Anatomy of a DCC Decoder

Reader Feedback (click here)

DCC Impulses Column

by Bruce Petrarca

photos by the author, unless otherwise specified

Understanding what is inside will help your installations.

Last month's column about sound installation in a HO-scale Kato NW2 was long and detailed. That column, and the companion video (http://model-railroad-hobbyist.com/magazine/mrh-2013-01-jan/dcc-full-feature-video), was the culmination of many months of work. Hopefully you found some hint or idea in there that you can apply to your pike.

This month's column will be a bit less ambitious. I'm going to delve into a topic for every DCC user: what is going on inside the decoders we use and how to make the best use of what you are provided, internally and externally.

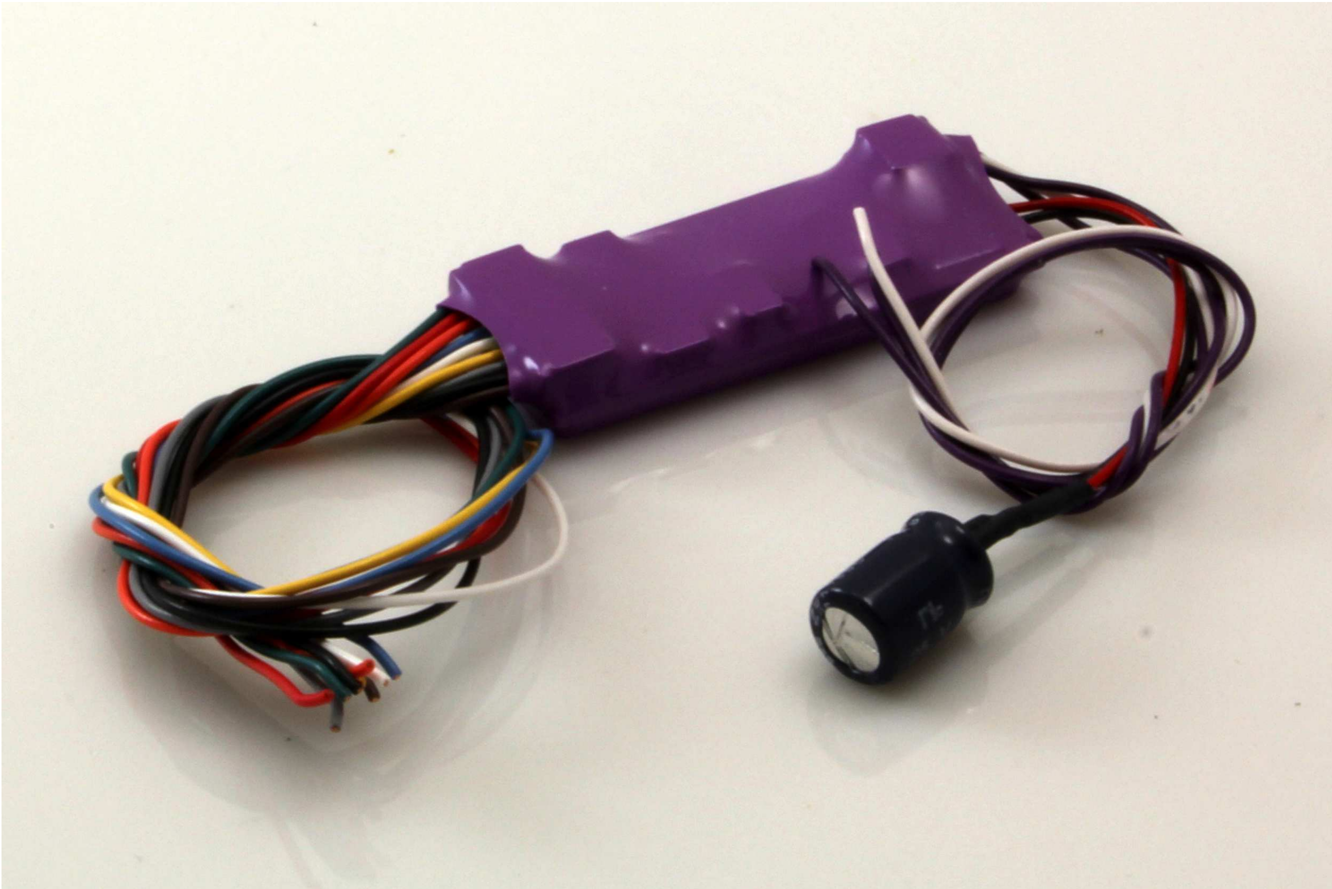
If you need a refresher course in DCC Basics, you may wish to review my inaugural column from October 2011 (http://model-railroad-hobbyist.com/magazine/mrh-2011-10-oct/dcc_impulses).

What is happening

Functionally, the decoder takes (packets of) data off the track and uses them to decide what to do: drive a motor, turn on lights, generate sounds, etc. Let's look inside and see the basic functions necessary to make all of this happen.

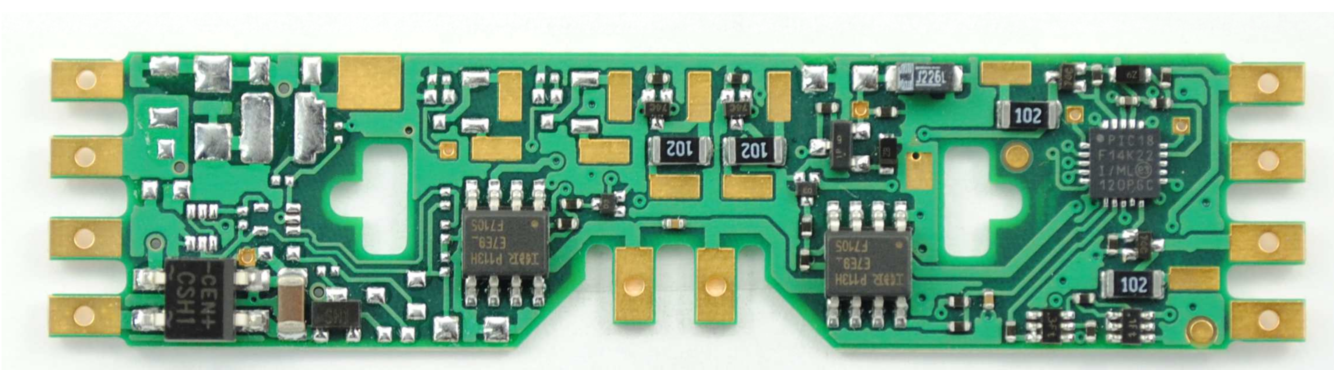
When I reference colors of wire, I'll use NMRA recommended practices wherever they are defined. For the less well defined, I'll use industry practices to explain the situation.

There are two basic styles of decoders: wrapped and open boards.



