

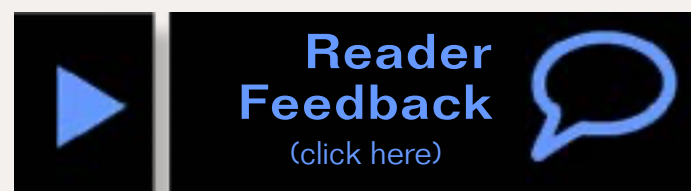


## About our DCC columnist



**Bruce Petrarca** is a well-known expert on all things DCC.

# DCC Impulses: Basic Electronics for DCC Going Beyond the Basics



## Understanding a few concepts helps remove mystery ...

Last month's column was on the light and breezy side, so it is time to get back to some meat and potatoes.

In addition to dealing with DCC items, this column will also be a basic primer on electronics for everyday use.

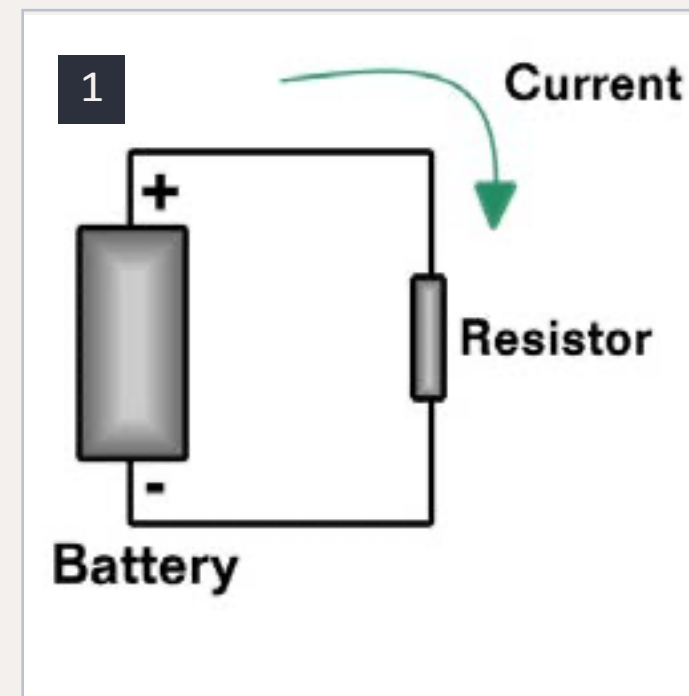
I have been teaching electronics in various formats since my senior year in college (1969), when I taught a freshman electronics laboratory wherein the students explored the theory of radio receivers and built themselves a transistor radio in the process.

The goal here is to make it simple. Yes, there are more exacting and complex ways to say what I'm going to say, but the underlying theory is accurate.

## Water analogy

It is hard to see electrons running around inside wires. If you get them to jump and make a spark, you can see them. However, since we really want to keep them inside the wires

and other electronic components, let's look at them another way.



### 1: Electrical flow.

Folks seem to understand water flowing better, so I'll use a lot of water analogies, to help your understanding.



### 2: Water flow.

Do you relate to 2 better than 1? Most folks do.

I will talk about current flowing from the positive terminal of a battery toward the negative terminal. I know that this is contrary to semiconductor theory, but it is easier for the layman to understand.

Yes, I live in the U. S. A. and will refer to units commonly understood here. I'm not going to complicate things by adding scientific or other units. Sorry.

## DC vs. AC vs. DCC

For the purpose of this column, there are three types of electricity, named by the way current flows in a circuit.

