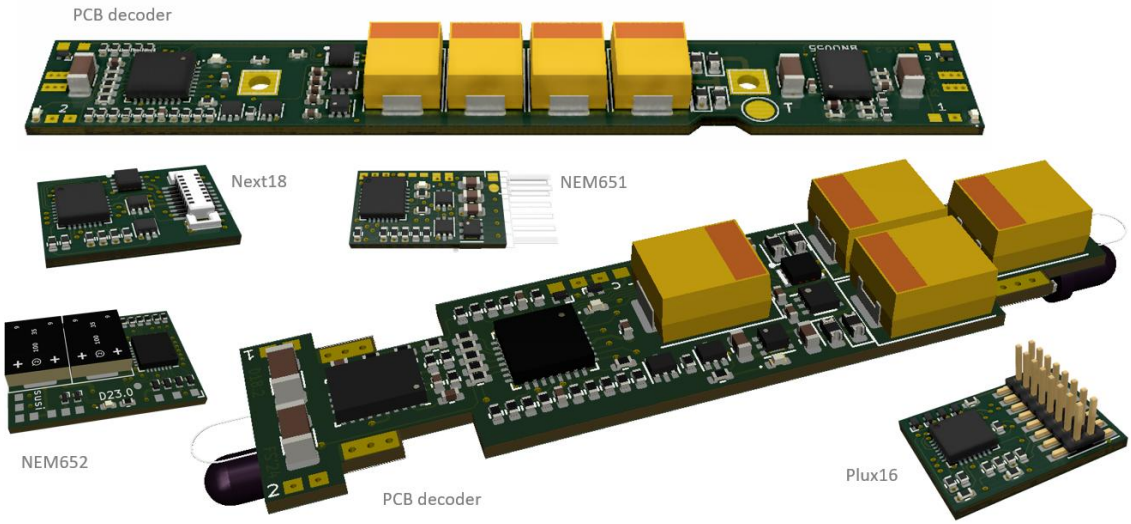
Decoder

Reference Guide

Frank Schumacher, 2025



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1 Change Log

	Jan 2022	**Initial version of this document**
Revision 1	April 2024	Mod: Railcom Page-1 CV data, Add: Railcom chapter
Revision 2	Mai 2024	Add: URLs
Revision 3	Aug 2024	Add: Service Mode
Revision 4	Sep 2024	Add: D20, D21 and D22, Mod: Gen2 motor driver
Revision 5	Dec 2024	Add: D23, Updated D12
Revision 6	May 2025	Add: documentation, Mod: CV definitions
Revision 7	June 2025	Add: Servo, Coupler motion, Mod: motor CVs
Revision 8	Sept 2025	Mod: corrections in documentation
Revision 9	Nov 2025	Add: WS28xx neo pixel port mode
Revision 10	Jun 2026	Mod: CV definitions

2 Legal

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```
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```

3 Overview

There are two types of decoders: motor decoders and LED decoders. Motor decoders are used to drive locomotives, and LED decoders are used to illuminate train cars.

My decoders are based on the widely used Microchip AVR microcontroller platform to ensure long-term hardware availability.

The motor load control runs at 22, 45, and 90 kHz clock frequencies to meet the requirements of modern coreless motors. Motor control is constantly being developed to further improve low-speed driving performance and reduce noise.

All RTB decoders have numerous outputs for controlling lights and additional functions and can control RC servos or SUSI modules if required. RTB decoders are DCC, DCC-A, and DCC-R protocol decoders; analog operation is planned.

Up to 68 functions are possible, to which special functions can be assigned using RTB-specific function mapping and output automation.

All decoders are tailored for N-scale.

4 DCC Adress Configuration

4.1 Static Addresses

Static address assignment is the classical DCC address management.

***Note**: The heartbeat LED indicates a static long address via a 'single pulse' per second.*

4.1.1 Static Short Address

CVs: 1, 29

The short address range is from 1..127 and will be configured as follows.

```
CV1           = <DCC address>
CV29.bit5     = 0
```

4.1.2 Static Long Address

CVs: 17, 18, 29

The long address range is from 128..10239 and will be configured as follows.

```
CV17          = (<DCC address> / 256) + 192
CV18          =  <DCC address> - (CV17 * 256)
CV29.bit5     = 1
```

Example: Configure decoder for long address 1000

```
Mod           = (1000 / 256)          = (3)
CV17          = (Mod) + 192           = (3) + 192       = 195
CV18          = (1000 - (Mod * 256))  = (1000 - (768))  = 232
```

4.2 Dynamic Addresses (LOGON)

CVs: 28, 29, 119

The RTB decoders support dynamic address assignment via DCC-A (RCN-218) and the RTB specific DCC-R logon process. To enable automatic logon,

```
CV28.bit7      = 1
CV29.bit3      = 1
```

The decoder will automatically select the logon type (DCC-A/DCC-R) to which is active on the tracks. Should neither of the logon protocols be found active on the track, the decoders will automatically revert to their static address (CV1 or CV17/18). In case both logon protocols are active simultaneously, the DCC-R logon will take precedence.

Priority of protocol selection (see also Chapter),

- Priority 1: **DCC-R**
- Priority 2: **DCC-A**
- Priority 3: **DCC**

CV119 reports the most recent logon that has been selected by the decoder.

Note: The heartbeat LED indicates a dynamic address via ‘double pulse’ like a heartbeat.

4.2.1 Automatic switch back to static addresses

If the decoder was previously active on a DCC-R or DCC-A system, it takes approximately 5 seconds for the decoder to return to regular DCC mode. After this switch-back, the decoder will start in DCC mode without delay upon subsequent power-on.

4.2.2 DCC-A timing signature

The decoder will detect the (optional) DCC-A timing signature on the start-bit, according to the RCN-218 specs. Currently, no further action is taken by the decoder. The captured timing can be exhibited by reading CV344 and CV345.

5 Driving Characteristics

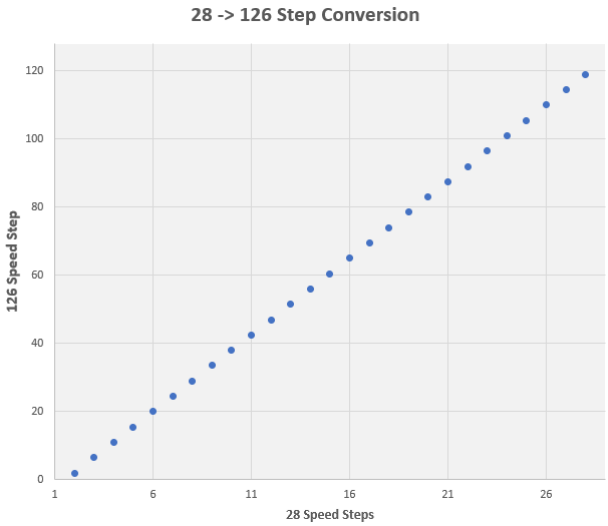
The target motor RPM is determined in several steps in the following order.

5.1 Conversion 28 to 126 speed steps

CVs: 67-94

If the decoder receives a 28-speed-step command, the 28 speed steps are normalized to 126 speed steps. This is done via a lookup table defined by CVs 67 to 94.

By default, the conversion table is loaded with a linear mapping. This can be customized by modifying the CVs.



Formula:

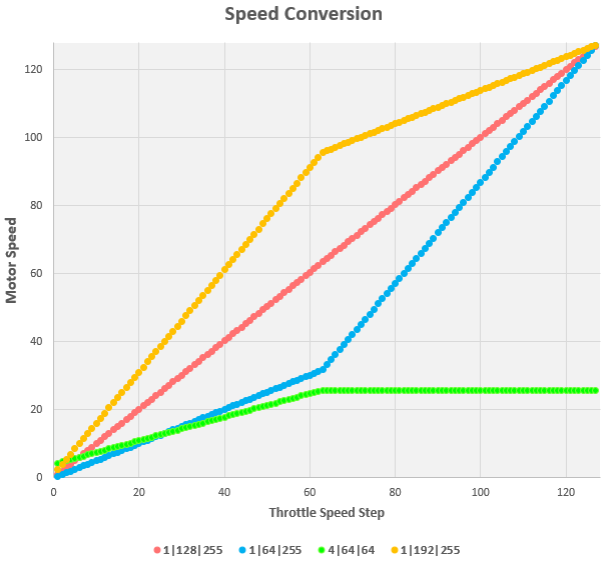
```
Y = CV[66 + X]        with X=[1..28]
```

5.2 Conversion throttle to motor speed

CVs: 2, 5, 6

Each of the 126 speed steps mentioned above is then converted into the corresponding motor target speed. This conversion table can be customized using the "min" (CV2), "mid" (CV6), and "max" (CV5) parameters.

By default, the CVs are loaded with a linear conversion.



Formula:

```
Min = CV2
Mid = CV6 *  63 / 127
Max = CV5 * 126 / 255
```

5.3 Setting the maximum motor RPM

CVs: 55, 56

The maximum motor RPM at “Motor Speed = 126” is determined by the setting of CV55 and CV56. CV55.bit3 can lower the motor RPM by 50%, whereas CV56 will fine tune the top RPM setting.

5.4 Acceleration/Deceleration

CVs: 3, 4, 124, 125

Acceleration (CV3) and Deceleration (CV4) are adjusted via two CVs. Each CV defines the number of milliseconds delay between an internal speed increment/decrement.

Example:

```
CV3             = 100
CV4             = 50
```

The decoder will accelerate from zero to full speed (Speed Step = 126) in 12.6 seconds (126 x 100ms) and come to a complete stop after 6.3 seconds (126 x 50ms).

The acceleration/deceleration ramp can be disabled via function keys from the Environment settings. Please refer to Chapter.

5.5 Dead Man Interval

CVs: 11

The decoder will require at least one command sent to its DCC command within the dead man interval. Otherwise, the decoder will STOP. This is to prevent run-away decoders in case the command station has lost contact to its decoders.

```
CV11            = <N x 128ms>
```

5.6 Speed calculations

CVs: 61, 62, 63, 66

The decoder calculates model speed (mm/s) by monitoring Back EMF. To calibrate the accuracy of this estimation, use the following CVs:

```
CV61            = Low speed trim
CV62            = High speed trim
CV63            = Directional trim (Forward/Reverse balance)
CV66            = Model Scale/Gauge (e.g., 160 for 1:160, 87 for 1:87)
```

Calibration Steps:

1. **Initialize**: Set CV63 to 128.
2. **Low-Speed Calibration**: Drive the model forward at approximately 20% of maximum speed. Adjust CV61 until the reported mm/s matches the actual model speed.
3. **High-Speed Calibration**: Drive forward at approximately 80% speed. Adjust CV62 to calibrate the reported mm/s.
4. **Directional Balance**: Drive in reverse and adjust CV63 until the reverse speed matches the forward speed readings.
5. **Scale Conversion**: Enter your model's scale ratio in CV66 to finalize the conversion from mm/s to km/h.

6 Motor Characteristics

CVs: 9, 10, 55, 56

The load control loop of the motor driver is set by the following parameters.

6.1 Recommended settings

Please use the following value as a starting point depending on the motor type. All values may be fine adjusted, if needed. It's a bit trial an error.

	Motor PWM	EMF gap	Motor	Max RPM	
	CV9	**CV10**	**CV55**	**CV56**	
3-pol	1	100	xxx0-0000	128	
5-pol	1	50	xxx0-0000	128	
Coreless	0	0	xxx0-0101	192	

6.2 3-pol motor

These motors typically have high inductance and a noticeable cogging torque. Fine tuning of these parameters is often required to make the motors run smoothly.

- CV9 if decoder gets hot, set to 2
- CV10 should be >=100
- CV55 should have bit-2 set to zero
  may need bit-3 set to one for double speed
- CV56 adjusts the max RPM of the motor

6.3 5-pol motor

5-pol motors are less sensitive to parameter settings and operate in a wide range reasonably well.

- CV9 if decoder gets hot, set to 2
- CV10 should be >=50
- CV55 should have bit-2 set to zero
- CV56 adjusts the max RPM of the motor

6.4 Coreless motor

The motor driver handles coreless motors differently. I often observe engines with GA motors tend to run slower. That's why CV56 may need to be increased.

- CV9 set to 0 or 1, but if decoder gets hot set to 2
- CV10 can be as low as 0
- CV55 must have bit-2 set to one
  may need bit-3 set to one for double speed
- CV56 adjusts the max RPM of the motor

7 Function Outputs

7.1 Programming

CVs: 160-191, 513-600

The decoder firmware supports 10 conventional function outputs (F0f, F0r, AUX 1–8) and up to 32 extended outputs (Port 1–32), primarily, but not exclusively, intended for LEDs. Not every decoder implements all outputs. Please refer also to an example.

Each port is configured via 4 CVs:

CV [x]	Function	F0...F68
CV [x+1]	Type	led, bulb, neon, mars, ditch, …
CV [x+2]	Automation	head/taillight, engine, cabin, …
CV [x+3]	reserved	future use

7.2 Hardware dimming

CVs: 152-159

Depending on the decoder hardware, up to 10 ports (FL, AUX) can be dimmed by hardware PWM (93kHz). This dimming works independently of the device's emulation.

The maximum intensity can be adjusted via CV152-159.

Example: Dimming FL and FR to 50% intensity.

```
CV152          =     128
CV153          =     128
```

8 SUSI

CVs: 200, 201, 202

Some RTB decoders support the SUSI/SUSI3 (3.3V voltage level) extension protocol. By default, SUSI is disabled but can be enabled by setting CV202 to a value other than 0.