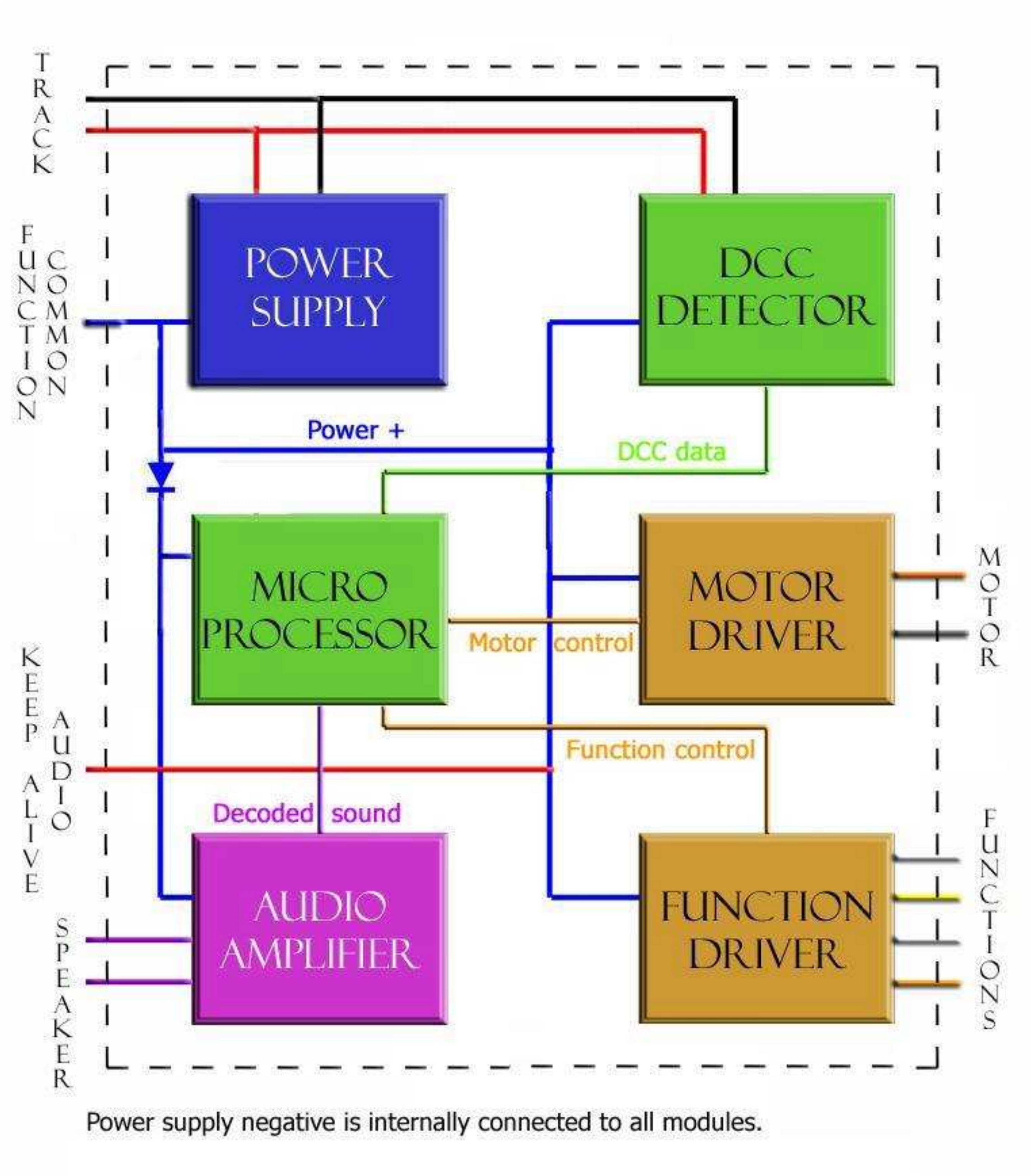
1: Wrapped decoder example – SoundTraxx Tsunami TSU-1000

The wrapped units (1) have shrink tubing surrounding the decoder board with wires coming out of one or both ends. When I talk about wiring colors in this column, I'll be referring to this style of decoder.



2: Open board decoder example – TCS A4X – photo courtesy TCS

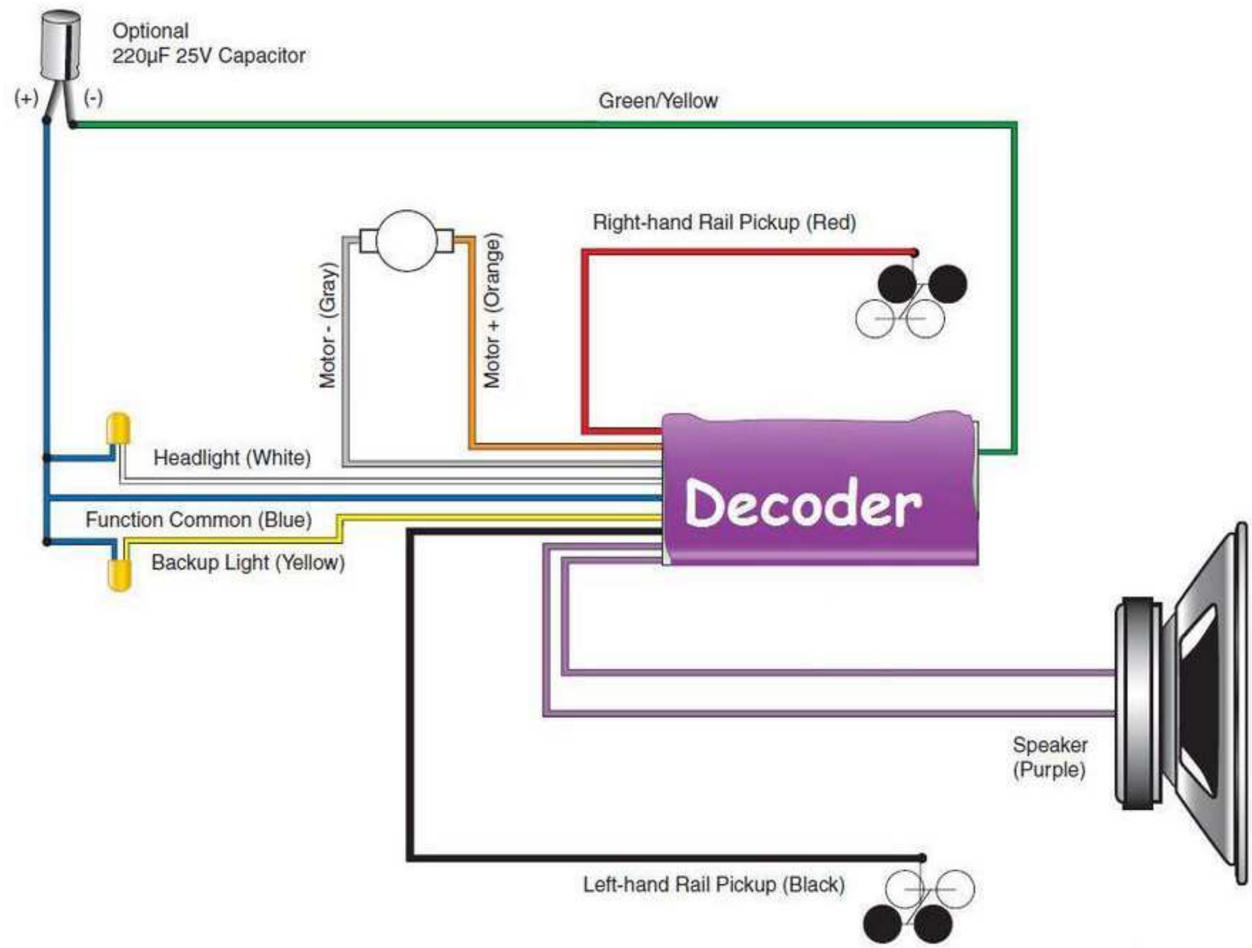
Open board decoders (2) don't have the shrink tubing and frequently have contact points for wiring connections. The connection points are labeled or referenced in the instructions with this style of decoder.