D. C. (DC or Direct Current) is what comes from a battery. It flows in one direction only (1).

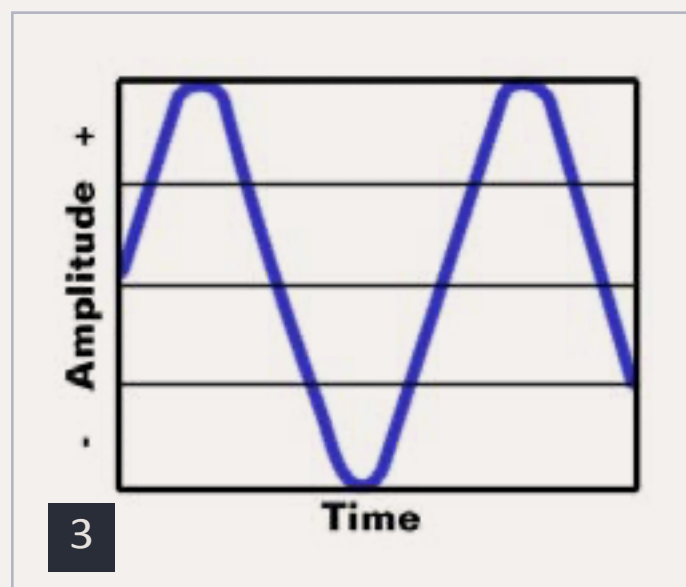
A. C. (AC or Alternating Current) is what is supplied to your house and is usually a sinusoidal waveform. It goes back and forth in polarity. Forget the big words, it looks like figure 3 (next page). For power mains, the frequency is most commonly 60 or 50 cycles per second (Hertz).

DCC uses a train of pulses to carry the data. So, it acts a bit like AC and a bit like DC (4 next page).

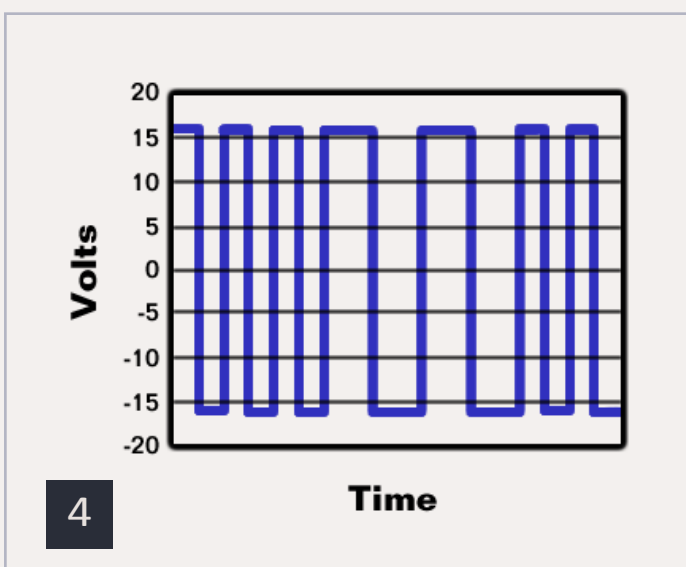
Some folks refer to it as AC, because it has a frequency associated with it, but it is really different than power line AC and requires different tools to

measure it. When you look at it on an oscilloscope, you see something like figure 4.

The highest frequency for DCC (the narrowest pulses in 4) is about 9,000 cycles per second or 150 times as fast as the power mains.



3: AC sinusoidal waveform.



4: DCC waveform set at 16 track volts.

## Voltage

The force pushing electrons around is called electromotive force (EMF).

Since it is measured in volts, it is commonly referred to as voltage.

Water pressure is the force that pushes water molecules through a pipe and is measured in pounds per square inch (PSI).

## Current

The number of electrons flowing per second is the current flow. It is commonly measured in amps, which is a whole lot of electrons per second. A common unit in model railroading is the milliamp, which is 0.001 amp or 1/1000 amp.

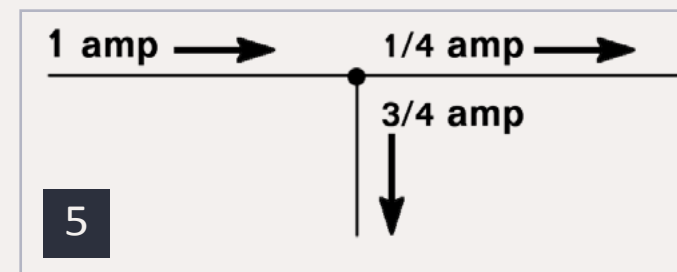
Water flow is frequently measured in gallons per minute. A gallon is a whole lot of water molecules. See the relationship?

If you move one gallon per minute of water at 5 PSI, doubling the pressure to 10 PSI will give you two gallons per minute.

If you have 1 amp flowing in a circuit with 5 volts applied, doubling the voltage (pressure) to 10 volts will cause 2 amps to flow.

There is one more thing to think about relative to current. The total current in a given connection will be zero. That is, the current flowing into a connection will equal the current flowing out.