Example: Enabling SUSI with

- CV200
  - Speed real (km/h)
  - Speed set (speed step 0…126)
  - Motor load
  - F0-F4
- CV201
  - <no selection>
- CV202
  - Enable SUSI with cycle time 20us

```
CV200          =      135
CV201          =      0
CV202          =      10
```

9 General Functions

9.1 Decoder Reset

CVs: 8

CVs can be set to factory default with writing to CV8. For details, please refer to the CV8 description.

The defaults vary between the different decoders. Please refer to GitHub of the respective to decoder to find the DxxFyyyy_default.txt file. (xx decoder model, yyyy firmware version) in the firmware directory.

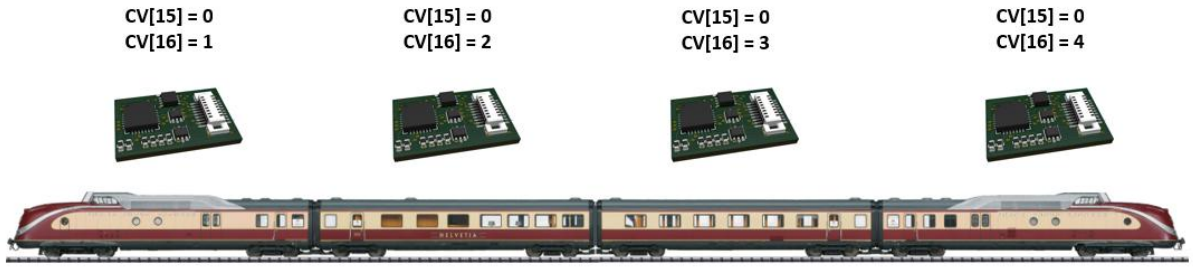
9.2 Decoder Programming Lock

CVs: 15, 16

Should more than one decoder be installed in the same chassis, the selection of individual decoder may become challenging. The service mode programming (programming track) does not use addresses, so all decoders installed will respond to programming. The same will also apply for Railcom programming on main track, should the decoders have identical DCC addresses.

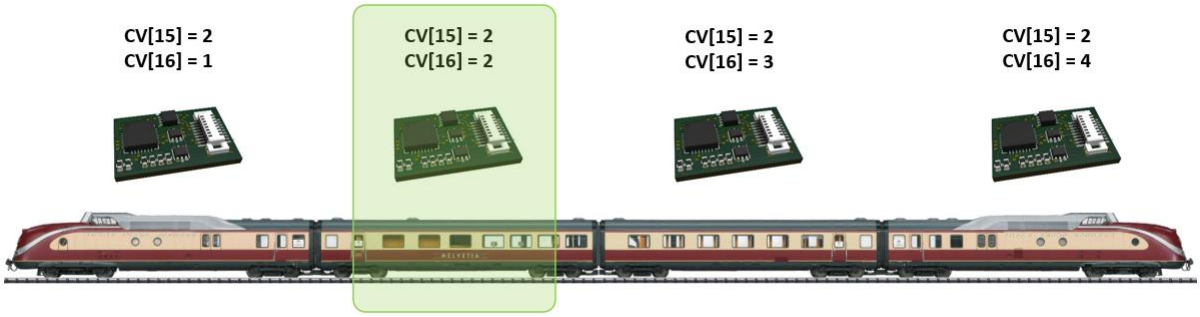
To resolve this situation, each Decoder should get a unique “Lock ID = CV[16]” before being installed.

Example Assume four decoders are installed in VT11. Before installation, each decoder is programmed to have a unique Lock ID stored in CV[16].



If the train is now brought onto the programming track, each decoder may be selected for programming by writing the respective Lock KEY into CV[15]. Only the decoder where CV[15] matches CV[16] will respond to further programming (read and write). All other decoders will discard the programming commands. For further details refer to CV 15/16.

Here we select the decoder in the second car for programming.



After programming is complete, a value of zero should be written into CV15 to lock all decoders again.

9.3 Heartbeat LED Mode

CVs: 65

The heartbeat LED can be put into different display modes mainly for troubleshooting purposes.

Example: To disable the heartbeat LED,

```
CV65            =       0
```

To use the heartbeat LED as a fault indicator,

```
CV65            =       3
```

9.4 Buffer Capacitor Control

CVs: 95

Some decoders feature external buffer capacitor control. By default, Buffer Caps are handled automatically. This means Buffer Caps are **Enabled** by default but **disabled** on programming track automatically.

```
CV95            =       bit mask
```

9.5 Extended Ports

CVs: 642, 643

Some decoders feature up to 32 extended ports. These ports will be external to the decoder PCB and controlled via a serial protocol.

Example: CV642 allows testing of LED ports. For normal operation this CV must be set to zero.

Activate **all** 32 extended ports,

```
CV642           =       255
```

Activate a **selected** extended port,

```
CV642           =       [1..32]
```

Example: CV643 defines the physical communication protocol used to drive the extended ports,

- SR: Shift register mode (SPI)
- WS: Neo pixel mode (WS28xx bus)

```
CV643           =       0: SR, 1: WS mode
```

9.6 Decoder Identification

CVs: 257-268

Each RTB decoder has a unique serial number. This number is derived from the SN of the Microcontroller chip.

```
CV257..CV258   =     16bit vendor code (NMRA)
CV261..CV264   =     32bit decoder model
CV265..CV268   =     32bit serial number
```

9.7 Overcurrent Protection

All RTB Decoders are protected against short circuits, overcurrent and over temperature.

Caution: This does not make the Decoder indestructible. Incorrect wiring can still permanently damage the decoder hardware.

9.7.1 Motor overcurrent

CVs: 58

The engine driver detects motor short circuits and chops the H-bridge until the short has been removed. In addition, the driver circuit monitors the average motor current and raises an alert if the threshold set in CV58 is exceeded. This could indicate a worn-out motor that needs service.

Example: Set the maximum motor current to 1000mA (CV58 * 10mA)

```
CV58           =     100
```

9.7.2 Decoder over temperature

CVs: 59

Should the decoder temperature exceed the value set in CV59, an alert is set in CV30.

Example: Set the maximum decoder temperature to 60 degrees

```
CV59           =     60
```

9.7.3 AUX overcurrent

CVs: 64

If the average current on all AUX ports combined exceed the value set in CV64, the AUX ports are switched off for 1 second and then re-enabled.

If the combined AUX current exceeds 50% of the value set in CV64, an alert is set in CV30.

Example: Set the maximum decoder temperature to 500 mA (CV64 x 10mA)

```
CV64           =     50
```

10 Runtime Statistics

The decoder tracks different statistics about protocol, bit timing and core runtime. The statistics can be accessed via CVs and get reset to zero if the decoder goes through a cold start (POR = power on reset).

10.1 Electrical Stats

CVs: 356-357, 358

The decoder monitors the Voltage level on each side of the tracks. For (future) ABC functionality, it calculates the delta between the two.

Track Voltage: The track voltage is measured on the DCC stop bit of each frame,

```
CV356:              Right side track
CV357:              Left side track
```

ABC Voltage: Voltage difference, which is relevant for ABC behavior,

```
CV358:              signed_delta(CV356 - CV357)
```

10.2 Speed and Distance Stats

CVs: 328-331, 332-333

The decoder can be configured to measure the distance travelled very precisely. The distance and speed error can be as low as 1% when engine runs at medium speeds. The error increases at very slow speeds because the noise on the EMF becomes significant compared to the signal itself.

Distance: Accumulated distance travelled [mm],

```
CV328..331:         signed 32bit value (little endian)
```

Model Speed: Current model speed [mm/s],

```
CV332..333:         unsigned 16bit value (little endian)
```

The decoder also regularly transmits the "distance traveled" and "current speed" via Railcom. This informs the control center about the locomotive's position on the track and within a single block section.

10.3 DCC protocol stats

CVs: 334-337, 338-339, 340-341, 342-343, 352, 353, 354, 355

DCC stats: Total DCC frame count that were successfully received. This value is ever increasing. With a typical DCC frame rate of 120 fps the counter would wrap 414 days of continuous operation.

```
CV334..337:          unsigned 32bit value (little endian)
```

Preamble: Preamble half bit count,

```
CV352:               Number of preamble half bits
```

Polarity: DCC polarity,

```
CV353:               0: normal, 255: inverse
```

FPS: DCC frames per second,

```
CV354:               FPS
```

APS: DCC address frames per second. A measure, how often the decoder has been addressed by the command station (refresh rate).

```
CV355:               APS
```

Protocol errors: DCC protocol errors that will cause the frame to be discarded by the decoder are counted here. All metrics are unsigned 16bit integer (little endian),

```
CV338..339:          DCC bit errors
CV340..341:          XOR errors
CV342..343:          Command length errors
```

10.4 DCC timing stats

CVs: 344, 345, 346, 347, 348, 349, 350, 351

DCC bit timing is measured with 1us granularity.

```
CV344:              DCC startbit timing [us] (first half)
CV345:              DCC startbit timing [us] (second half)

CV346:              DCC 0-bit timing [us] (first half)
CV347:              DCC 0-bit timing [us] (second half)

CV348:              DCC 1-bit timing [us] (first half)
CV349:              DCC 1-bit timing [us] (second half)

CV348:              TCS timing [us]
CV349:              TCE timing [us] (add +400)
```

***Note**: AVRxx**DA**yy microcontroller-based decoders can measure timing precisely. While dual-voltage AVRxx**DD**yy microcontroller-based decoders exhibit a skew of approximately 1-2µs due to the electrical conditions on the input ports.*

10.5 Decoder runtime stats

CVs: 359-374

The decoder uses a multi-threading core and tracks its statistics mainly for development purposes.

Reset reason: The most recent CPU reset reason is stored in this variable.

```
CV359:        bit mask
```

WDR: Watchdog reset counter. A WDR may be an indication of a software issue. Under normal conditions there should not be any WDR events counted.

```
CV360:        8-bit counter
```

BOR: Brown out reset counter. A BOR event indicates the decoder experiencing poor power conditions (e.g. dirty tracks). Under ideal conditions there should not be any BOR events counted.

```
CV361:        8-bit counter
```

SWR: Software reset counter. A SWR event indicates a decoder reset that has been triggered by the software.

```
CV362:        8-bit counter
```

Reset counter: Counting the total number of resets.

```
CV363..364:   16-bit counter (little endian)
```

Error code: Last error condition the decoder has detected.

```
CV365:        most recent error code (persistent)
```

Stack: Minimum free stack space per task in bytes. Each task tracks its stack usage and reports the minimum free stack in these variables.

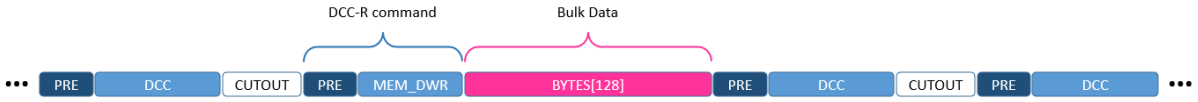
```
CV366:        IDLE task
CV367..374:   Task0..Task7
```

11 Firmware update

CVs: none

All decoders feature firmware updates via main tracks. This ensures fast and reliable updates during system operation. A decoder firmware update typically takes about 10–20 seconds.

The bulk data is sent at a higher frequency (~100 kHz) outside the DCC frame (after the stop bit). Normal decoders interpret this as a non-DCC protocol and ignore its content, while RTB decoders respond to these commands according to the DCC-R specifications.



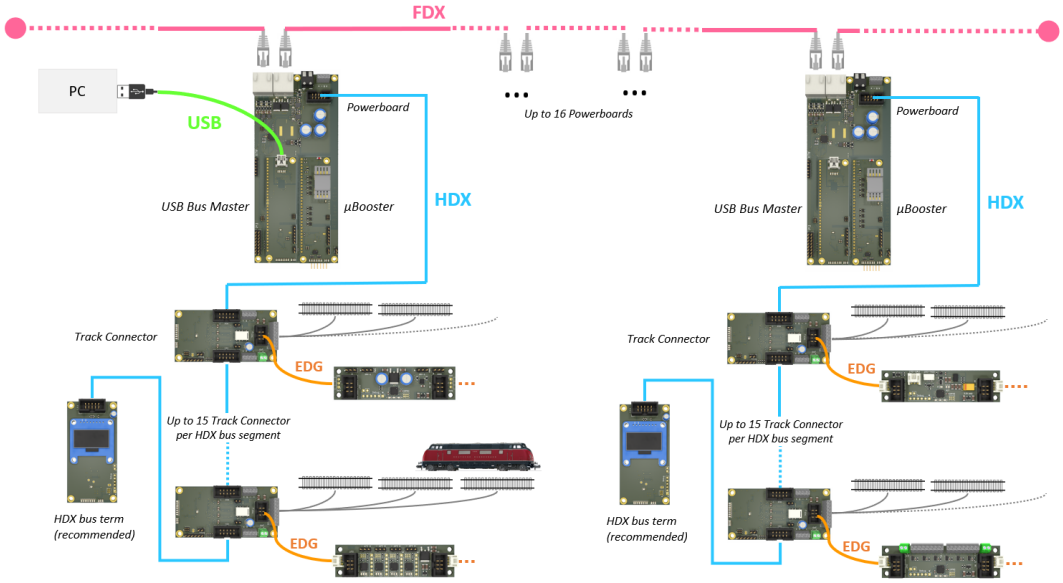
The DCC-R update protocol also allows the transmission of bulk data in regular DCC encoding. This is a fallback option in case a non-RTB decoder cannot tolerate such a high-frequency signal.

11.1 Required hardware

There are two hardware options available for doing decoder firmware updates.