3: Decoder Block Diagram

When I'm wiring open board decoders, I select wires with colors that match the NMRA recommended practices (http://www.nmra.org/standards/DCC/standards_rps/RP-9.1.1%20200801.pdf), as they help me remember "what is what" as I'm doing the installation and later, if I'm troubleshooting or reworking a locomotive.

Figure 3 shows a block diagram of a SoundTraxx Tsunami TSU-1000, which covers the features of most decoders. Don't be intimidated. Let's walk through it in detail. The dashed line represents the decoder itself. The lines that cross that dashed line represent the leads coming out of the wrapped decoder.



4: Decoder wiring diagram – from SoundTraxx' Micro Tsunami (TSU-750) instructions

Figure 4 is a wiring diagram, modified from the SoundTraxx Micro Tsunami instructions. The Micro Tsunami (TSU-750) is similar to the TSU-1000. The Micro is smaller and only has two functions, while providing less output power. You may wish to refer to figure 4 as you read this column, to keep in mind where things are connected outside the decoder.

The Power Supply

The most basic of needs in the decoder is to change the DCC signal from the track into DC power to run the decoder and to drive the motor and lights connected to it. The blue box in (3) depicts this. Figure 3 shows the internal connection of the positive voltage to other circuitry within the decoder. The negative voltage connections are not shown, but still exist.

The red and black track leads bring the DCC track voltage in.

The positive voltage from the power supply comes out of the decoder on the blue lead.

Some decoders bring the power supply negative out on a wire for keep-alive circuitry or other uses.

SoundTraxx brings the negative out of their Tsunami-1000 series decoders on a black wire that is wired to the external capacitor – different than the black wire connected to the track.

In the Micro Tsunami (TSU-750) series decoders, the negative wire is green-with-yellow stripe – a much less confusing color than having two black wires that are different on the same decoder.

TCS brings out the negative wire on most of their decoders with a black-with-white-stripe wire, per NMRA Recommended Practices, RP-9.1.1.

I'll discuss the diode shown in the positive lead in figure 3 later in this column. To my knowledge, it only exists on the Tsunami TSU-1000 series decoders.

Some open board decoders provide a power supply negative contact point on the board.

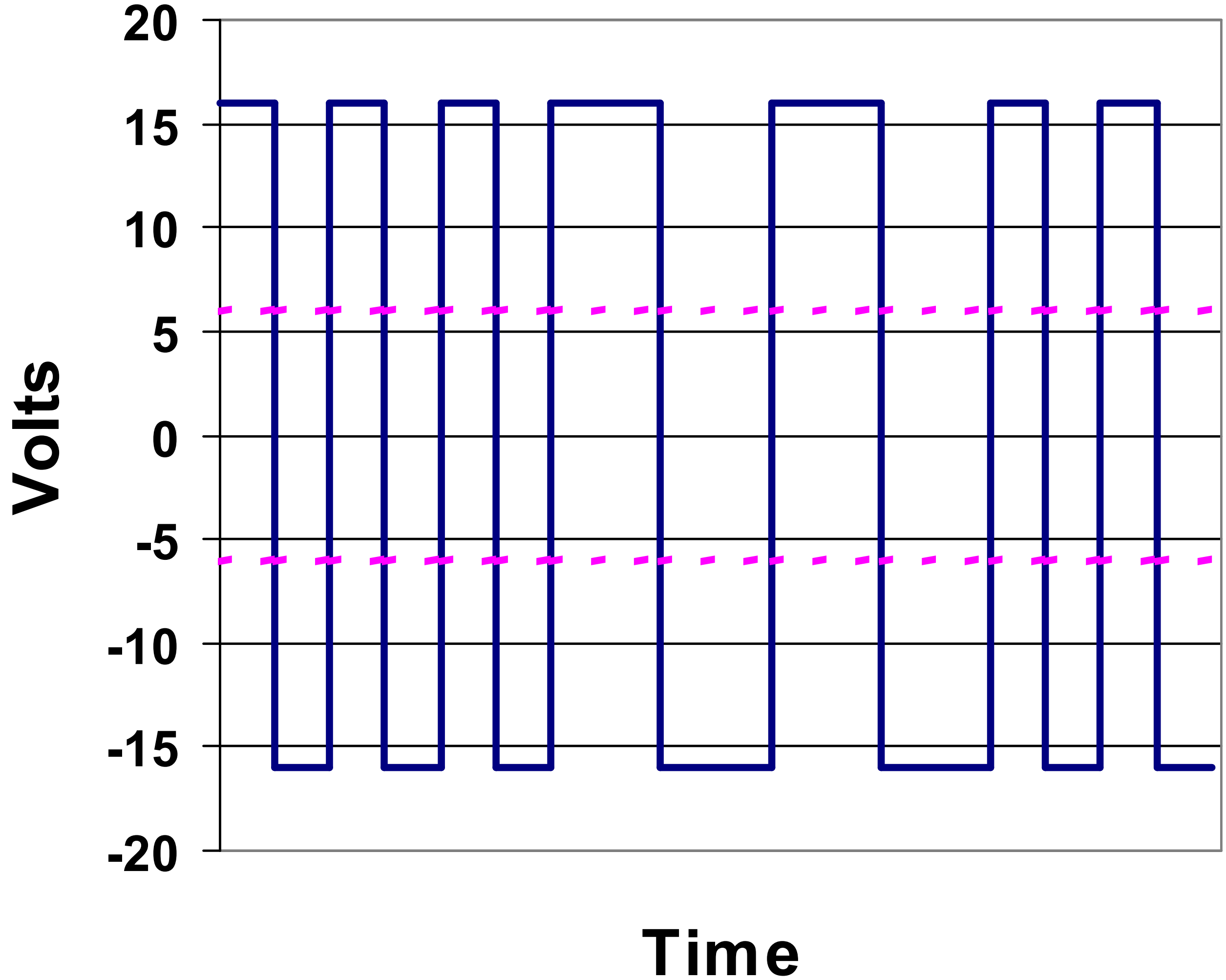
DCC Detector

The green boxes in figure 3 represent the circuitry that handles the DCC data inside the decoder.

The DCC Detector looks at the DCC pulses on the track and translates their timing into a stream of data pulses for the "brains" of the decoder to use. The next few paragraphs and figures will explain how different detector schemes work. If you don't care, jump ahead a couple of pages to the next section about the microprocessor.

The NMRA standards are that pulses that are nominally 55 microseconds (µS) apart represent a data one. Zeros are indicated by pulses more than 110 µS apart. So, to identify the pulses, the detector needs to decide when a transition has occurred.