In figure 5 there is 1 amp flowing in (positive) from the left to the point and  $\frac{1}{4}$  amp flowing out (negative) to the right and  $\frac{3}{4}$  flowing out (negative) downward. The total current is zero:  $+1 - \frac{1}{4} - \frac{3}{4} = 0$ .



5: Current flow in a connection.

## Power

The power being used is the product of the voltage and the current. It is most frequently measured in watts.

If you apply 10 volts and  $\frac{1}{2}$  amp flows, then you are dissipating 5 watts ( $10 \times \frac{1}{2} = 5$ ).

Yes, this is correct for DC. While it is not totally correct for AC or DCC, it will be close enough for our needs.

So, let's consider a 5 amp DCC system with 15 volts on the track. The power that the system can supply is 75 watts ( $5 \times 15 = 75$ ). Consider how hot a 75-watt bulb gets. Some of the energy being consumed by the bulb is being converted to light, so not all of the 75 watts becomes heat. Without effective short-circuit protection, this is the kind of heat that can be put into the wheel of a car that is shorting on a DCC layout.

## Shorts

The word "short" is probably the most misused in electronics. Folks tend to call any malfunction a short. That is not true.

A "short" occurs when something that should be receiving electricity has been bridged or otherwise connected across.

When a wire breaks, that is an "open," not a "short."

As previously discussed, when a wheel bridges between the tracks, that is a short.

When main power (either your house mains or your track) is shorted, lots of current is drawn and, hopefully, a circuit breaker opens to relieve the short.

With some of the basics established, let's turn our attention to electronic components.

## Resistors

Resistors are components designed to limit the current flow through a section of a circuit.

Okay, what does that mean?

Back to the water analogy. If you think about a dam on a river, it keeps the water from flowing down the canyon where it is built (6).

Normally, we allow some water to run through generators and exit the dam. There is resistance to the flow limiting the amount of water coming through the powerhouse and out. The height of the dam determines the pressure (voltage) driving through the resistance of the piping and generators.



6

6: Hoover Dam stores a lot of energy on the Colorado River.

If you connect a wire directly across a battery, you get a lot of current flow and energy (heat). Similarly, if you break the dam, you get a lot of energy in the form of flowing water.

Bringing this down to a more reasonable level, think of plumbing in your house. Copper tubing that is 3/4 inch in diameter has slightly more than twice the cross sectional area that 1/2 inch tubing has. Thus, the larger tubing has less resistance, allowing more water to flow for the same pressure – less resistance means more current for the same voltage.

Electrical resistance is measured in ohms ( $\Omega$ ). The components used to add resistance to the circuit are called resistors and sized by the amount of power (watts) that they can dissipate.

Resistors in the DCC world are frequently valued in thousands of ohms, called kilohms ( $k\Omega$ ).

## Ohm's Law

Ohm's Law dictates the relationship between voltage, current, resistance and power.

One amp will flow when one volt is connected across a one-ohm resistor and there will be one watt of power dissipated as heat in the resistor.

The formulas are:

$$E = I \times R \text{ (volts = amps} \times \text{ohms)}$$

$$P = E \times I \text{ (watts = volts} \times \text{amps)}$$

Rearranging these formulas gives us:

$$I = E / R = 1 \text{ volt} / 1 \text{ ohm} = 1 \text{ amp}$$

$$P = E \times I = 1 \text{ volt} \times 1 \text{ amp} = 1 \text{ watt}$$

Scaling this by 1000, one milliamp will flow when 1 volt is applied to 1 kilohms.

$$I = E / R = 1 \text{ volt} / 1 \text{ kilohms}$$

$$= 1 \text{ milliamp}$$

## Capacitors

Okay now things can get complicated. I'll try to keep it simple.

A capacitor is simply two parallel plates with a dielectric (insulating) material in between them. Oh, boy, that sounds complicated. But it's not.

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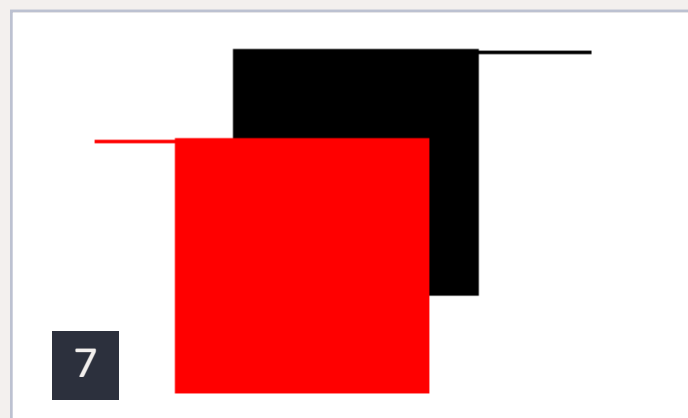
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Figure 7 shows a simple capacitor. Just two conductive plates held parallel to each other with wires connected to them surrounded by air.