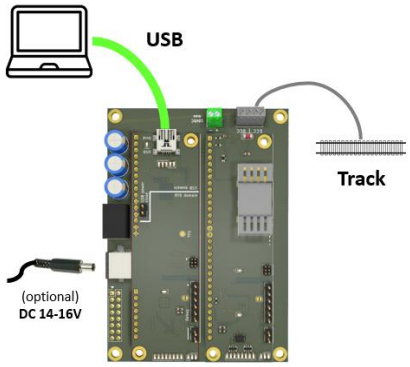
11.1.1 Option 1

You have an RTB layout infrastructure deployed on your layout. (RTB User Guide)



11.1.2 Option 2

Alternatively, the RTB Decoder Tester hardware may be used. (RTB Decoder Tester)



Both options offer the same functionality using the same software stack.

11.2 Example

Single update

Update of a decoder with **UID** <000dd160-da1980b9> with firmware version <0001>.

```
P:\>rtbclient --update 000dd160-da1980b9 --rtb 0001

[000dd160-da1980b9] Sending firmware              [success]
Success: 9429[ms]

P:\>
```

Mass updates

The process also allows mass updates for all decoders currently registered on the system. Using the "-f" force option, no further prompts are displayed. The update process automatically selects the latest firmware for each decoder model.

```
P:\>rtbclient --update –rtb 0001 -f

[000dd120-f73e729e] Sending firmware              [success]
[000dd200-74984223] Sending firmware              [success]
[000dd210-55eb4a46] Sending firmware              [success]
[000dd220-612e1f2e] Sending firmware              [success]
[000dd220-eecebd2c] Sending firmware              [success]
[000dd230-ec3537d6] Sending firmware              [success]
Success: 79597[ms]

P:\>
```

This enables a convenient, fast and reliable software update of all RTB decoders on the layout without having to move them to a service track.

Low Speed Mode

Below is an example of using normal DCC encoding for bulk transfer. Please note, the update will take approximately 8x longer than using high speed bulk data.

```
P:\>rtbclient --update 000dd230-ec3537d6 –rtb 0001 –normalwrite

[000dd230-ec3537d6] Sending firmware              [success]
Success: 67155[ms]

P:\>
```

***Note**: If the update is interrupted for any reason, this will not cause damage to the decoder, and the update can be repeated.*

12 Decoder Programming

For any of the programming methods described below, the *Decoder Programming Lock* described here is relevant.

There are three methods to program the CVs of an RTB decoder,

- POM
- POM via ‘long 0000’
- Service Mode

12.1 POM

CVs: 28, 29

RTB decoders are usually programmed directly on main tracks. This is called *Programming On Main* (POM). For this, the decoder’s DCC address must be known, and Railcom Channel-2 must be enabled.

Setting to enable for POM,

```
CV28.bit1           = 1
CV29.bit4           = 1
```

12.2 POM via ‘long 0000’

CVs: none

POM via ‘long 0000’ is defined in the RCN-217. It practically mimics *Service Mode Programming* using Railcom instead of ACK.

The feature is always enabled on all RTB decoders and cannot be disabled.

How it works: The decoder is addressed via the standardized programming address (long DCC address zero). This address acts like a broadcast address for programming. Every RTB decoder always accepts POM commands sent to ‘long 0000’ and responds via Railcom accordingly - regardless of whether Railcom is enabled or not.

Important: For this reason, decoders must be located on an isolated track, as with Service Mode programming.

Note: At the time of writing, only the RTB command station is known to support POM via ‘long 0000’.

12.3 SMP (Service Mode Programming)

CVs: none

Service mode programming (SMP), often called ‘programming track’, may sometimes be the last resort when it comes to decoder programming. SMP needs to be executed on an isolated track, just like POM via ‘long 0000’.

Note: RTB motor decoder will require a motor to be connected, otherwise the ACK pulse cannot be generated. The RTB LED decoders have built in resistors to generate the ACK pulse.

13 Railcom

CVs: 28, 29

The RTB decoders are designed to work on Railcom layouts and offer an extensive set of Railcom features.

By default, Railcom is enabled for all RTB decoders allowing programming-on-main (POM), telemetric data (e.g. temperature, motor current, track voltage, …) and automatic logon.

Example: All Railcom features enabled

```
CV28            =     159
CV29.bit4       =     1
```

13.1 Channel 1

CVs: 47, 48

Channel-1 is a broadcast channel defined by the standard. Decoders send unsolicited data to the command station and allow decoders to gain attention. This mechanism is prone to collisions if multiple decoders are located behind a single detector.

The timing of channel 1 can be adjusted via CVs if necessary. Normally, the default timing should work reliably with typical Railcom detectors found on the market.

```
TTS1[us]: 80 + CV47 + rnd(CV48 & 0xf)

CV47            =     4           ; default fixed timing offset
CV48            =     0           ; optional artificial timing jitter
```

ADR (ID1 & ID2) All decoders support Channel-1 address broadcast as defined in RCN-217.

INFO1 (ID3) All decoder support Info1 datagram broadcast on Channel-1 as defined in RCN-217.

13.2 Channel 2

CVs: 49, 50

Channel-2 is a per decoder data response channel. Decoders respond with data after being addressed by the central. This makes communication reliable and prevents collisions on the upstream.

The timing of channel 2 can be adjusted via CVs if necessary. Normally, the default timing should work reliably with typical Railcom detectors found on the market.

```
TTS2[us]: 193 + CV49 + rnd(CV50 & 0xf)

CV49          =     4           ; default fixed timing offset
CV50          =     0           ; optional artificial timing jitter
```

ACK

All decoders support ACK as defined in RCN-217. The standard reserves two encodings as ACK. The RTB decoders use the ACK_1 encoding for standard acknowledgment.

Note: Future firmware may also utilize ACK_2 to distinguish different acknowledgements. This differentiation will be analyzed by the RTB layout infrastructure.

ACK_1	0b00001111
ACK_2	0b11110000

NACK

All decoders send NACK (defined in RCN-217) if the received DCC command is unsupported.

NACK	0b00111100

POM (ID0)

All decoders support POM as defined in RCN-217.

Note: RTB decoders always respond in the same DCC frame with the POM answer. Therefore, there is no need to repeat POM readings. POM writes must be repeated once for safety reasons as defined by RCN-214.

INFO (ID4)

All decoders support ID4 as planned in RCN-217. Currently the 32-bit payload holds the DCC frame counter of the decoder awaiting final definition by the Rail-Community.

DYN (ID7)

Decoders support several DYN messages. ID7 metrics are sent in pairs (=tuple) in each Railcom frame. The decoder cycles through the list below.

Index	Defined	Description	Update every
0	RCN-217	km/h [0...255]	128ms
1	RCN-217	km/h [256...511]	
2	RCN-217	bit7 = 0: Motor Load 0...100% bit7 = 1: Speed step 0...126	always
7	RCN-217	QoS (Frame Errors / sec)	1000ms
8	Custom	Motor current	always
9	Custom	Brown Out counter (decoder hot restart)	always

10	Custom	Firmware Task switches / sec (value * 4)	always
11	Custom	CPU load (0...100%)	always
12	Custom	Speed [mm/s] (ID12=LB, ID13=HB)	always
13	Custom		
14	Custom	ABC track (L/R) voltage delta [100mV]	always
15	Custom	Decoder addressing/sec	always
16	Custom	Decoder absolute orientation (ID16=pitch, ID17=roll)*	128ms
17	Custom		
18	Custom	Min stack free space	always
19	Custom	Task ID of value reported in (18)	always
24	RCN-217	16bit distance travelled in [mm] (ID24=LB, ID25=HB)	always
25	RCN-217		
26	RCN-217	Decoder temp (0 = -50 … 255 = +205 deg C)	always
27	RCN-217	East/West information	always
46	RCN-217	Track voltage (5V + value * 100mV)	always

*) Decoder must have BNO055 installed

XPOM (ID8-ID11)

All decoders support XPOM as defined in RCN-217.

Note: Decoders always respond in the same DCC frame with the xPOM answer. Therefore, there is no need to repeat xPOM reads. xPOM writes must be repeated once for safety reasons as defined by RCN-214.

DCC-A (ID13)

Decoders support ID13 as defined in RCN-218.

DCC-A (ID15)

Decoders support ID15 as defined in RCN-218.

14 CV definitions

14.1 Page 0

This page uses big-endian numbers.

CV	Default	Range	RW	Description
1	3	1..127	RW	**DCC short address** *Note: The decoder also implements Programming-On-Main (POM) for 'long address 3', according to RCN-217.*
2	1	1..127	RW	**Minimal speed** Sets the minimum motor speed. *Note: CV 2, 5 and 6 define a 3-point speed conversion table.*
3	8	0..255	RW	**Acceleration** Milliseconds per speed step increment.
4	8	0..255	RW	**Deceleration** Milliseconds per speed step decrement.
5	255	0..255	RW	**Maximum speed** Sets the maximum motor speed. (see CV2)
6	128	0..255	RW	**Mid speed** Sets the mid-point motor speed. (see CV2)
7	-	0..255	RO	**PCB hardware version**
8	13	-	RO	**Vendor ID** Reading this CV will return the vendor ID (0x0d). Writing to this CV will trigger the following operations, 0: <does nothing> 1: Hard Reset (clear PERM, SRVL, ZERO space) 2: Cold Reset (clear ---, SRVL, ZERO space) 3: Warm Reset (clear ---, ----, ZERO space) 4: Watchdog Reset (timing forced to 8ms) 5: Watchdog Reset (current timing) 6..7: <does nothing> 8: Reset to factory default (all CVs) 9: Reset DCC address (CV 1, 17, 18, 19, 20, 29) 10: Reset motor parameter (CV 2, 5, 6, 9, 10, 55, 56, 57) 11: Reset speed table (CV 67-94) 12: Reset AUX mapping (CV 160-191) 13: Reset PORT mapping (CV 513-600) *Note: To avoid sudden stops, the decoder will be rejected any write to this CV while the motor is running.*
9	1	0..3	RW	**Motor PWM frequency** Bit-0/1: 0: 92kHz, 1: 46kHz, 2: 23kHz, 3: reserved 0: can be used with coreless engines 1: compromise between high and low frequency PWM 2: should be used if decoder gets hot *Note: PWM frequency is selected during decoder startup. It is required to power cycle the decoder changing this CV.*

CV	Default	Range	RW	Description	
10	50	0..255	RW	**Motor EMF sample point** Gap[us] = (160 + (CV10 * 4)) *Note: The EMF sample point depends on the motor characteristics as well as the PCB layout of the loco. This value has a big impact on motor control. Setting the value too low will make the motor run dodgy or even not spinning the motor at all.*	
11	16	0..255	RW	**Dead-man interval** While driving, the maximum tolerated time between two successfully received speed commands by the decoder, else the decoder will stop. **T[ms]** = CV11 * 128	
12	4	4	RO	**Protocol support** Currently the decoder only supports DCC. Bit-0: - Bit-1: - Bit-2: DCC Bit-3: - Bit-4: - Bit-5: - Bit-6: - Bit-7: -	
15	1	0..239, 255	RW	**Lock KEY** If 255 is written to this CV, the content of CV[16] is copied here to unlock this decoder.	Decoder programming lock. CVs can only be read or written if (CV015==CV016) otherwise there will not be any Railcom response nor Service Mode ACK. There is one exception to this rule: CV015 can always be written.
16	1	0..239	RW	**Lock ID** *Note: In compliance with RCN-225, this CV should not be set to zero.*	
17	195	192..255	RW	**DCC long address** (HB)	Default address: 1000
18	232	0..255	RW	**DCC long address** (LB)	
19	0	0..255	RW	**Consist (LB)** Short consist address = CV19 (with CV20 set to zero) If CV19 is set to 0 the consist address is disabled. If set to >0, speed and direction is controlled by the consist address (CV19+CV20*100) and no longer controlled the decoders unicast address (CV1, CV17/18).	
20	0	0..102	RW	**Consist (HB)** Long consist address = CV19 + (CV20 * 100)	
21	0	0..255	RW	**Consist FN1-FN8** FN is controlled by base address if bit is the to '0' or controlled by consist address if bit is set to '1'. Bit-0: FN1 Bit-1: FN2 Bit-2: FN3 Bit-3: FN4 Bit-4: FN5 Bit-5: FN6 Bit-6: FN7 Bit-7: FN8	

CV	Default	Range	RW	Description
22	0	0..255	RW	**Consist FN9-FN68** FN is controlled by base address if bit is the to '0' or controlled by consist address if bit is set to '1'. Bit-0: FN0 Bit-1: FN9 Bit-2: FN10 Bit-3: FN11 Bit-4: FN12 Bit-5: FN13-FN28 Bit-6: FN29-FN68 Bit-7: -
27	0	0..3	RW	**Automatic STOP** The motor will stop if an asymmetrical DCC signal detected. Bit-0: STOP with voltage trk-R greater than trk-L Bit-1: STOP with voltage trk-L greater than trk-R (not yet implemented)
28	130	0..255	RW	**Railcom** The Decoder will respond to POM on programming address 'long 3' regardless of Bit-1 and Bit-4. Bit-0: enable channel-1 Bit-1: enable channel-2 Bit-2: enable dynamic channel-1 Bit-3: enable ID3 on channel-1 Bit-4: enable prog address (long 3) Bit-5: - Bit-6: - Bit-7: enable automatic logon (DCC-A, DCC-R)
29	10	0..255	RW	**Config** Bit-0: enable reverse direction Bit-1: enable 28/126 speed steps Bit-2: - Bit-3: enable Railcom Bit-4: enable custom speed table (CV67..CV94) Bit-5: enable long address (CV17/18) Bit-6: - Bit-7: -
30	0	0..15	RW	**Decoder error information** Bits can be cleared by writing "0" to this CV. Bit-0: Motor overcurrent (s. CV 58) Bit-1: FL/AUX overcurrent (s. CV64) Bit-2: Decoder overtemp (s. CV59) Bit-3: High voltage (s. CV60) Bit-4: - Bit-5: - Bit-6: - Bit-7: -
31	0	-	RW	**CV page index** (LB)
32	255	-	RW	**CV page index** (HB)