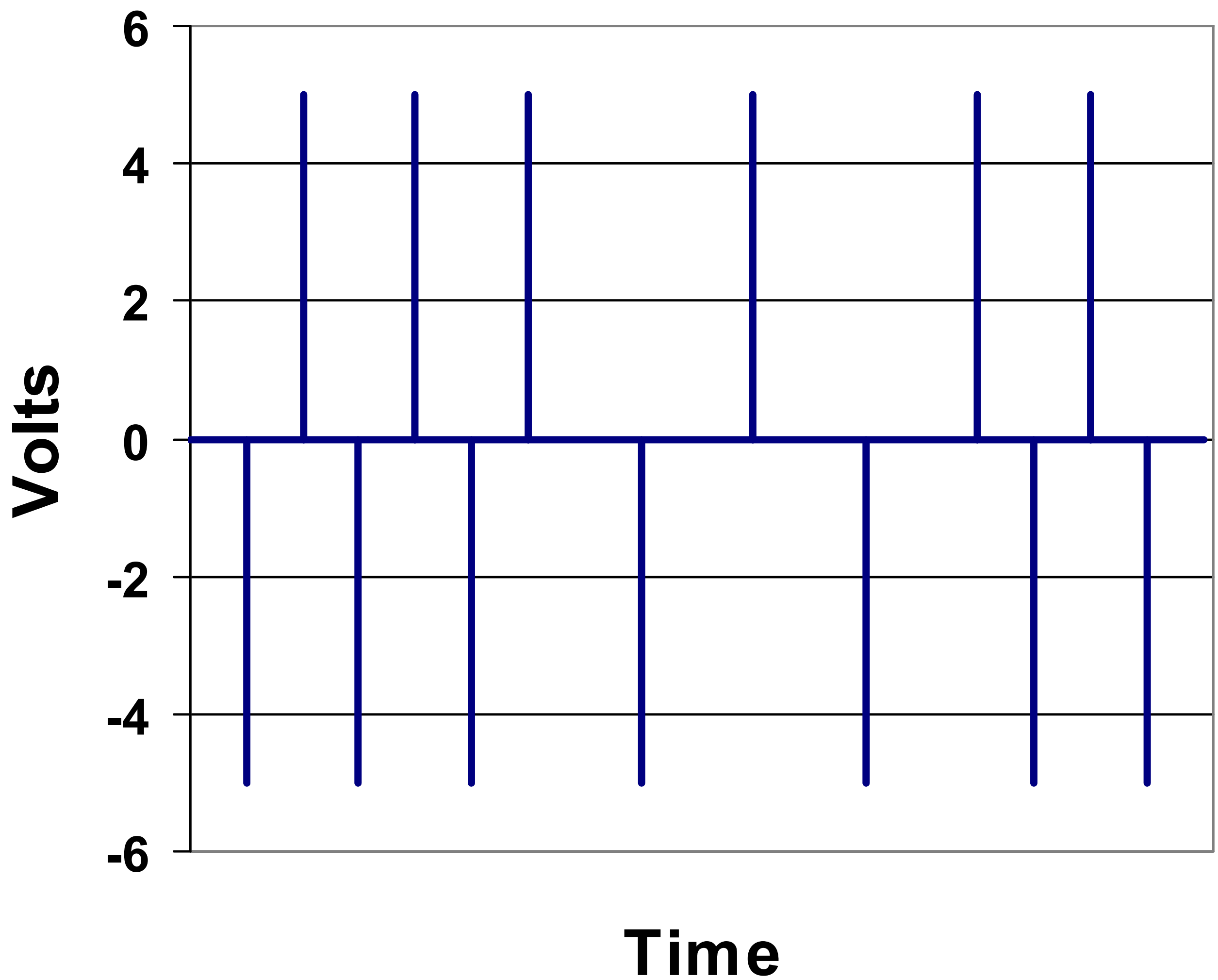
The most common method is to set a threshold (say 6 volts) and presume that when the voltage goes above or below that level, a transition has occurred. The disadvantage of this method is that dirt on the track and other discontinuities may drop the DCC signal level enough that transitions are missed. If that happens, instead of a group of ones and zeros, the detector decides that there was a long zero. Remember, zeroes are deemed to be anything longer than 110 µS without a transition.



5: Threshold Detection – looking for when the DCC signal goes through 6 volts – DCC data = 111111000011

About 10 years ago, Lenz released their Gold series decoders that used a differentiator to determine when a transition occurred. In English, this means that, instead of looking at the level of the DCC signal, the detector looks at the fact that there is a change (difference) of voltage. Figure 6 shows the same waveform as shown in Figure 5 as the Lenz detector analyzes it. Comparing the two figures, you can see that the timing data is exactly the same. Running the DCC signal (5) through a capacitor creates the signal in figure 6. So why bother?

If you remember my December 2012 column on Basic Electronics (http://model-railroad-hobbyist.com/magazine/mrh-2012-12-dec/di_basic-electronics-for-dcc), two parallel conductors separated by an insulator make a capacitor. Well, your locomotive's wheel and the track, separated by insulating dirt, make a capacitor.



6: Transition Detection – looking at the change in the DCC signal – DCC data = 111111000011

So, if your detector is designed to decode the signal in figure 6 and your loco runs over a dirty spot on the track, the amplitude of the (6) signal will diminish, but the shape of the waveform won't. Thus, the decoder can read the DCC signal even through a sheet of paper. If you are detecting signal level (5) the sheet of paper will reduce the level to zero and the decoder won't see any transitions.

Either detector will create a data stream for the microprocessor to analyze and act upon.

Microprocessor

The block in figure 3, labeled Micro Processor, includes a lot of things, including the memory where the program and sound files are stored and the clock that keeps time for everybody. I lumped them together, as many times the microprocessor chip will have built in memory and the clock is typically not connected elsewhere.

Here is some of what the microprocessor is doing almost simultaneously:

- Interpreting DCC commands
- Calculating motor speed & direction
- Creating motor drive pulses
- Turning functions on and off
- Generating lighting features
- Generating sounds
- Monitoring for safe operations

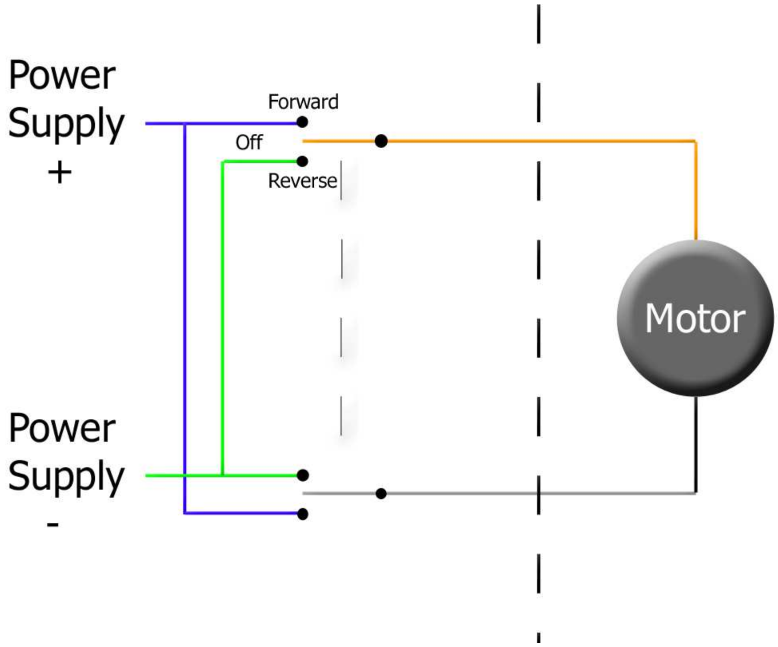
Motor Driver & Motor Controls

The motor driver circuitry is basically a switch that connects the motor to the full power-supply voltage whenever the microprocessor tells it to do so. The microprocessor also tells the driver which wire to connect to which polarity, to achieve forward or reverse movement.