### 7: Parallel plate capacitor.

There are lots of dielectric materials used: air, ceramic, Mylar, electrolyte, mica. The most common capacitor used in model railroading is

electrolytic, using a chemical solution for the dielectric material (8). This allows fairly large value capacitors to be of reasonable size.

Capacitors are rated in farads, although a farad is a really big number. The most common range for capacitors we use is between 0.1 and 10,000 microfarads ( $\mu\text{F}$  - millionths of a farad). There are some “super caps” that range from 0.1 to 1.0 farads, but they typically are only rated at 3 to 5 volts.

Capacitors have voltage ratings. Higher voltage ratings make for physically larger capacitors, which are more expensive. This is the reason for selecting adequate voltage ratings for safe operation (10% to 20% above

what you expect the capacitor to see) without going overboard.

The standard electrolytic capacitor has polarity markings that must be observed when connecting them (8).

Electrolytic capacitors that are connected backwards or run over voltage tend to boil the electrolyte inside the capacitor. Steam locomotive engineers know what happens when you boil something in a closed container. BOOM!

Okay, that’s what they are and how to connect them, but what do they do? They store charge. “Ask a simple question and get a dumb answer,” I hear you cry.



### 8: Capacitors: top: electrolytic – 2,200 $\mu\text{F}$ at 25 volts bottom: ceramic – 0.1 $\mu\text{F}$ at 50 volts

Let’s try the water analogy again. Think of a rain barrel. It collects water off the roof when it rains, so that you can have a constant supply of water, even on sunny days. Similarly, a capacitor turns pulsating DC into constant, or filtered, DC. Storing when there is excess and releasing when there is need. You will frequently hear them called “filter capacitors”.

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Okay let's look at some DCC applications for capacitors:

- Keep-alive – These capacitors allow your loco to run when the power drops out. They are usually polarized electrolytic units; 100 to 10,000  $\mu\text{F}$ ; frequently rated 25 or 35 volts (8).
- Radio Frequency Interference (RFI) suppression – The capacitors are the ones seen on the circuit boards from Bachmann to control the RFI when a decoder is not installed. They are frequently 0.1  $\mu\text{F}$  with a voltage rating over 25 volts (8).
- Speaker isolation – A capacitor is used to couple the sound to the speaker from an amplifier. Many early sound decoders (SoundTraxx

DSD and DSX series, for example) had this component external to the decoder for ease of installation. 33  $\mu\text{F}$  at 16 volts was a frequent value in this use. Many of these use a special style of electrolytic that isn't polarized, hence they don't have polarity markings and it doesn't matter which way they are connected.

- Super caps can be used to make anti flicker circuits for LEDs that will let them run for many minutes without track power.

