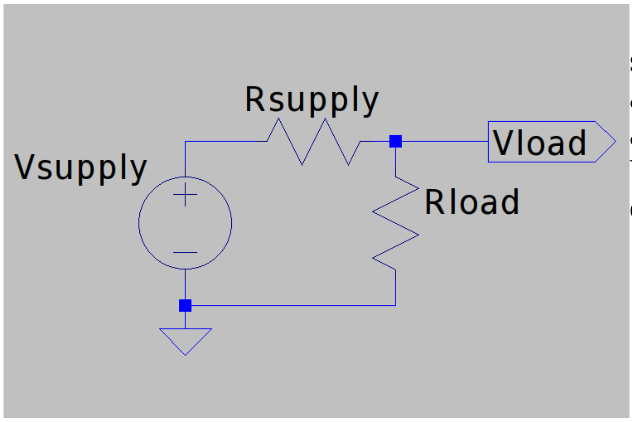
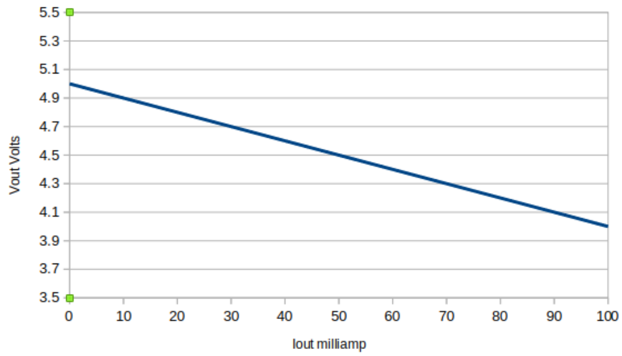
In our ballooning projects we have to fulfill many engineering requirements to achieve a set of science goals, and most of these systems require electrical power. With well executed weather predictions and balloon filling for given payload weights, we can usually expect a flight to take on order of 2.5 to 3 hours, with varying amounts of time waiting for recovery after landing. Many of our launches are done early in the morning, so assuming at least 2 hours for recovery, it could be 5 hours before the data can be recovered from the payload. For this workshop we will require at least 3 hours of operation, and data after that can be used to see how the payload is affected by the sun beating down on it.

To do any sensing or computing, we need a power source. A portable power source is usually a battery, which stores chemical energy, and releases that energy as electrical power through a positive and negative terminal. An ideal power source simply acts as a voltage or current source with no imperfections. However in the real world, all wires carry a small amount of electrical resistance and voltage and current sources always carry a small resistance internally. Lets examine the effect of various loads for a given voltage source.

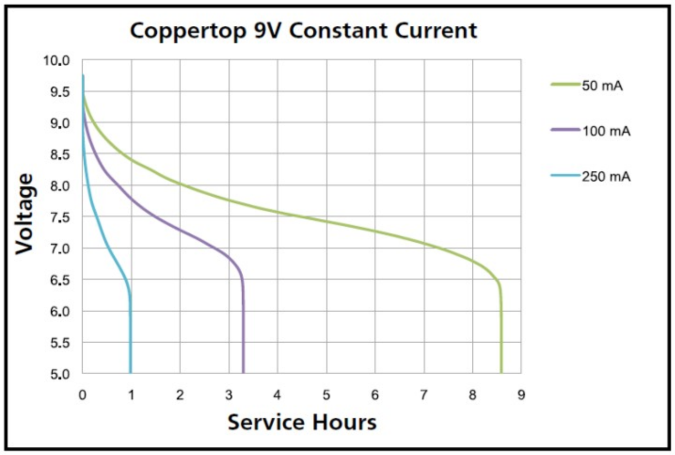
Assuming a voltage source is 5V with an internal resistance of 10 Ohms, the following is an example circuit showing the voltage absorbed by the source resistance for a given load current. Remember that ohms law is V=IR. Depending on the computations being done in a given microcomputer program, it will draw varying amounts of current, acting as varying resistor. To have a look at the voltage a device would see when powered by a battery with an internal resistance, we can use a voltage divider and vary a load resistor to simulate a device drawing varying amounts of current.



The voltage seen by the load is determined by the supply resistance, in that the supply resistance will actually absorb some voltage itself, depending on the amount of current being supplied to the load. Vout = Vbatt – Rbatt*Iload. Here is the Vout curve as the current draw increases from 1mA to 100 mA.



As can be observed by the graph, if a voltage supply is assumed to have only 10 ohms or resistance, the output voltage seen by the load will vary, and at 100mA, the output voltage will actually be 1volt lower than the supply. Recall that the TTL section of our lessons dictate that how the computer interprets voltages into zeros and ones, so its evident that variations in power drawn can possibly change how a logic level is interpreted. This situation also only describes device voltage variation from a given voltage and current draw, but real power sources have a varying voltage over their lifetime.