CV	Default	Range	RW	Description
47	4	0..15	RW	**Trim Channel-1 timing** Channel-1 timing can be adjusted if needed. **TTS1[us]:** 80 + CV47 + rnd(CV48 & 0xf)
48	0	0..15	RW	**Generate Channel-1 timing jitter** By default, the decoder's Railcom timing operates without jitter. This parameter allows you to add artificial jitter if needed. **TTS1[us]:** 80 + CV47 + rnd(CV48 & 0xf)
49	4	0..15	RW	**Trim Channel-2 timing** Channel-2 timing can be adjusted if needed. **TTS2[us]:** 193 + CV49 + rnd(CV50 & 0xf)
50	0	0..15	RW	**Generate Channel-2 timing jitter** By default, the decoder's Railcom timing operates without jitter. This parameter allows you to add artificial jitter if needed. **TTS2[us]:** 193 + CV49 + rnd(CV50 & 0xf)
51	255	0..255	RW	**Channel-2 DYN tuples** Select which datagram tuples to send in channel-2. Setting a bit to zero suppresses that tuple. Bit-0: ID4 Bit-1: { km/h , QoS } Bit-2: { temperature, track voltage } Bit-3: { distance LB, HB } Bit-4: { speed step, engine load } Bit-5: { RC version, east/west } Bit-6: { Bucket 01, 02 } Bit-7: { Bucket 03, 04 }
52	15	0..15	RW	**Channel-2 DYN tuples** Select which datagram tuples to send in channel-2. Setting a bit to zero suppresses that tuple. Bit-0: { Bucket 05, 06 } Bit-1: { Bucket 07, 08 } Bit-2: { Bucket 09, 10 } Bit-3: { Bucket 11, 12 } Bit-4: - Bit-5: - Bit-6: - Bit-7: -
54	0	0..7	RW	**Direction settings** Bit-0: DCC-L/R (0: normal, 1: inverse) Bit-1: Motor rotation (0: normal, 1: inverse) Bit-2: Light direction (0: normal, 1: inverse) Bit-3..7: <reserved>
55	0	0..255	RW	**Motor settings** Bit-0: Motor speed (0: linear, 1: exponential) Bit-1: Buffer Cap used (0: CPU, 1: CPU+Motor) Bit-2: Motor type (0: brushed DC, 1: coreless) Bit-3: Max motor speed (0: normal, 1: double speed) Bit-4: PWM mode (0: fast decay, 1: slow decay) Bit-5..7: <reserved>

CV	Default	Range	RW	Description
56	128	0..255	RW	**Motor RPM max** Fine adjust maximum motor speed. <128: reduce top speed =128: mid-point >128: increase top speed
58	100	0..255	RW	**Motor maximum current** Sets the maximum motor current. If the current exceeds Imax, the H-bridge hardware throttles the motor current. If 75% of Imax is exceeded, the warning flag in CV30 is set and the motor stops. **Imax** = (CV58) * 10[mA].
59	65	0..255	RW	**Decoder maximum temperature** Sets the maximum operational decoder temp. If exceeded, the warning flag in CV30 is set and the motor stops. **Tmax** = (CV59) [C]
60	180	0..255	RW	**Maximum track voltage** Sets the maximum operational track voltage. If exceeded, the warning flag in CV30 is set and the motor stops. **Umax** = (CV60) / 10 [V]
61	128	0..255	RW	**Distance scale (slow spinning)** Scale the distance measurements by the decoder to match the motor characteristics and transmission at slow speeds. 255: distance x 1.99 >128: increase calculated distance =128: mid-point (default) <128: decrease calculated distance 001: distance x 0.08
62	128	0..255	RW	**Distance scale (fast spinning)** Same as CV61, but for fast driving speeds
63	128	0..255	RW	**Distance trim (fwd/rev)** Trim the distance scale between forward and reverse driving. >128: trim towards fwd =128: mid-point (default) <128: trim towards rev
64	40	0..255	RW	**AUX maximum current** Sets the maximum total auxiliary current. Depending on the decoder model, current is capped to protect Decoder HW. If exceeded, the warning flag in CV30 is set. **Imax** = (CV64 * 10)[mA].
65	2	0..4	RW	**Heartbeat LED mode** Sets the heartbeat LED behavior. This LED can be programmed for informational and/or trouble shooting purposes. 0: permanently OFF 1: permanently ON 2: LOGON mode (1 pulse: DCC, 2 pulse: DCC-R, 3 pulse: DCC-A) 3: Error thresholds exceeded (s. CV30) 4: DCC frame corruption

CV	Default	Range	RW	Description	
66	160	87 120 160 220	RW	**Model scale (1:N)** This model scale is used for various calculations within the Decoder software, for example to scale model speed mm/s to real km/h.	
67 - 94	<linear>	1..126	RW	**Custom speed curve** The default speed curve is linear: [1*126/28 … 28*126/28]	
95	0	0..255	RW	**Power options** This setting controls different power-related options. Bit-0: Buffer Caps (0: automatic, 1: caps turned off) Bit-1...7: <reserved>	
96	6	-	RO	**FN assignment method (RCN-225)**	
97	-	0..255	RO	**HID** (LB)	**16bit Hardware ID** 0xHHLL = 'HHLL' decoder
98	-	0..255	RO	**HID** (HB)	
99	13	-	RO	**VID** (LB)	**16bit Vendor ID** 0x000d = 'do it yourself'
100	0	-	RO	**VID** (HB)	
101	-	0..255	RO	**DID** (LB)	**32bit Decoder ID** Decoder serial number
102	-	0..255	RO	**DID**	
103	-	0..255	RO	**DID**	
104	-	0..255	RO	**DID** (HB)	
105	0	0..255	RW	**User variable**	Free for user specific information
106	0	0..255	RW	**User variable**	
107	1	-	RO	**Extended vendor ID** (HB)	0x0109 identifies the RTB project
108	9	-	RO	**Extended vendor ID** (LB)	
109	-	0..255	RO	**App code rev** (major)	**Application version** major.minor
110	-	0..255	RO	**App code rev** (minor)	
111	-	0..255	RO	**Bld code rev** (major)	**Bootloader version** major.minor
112	-	0..255	RO	**Bld code rev** (minor)	
113	-	0..255	RO	**Rom code rev** (major)	**ROM version** major.minor
114	-	0..255	RO	**Rom code rev** (minor)	
115	-	0..255	RO	**Bld backup rev** (major)	**Bootloader backup version** major.minor
116	-	0..255	RO	**Bld backup rev** (minor)	
117	-	0..255	RO	**PCB rev**	**Decoder hardware rev**
118	-	0..255	RO	**EEPROM rev**	**EE layout version**
119	-	0..255	RO	**DCC address management mode** Indicates by which the decoder selected its currently active DCC address. Bit-0: DCC static address (CV1 or CV17/CV18 or CV19/CV20) Bit-1: DCC-R dynamic address assignment Bit-2: DCC-A dynamic address assignment Bit-3..7: <reserved>	
120	1	0..68	RW	**FN # Coupling side 1** Decoder side 1 is coupled.	
121	2	0..68	RW	**FN # Coupling side 2** Decoder side 2 is coupled.	
122	3	0..68	RW	**FN # Shunting** Activate shunting mode.	
123	4	0..68	RW	**FN # Parked** Set the decoder to 'parked' state.	

CV	Default	Range	RW	Description
124	5	0..68	RW	**FN # Acceleration** Disable acceleration ramp (see CV3).
125	6	0..68	RW	**FN # Breaking** Disable breaking ramp (see CV4).
126	255	0..68	RW	**<reserved>**
127	255	0..68	RW	**<reserved>**
128	255	0..68	RW	**<reserved>**
129	255	0..68	RW	**<reserved>**
130	255	0..68	RW	**<reserved>**
131	255	0..68	RW	**<reserved>**
132	255	0..68	RW	**<reserved>**
133	255	0..68	RW	**<reserved>**
134	255	0..68	RW	**<reserved>**
135	255	0..68	RW	**<reserved>**
136	61	0..68	RW	**FN # Location - Main**
137	62	0..68	RW	**FN # Location - Station**
138	63	0..68	RW	**FN # Location - Tunnel**
139	64	0..68	RW	**FN # Location - Depot**
140	65	0..68	RW	**FN # Location - Siding**
141	66	0..68	RW	**FN # Location - Hidden**
142	67	0..68	RW	**FN # Location - Fiddle**
143	68	0..68	RW	**FN # Location - Crossing**
144	255	0..68	RW	**<reserved>**
145	255	0..68	RW	**<reserved>**
146	255	0..68	RW	**<reserved>**
147	255	0..68	RW	**<reserved>**
148	255	0..68	RW	**<reserved>**
149	255	0..68	RW	**<reserved>**
150	255	0..68	RW	**<reserved>**
151	255	0..68	RW	**<reserved>**
152	255	0..255	RW	**Dim Headlight 1** 8-bit scale with a PWM frequency of 93kHz to set the maximum brightness of the light. The value specifies the raw duty ratio without any gamma correction. 000: always OFF (duty = 0/255) 001: lowest brightness (duty = 1/255) 255: maximum brightness (duty = 255/255)
153	255	1..255	RW	**Dim Headlight 2** same as CV 152
154	255	1..255	RW	**Dim AUX 1** same as CV 152
155	255	1..255	RW	**Dim AUX 2** same as CV 152
156	255	1..255	RW	**Dim AUX 3** same as CV 152
157	255	1..255	RW	**Dim AUX 4** same as CV 152
158	255	1..255	RW	**Dim AUX 5** same as CV 152
159	255	1..255	RW	**Dim AUX 6** same as CV 152

CV	Default	Range	RW	Description
160	0	0..68	RW	**Headlight 1 – FN#** FN function (0..68) to enable decoder output **LF**
161	2	0..255	RW	**Headlight 1 – Type** Emulation of specific equipment on output **LF**
162	2	0..255	RW	**Headlight 1 – Automation** Automation of decoder output **LF**
163	-	0..255	RW	**Headlight 1 – Parameter** Depending on *Automation* setting
164 165 166 167	0 2 3 -	0..68 0..255 0..255 0..255	RW	**Headlight 2** see CV160-163 CV164: FN#, CV165: type, CV166: automation, CV167: parameter
168 169 170 171	-	-	RW	**AUX 1** see CV160-163 CV168: FN#, CV169: type, CV170: automation, CV171: parameter
172 173 174 175	-	-	RW	**AUX 2** see CV160-163 CV172: FN#, CV173: type, CV174: automation, CV175: parameter
176 177 178 179	-	-	RW	**AUX 3** see CV160-163 CV176: FN#, CV177: type, CV178: automation, CV179: parameter
180 181 182 183	-	-	RW	**AUX 4** see CV160-163 CV180: FN#, CV181: type, CV182: automation, CV183: parameter
184 185 186 187	-	-	RW	**AUX 5** see CV160-163 CV184: FN#, CV185: type, CV186: automation, CV187: parameter
188 189 190 191	-	-	RW	**AUX 6** see CV160-163 CV188: FN#, CV189: type, CV190: automation, CV191: parameter
192 193 194 195	-	-	RW	**AUX 7** see CV160-163 CV192: FN#, CV193: type, CV194: automation, CV195: parameter
196 197 198 199	-	-	RW	**AUX 8** see CV160-163 CV196: FN#, CV197: type, CV198: automation, CV199: parameter

CV	Default	Range	RW	Description
200	135	0..255	RW	**SUSI option 1** Enable option to be sent to the SUSI slaves. Bit-0: Enable real velocity Bit-1: Enable set velocity Bit-2: Enable load Bit-3: - Bit-4: - Bit-5: - Bit-6: - Bit-7: Enable Group1 (F0-F4)
201	3	0..255	RW	**SUSI option 2** Enable function groups to be sent to the SUSI slaves. Bit-0: Enable Group2 (F5-F12) Bit-1: Enable Group3 (F13-F20) Bit-2: Enable Group4 (F21-F28) Bit-3: Enable Group5 (F29-F36) Bit-4: Enable Group6 (F37-F44) Bit-5: Enable Group7 (F45-F53) Bit-6: Enable Group3 (F54-F60) Bit-7: Enable Group3 (F61-F68)
202	0	0..255	RW	**SUSI clock speed** The SUSI standard defines 10..500[us]. 0: SUSI off 1..255: Cycle time = (10 + value)[us]
203	120	0..255	RW	**Servo left boundary** Left boundary. (must be less than CV204) <128: Left to center 128: Center position >128: Right to center
204	136	0..255	RW	**Servo right boundary** Right boundary. (must be greater than CV203) <128: Left to center 128: Center position >128: Right to center
205	128	0..255	RW	**Servo speed** Sets the motion speed of the servo. <128: slower 128: mid-point >128: faster
206	128	0..255	RW	**Servo position** Sets the target position of the servo within the boundaries defined by [CV203...CV204].
207	(4*16) + (4)	0..255	RW	**Coupler – attach (distance)** Attach motion path definition. Lower nibble: Millimeters (push) Upper nibble: Millimeters (pull)
208	(8*16) + (8)	0..255	RW	**Coupler – attach (speed)** Attach motion path definition. Lower nibble: Speed [step/126] (push) Upper nibble: Speed [step/126] (pull)

CV	Default	Range	RW	Description
209	(4*16) + (4)	0..255	RW	**Coupler – detach (distance)** Detach motion path definition. Lower nibble: Millimeters (push) Upper nibble: Millimeters (pull)
210	(8*16) + (8)	0..255	RW	**Coupler – detach (speed)** Detach motion path definition. Lower nibble: Speed [step/126] (push) Upper nibble: Speed [step/126] (pull)

14.2 Page 1

This page uses little endian numbers.