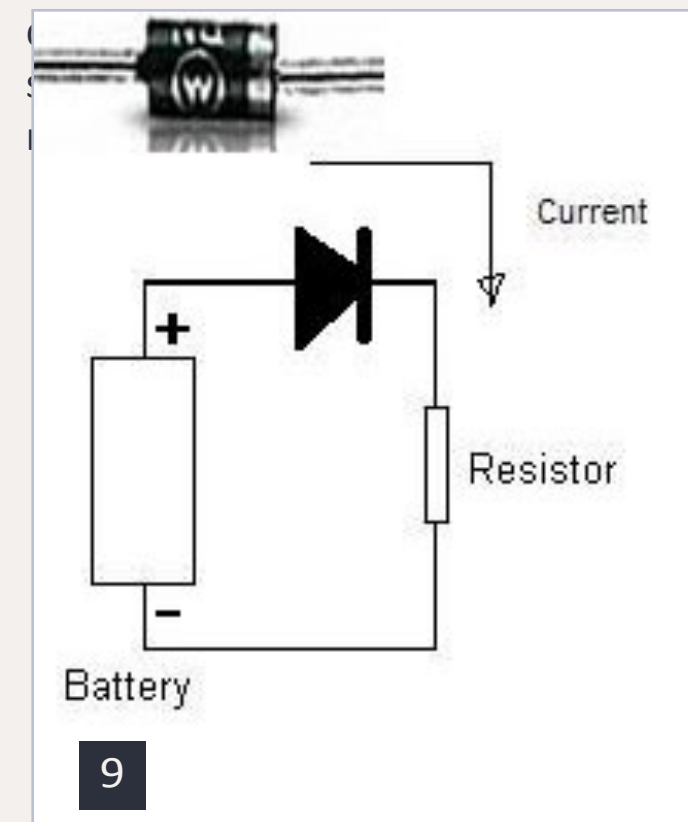
## Diodes

Another component that has lots of uses in DCC is the diode. Basically, it allows current to flow in one direction only, like a water check valve. Most of

the uses in model railroading are for what are known as rectifier diodes – designed to control amps of current at 50 or more volts.

A common example is the 1N4001 series of diodes. The 1N4001 is rated at 1 amp of current flow with a (reverse) voltage of 50 volts. Feel safe substituting other diodes in the series from the 1N4002 through the 1N4007. They have the same current rating, but with increasing voltage ratings up to 1000 volts.

The direction of flow in a diode is noted by the band on the body. Figure 9 shows a photo of a diode and a circuit diagram. The photo of the diode and the circuit diagram are same polarity. If the battery were reversed, no current would flow.



9: Diode circuit diagram with photo of diode.

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Another use for diodes is to provide a consistent low voltage. Think back to the check valve used in plumbing. When you install one, the pressure downstream from it is a bit lower than it is upstream. In fact, if you measured across the check valve, you would see a pressure drop across the check valve.

Diodes, such as the 1N4001, mentioned earlier, drop about 0.6 to 0.7 volts when they are conducting. So, if you put two of them in series and drive current through them, you will get 1.2 to 1.4 volts across them. This is a perfect voltage to illuminate 1.5 volt bulbs. I cover this on my web site ([mrdccu.com/curriculum/Lighting/1.5Volt.htm](http://mrdccu.com/curriculum/Lighting/1.5Volt.htm)).

A specialized diode is the Light Emitting Diode (LED). I covered these useful critters in my March 2012 column ([model-railroad-hobbyist.com/magazine/mrh-2012-03-mar/dcc\\_impulses](http://model-railroad-hobbyist.com/magazine/mrh-2012-03-mar/dcc_impulses)). So I won't go into them here.

## Wire

Wire is to electronics like pipe to plumbing. The larger the diameter, the more current can flow. However, unlike pipe, if you try to force too much current through wire, it gets hot. Hot enough to melt the insulation and then even enough to melt the wire.

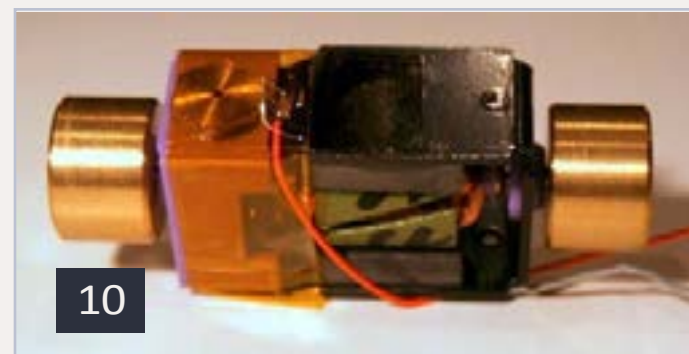
Stranded wire is more flexible than the same gauge of solid wire.

Wiring of your layout was the subject of my December 2011 column ([model-railroad-hobbyist.com/magazine/mrh-2011-12-dec/dcc\\_impulses](http://model-railroad-hobbyist.com/magazine/mrh-2011-12-dec/dcc_impulses)).

## Motors

Where would model railroading be without motors? Okay, let's talk a bit about them.

Analysis of the different styles of motors used in model railroading could consume an entire article or two, so I'm just going to hit some of the important issues.



**10: Motor from an HO Atlas S-1 locomotive.**

Motors convert electrical power into rotating energy. They can go the other way, converting rotating energy to voltage, also called a generator. When they are being driven as a motor, they generate a voltage in the opposite direction of the voltage being applied to them. This reverse voltage is known as "back electromotive force", abbreviated as BEMF. Some DCC decoders use this BEMF to keep the motor moving at very low speeds. Now, you know what that set of letters refers to.