Consider also a 9V battery and its characteristic curve. The following graph is the voltage of a coppertop 9V Duracell battery over its lifetime assuming three different constant currents.

It should be obvious that the specific current drawn from the battery will actually affect the effective battery capacity. And to maximize capacity, its favorable to draw the least current necessary. This should also show that the voltage from a battery will also change along its lifetime.

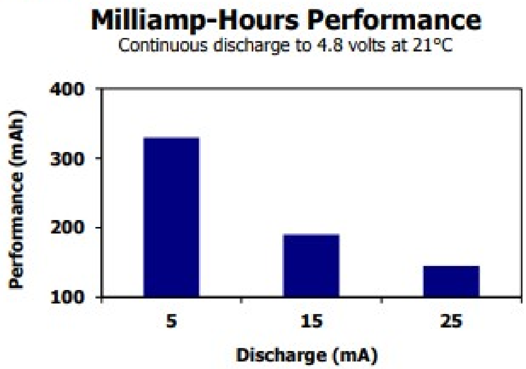
To make sure that the effects introduced by a battery's imperfections and limited capacity are isolated from a device, we use power regulators.

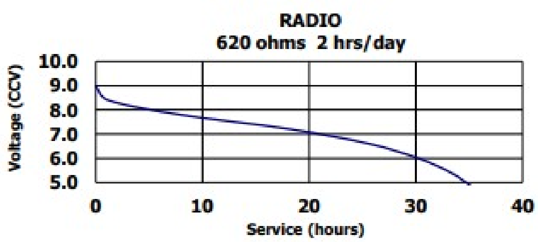
Power regulation is done in two styles, linear regulation and switch regulation. Linear regulation is done using devices like the LM7805 5Volt linear regulator or the LM317 adjustable linear regulator as the most popular options, and switching regulators come in many exotic varieties usually turning a dc power source into an ac signal and using a combination of inductors and capacitors to vary the voltage on their output. Linear regulators generally absorb excess voltage to hold the output at a specified voltage, which means they only output voltage lower than their input. Switching regulators convert battery energy to electro-magnetic energy in capacitors which store voltage and inductors which store current, to be delivered to the load as it needs. This exchange between battery energy to stored electromagnetic energy is done with elements with very low resistances, following P=IV or P=IIR, the wasted dissipated energy is usually very low compared to linear regulators. A 5V linear regulator using an LM7805 chip can be reasonably around 60% efficiency, wasting 40% of the electrical energy drawn from the battery on the regulation action itself. While a well designed switching regulator can be much higher efficiencies, up to 95%, and it follows that they generate less heat.

Switching regulators use a switching signal to pump electricity through an inductor and capacitor to create 3 general types , buck, boost, and buck/boost. Buck switching regulators "buck" excess voltage from the input to produce an output, or they output a voltage lower than the input voltage. Boost regulators output a voltage higher than the input voltage. And buck/boost regulators can output lower or higher voltages than their input. However the underlying circuit configurations are inherently not the same efficiency. In order, buck regulators are normally the highest efficiency, then buck, then buckboost regulators. Linear regulators are most efficient when they don't have to absorb very much excess voltage, or when their input voltage is only slightly above the output voltage, but switching regulators can maintain a high efficiency regardless of the relative difference between the input and output as long as its within the regulator's specified limits. The benefits of linear regulators are the complexity and size, linear regulators are usually very simple single chip devices that can be made at a fraction of the physical size of a given switching regulator.

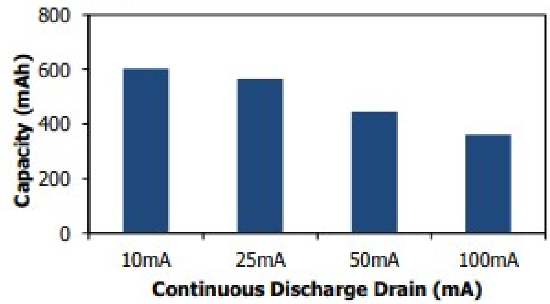
Regulators make sure that power sources stay steady for the systems they run, but not all power sources are created equal. In fact, they are in fact composed from different underlying chemistries providing different power source behavior. The following are datasheet charts comparing the behavior of a leading brands nickel metal hydride, alkaline, and lithium ion batteries in a common 9V form factor.

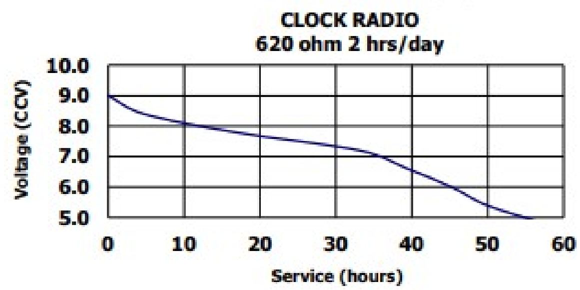
Classification: Super Heavy Duty
Chemical System: Leclanché
Zinc-Manganese Dioxide (Zn/MnO_2)
Nominal Voltage: 9.0 volts
Typical Weight: 37.0 grams (1.3 oz.)



