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DIGITAL TESTER OF THE DCC SIGNAL RECEPTION QUALITY

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Abstract: DCC (Digital Command and Control) is an operation standard for digital model train networks. By means of the DCC signal, broadcasted throughout the entire digital railway system, every item performs like its real-life counterpart. Despite the hardware and software safety measures, the extent and shape of large railway systems and the contacts between the rails, wheels and pickup collectors of model trains can impede the reception of the DCC signal, which may lead to the malfunction of their digital decoders. Thus, it is important to assess the quality of the DCC signal that reaches the digital decoders of model trains. The authors designed a DCC quality tester, which counts the valid DCC packets per second collected from the tracks of a digital railway system. It is built around a custom-programmed microcontroller and shows if the tested model train receives the DCC signal within an acceptable error rate that its decoder can handle properly. A high error rate warns that the model train and/or the tracks have problems. Thus, this digital DCC tester certifies the adequate operation of the tested digital model train, proving itself to be a useful quality-testing tool for model railroaders.
Key words: digital tester, signal, quality

1. INTRODUCTION

Generally, *modeling* is an activity about building models of machines and devices at small-scale, with respect to reality as close as possible. The beginning of this activity is lost in the mist of time, since man always liked to have things reminding of the surrounding reality, more or less accurately. [1]
Model railroading refers to constructing and collecting locomotives, wagons, railroad, signals, buildings and other set pieces which copy their real-world counterparts at a certain scale. These models can be grouped as carpet or table temporary railroad circuits, but also as definitive elaborate dioramas, modular or not, that represent railway stations, urban and/or rural sceneries, spectacular landscapes from real famous zones or even places from other days, built by the owner with great care to observe reality in as much as possible details, or following a personal idea. [1]
Model trains are built in two different ways: analog and digital. Briefly, the digital model trains are fitted with *digital decoders* [2], which pick the digital signal from the tracks, decode it and perform the specific operations that were sent from the *central digital command station*. Such digital signals are standardized, and one of these standards is DCC, which stands for *Digital Command and Control*.
It is very important that the digital signal is present on the entire digital railway system, so that every digital item can properly receive and decode it. Several hardware and software measures are taken to ensure adequate transmission and reception of the digital signal, such as multiple power supply connectors, digital boosters [3], rail occupancy detectors [4], error detection algorithms [3] etc. These safety measures are sufficient in most cases, but on the digital railway systems incidents still may occur, such as losing control over random model trains, which freeze on the rails or suddenly start to run at maximum speed, scrambled feedback and/or command signals that jam the digital system etc.
There are several reasons for these malfunctions, and one of them is the extent and shape of large digital railway systems, which may lead to interferences, reflections, attenuations, standing waves etc., resulting in distortion of the digital signal over the affected railway sectors. These propagation problems can be alleviated by careful design of the railway network, usage of snubbers at the ends of the railway tracks and so on.
The most frequent problems are caused by the imperfect dynamic contacts between the rails, wheels and current pickup collectors of the digital model trains, either moving or standing still. These contact problems can be alleviated by optimal design of the model trains, with multiple pickup collectors, usage of buffer capacitors, careful design of the railway system (flat or at least smooth rails, minimization of isolated portions, adequate shape of the lines etc.), proper maintenance of both model trains and railway system etc.

The authors designed and built a tester of the digital signal reception quality, which can be used either to check the digital signal propagation at any spot of the digital railway network, or to test the quality of the digital signal reception within a certain digital model train. Because both authors use the DCC standard at their digital railway systems, they will only refer to it in the following. Nevertheless, this tester can be adapted for use in other digital railway system standards.

2. DATA TRANSMISSION AND SAFETY MEASURES IN DCC STANDARD

Figure 1 shows the electrical structure of a digital model locomotive and figure 2 shows some digital decoders. Briefly, the DCC signal is brought to the power input terminals of the digital decoder (red and black), where it is rectified to ensure power and it is decoded. The motor outputs (orange and grey), the lights outputs (white and yellow) and the auxiliary outputs (green, purple, pink, cyan etc.) will be activated by the decoder according to the specific commands that it received and decoded.