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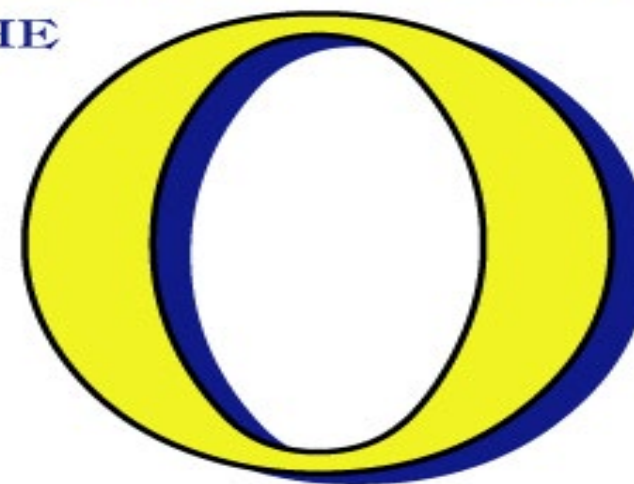


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The basic resistance of a motor determines its stall or starting current. The voltage being applied will cause a current to flow per Ohm's Law.

If your decoder supplies 15 volts and the motor resistance is 7.5 ohms, the initial current pulses will be 2 amps ( $I=E/R=15/7.5=2$ ). Once the motor gets moving, the BEMF generated will reduce the current flowing. Frequently, the current when running freely will be 1/10 to 1/4 of the stall current.

I discussed stall current as part of the process for decoder selection in my January 2012 column ([model-railroad-hobbyist.com/magazine/mrh-2012-01-jan/dcc\\_impulses](http://model-railroad-hobbyist.com/magazine/mrh-2012-01-jan/dcc_impulses)).

## Heat

Heat is a byproduct of most electronic activities. Solid-state components (transistors, integrated circuits, diodes, etc.) are most sensitive to it. Heat damage is usually permanent and not recoverable.

Decoder manufacturers, for the most part, design decoders to shut down before they get too hot and damage themselves. That wasn't always the case. Overheating can damage many of the early decoders.

This is why I recommend folks think about heat removal as part of their decoder installation design. You can read more about this in my February 2012 column ([model-railroad-hobbyist.com/magazine/mrh-2012-02-feb/dcc\\_impulses](http://model-railroad-hobbyist.com/magazine/mrh-2012-02-feb/dcc_impulses)). Also, check out this

month's sidebar, "From Mr. DCC's workbench" on page 39, where I discuss a new epoxy I've been using to help dissipate heat.

## Measurements

The go-to piece of electronic test equipment for the model railroader has become the digital multimeter (11). For less than \$10, you can measure voltage, current and resistance.