The brain says "on forward" and the driver connects the orange wire to the power supply positive and the gray wire to the negative. "On backward" will have the motor driver connect the wires to the opposite polarity from the power supply.

Okay, that will let the loco run forward or backward, but it will be at full speed. How does the decoder run the loco at slower speed?

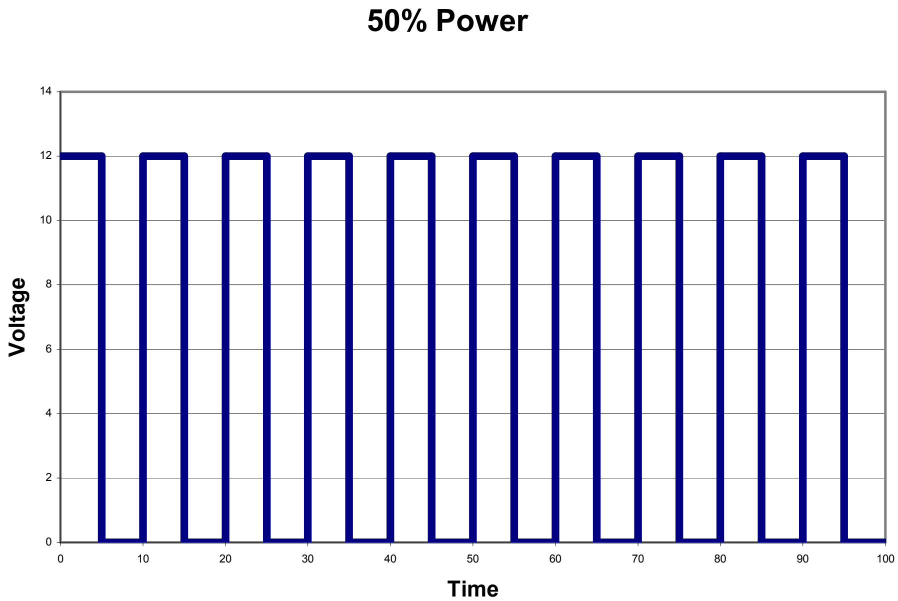
Motor control uses Pulse Width Modulation (PWM) to control motor speed. The microprocessor is programmed to turn the motor on every few microseconds for some time. The longer the motor is turned on (the wider the pulses), the faster the loco will go.



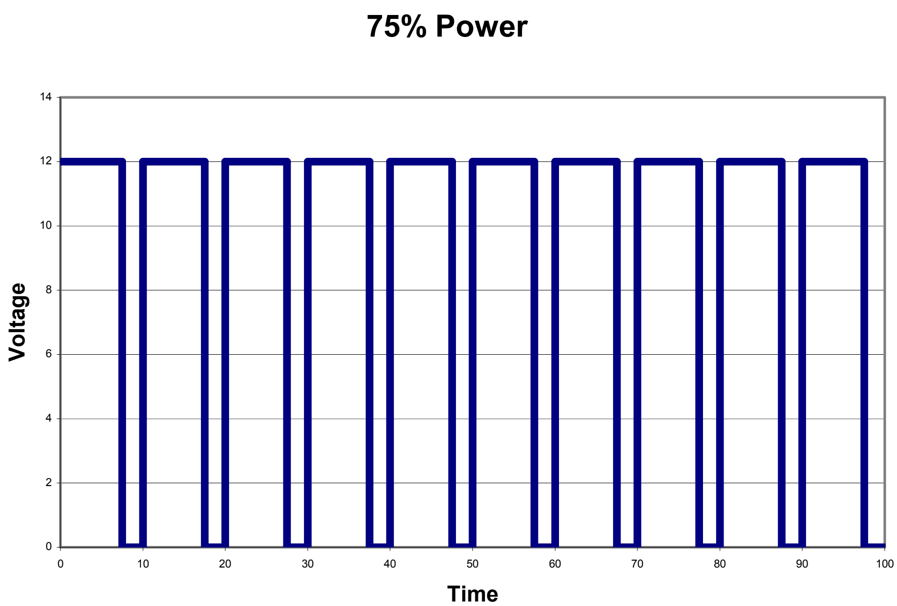
7: Motor Driver equivalent circuitry – a multiple transistor switch connects the motor to the power supply in one direction or the other or not at all

Think about driving your car by selecting drive and pushing the gas pedal all the way to the floor for ½ second and then letting off completely for ½ second and then repeating the cycle. That might result in the car going 30 miles per hour.

If you increased the time you hold the pedal down to ¾ second out of every second, the pulse rate would be the same, but the car would run faster, due to the throttle being held down longer (wider pulses of power).



8: Motor voltage pulses at 50% power going forward



9: Motor voltage pulses at 75% power going forward

Modern decoder designs have the pulse rate in the 15,000 to 30,000 times per second range. Why? This puts the drive pulses outside the range of human hearing. Even though the motor will "sing" just a bit, it will be beyond our ability to hear it. Manufactures call this feature things like "silent drive" or "supersonic drive".

BEMF (motor control)

Most decoders today offer BEMF motor control. As I discussed in my December 2012 column on Basic Electronics (http://model-railroad-hobbyist.com/magazine/mrh-2012-12-dec/di_basic-electronics-for-dcc), the motor will generate a reverse voltage (Back EMF) that is directly proportional to its speed. A detector across the orange and gray wires can sense this voltage during the time that the motor driver is switched off. Providing this data to the microprocessor allows it to adjust the width of future pulses based on the current speed of the motor, creating a feedback control system.

Various manufacturers utilize this in many different ways. Some allow the user to select a speed step beyond which the BEMF doesn't change the motor pulses, i.e. "BEMF Cutoff". Some allow the user to adjust the various components of the feedback control system.

BEMF control needs a BEMF detector connected across the gray and orange wires. When the microprocessor tells the BEMF detector that the motor is off, then the detector reads the voltage from the motor and translates that into a digital value, which is sent to the microprocessor. This circuitry is not shown in figure 3, to keep the complexity of that figure down.

Dither (motor control)

The disadvantage of driving the motor at a frequency above human hearing is that there is a loss of drive (torque) from the motor at low speeds. A solution for this loss was found. If the motor pulses are not exactly on time, much of the lost torque is regained.

