is not connected to anything, it isn't going to happen! It will start piling up and you won't be able to stuff the Coulomb in.

Gosh, you can already see why circuits are called “circuits” — these facts mean that the charge must go round and round and never pile up anywhere in the circuit.

Now let's introduce time: if one Coulomb goes into one end of a wire every second, one Coulomb must come out the other end every second. We are imagining it going in smoothly, not suddenly. So if it is going in at the rate of 1 Coulomb / second, then in a half second 0.5 Coulombs goes in and in 3 seconds 3 Coulombs goes in. And again, whatever goes in, must come out the other end of the wire.

This idea of a rate of movement of Coulombs is so fundamental we need a new unit, the Ampere (abbreviated A), and we write

$1\,\text{A} = \frac{1\,\text{C}}{1\,\text{s}}$

Whenever we are talking about the rate of charge movement, the units we measure it in are Amperes, and we call the rate of charge movement, current.

Second, What is Power?

We also brought in the Joule in the last class, so I might as well define the rate of usage or application of energy. As an example to have in mind, consider a blow dryer that requires 1000 Joules of energy every second to run. In 10 seconds, it would need 10,000 Joules.

I did some asides with the tangerine to more concretely illustrate the Joule. I am not writing up the asides in this handout, which is getting long already. Whoever is bringing Lance up to speed, you need to do the asides with Lance. And also do the example calculation that shows how many Joules you are entitled to when you buy 1kWh of power for 0.20¢ (or whatever it currently costs).

As an example, consider the blow dryer that requires 1000 Joules of energy every second to run. In uses this steadily, so in 10 seconds, it would need 10,000 Joules, and in 5 minutes it would need 300,000 Joules. The rate of usage is steady and is $\frac{1000\,\text{J}}{\text{s}}$.

The combination $\frac{\text{J}}{\text{s}}$ comes up so often, we need an SI (or mks) unit for that too. That unit is the Watt (abbreviated W). We write:

$$1\,\text{W} = \frac{1\,\text{J}}{1\,\text{s}}$$

The rate of usage, (or the rate of application), of energy is power and the amount of power is very often written in equations as *P*.

So for that blow drier that is using $\frac{1000\,\text{J}}{\text{s}}$, we can write

$$P = 1\,\text{kW}$$

Finally, What is a Resistor?

A resistor is a circuit element that resists current going through it in a very predictable way. The amount that it “fights back” is proportional to the current going through it. The following, Ohm’s Law is not a fundamental law of nature:

$$\mathcal{V} \propto I$$

I is the current going through the resistor. $\mathcal{V}$ is the voltage across the resistor. Ohm’s Law (again which is not a Law, it is a useful approximation), says that the voltage of a resistor is proportional to the current going through it. Ohm’s Law is a very useful approximation for many materials, and the mix of carbon and ceramic in a resistor is chosen because it obeys Ohm’s Law very well — up to a point. With too much current, it will heat up, its resistance will increase, and then if you keep putting current through it, it will burn up and become useless.

Now if two things are proportional to each other, we should probably define a proportionality constant. We write:

$$\mathcal{V} = I R$$

For a “small” resistor (which might be substantial in your hand, so I don’t mean small in the physical sense), R is small. For a big resistor (which might be tiny between your fingers, or even so small you need tweezers to pick it up), R is big.

Now you know exactly what was meant by "fights back" which is casual language we will immediately cease to use. It means that it requires energy to push charge through a resistor, and that for any given resistor there is a proportionality constant that measures the "size" of the resistor and that (unless you push too much charge through too fast), Ohm's Law is obeyed for the amount of "fighting back."

What are the Units of Resistance?

You can figure this out from

$$\mathcal{V} = I R$$

The proportionality constant, R, must have units of volts per ampere. Volts per ampere comes up so often, we need yet another new unit, the Ohm (abbreviated as omega, Ω). As an equation among the various units:

$$1\,\Omega = \frac{1\,\text{V}}{1\,\text{A}}$$

Conclusion

The units that appeared in the previous handout were the Coulomb, the Joule, and the Volt (abbreviated C, J, and V), and the corresponding concepts or quantities are charge, energy, and voltage, usually denoted q, E, and $\mathcal{V}$.

The new units that have been introduced in this handout are the Ampere, the Watt, and the Ohm (abbreviated A, W, and Ω), and the corresponding concepts or quantities are current, power, and resistance, usually denoted I, P, and R.

You are starting to have most of the foundational concepts in electronics. That's kind of like saying you have been introduced to gasoline, metal, and rubber, so now you know have the foundational concepts in automobile manufacturing. Of course, you'd have a long ways to go before you built a Ferrari, but the fundamentals of gasoline, metal, and rubber, would nonetheless already be present.