CV	Default	Range	RW	Description	
257	9	-	RO	**Extended vendor ID** (LB)	Same as CV 107..108
258	1	-	RO	**Extended vendor ID** (HB)	
261	-	-	RO	**PID** (LB)	**Product ID** The PID is the concatenation of the VID and HID. (same as CV 97..100) PID = (VID << 16 + HID)
262	-	-	RO	**PID**	
263	-	-	RO	**PID**	
264	-	-	RO	**PID** (HB)	
265	-	-	RO	**DID** (LB)	**32bit Decoder ID** Same as CV 101..104
266	-	-	RO	**DID**	
267	-	-	RO	**DID**	
268	-	-	RO	**DID** (HB)	
269	-	0..255	RO	**Acc.X.lb**	**3-axis accelerometer**
270	-	0..255	RO	**Acc.X.hb**	
271	-	0..255	RO	**Acc.Y.lb**	
272	-	0..255	RO	**Acc.Y.hb**	
273	-	0..255	RO	**Acc.Z.lb**	
274	-	0..255	RO	**Acc.Z.hb**	
275	-	0..255	RO	**Mag.X.lb**	**3-axis magnetic field**
276	-	0..255	RO	**Mag.X.hb**	
277	-	0..255	RO	**Mag.Y.lb**	
278	-	0..255	RO	**Mag.Y.hb**	
279	-	0..255	RO	**Mag.Z.lb**	
280	-	0..255	RO	**Mag.Z.hb**	
281	-	0..255	RO	**Gyr.X.lb**	**3-axis gyroscope**
282	-	0..255	RO	**Gyr.X.hb**	
283	-	0..255	RO	**Gyr.Y.lb**	
284	-	0..255	RO	**Gyr.Y.hb**	
285	-	0..255	RO	**Gyr.Z.lb**	
286	-	0..255	RO	**Gyr.Z.hb**	
287	-	0..255	RO	**Eul.H.lb**	**Euler Angles** H: heading R: roll P: pitch
288	-	0..255	RO	**Eul.H.hb**	
289	-	0..255	RO	**Eul.R.lb**	
290	-	0..255	RO	**Eul.R.hb**	
291	-	0..255	RO	**Eul.P.lb**	
292	-	0..255	RO	**Eul.P.hb**	
293	-	0..255	RO	**Qua.W.lb**	**Quaternion**
294	-	0..255	RO	**Qua.W.hb**	
295	-	0..255	RO	**Qua.X.lb**	
296	-	0..255	RO	**Qua.X.hb**	
297	-	0..255	RO	**Qua.Y.lb**	
298	-	0..255	RO	**Qua.Y.hb**	
299	-	0..255	RO	**Qua.Z.lb**	
300	-	0..255	RO	**Qua.Z.hb**	
301	-	0..255	RO	**Lia.X.lb**	

CV	Default	Range	RW	Description	
302	-	0..255	RO	**Lia.X.hb**	
303	-	0..255	RO	**Lia.Y.lb**	
304	-	0..255	RO	**Lia.Y.hb**	
305	-	0..255	RO	**Lia.Z.lb**	
305	-	0..255	RO	**Lia.Z.hb**	
307	-	0..255	RO	**Grv.x.lb**	**Gravity vector**
308	-	0..255	RO	**Grv.X.hb**	
309	-	0..255	RO	**Grv.Y.lb**	
310	-	0..255	RO	**Grv.Y.lb**	
311	-	0..255	RO	**Grv.Z.lb**	
312	-	0..255	RO	**Grv.Z.hb**	
313	-	0..255	RO	**BNO.temp**	BNO temperature
314	-	0..255	RO	**BNO.calib**	BNO calibration status
315	-	0..255	RO	**BNO.stres**	BNO reset
316	-	0..255	RO	**BNO.stat**	BNO status
317	-	0..255	RO	**BNO.err**	BNO error code
318	-	0..255	RO	**Euler.H.lb**	**Heading** (16 bit) 0..359 degrees (step 1/16th)
319	-	0..255	RO	**Euler.H.hb**	
320	-	0..255	RO	**Euler.P.lb**	**Pitch** -12.7 .. +12.7 degrees (step 0.1)
321	-	0..255	RO	**Euler.R.lb**	**Roll** -12.7 .. +12.7 degrees (step 0.1)
327	-	0..255	RO	**MCU voltage**	**Voltage = CV * 40 [mV]** Only valid for AVGxxDDyy based decoder otherwise zero.
328	-	0..255	RO	**Distance Integral (LB)**	**Distance integral** 32bit Note: Should be read via xPOM to get the 32-bits atomically.
329	-	0..255	RO	**Distance Integral**	
330	-	0..255	RO	**Distance Integral**	
331	-	0..255	RO	**Distance Integral (HB)**	
332	-	0..255	RO	**Current Speed [LB]**	**Speed [mm/s]** 16bit Note: Should be read via xPOM to get the 16-bits atomically.
333	-	0.255	RO	**Current Speed [HB]**	
334	0	0..255	RO	**DCC frame counter (LB)**	**DCC frame counter** 32bit Note: Should be read via xPOM to get the 32-bits atomically.
335	0	0..255	RO	**DCC frame counter**	
336	0	0..255	RO	**DCC frame counter**	
337	0	0..255	RO	**DCC frame counter (HB)**	
338	0	0..255	RO	**DCC bit error counter (LB)**	**Bit timing errors** 16bit Bit timing violating RCN-210 will be counted. Wraps after 0xffff.
339	0	0..255	RO	**DCC bit error counter (HB)**	
340	0	0..255	RO	**DCC xor error counter (LB)**	**DCC cmd xor errors** 16bit Any RCN-211 XOR error will be counted. Wraps after 0xffff.
341	0	0..255	RO	**DCC xor error counter (HB)**	

CV	Default	Range	RW	Description	
342	0	0..255	RO	**DCC len error counter (LB)**	**DCC cmd len errors** 16bit Unknown DCC cmd length will be counted. Wraps after 0xffff.
343	0	0..255	RO	**DCC len error counter (HB)**	
344	-	90..119	RO	**DCC start bit-0 (1st half)**	**Timing** Half bit timing = value[us]
345	-	90..119	RO	**DCC start bit-0 (1st half)**	
346	-	90..119	RO	**DCC bit-0 (1st half)**	
347	-	90..119	RO	**DCC bit-0 (2nd half)**	
348	-	52..64	RO	**DCC bit-1 (1st half)**	
349	-	52..64	RO	**DCC bit-1 (2nd half)**	
350	-	26..32	RO	**Railcom Cutout TCS** TCS = value[us]	
351	-	54..88	RO	**Railcom Cutout TCE** TCE = (400 + value)[us]	
352	-	20..255	RO	**DCC Preamble half bit count** Measured in half bits [20..254]: half bit count [255]: more than 254 half bits	
353	-	0,255	RO	**DCC polarity** First half of <DCC start bit> on TRK-R (RCN-210) [0]: negative (falling edge) [255]: positive (rising edge)	
354	-	0..255	RO	**DCC frames per second** Each successful detection of 20 (or more) preamble half-bits is counted as a frame. The counter is updated once per second. The central station typically transmits 100–120 DCC frames per second. The higher the value, the better.	
355	-	0..255	RO	**DCC addressings per second** Every DCC command sent to this decoder is counted. The counter is updated once per second. This measures how many commands are sent to this decoder per second. The decoder can respond to each of these commands via RailCom channel 2.	
356	-	0..255	RO	**Voltage right track** The unit of Value is decivolt. Example: 160 yields 16.0V Value = Track Voltage[mV] / 100	
357	-	0..255	RO	**Voltage left track** The unit of Value is decivolt. Example: 125 yields 12.5V Value = Track Voltage[mV] / 100	
358	-	0..255	RO	**Track voltage delta (R-track vs. L-track)** The unit of Delta is decivolt. The midpoint is 128. Value = (Voltage(R) – Voltage(L)) + 128 *Example:* *128 yields 0.0V* *120 yields -0.8V* *140 yields +1.2V*	

CV	Default	Range	RW	Description	
359	-	0..255	RO	**Decoder Reset reason** Source of the last decoder MPU reset. Bit-0: (POR) Power-on Reset Bit-1: (BOR) Brown-out Reset Bit-2: - Bit-3: (WDR) Watchdog Reset Bit-4: (SWR) Software Reset Bit-5: - Bit-6: - Bit-7: -	
360	0	0..255	RO	**Watchdog Reset counter** Counts the number of WDR events, indicating a potential decoder firmware issue. This counter should be always zero and wrap after 255.	
361	0	0..255	RO	**Brownout Reset counter** Counts the number of BOR events, indicating power glitches. This counter typically increases while mobile decoders are in motion and wrap after 255.	
362	0	0..255	RO	**Software Reset counter** Counts the number of SWR events. This counter increases if the decoder is requested to reset itself. The counter wrap after 255	
363	0	0..255	RO	**CPU reset counter (LB)**	Counts the number of CPU resets. The counter is set to zero after every Power-On-Reset (POR).
364	0	0..255	RO	**CPU reset counter (HB)**	
365	255	0..255	RO	**Firmware error code** Error conditions within the firmware are signaled here.	
366	-	0..255	RO	**IDLE stack**	Minimum stack free space per task. Value should be bigger than 2 for safety reason.
367	-	0..255	RO	**TASK-0 stack**	
368	-	0..255	RO	**TASK-1 stack**	
369	-	0..255	RO	**TASK-2 stack**	
370	-	0..255	RO	**TASK-3 stack**	
371	-	0..255	RO	**TASK-4 stack**	
372	-	0..255	RO	**TASK-5 stack**	
373	-	0..255	RO	**TASK-6 stack**	
374	-	0..255	RO	**TASK-7 stack**	
375	-	0..255	RO	**CID (LB)**	Central ID broadcast via DCC-A or DCC-R protocol.
376	-	0..255	RO	**CID (HB)**	
377	-	0..255	RO	**SID**	Session ID broadcast via DCC-A or DCC-R protocol.
378	-	0..255	RO	**Active DCC Address (LB)**	Activated primary-DCC address
379	-	0..255	RO	**Active DCC Address (HB)**	
380	-	0..255	RO	**Active DCC Address (LB)**	Activated consist-DCC address
381	-	0..255	RO	**Active DCC Address (HB)**	
382	85	85	RO	**Indicates 'end of CV list'**	

14.3 Page 2

This page uses big-endian numbers.

CV	Default	Range	RW	Description
513 514 515 516	-	-	RW	**PORT 1** see CV160-163 CV513: FN#, CV514: type, CV515: automation, CV516: parameter
517 518 519 520	-	-	RW	**PORT 2** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
521 522 523 524	-	-	RW	**PORT 3** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
525 526 527 528	-	-	RW	**PORT 4** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
529 530 531 532	-	-	RW	**PORT 5** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
533 534 535 536	-	-	RW	**PORT 6** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
537 538 539 540	-	-	RW	**PORT 7** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
541 542 543 544	-	-	RW	**PORT 8** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
545 546 547 548	-	-	RW	**PORT 9** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
549 550 551 552	-	-	RW	**PORT 10** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
553 554 555 556	-	-	RW	**PORT 11** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
557 558	-	-	RW	**PORT 12**

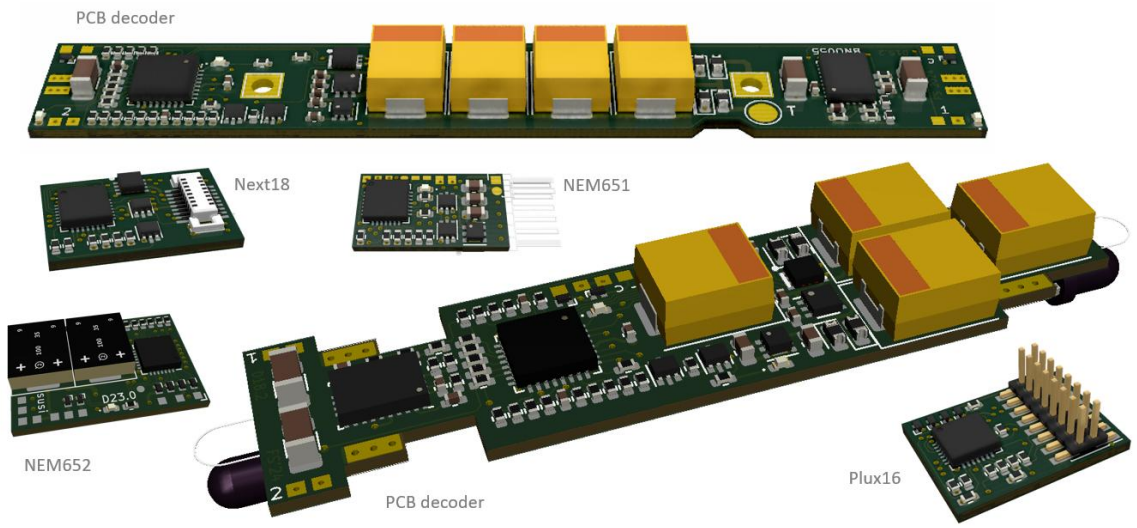
CV	Default	Range	RW	Description
559 560				see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
561 562 563 564	-	-	RW	**PORT 13** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
565 566 567 568	-	-	RW	**PORT 14** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
569 570 571 572	-	-	RW	**PORT 15** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
573 574 575 576	-	-	RW	**PORT 16** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
577 578 579 580	-	-	RW	**PORT 17** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
581 582 583 584	-	-	RW	**PORT 18** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
585 586 587 588	-	-	RW	**PORT 19** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
589 590 591 592	-	-	RW	**PORT 20** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
593 594 595 596	-	-	RW	**PORT 21** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
597 598 599 600	-	-	RW	**PORT 22** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
601 602 603 604	-	-	RW	**PORT 23** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
605 606 607	-	-	RW	**PORT 24** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter

CV	Default	Range	RW	Description
608				
609 610 611 612	-	-	RW	**PORT 25** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
613 614 615 616	-	-	RW	**PORT 26** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
617 618 619 620	-	-	RW	**PORT 27** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
621 622 623 624	-	-	RW	**PORT 28** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
625 626 627 628	-	-	RW	**PORT 29** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
629 630 631 632	-	-	RW	**PORT 30** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
633 634 635 636	-	-	RW	**PORT 31** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
637 638 639 640	-	-	RW	**PORT 32** see CV160-163 CV517: FN#, CV518: type, CV519: automation, CV520: parameter
641	255	0..255	RW	**Port Testing PWM duty** Set the PWM duty range used for port testing. bit0-3: min PWM bit4-7: max PWM
642	0	0,1-32, 255	RW	**Port Testing Index** The port index set in this CV activates the port. This is for testing the hardware or locating an individual LED on the PCB. To deactivate this test function, set this CV to zero. **Warning**: The port(s) remain activated until the CV is set to zero or a decoder power cycle. This could be important for devices (e.g. couplers) that must not operate permanently.