Think of a teen-age garage band. They might be able to play a hit song, but they can't all stay on the beat. Assume that the drummer is spot-on with his beat, but sometimes the singer is ahead of him and some times behind. Various decoder manufacturers call this variation around the "correct" time "dither" or "torque compensation".

Yes, it is possible to have dither and BEMF in the same decoder. The current offerings from TCS and others do so.

Momentum

The delay in starting and stopping the motor is called momentum or acceleration and deceleration delay. It is generated by the microprocessor. You turn the throttle from 0 speed to 50% speed and the microprocessor tells the motor to go 0%, then 1%, then 2%, etc., until it reaches 50%. The quicker these commands to the motor are sent, the less the momentum.

Stopping works in reverse: 50%, 49%, etc.

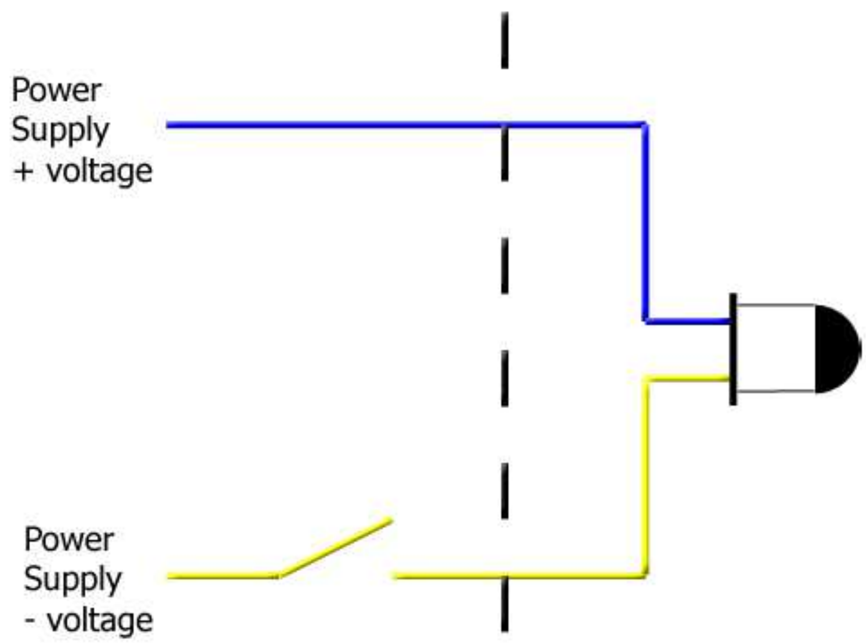
Emergency stop removes the delay: 50% goes directly to 0%.

Function Driver & Lighting Functions

The function driver switches full voltage to the function pads or wires. It doesn't have to work with reversing the polarity, as the motor driver needs to do.

The blue wire provides the positive voltage for the LED or whatever a function wire is controlling. The colored wire (yellow in figure 10) connects the bulb, in this case, to the negative voltage.

Once again, the driver is just a switch. If you have a light on at full brightness, the switch closes when you select a function and opens when you turn it off.



10: Function Driver equivalent circuit with an external bulb or 12 volt LED – rear (yellow) function shown

The microprocessor can be programmed to generate lighting effects, like Mars lights or firebox flicker. The decoder adjusts light level the same way that it adjusts speed, Pulse Width Modulation (PWM). Figures 8 and 9 show how PWM can provide 50% or 75% power to whatever is connected to it.

Some decoders have built in voltage regulators or current regulators or dropping resistors for direct connection of LEDs or low-voltage bulbs. Using these "features" may be addressed in a future column.

So, the designer of the decoder can tell the microprocessor that a sequence of pulses will look like a Mars light. Here comes a rub. Incandescent bulbs and LEDs generate different amounts of light based on the applied power. So, what looks good for a bulb won't look correct for an LED – the LED will come on sooner. Many manufacturers allow the user (through CVs) to tell the decoder whether a particular function is connected to a bulb or an LED. The decoder will change the algorithm (program) accordingly. Telling the microprocessor to generate a LED-style function won't (at least in currently-available decoders) adjust the voltage or current available on a function output for LED operation. The installer still needs to provide a resistor or other control component(s).

Half-Wave Lighting

In last month's column, I briefly discussed half-wave lighting (http://model-railroad-hobbyist.com/magazine/mrh-2013-01-jan/di_dcc-sound) and several situations where its use might be useful. Here is how it works.

To connect a function in a half wave lighting fashion, a rail connection is used instead of the decoder power supply. Instead of connecting the positive side of the load to the blue wire, it is connected to, for example, the rail red wire.

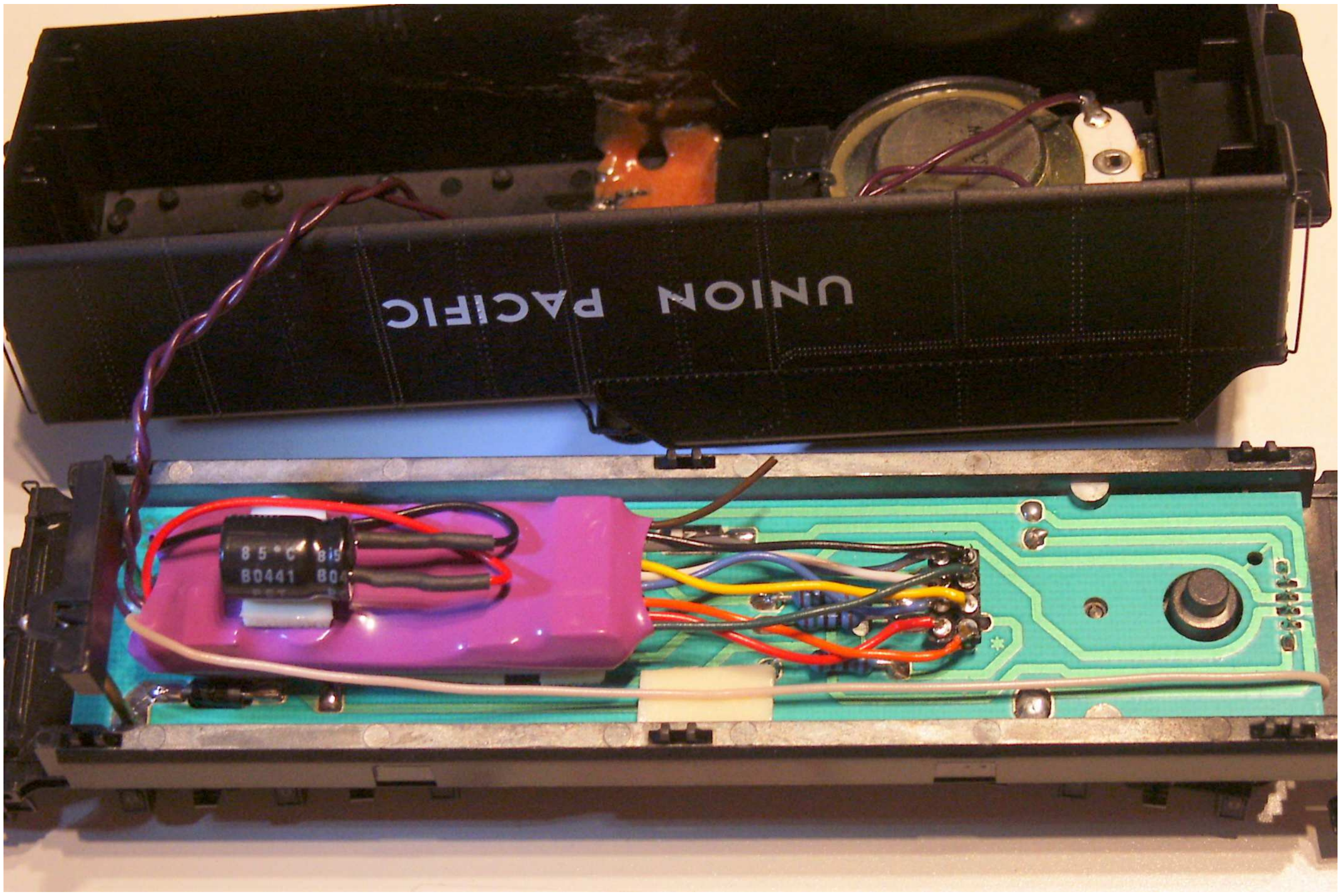
In figure 3, you can see that the only thing between the track and the blue wire is the power supply. Since the DCC track voltage (5) is positive about half the time and negative about half the time, connecting a load between it and the negative terminal generated by the power supply (through a function lead) will have current flowing through the load about half the time.