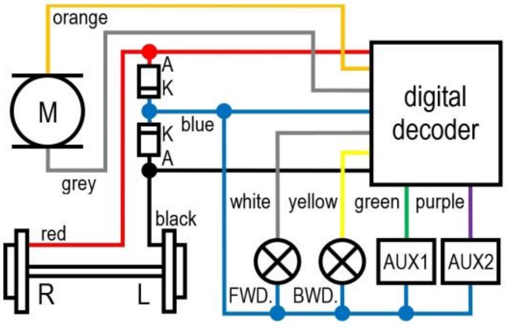

Fig. 1. Electrical structure of a digital model locomotive, [3]

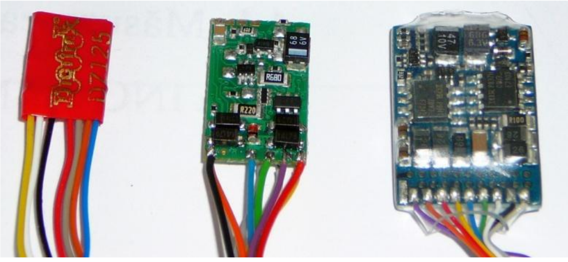

Fig. 2. Digital decoders for model trains: Digitrax (left), train-O-matic (center), ESU (right), [2]

As shown in [3], the DCC signal consists of positive and negative pulses that are continuously sent to the rails by the digital command station, according to NMRA (National Model Railroad Association) regulations, which establish a set of rules for encoding, decoding, signal amplitude and durations etc. [5, 6]. The information (both commands and data) is coded in "packets" by the central digital command station. Figure 3 shows how the digital signals "0" and "1" are encoded, and figure 4 shows the contents of one DCC packet.

The address byte contains the address of the decoder that is called by the central digital command station, and the following bytes carry the commands and data to be performed by the called digital decoder. The last byte contains an error code that is automatically checked by the decoder. *All the commands are ignored* if the decoder address does not match the address byte or if the error code does not match the result of the standardized safety algorithm.

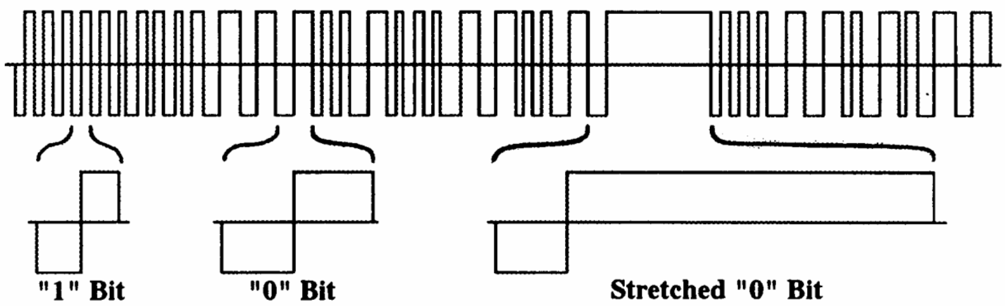

Fig. 3. DCC signal for bit "1" and bit "0" [5].

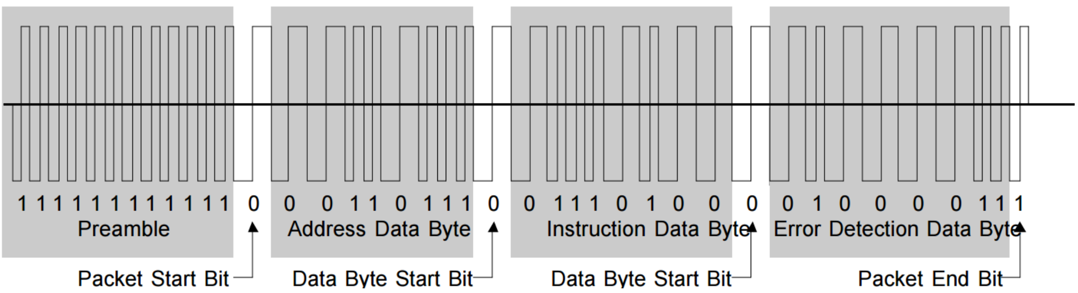

Fig. 4. Example of a transmitted DCC packet [6].

This software safety measure is useful when few bits of the received DCC signal are altered. However, this is not effective anymore when the DCC signal gets severely distorted, and it may happen that the decoder responds erratically, loses its memorized settings or even gets damaged. These severe malfunctions may occur within a digital model train if the DCC signal is already distorted in some places on the railway network because of interferences, standing waves, reflections, attenuations, random interruptions caused by bad connections, dirty or uneven tracks etc., and they may also occur if the digital model train itself has electrical and/or mechanical problems.
This is why a digital tester of the DCC signal reception quality is needed.