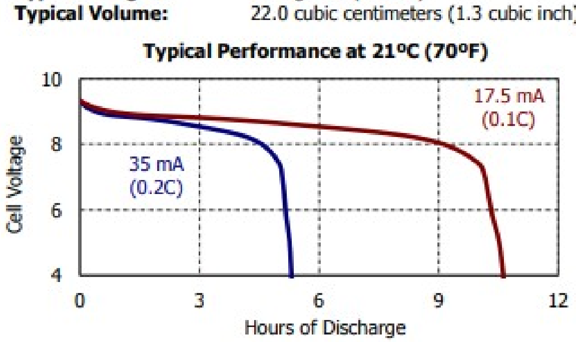


Classification: Alkaline
Chemical System: Zinc-Manganese Dioxide (Zn/MnO_2)
Nominal Voltage: 9.0 volts
Operating Temp: -18°C to 55°C
Typical Weight: 45.0 grams (1.58 oz.)

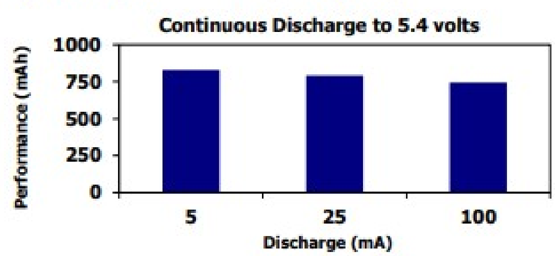


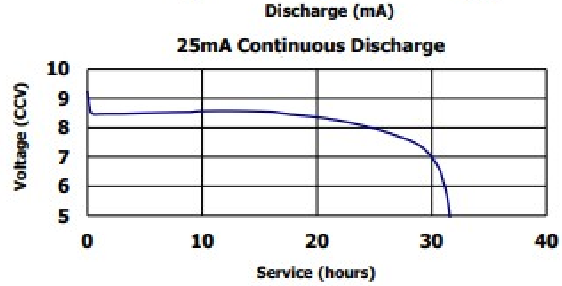


Classification: Rechargeable
Chemical System: Nickel-Metal Hydride (NiMH)
Nominal Voltage: 8.4 Volts
Rated Capacity: 175 mAh* at 21°C (70°F)
Typical Weight: 42.0 grams (1.5 oz.)
Typical Volume: 22.0 cubic centimeters (1.3 cubic inch)



Classification: Lithium 9V
Chemical System: Lithium-Manganese Dioxide (Li/MnO_2)
Nominal Voltage: 9.0 volts
Max Discharge : 1000 mA continuous
Typical Weight: 33.9 grams (1.2 oz.)





We can compare the energy density of these batteries by comparing their capacity per weight at similar current draw. At 25milliamps, Eveready is around 150mAH per 37 grams, or 4.05mAH/g. The Industrial Energizer is 13.3mAH/g. The rechargeable battery is 4.17mAH/g. And finally the lithium variant is 22.1mAH/g. From these comparisons we can see that the lithium battery is 10% lighter than the next lightest option, the “Eveready” variant, while being around 5.5 times the energy density. Comparing the Eveready battery to the Industrial battery, we can see that while the chemistry is the same, the Eveready battery is lighter and lower capacity. A quick check for a 4 pack of each on Amazon reveals that Eveready is around 37% cheaper than the industrial variant. This probably means, they’re both essentially the same but one will less electrochemical material to store energy, and therefore less capacity. Battery insulation should be considered since most of these batteries will cease operating properly at temperatures around 0 degrees F, while the upper earth atmosphere can get as cold as -40 degrees F. The batteries can be protected from extreme temperatures using insulation.

Now that we understand a little bit about power, lets set some ballpark constraints. We want to record data for at least a 3 hour flight, and if we assume a maximum average power draw to be 100mA, then we need at least a 300 mAH capacity battery. Comparing this to our battery specs, we can see the industrial 9V and the lithium 9V are ok options, though the industrial variant’s capacity is a bit close to the 300mAH mark, so lithium would be the best choice. Even better yet, lithium batteries are usually rated for a wider temperature range, which also makes them ideal for our purposes. If the system power consumption can be minimized, we can use an even wider range of cheaper batteries.

Now how about regulation? Well, an Arduino UNO actually has a built in linear regulator that regulates voltage from the barrel jack or from the Vin pin, and outputs a steady 5 V. However, if regulation is being done externally, this can be connected to the 5V pin, but care must be taken to avoid powering the system at the wrong voltage, which can damage the system.