CV	Default	Range	RW	Description
				0: off (normal operation) 1-32: port# activated 255: all 32 ports activated
643	0	0,1	RW	**Port Bus** Selects the output bus mode. 0: HC595 mode (Shift Register Mode) 1: WS28xx mode (Neo Pixel Mode)

15 Decoder Hardware

All decoders share the same code base and therefore similar functionality.



PCB decoder

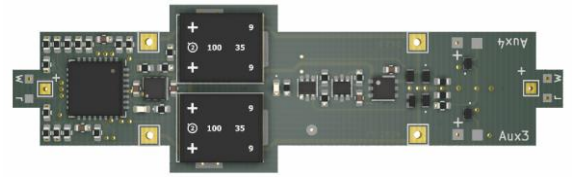
Decoder Type	PCB	Socket		Model
Motor	C12.x	PCB	V100	Fleischmann 7230
LED	C13.x	PCB	Coach	Minitrix 15795
Motor	C14.x	PCB	V200	Minitrix 12402
Motor	C15.x	PCB	V160	Minitrix 12460
Motor	C17.x	PCB	E10/E40	Minitrix
Motor	C18.x	PCB	E10/E40	Hobbytrain

Standard NEM decoder

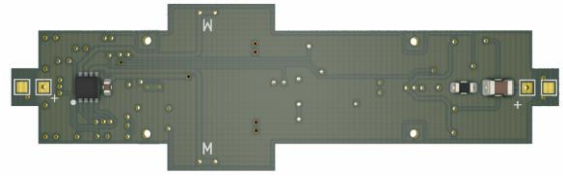
Decoder Type	PCB	Socket		Dimensions[mm]	Comment
Motor	C16.x	NEM 651	6-pin	17 x 11	single sided
Motor	C20.x	NEM 651	6-pin	14 x 8	double sided
Motor	C21.x	NEM 662	Next18	15 x 9	double sided
Motor	C22.x	NEM 658	Plux-16	15 x 11	double sided
Motor	C23.x	NEM 652	8-pin	19 x 13	double sided

15.1 D12 (Fleischmann #7230)

Drop-in PCB replacement for Fleischmann #7230 (V100).



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d12
GitHub: https://github.com/git4dcc/RTB_D12

15.1.1 Hardware

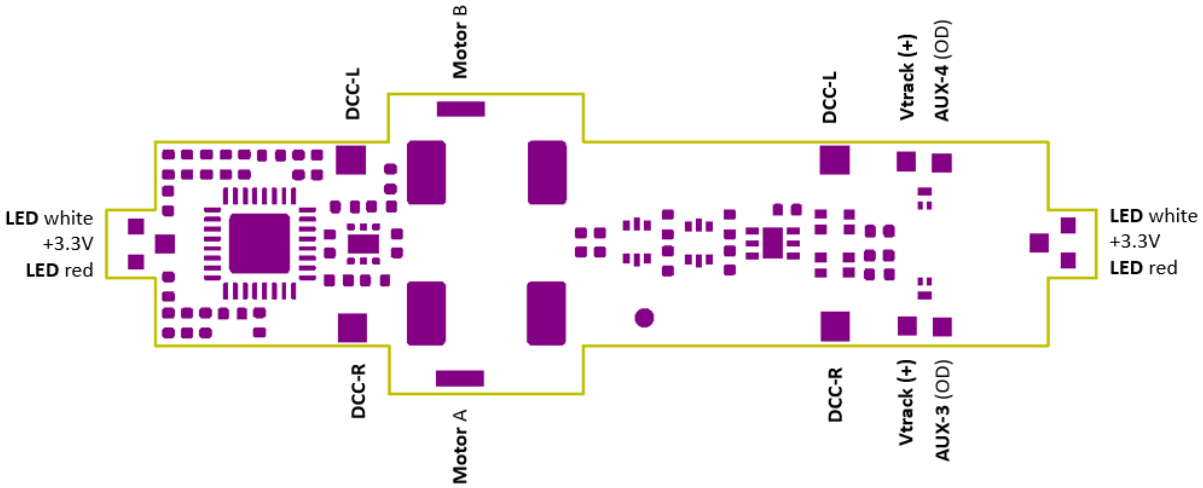
- 7-18V track voltage
- <10mA idle power consumption
- heartbeat LED
- adjustable motor current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable headlights)
- Function output: AUX1/AUX2 (dimmable taillights)
- Function output: AUX3/AUX4 open drain
- Function output: AUX5 for driver cabin (LEDs on PCB)
- onboard 2x 330uF buffer capacity
- inrush limited

15.1.2 Firmware

- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - CPU load
    - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.1.3 Ports

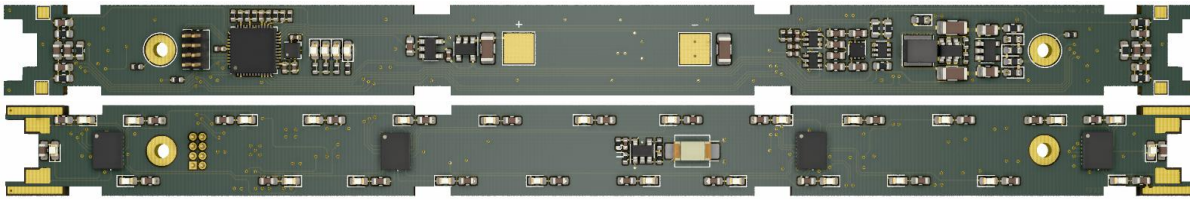
Pad		Description	Note
LED x	LL	Logic level IO for the front/rear LEDs of the loco	
+3.3V		3.3V for the front/rear LEDs of the loco	
AUX3	OD	Open drain can sink up to 250mA from Vtrack	
AUX4	OD		
Vtrack		Track voltage after rectifier	
DCC L/R		DCC track (left/right) connection	
Motor A/B		Motor connection	



Example configuration here.

15.2 D13 (Minitrix LED Decoder #15795)

LED Decoder tailored for Minitrix (#15795) 2nd class couchette.



Online: https://rtb4dcc.de/hardware/decoder/d13
GitHub: https://github.com/git4dcc/RTB_D13

15.2.1 Hardware

- 7-24V track voltage
- <10mA total with all LEDs at 100% intensity
- heartbeat LED
- 26 independent LEDs (aisle, cabin, lavatory)
- 4 independent tail LEDs (2x front, 2x rear)
- Ambient light sensor
- on board 4F SuperCap buffer enable/disable by software (inrush limited)
- Railcom sender/receiver
- motion sensor

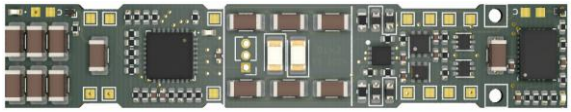
15.2.2 Firmware

- DCC, DCC-A, DCC-R
    - SDF (Speed, Direction, Function) support
    - ‘Long 3’ programming address support
    - consist (short & long address)
- Railcom (RCN-217)
    - Railcom collision detection
    - DCC Logon (DCC-A / DCC-R)
    - Read/Write: POM, xPOM
    - DYN
        - QoS
        - Temperature
        - Track voltage
        - Ambient light
        - SuperCap charge %
        - CPU load
        - MTK context switches/sec
- Software update via DCC-R on main tracks
- Light animations
- Service mode programming (RCN-216)

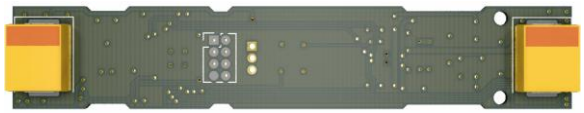
Example configuration here.

15.3 D14 (Minitrix #12402)

Drop-in PCB replacement for Minitrix #12402 (V200).



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d14
GitHub: https://github.com/git4dcc/RTB_D14

15.3.1 Hardware

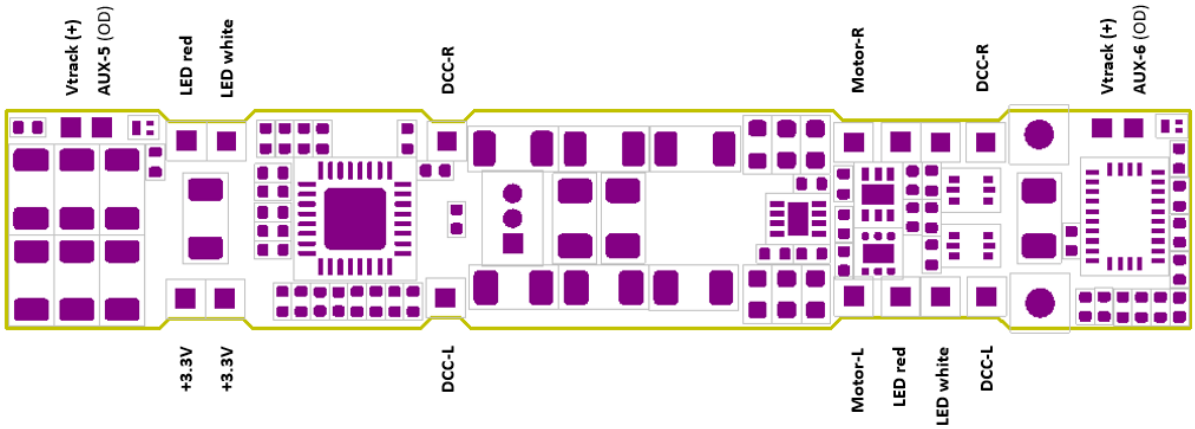
- 7-18V track voltage
- <10mA idle power consumption (~20mA with motion sensor active)
- heartbeat LED
- adjustable motor current (default 400mA)
- over temp protection
- Function output: LV/LR (dimmable headlights)
- Function output: AUX1/AUX2 (dimmable taillights)
- Function output: AUX3/AUX4 for driver cabin (LEDs on PCB)
- Function output: AUX5, AUX6 open drain
- onboard 2x 330uF + 12x 47uF buffer capacity (inrush limited)
- optional 9-axis motion sensor

15.3.2 Firmware

- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - CPU load
    - MTK context switches/sec
    - XYZ coordinates (Euler / Quaternion)
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.3.3 Ports

Pad		Description	Note
LED x	LL	Logic level IO for the front/rear LEDs of the loco	
+3.3V		3.3V for the front/rear LEDs of the loco	
AUX5	OD	Open drain can sink up to 250mA from Vtrack	
AUX6	OD		
Vtrack		Track voltage after rectifier	A capacitor (up to 4700uF) may be connected
GND		Decoder GND	
DCC L/R		DCC track (left/right) connection	
Motor L/R		Motor (left/right) connection	



Example configuration here.

15.4 D15 (Minitrix 12460)

Drop-in PCB replacement for Minitrix 12460 (V160).