3. THE DIGITAL TESTER OF THE DCC SIGNAL RECEPTION QUALITY

The digital tester is built around a custom-programmed microcontroller PIC16F677, which picks up the DCC signal from the railway tracks, counts the number of valid DCC packets per second and displays it either as is, or as the percentage of actual valid packets out of the memorized maximum number of valid DCC packets. The result is displayed on a three-digit common-cathode LED display, as the number of valid DCC packets per second or as the above-mentioned percentage followed by an activated digital point. The transition between these two display modes is carried out by pressing a push-button.
All these are achieved by means of a custom-written software that was programmed into the microcontroller, so that it recognizes the DCC standard input signal according to the above-mentioned NMRA regulations and it can check the validity of the received DCC packets. Considering that different central digital command stations broadcast the DCC packets at different rates, it is useful to memorize the maximum number of received DCC packets in ideal conditions, and then to display the percent of actual valid packets out of the previously memorized value, thus to assess in a similar way the reception quality on different operating conditions.
Figure 5 shows the electronic diagram of the DCC tester, and figure 6 shows the tester by itself and mounted on a H0 (1:87) freight car. The tester displays 120 valid DCC packets per second, issued by tOm-programmer [7], and then the 100 percent of valid DCC packets received in ideal conditions.
In order to check the adequate propagation of the DCC signal along the tracks of the railway system, the inputs of the tester are connected to the wheel current pickup collectors of the freight car on which the tester is mounted.

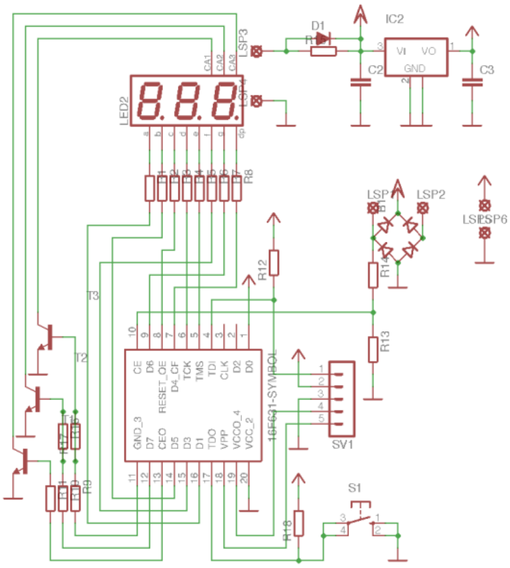

Fig. 5. The digital tester of the DCC signal reception quality – electronic diagram.

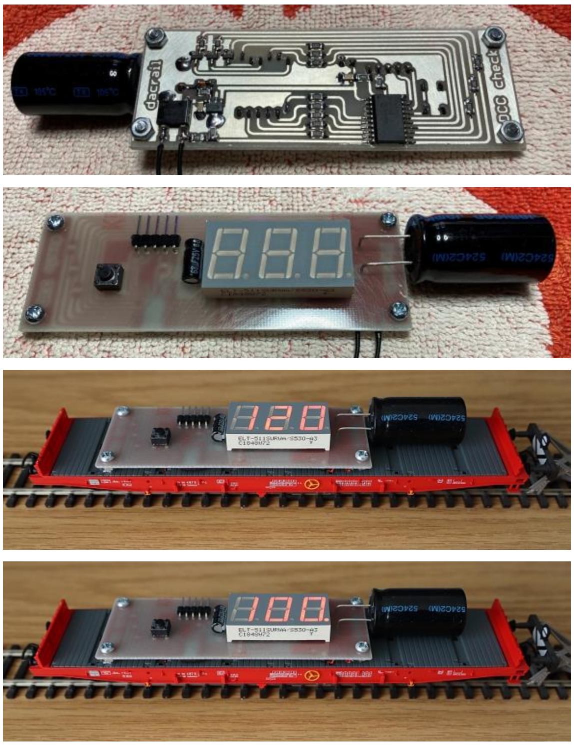

Fig. 6. The digital tester of the DCC signal reception quality, by itself (up) and mounted on a H0 freight car (down).

Then the tester can be run on the entire railway network, either by hand or hauled by a locomotive, to spot the places where the DCC signal loses its quality. Such places are indicated by the lowered percentage of valid DCC packets, and may be the frogs of the turnouts, small dirt spots on the tracks, bad connections or even places where interferences, attenuation, standing waves, reflections and other such phenomena occur. These local conditions impede the correct propagation of the DCC signal and cause problems to the passing digital trains, so they must be adequately handled in order to improve the operation.

In order to check the adequate reception of the DCC signal within a model train, the inputs of the tester will be connected to the wheel current pickup collectors of the model train under test, and the supporting freight car will be coupled to it.

