Internal resistance and why it's important to model flyers

Resistance

Everything in the world has electrical resistance. Resistance is what determines how much current flows from a particular energy source or voltage. Some materials have very high resistance and are called insulators. Some, mostly metals, have very low resistance and are called conductors. A few have resistance somewhere in between and are called semi-conductors. This is a bit of an odd choice for a name as they are much more like conductors than insulators. They are definitely not materials that only conduct in one direction as the name might suggest. Those are called diodes.

Only one group of materials has zero resistance. They are called super-conductors, but only behave like that when made very cold, currently usually below 20 kelvin (-253°C), or more recently at higher temperature but very high pressure. That's why the coils in medical scanners that use high magnetic fields, for example MRI machines, have to be cooled with liquid helium to reduce the wasted energy from the high currents. Its also why we shouldn't waste the limited supply of helium on balloons and squeaky voices.

Because of the limbo in which they live, semiconductors behave oddly. It only takes a small temperature change to change their resistance. Higher temperature means their resistance goes down, which is opposite to metals. When I started playing with transistors there were only germanium ones – yes that long ago. If you passed even a little too much current through them they got warmer, the resistance went down, the current increased, they got even hotter and then failed. That was called thermal runaway, and resulted in one week's pocket money gone.You can make a glass rod conduct from mains type voltages if you heat it to near its melting point.

Adding impurities to semiconductors (doping) alters their properties dramatically. It is that fact that allowed the whole semiconductor industry to develop the minute circuits for the marvellous devices we all now use. They dope tiny areas with different elements to make circuits on wafers of silicon. It is why some of the alloys have such great names, like the gallium-arsenide-phosphide that is used in light emitting diodes. All of the electronic devices that we use in models, the car in which we travel to the field or slope and the phone that we use to say that we will be late back, rely on semiconductor 'chips'.

Silicon (glass) is the most commonly used semiconductor because it is plentiful, cheap, robust and withstands high temperatures. Though not exactly a semiconductor, graphene – a layer of carbon one atom thick - behaves like one in some ways and might well replace silicon in some applications.

Georg Simon Ohm discovered the electrical properties of conductors. That's why the unit of resistance, the ohm (Ω - omega), is named after him. He devised the equation that we call Ohm's Law:

Resistance = Voltage / Current $R = V / I$
and Voltage = Current x Resistance $V = I \times R$

So what is internal resistance?

Try an experiment. Take a battery, a light bulb and a digital voltmeter. Connect the voltmeter leads to the battery terminals and note the voltmeter reading without the bulb connected. Then connect the bulb. You will see the voltage drop. But why?

The stuff that the battery is made from has resistance, called ‘internal resistance’. The current the battery produces flows through this stuff and some of the voltage is ‘lost’. Voltage is energy. The lost energy warms the stuff in the battery. The lost voltage reduces the voltage at the battery terminals. The higher the current the greater the drop in voltage. And of course the higher the internal resistance the more voltage is lost.

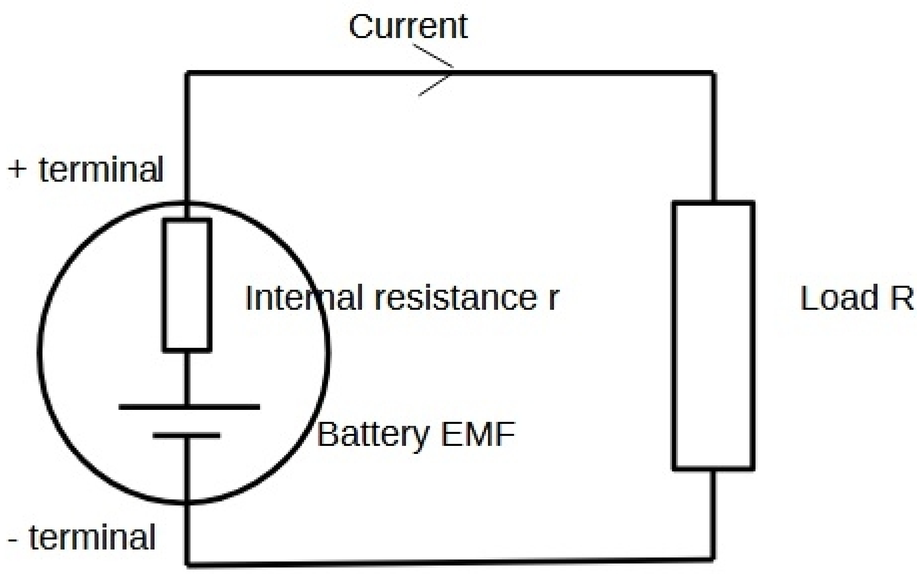

Figure 1

Let’s look at Figure 1.

The electromotive force - EMF or voltage V - causes a current I to flow. I flows through both resistors r and R. Each has a voltage (energy) drop across it. The voltage drop across internal resistance r means that the voltage between the + and – terminals is that much less. Connected to a high resistance load the difference will be small. Connected to a low resistance load that takes a lot of current, like one of our ESCs or motors, it could be high. This also why if you want to get an accurate battery voltage reading, or a component in a circuit, you should use a high resistance voltmeter.

Consider a practical example.

We have a 3S lipo battery that reads 12.6 V when fully charged. Each of the three cells has an internal resistance of 4 milliohms (mΩ). We run a motor that takes 30 A.
The voltage lost in the battery = current x internal resistance = 30 x (3 x 4 / 1000) = 0.36 V.
The battery will now show a voltage of 12.24 V.
If you have telemetry you can see how the battery voltage drops as you move to full throttle current and goes back up as you throttle back.

As a battery ages its internal resistance rises. Up to 10 mΩ is alright. In fact this was the standard for new lipos until a couple of years ago, now down to around 4 mΩ on average. Once it gets much above 10 you start to get a vicious circle, the speed of which is unpredictable. The wasted energy heats and degrades the stuff inside even more and the gases that are generated cause the battery to swell irreversibly. The message is that when a battery starts to swell it is a good idea to measure the internal resistance to see if it's time to recycle it. Most newish chargers will measure it. It might still be fine, but I put an amber sticker on suspect ones to warn me to check regularly.

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