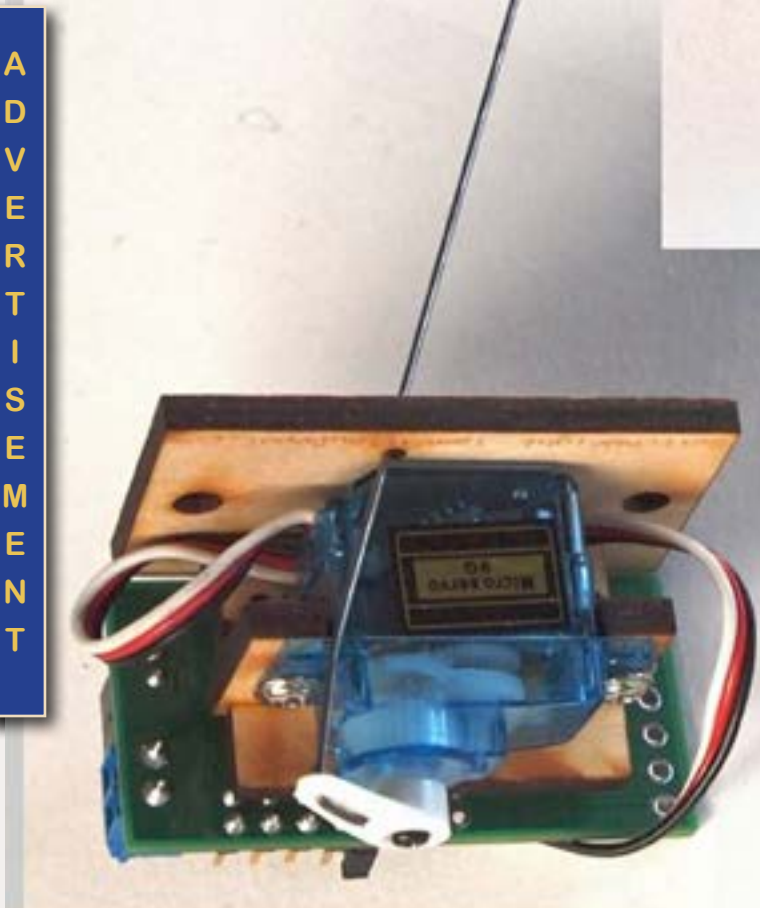
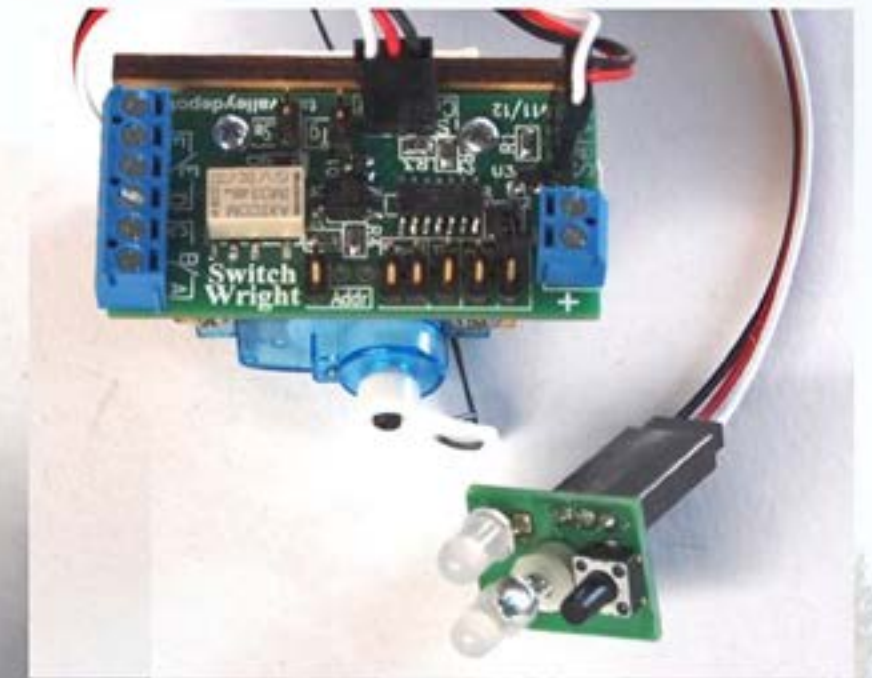


**11: Digital Multimeter – photo courtesy of Litchfield Station.**

My word of caution here is that they are designed to measure DC voltage, current and resistance. They convert AC to DC and measure the result. They are calibrated to read the (RMS) value of sine wave AC (3) applied to them. The waveforms in figures 3 and 4, show that there is a different

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amount of energy in one waveform than there is in the other. What this means is that multimeters are inaccurate when measuring DCC voltage and are not equipped to measure DCC current directly.

Yes, you can put them on the AC voltage scale and get some relative measurements on DCC track. For example, if you measure 13 volts on one stretch of track and 14 volts elsewhere, you have a good indication that the one section does have more voltage. But the absolute values of 13 and 14 and 1 are suspect.

An oscilloscope, a piece of sophisticated electronic test equipment, will

measure DCC voltage. An oscilloscope cannot easily read DCC current.

In my May 2012 column, I discussed the RRampmeter ([model-railroad-hobbyist.com/magazine/mrh-2012-05-may/dcc\\_impulses](http://model-railroad-hobbyist.com/magazine/mrh-2012-05-may/dcc_impulses)). It is the most cost effective way to measure DCC voltage and current, in my opinion.

### A misuse of terminology

Folks often incorrectly refer to the decoders installed into locos as “chips” and the process of installing the decoder as “chipping”.

Chips are the electronic devices (integrated circuits, resistors, etc.) that make up the decoder; they are not the entire decoder.