With LEDs, this technique results in a slight reduction in light output. Sometimes it is so little that you may not even notice. Reducing your series resistor by one standard value (1K to 910 ohms, for example) will probably restore any lost brightness, if necessary.

With bulbs, the light reduction is somewhat more pronounced. However, most folks seem to be happy with the results, with either bulbs or LEDs, with little or no changes.

Sound and the Audio Amplifier

The microprocessor in sound decoders is programmed to know when to generate what sound, based on throttle setting, momentum, load (measured by BEMF), and function inputs. It calls upon sound waveform files stored in memory to allow it to generate the appropriate sounds at the proper time.



11: Tsunami decoder plugged into a Proto Heritage 2-8-8-2 tender wired to the speaker in the shell

In a full-featured sound decoder, the microprocessor is very busy. In addition to decoding the DCC data being sent to it, it may be generating 5 or 6 sounds, calculating what pulses to send to the motor and as many as 4 different function leads - all at the same time. Talk about multitasking.

Once the sound waveform is created by the microprocessor, the amplifier section of the decoder drives the attached speaker.

Keeping the decoders small limits the flexibility of amplifier design. They are typically designed to work with a specific speaker load (frequently 8 ohms). Higher impedance (say, 16 ohms) will work, but the volume may be diminished a bit. Lower impedance (4 ohms) may damage the amplifier.

How fast am I going?

One of the more difficult things to do right is to generate the proper sounds for the speed your loco is actually moving.

BEMF can tell the decoder how fast the motor is turning, which is related by the gears to how fast the wheels are turning.

In diesel sound decoders, the question is which of the 8 notches of the motor sound should be being generated. Simply, the decoder will divide the speed ranges into 8 parts and assign a sound to each one.

But a diesel running in, say notch 5, will sound different if it is pulling hard or if it is running light. Sophisticated sound decoders use user input and BEMF to decide where in the range of notch 5 sounds it should be.

Some decoders allow the user to manually move through the notches, for more realistic operation. All seem to come with an automatic selection process enabled.

Now comes the conundrum of steam locomotives. The chuff should be directly related to specific mechanical positions on the loco, either wheel position on rod locos or motor rotation on geared locos.

12: SoundTraxx 810038 chuff cam mounted on the inside of an HO steam driver – this is a cam for an articulated style of loco with two sets of cylinders and drivers

Deciding when the chuff sound should be generated can be handled by the microprocessor, based on motor speed, once the user adjusts the chuff rate (via CV). However, this will only be correct for the single speed where the user calibrated the decoder to the locomotive.

How correct the chuffs are over a speed range is a big question. Some locos and decoders play well together and, once the chuff is adjusted at a medium speed, they will look in sync from a few scale-MPH until the wheels are turning too fast for the eye to follow. Others are in sync over a very narrow range of speeds.

The one sure way to synchronize the sound is with a switch that tells the decoder exactly when to make a chuff sound, based on wheel rotation. These chuff cams are usually very tricky to install. Most folks who use them do so out of a love of perfection. The time necessary for an after-market cam installation makes them very expensive if one is hiring the work done.

All the chuff cam does is tell the microprocessor, “now” when it needs to initiate a chuff sound. The chuff cam wiring is just a single wire into the microprocessor block. I left it off figure 3 for clarity.

Keep-Alive Circuitry

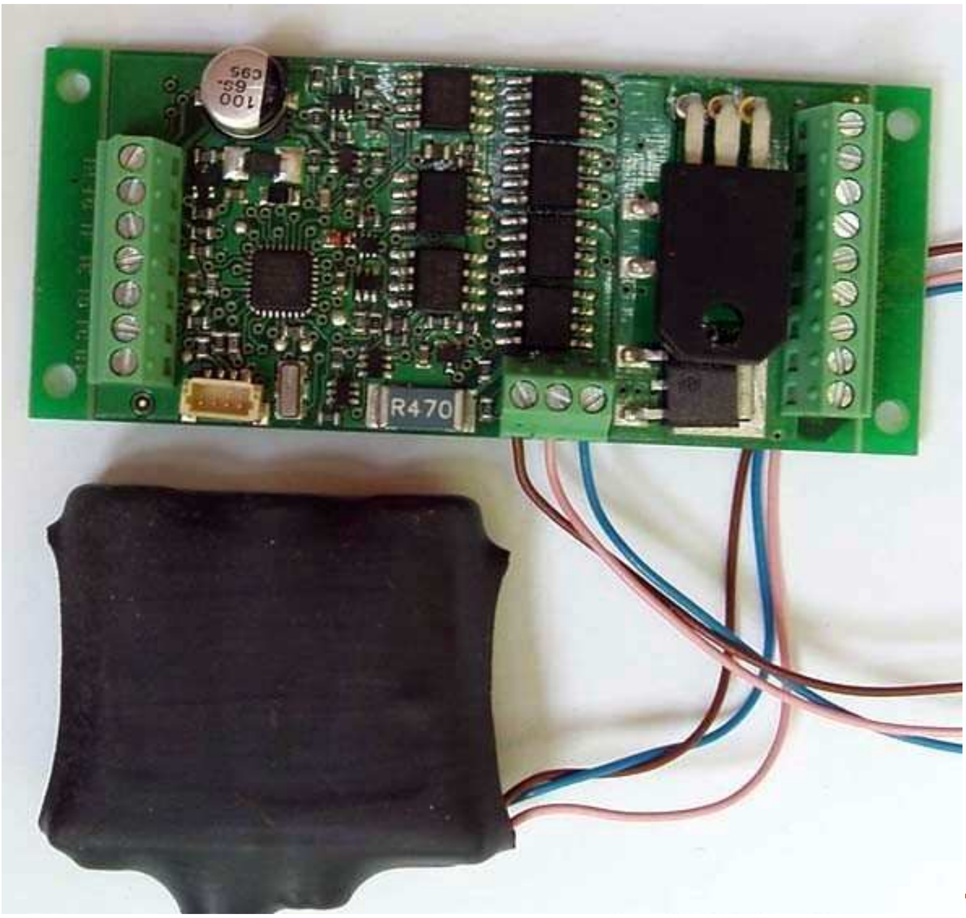
With sound decoders came sensitivity to power dropouts on the track. The loco could be running down the track at 1/3 speed and hit a bit of dirt. If that power dropout was long enough to reset the microprocessor, then when it woke up, it thought the loco was standing still and ran through the “fire up” sequence. Nothing is more concerting than a loco running down the track but emanating the sound of a diesel motor cranking over!