Top view

Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d15
GitHub: https://github.com/git4dcc/RTB_D15

15.4.1 Hardware

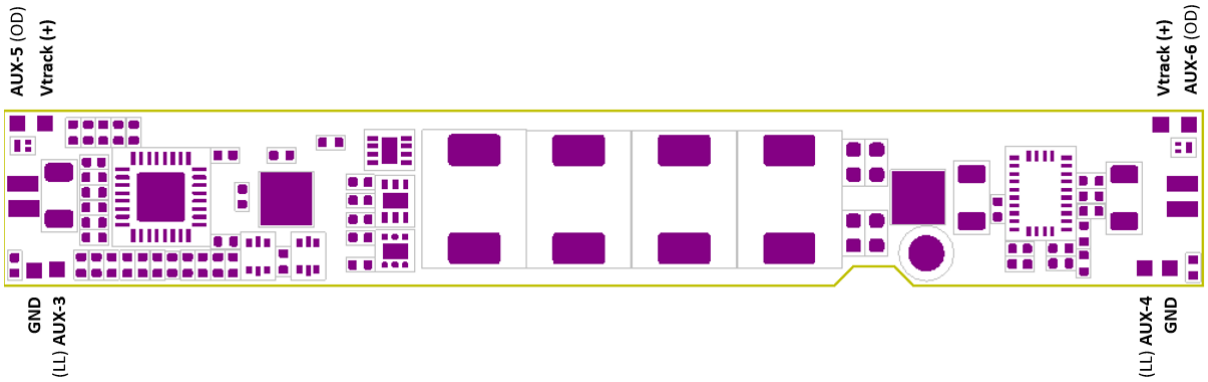
- 7-18V track voltage
- <10mA idle power consumption (~20mA with motion sensor active)
- heartbeat LED
- adjustable max motor current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable headlights)
- Function output: AUX1/AUX2 (dimmable) for driver cabin (LEDs on PCB)
- Function output: AUX3/AUX4 logic level
- Function output: AUX5/AUX6 open drain
- onboard 4x 330uF buffer capacity (inrush limited)
- optional 9-axis motion sensor

15.4.2 Firmware

- DCC, DCC-A, DCC-R
    - SDF (Speed, Direction, Function) support
    - ‘Long 3’ programming address support
    - consist support (short & long address)
- Railcom (RCN-217)
    - DCC Logon (DCC-A / DCC-R)
    - Read/Write: POM, xPOM
    - DYN
        - Speed
        - QoS
        - Temperature
        - Track voltage
        - Motor current
        - CPU load
        - MTK context switches/sec
        - XYZ coordinates (Euler / Quaternion)
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

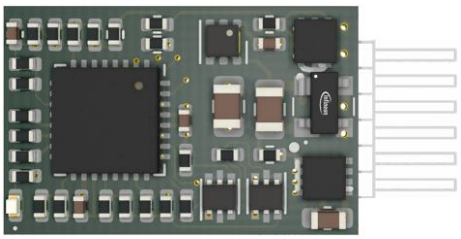
15.4.3 Ports

Pad		Description	Note
AUX3	LL	3.3V logic level IO and can drive LEDs directly	
AUX4	LL		
AUX5	OD	Open drain can sink up to 250mA from Vtrack	
AUX6	OD		
Vtrack		Track voltage after rectifier	A capacitor (up to 4700uF) may be connected
GND		Decoder GND	

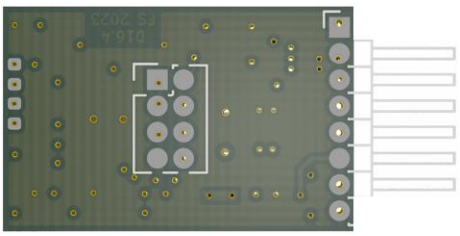


15.5 D16 (NEM-651 Decoder)

Universal Loco Decoder with 6pin (NEM 651) plug.



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d16
GitHub: https://github.com/git4dcc/RTB_D16

15.5.1 Hardware

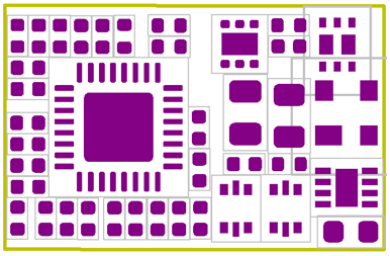
- Single side
- Dimension: 17 x 11 mm
- 7-28V track voltage
- heartbeat LED
- adjustable max motor current (default 500mA)
- adjustable max AUX current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable) open drain
- Function output: AUX1/AUX2/AUX3 logic level (3.3V)
- optional external buffer capacitor (max. 1500uF)
- <10mA idle power consumption

15.5.2 Firmware

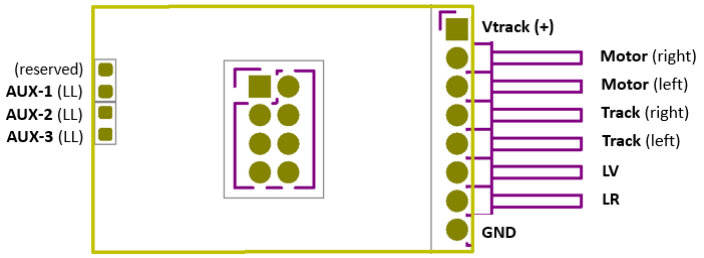
- DCC, DCC-A, DCC-R
    - SDF (Speed, Direction, Function) support
    - ‘Long 3’ programming address support
    - consist (short & long address)
- Railcom (RCN-217)
    - DCC Logon (DCC-A / DCC-R)
    - Read/Write: POM, xPOM
    - DYN
        - Speed
        - QoS
        - Temperature
        - Track voltage
        - Motor current
        - AUX current
        - CPU load
        - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.5.3 Ports

Pad		Description	Note
AUX1	LL	3.3V logic level IO can drive LEDs directly	
AUX2	LL	3.3V logic level IO can drive LEDs directly	
AUX3	LL	3.3V logic level IO can drive LEDs directly	
Vtrack		Track voltage after rectifier	A capacitor (up to 4700uF) may be connected
GND		Decoder GND	



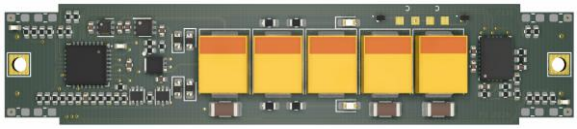
Top view



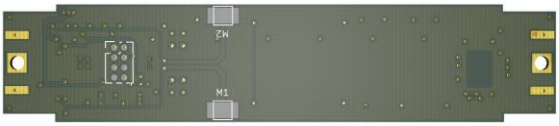
Bottom view

15.6 D17 (Minitrix E10/E40)

Drop-in PCB replacement for Minitrix E10/E40 series.



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d17
GitHub: https://github.com/git4dcc/RTB_D17

15.6.1 Hardware

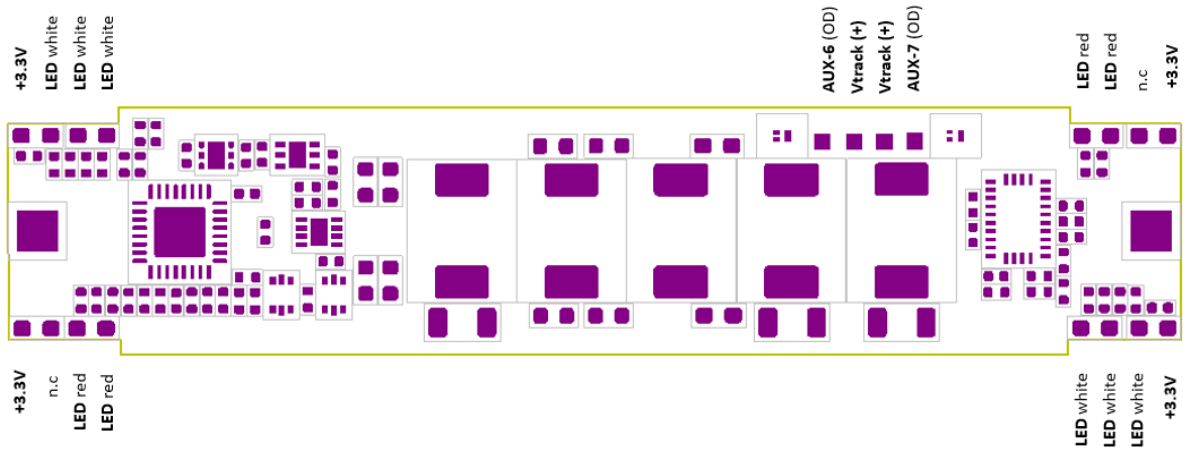
- 7-18V track voltage
- <10mA idle power consumption (~20mA with motion sensor active)
- heartbeat LED
- adjustable max motor current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable headlights)
- Function output: AUX1/AUX2 (dimmable taillights)
- Function output: AUX3/AUX4 for driver cabin (LEDs on PCB)
- Function output: AUX5 engine light (LEDs on PCB)
- Function output: AUX6, AUX7 open drain
- onboard 5x 330uF buffer capacity (inrush limited)
- optional 9-axis motion sensor

15.6.2 Firmware

- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - CPU load
    - MTK context switches/sec
    - XYZ coordinates (Euler / Quaternion)
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.6.3 Ports

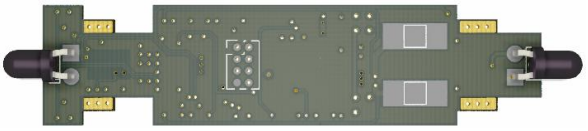
Pad		Description	Note
LED x	LL	Logic level IO for the front/rear LEDs of the loco	
+3.3V		3.3V for the front/rear LEDs of the loco	
AUX5	OD	Open drain can sink up to 250mA from Vtrack	
AUX6	OD		
Vtrack		Track voltage after rectifier	A capacitor (up to 4700uF) may be connected
GND		Decoder GND	



15.7 D18 (Hobbytrain E10/E40)

Drop-in PCB replacement for Hobbytrain E10/E40 series.

Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d18
GitHub: https://github.com/git4dcc/RTB_D18

15.7.1 Hardware

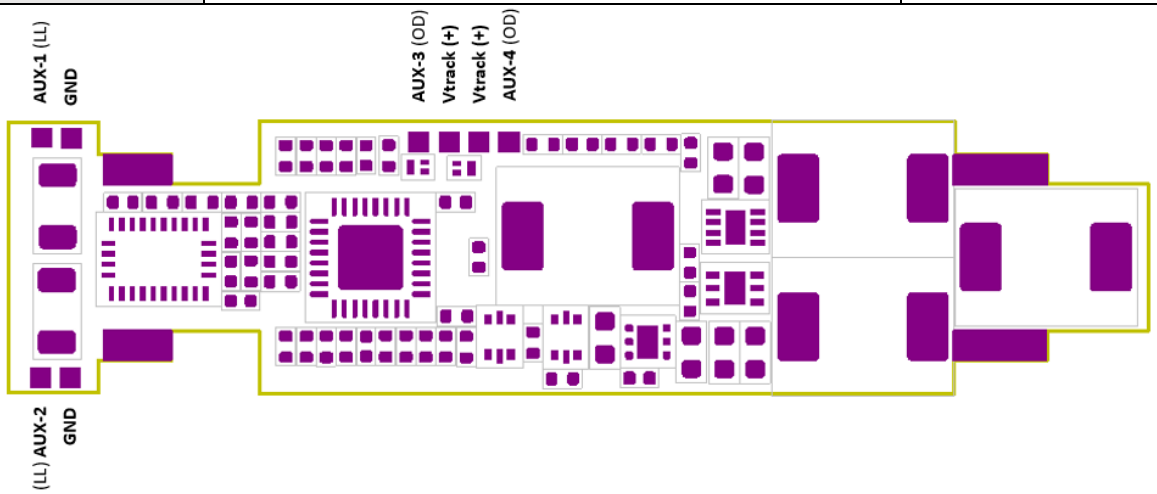
- 7-18V track voltage
- <10mA idle power consumption (~20mA with motion sensor active)
- heartbeat LED
- adjustable max motor current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable headlights)
- Function output: AUX1/AUX2 (dimmable) logic level (3.3V)
- Function output: AUX3, AUX4 open drain
- Function output: AUX5 engine room (LEDs on PCB)
- onboard 4x 330uF buffer capacity (inrush limited)
- optional 9-axis motion sensor

15.7.2 Firmware

- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN data
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - CPU load
    - MTK context switches/sec
    - XYZ coordinates (Euler / Quaternion)
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

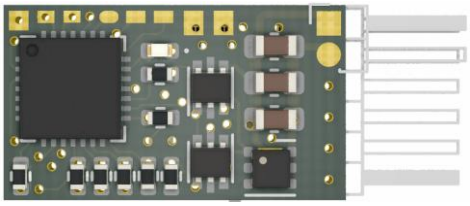
15.7.3 Ports

Pad		Description	Note
AUX1	LL	3.3V logic level IO and can drive LEDs directly	
AUX2	LL		
AUX3	OD	Open drain can sink up to 250mA from Vtrack	
AUX4	OD		
Vtrack		Track voltage after rectifier	A capacitor (up to 4700uF) may be connected
GND		Decoder GND	

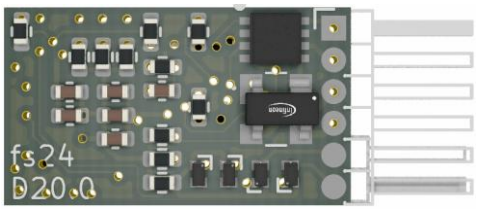


15.8 D20 (NEM-651 Decoder)

Universal Loco Decoder with 6-pin (NEM 651) plug.