The custom-made software (figure 7) "teaches" the microcontroller the DCC code, so that it recognizes the DCC packets, checks their validity according to the above-mentioned regulations and software safety measures [5, 6], counts the number of the valid packets per second and displays either its absolute value or a percent of the current valid packets over a maximum memorized value. The software was written in assembly language and compiled using Microchip's MPLAB IDE v8.80. The prototype was designed using EAGLE software and was built on single-face copper plated PCB, with both SMD (surface-mount device) and THT (through-hole technology) electronic components. The miniature 1:87 digital railway networks and train collections of both authors were used for testing and measurements.

```
; DCC packet
Packetclrfbytes
     clrfbyte1
     clrfbyte2
     clrfbyte3
     clrfbyte4
     clrfbyte5
     clrfbyte6
sync movlw.12;                look for preamble
     movwfcount
sync1calldccbit
     btfssnewbit
     gotosync
     decfszcount,f
     gotosync1
sync2calldccbit;              12 DCC-1 counted
     btfscnewbit;               wait for DCC-0
     gotosync2
; get up to 6 DCC bytes
sync3movlw.6
     movwfcount1
dcc2 movlw.8
     movwfcount
dcc1 calldccbit;               (max 80uS)
     rlfflags,w
     rlfbyte6, f
     rlfbyte5, f
     rlfbyte4, f
     rlfbyte3, f
     rlfbyte2, f
     rlfbyte1, f
     decfszcount,f
     gotodcc1
     incfbytes,f;no. of DCC bytes
     calldccbit;(max 80uS)
     btfscnewbit; check if DCC-0
     gotoend_p; if DCC-1 assume packet end
     decfszcount1,f
     gotodcc2
     gotopacket; DCC-0 after 6 bytes, restart
;error detection
end_pmovfwbyte1
     xorwfbyte2,w
     xorwfbyte3,w
     xorwfbyte4,w
     xorwfbyte5,w
     xorwfbyte6,w
     btfssSTATUS,2;check error
     gotopacket;if Z=0 restart routine
```

Fig. 7. Excerpt of the custom-made software for the DCC signal reception quality tester.

4. RESULTS AND DISCUSSIONS

There were reports about sudden erratic behaviour of random digital locomotives on extended railway layouts, which start to run abruptly at full speed and can only be stopped by fully disconnecting the entire system, causing disruptions of normal operation. Partially this can be explained by older versions of the command-and-control software and/or hardware, and it be alleviated by regular updating of the software and maintenance / repairing / replacement of the hardware devices. However, the length of the railway sectors, the imperfect contacts between the rails and other random factors can alter the shape and parameters of the DCC signal, which can confuse the digital decoders of the passing or standing trains. Such events may lead to erratic responses, loss or alteration of memorized settings, sudden switching from DCC (digital) mode to DC (analog) mode etc., and it may also happen that the affected digital decoders get damaged by spikes, sudden increases in amplitude and/or severe distortions of the DCC signal.

These situations are dangerous and can lead to accidents, thus they must be handled properly in order to ensure safe operation of the digital railway systems. The digital tester of the DCC signal reception quality, designed and built by the authors, can detect the spots affected by such problems by reading and checking the DCC signal along the tracks of the digital railway system under test. Due to its robustness, this tester itself is protected against damage that could be caused by sudden changes in the amplitude of the severely distorted DCC signal. The non-valid packets of the DCC signal, either distorted or within normal parameters, are simply not counted, and the sudden decrease of the displayed result will warn of the problems in that particular spot.

Fortunately, such problems were not noticed at the digital railway systems of both authors, because of their rather small extent and careful design. Small decreases of the received DCC reception signal quality were noticed at higher speeds of the trains, on the frogs of the turnouts, on sectors with dirty and/or uneven tracks etc., which is normal, but no interferences, reflections, standing waves or other such phenomena were detected, even at the buffer track ends (figure 8).

Fig. 8. The digital tester of the DCC signal reception quality, on the digital railway system.

If a single model train frequently experiences trouble while all others work perfectly, then it must be examined for mechanical or electrical problems. If everything seems to be OK but the operation is still problematic, then the model train should be tested with this device to check the quality of the DCC signal that eventually reaches its digital decoder. If quality losses are detected at any random spots of the railway system, then the model train must be re-examined more thoroughly for problems. If the received signal has very good quality, then the decoder itself has problems that need attention, such as loss or alteration of the memorized settings, imperfect contacts, damaged components etc.

5. CONCLUSIONS

This digital tester of the DCC signal reception quality is a very useful tool for the digital railway enthusiasts, if problems are reported about the data transmission, reception, decoding and execution. This is just one of the many interesting uses of microcontrollers, programming etc. And let's not forget that railroad models can be great ways to learn new things or to increase our knowledge [8], gain new skills, or just relax after a hard day's work, along with other hobbies that light up out lives.

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