SoundTraxx supplies many of their Tsunami decoders with external keep-alive capacitors. Here is where the diode in figure 3 comes into operation.

If you wire a keep-alive capacitor external to the red and black leads in the TSU-1000 series, the capacitor stores energy on the microprocessor and amplifier side of the diode. Remember from my column on Basic Electronics (http://model-railroad-hobbyist.com/magazine/mrh-2012-12-dec/di_basic-electronics-for-dcc), a diode is like a check valve in plumbing. It will allow current to flow in one direction and not in the other. Thus, with energy storage on the microprocessor side of the diode, when a dropout occurs, the microprocessor and the amplifier keep generating sounds. After the dropout, the rest of the decoder comes back to life and starts decoding packets of data again and running the motor and the lights on the function leads.

Lenz pioneered a concept called USP – Uninterruptible Signal Processing – based on the detector scheme I described earlier in this column. Along with that, they offered power storage modules that could connect to their decoders that would allow operation without track power for a period of time.

At the NMRA National convention in Seattle in 2004, Lenz demonstrated the combination of the two: their G-scale Gold-Maxi decoder with USP and their Power-3 energy storage module.



13: Lenz USP system – Gold-Maxi decoder and Power-3 module

They ran a G-scale loco down the track – about 12 feet on a table in the clinic room. Okay, fine. Then they ran it back, but put a piece of paper covering one rail for 11 inches of the track. The loco slowed a bit, but ran across the complete power interruption, with its light on! The final demonstration, showing the power of the USP system, was when the Lenz folks ran the loco onto the paper, stopped it (proving it was receiving commands through the paper), turned off the light, turned on the light and drove off the paper! The final demo was to pick the running loco off the track and set it on the table. It continued running for about a foot.

I don't know of another manufacturer who is offering the USP style of DCC decoding today. However, lots of folks are working with energy storage in various forms, including batteries (hybrid drive), capacitors, super-capacitors, etc.

As you can see, we have just scratched the surface of this keep-alive concept and there is a lot more to discuss. Wait until March's column when we will be talking about "Stayin' Alive". This is fair warning for you aficionados to get your disco clothes out again.

Until then, I hope that you have green boards. If you liked this article, please click on the Reader Feedback icon and rate it ***awesome***. Thank you.

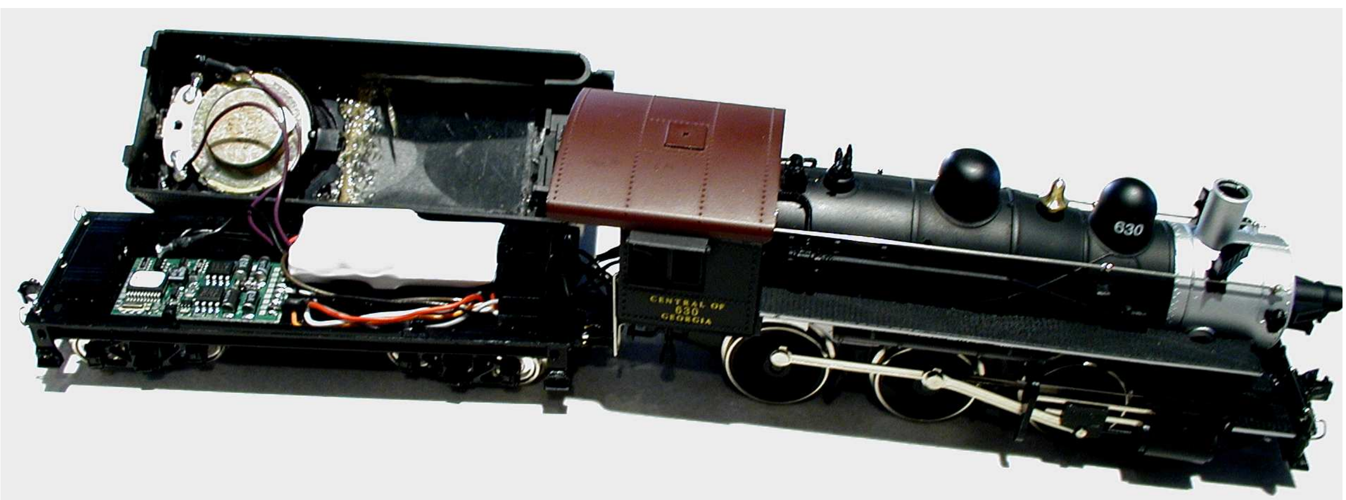
From Mr. DCC's workbench

One loco with two decoders

There was a thread on the MRH web site about working with two decoders in one loco. How to set them up and program them. That prompted me to deal with the topic here.

Recently the concept of decoder locking has become popular amongst decoder manufacturers. This involves setting CV 15 and CV 16. If CV 16 = 0, locking is disabled. If CV 16 is set to a value between 1 and 7, then the decoder can only be programmed when CV15 is set to the same value. When locked, the decoder will only allow you to change CV15 or CV16. There are some recommended values for CV16, depending upon what the specific decoder is doing. Check out the NMRA site for these ideas: (http://www.nmra.org/standards/DCC/WGpublic/0305051/0305051.html).

But what do you do if you have an older decoder without the lock feature? Here's what I do to keep it simple.



14: Two decoders in loco #630: Lenz motor and light decoder with SoundTraxx DSX sound module without the loco feature

Let's look at the Central of Georgia #630.

I installed the Lenz decoder for motor and lights and programmed it to a short address of 30 and a long address of 630, with the short address active. I created a DecoderPro file for this decoder, called 630-motor.

Then I connected the DSX decoder to the speaker (to provide a load for programming) and clipped the track leads to my programming track – the loco was NOT on the track. I programmed the DSX to a short address of 6 and a long address of 630, with the short address active. The DecoderPro file for the DSX was called 630-sound.

When I finished the installation, the loco would run on address 30, but the sound controls were on address 6. So, I created a consist with 30 and 6 to run the loco while I used DecoderPro to tune the lights, motor and sound to my desires, using programming on the main and the two definition files previously created. DecoderPro will allow you to have two decoder files open and program on the main from either of them.

When I was happy, I changed both DecoderPro files to utilize the long addresses and wrote those changes to the locomotive. The loco then ran as 630.

Future adjustments are easy, just set the decoders both back to the short address mode, run them as a consist while you tinker. Put them back in long address mode to finish.