Referring to a decoder as a “chip” is like calling the motor for your car a “carburetor”.

### Until next month

Hopefully, I have cleared up some confusion for many folks. If so, please click on the Reader Feedback link and rate this column “awesome”. Feel free to join in the conversation this likely to be unfolding there.

I wish you green boards until next month!

*A Sidebar continues on page 39*

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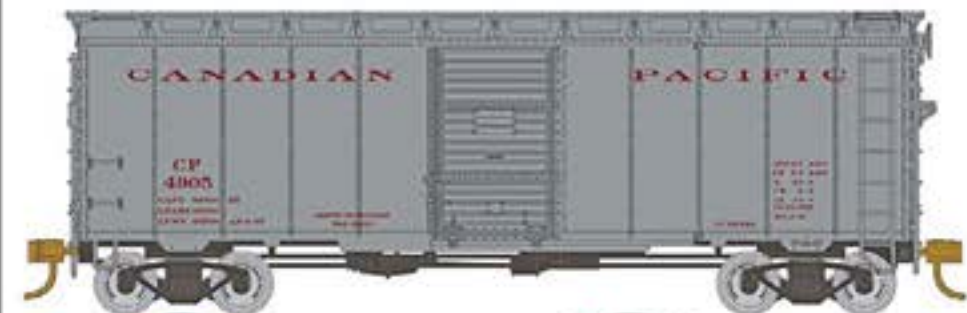
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## From Mr. DCC's workbench – Arctic Alumina™ Thermal Adhesive

I've recommended on my web site, and in prior columns, the use of caulk to attach decoders to metal parts. This allows heat to flow from the decoder into the metal and keeps the decoder cooler.

Since the SoundTraxx Micro Tsunami (TSU-750 series) is very sensitive to overheating, it frequently needs such assistance.

Caulk is not a very good thermal conductor, but it works and it allows the decoder to be removed without damage.

Recently, I've found a new best friend for these installations. I stumbled upon Arctic Alumina™ Thermal Adhesive ([arcticsilver.com/arctic\\_alumina\\_thermal\\_adhesive.htm](http://arcticsilver.com/arctic_alumina_thermal_adhesive.htm)). It is a 5-minute epoxy that is filled with ceramic particles. That makes it thermally conductive, but electrically insulating. Perfect for the need.

It comes in a set of two tubes. The epoxy and the hardener are mixed

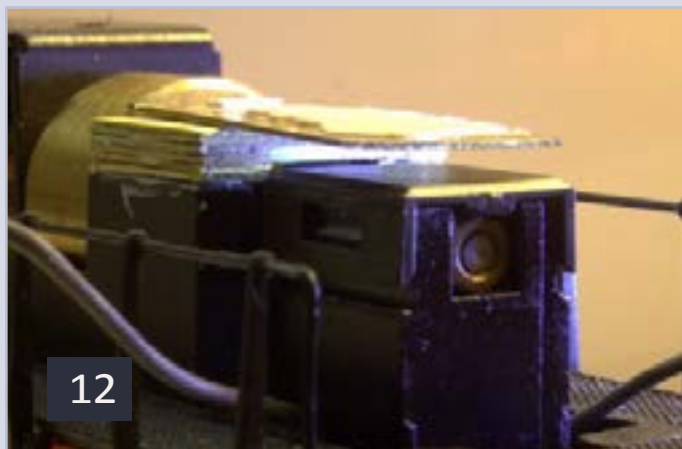
in equal parts and applied similarly to most two part epoxies. It is bright white.

I purchased a set of tubes through Amazon for about \$6 with free shipping. This was only a few dollars more than I pay for JB Quick Weld, also a 5-minute epoxy.

I used it for installing Micro Tsunamis in Atlas S-1 style locos. Folks may remember that, to provide reliable operation, these locos need a brass heat sink built up on the front of the frame and then the decoder attached to the heat sink.

I report full success. The installation was easier and less expensive than prior times when I used silver epoxy. The silver epoxy is electrically conductive and, therefore, troublesome to use.

I had a need to remove a decoder after the epoxy had set. I was able to pop it off the brass plate without damage. ■



12: Detail of the heat sink build up on the front of an HO Atlas S-1 frame using Arctic Alumina™.



13: The same Atlas S-1 with the decoder installed and partially wired – blue tape holds the headlight wires out of the way.



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