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d20
GitHub: https://github.com/git4dcc/RTB_D20

15.8.1 Hardware

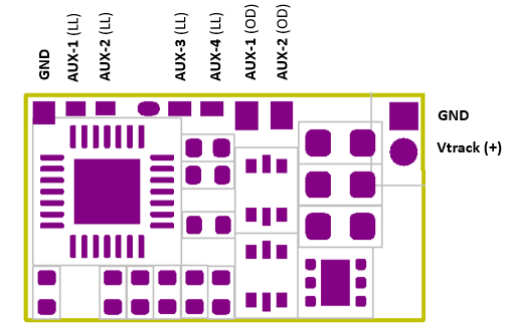
- Dimension: 14 x 8 mm, double sided
- 7-28V track voltage
- <10mA idle power consumption
- heartbeat LED
- adjustable max motor current (default 500mA)
- adjustable max AUX current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable)
- Function output: AUX1/AUX2 logic level (3.3V) and open drain
- Function output: AUX3/AUX4 logic level (3.3V)
- optional external buffer capacitor

15.8.2 Firmware

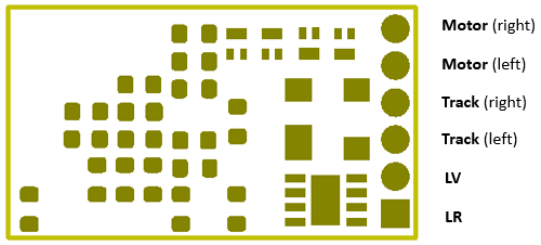
- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - AUX current
    - CPU load
    - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.8.3 Ports

Pad		Description	Note
AUX1	LL	3.3V logic level IO (may drive LED)	
	OD	can sink up to 250mA from Vtrack	
AUX2	LL	3.3V logic level IO (may drive LED)	
	OD	can sink up to 250mA from Vtrack	
AUX3	LL	3.3V logic level IO (may drive LED)	
AUX4	LL	3.3V logic level IO (may drive LED)	
Vtrack		Track voltage after rectifier	A capacitor (up to 1500uF) may be connected
GND		Decoder GND	



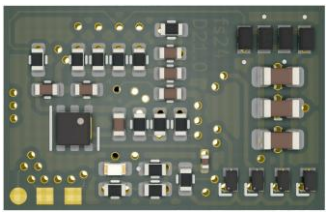
Top view



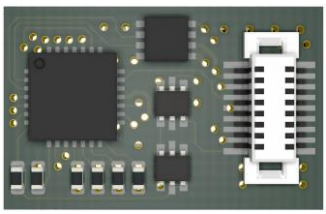
Bottom view

15.9 D21 (Next18 Decoder)

Universal Loco Decoder with Next18 (NEM 662) plug.



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d21
GitHub: https://github.com/git4dcc/RTB_D21

15.9.1 Hardware

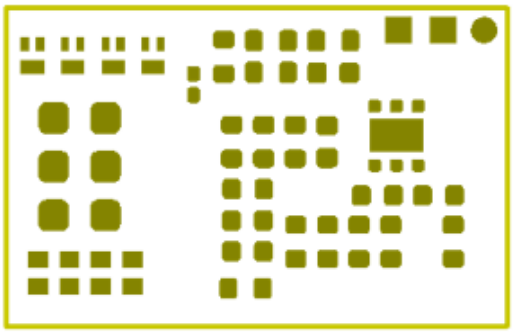
- Dimension: 15 x 9 mm, double sided
- 7-28V track voltage
- <10mA idle power consumption
- heartbeat LED
- adjustable max motor current (default 500mA)
- adjustable max AUX current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable)
- Function output: AUX1/AUX2 (dimmable) logic level (3.3V) and open drain
- Function output: AUX3/AUX4 logic level (3.3V) or SUSI3
- Function output: AUX5/AUX6 logic level (3.3V)
- optional external buffer capacitor

15.9.2 Firmware

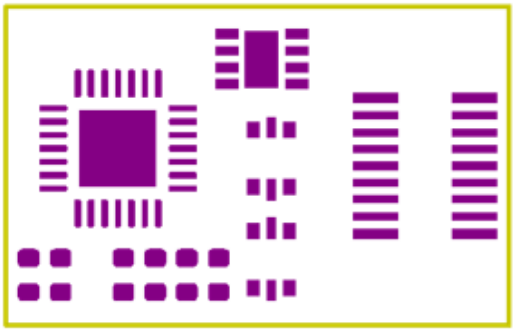
- DCC, DCC-A, DCC-R
    - SDF (Speed, Direction, Function) support
    - ‘Long 3’ programming address support
    - consist (short & long address)
- Railcom (RCN-217)
    - DCC Logon (DCC-A / DCC-R)
    - Read/Write: POM, xPOM
    - DYN
        - Speed
        - QoS
        - Temperature
        - Track voltage
        - Motor current
        - AUX current
        - CPU load
        - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.9.3 Ports

Pad		Description	Note
F0_f	OD	can sink up to 250mA from Vtrack	pin 8
F0_r	OD	can sink up to 250mA from Vtrack	pin 17
AUX1	OD	can sink up to 250mA from Vtrack	pin 3
AUX2	OD	can sink up to 250mA from Vtrack	pin 12
AUX3	LL	3.3V logic level outputs or SUSI3.clk	pin 4
AUX4	LL	3.3V logic level outputs or SUSI3.dat	pin 13
AUX5	LL	3.3V logic level outputs	pin 16
AUX6	LL	3.3V logic level outputs	pin 7
Vtrack		Track voltage after rectifier	A capacitor (up to 1500uF) may be connected
GND		Decoder GND	



Top view

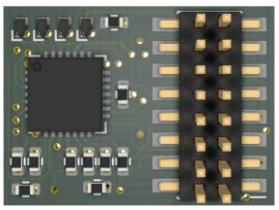


Bottom view

15.10 D22 (Plux16 Decoder)

Universal Loco Decoder with Plux16 (NEM 658) plug.

Top view


Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d22
GitHub: https://github.com/git4dcc/RTB_D22

15.10.1 Hardware

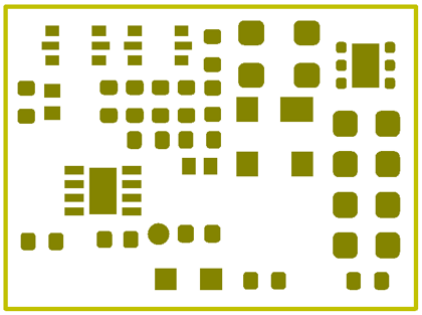
- Dimension: 15 x 11 mm, double sided
- 7-28V track voltage
- <10mA idle power consumption
- heartbeat LED
- adjustable max motor current (default 500mA)
- adjustable max AUX current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable)
- Function output: AUX1/AUX2 (dimmable) logic level (3.3V) and open drain
- Function output: AUX3/AUX4 logic level (3.3V)
- Function output: AUX5/AUX6 logic level (3.3V) or SUSI3
- optional external buffer capacitor

15.10.2 Firmware

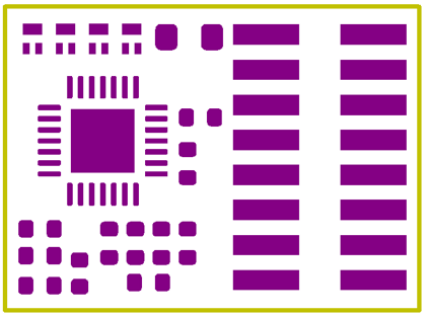
- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - AUX current
    - CPU load
    - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.10.3 Ports

Pad		Description	Note
F0_f	OD	can sink up to 250mA from Vtrack	pin 7
F0_r	OD	can sink up to 250mA from Vtrack	pin 13
AUX1	OD	can sink up to 250mA from Vtrack	pin 16
AUX2	OD	can sink up to 250mA from Vtrack	pin 18
AUX3	LL	3.3V logic level outputs	pin 15
AUX4	LL	3.3V logic level outputs	pin 17
AUX5	LL	3.3V logic level outputs or SUSI3.clk	pin 3
AUX6	LL	3.3V logic level outputs or SUSI3.dat	pin 4
Vtrack		Track voltage after rectifier	A capacitor (up to 1500uF) may be connected
GND		Decoder GND	



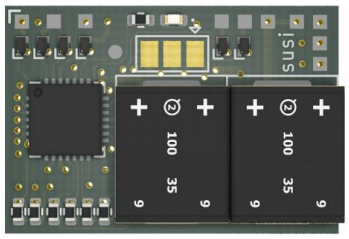
Top view



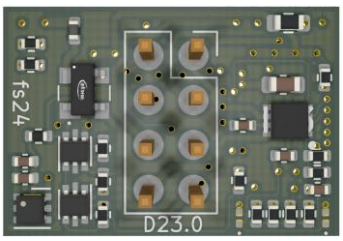
Bottom view

15.11 D23 (NEM652 Decoder)

Universal Loco Decoder with 8-pin (NEM 652) direct plug.



Top view



Bottom view

Online: https://rtb4dcc.de/hardware/decoder/d23
GitHub: https://github.com/git4dcc/RTB_D23

15.11.1 Hardware

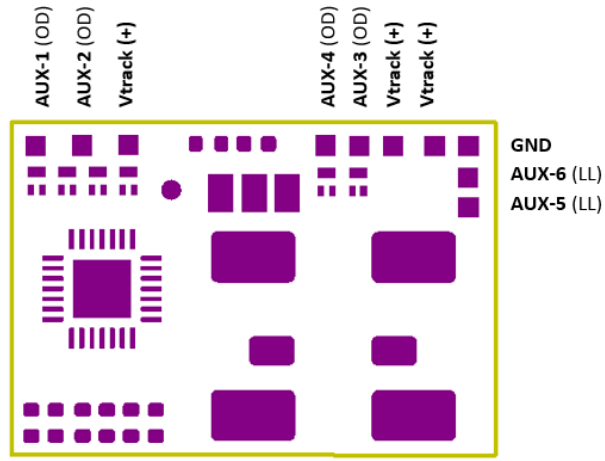
- Dimension: 19 x 13 mm, double sided
- 7-28V track voltage
- <10mA idle power consumption
- heartbeat LED
- adjustable max motor current (default 500mA)
- adjustable max AUX current (default 500mA)
- over temp protection
- Function output: LV/LR (dimmable) open drain
- Function output: AUX1/AUX2 (dimmable) open drain
- Function output: AUX3/AUX4 open drain
- Function output: AUX5/AUX6 logic level (3.3V) or SUSI3
- 2x 100uF/35V buffer capacitor on PCB

15.11.2 Firmware

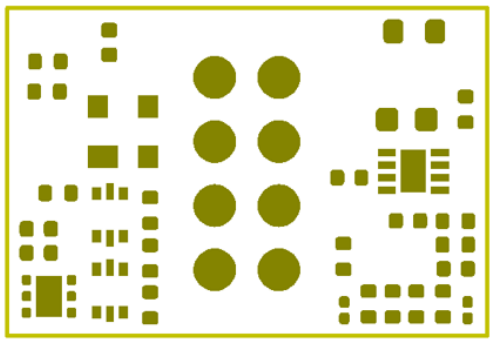
- DCC, DCC-A, DCC-R
  - SDF (Speed, Direction, Function) support
  - ‘Long 3’ programming address support
  - consist (short & long address)
- Railcom (RCN-217)
  - DCC Logon (DCC-A / DCC-R)
  - Read/Write: POM, xPOM
  - DYN
    - Speed
    - QoS
    - Temperature
    - Track voltage
    - Motor current
    - AUX current
    - CPU load
    - MTK context switches/sec
- Software update via DCC-R on main tracks
- Service mode programming (RCN-216)

15.11.3 Ports

Pad		Description	Note
F0_f	OD	can sink up to 250mA from Vtrack	pin 6
F0_r	OD	can sink up to 250mA from Vtrack	pin 2
AUX1	OD	can sink up to 250mA from Vtrack	pin 3
AUX2	OD	can sink up to 250mA from Vtrack	solder pad
AUX3	OD	can sink up to 250mA from Vtrack	solder pad
AUX4	OD	can sink up to 250mA from Vtrack	solder pad
AUX5	LL	3.3V logic level outputs or SUSI3.clk	solder pad
AUX6	LL	3.3V logic level outputs or SUSI3.dat	solder pad
Vtrack		Track voltage after rectifier	A capacitor (up to 1500uF) may be connected
GND		Decoder GND	



Top view



Bottom view

16 Trouble shooting

A collection of tips and tricks for when something doesn't work as expected.

16.1 Decoder cannot be programmed

Please check the decoder locking CVs described here. To unlock the decoder forcefully, set the CV as shown below.

```
CV15    =    255
```

16.2 Loco runs rough and dodgy

A rough and dodgy motor may indicate intermittent motor overcurrent shutdowns. Possible reasons may be,

- suppressor capacity (-> remove capacitor)
- dirty motor (-> clean motor)
- CV10 set to low (-> increase value above 100)

16.3 Loco does not move at all

- Check if the overcurrent bit is set in CV30. If so, there may be an electrical issue with the motor. Please check.
- Check if the maximum motor current is set appropriately (-> CV58)

16.4 Loco cannot drive slowly

For coreless motors, the motor driver must be enabled for this.

- For coreless motors (-> check the corresponding bit in CV55)

16.5 Loco is too slow

There may be multiple reasons for a slow driving loco. It could be caused by mechanical blockage or by misconfigured CV settings. In some cases, the loco is simply designed to drive slowly.

- Check if the motor driver is set to half speed (-> CV55)
- Check if motor driver speed tune is set too low (-> CV56)
- Check the max speed setting (-> CV5)

17 Function Output Automation

17.1 Type

#	Parameter	Description
0	-	**OFF** The port is always OFF.
1	-	**LED** The port shows instant ON/OFF behavior.
2	-	**Light bulb** Fade in/out behavior.
3	-	**Neon /w shimmer** Flickering start and light shimmer while ON to simulate high current environments (e.g. engine room in locomotive)
4	-	**Neon (KVG)** Much flickering during activation.
5	-	**Neon (VVG)** Reduced flicker during activation.
6	-	**Neon (EVG1)** Flicker free start but with some dim time.
7	-	**Neon (EVG2)** Slight variation of EVG1.
8	-	**Energy saving lamp** Very slow fade in.
9	-	**Emergency light** Very dim light.
10	-	**Mercury light (type A)** Pumping, slow start with some afterglow when switched off.
11	-	**Mercury light (type B)** Pumping, slow start with some afterglow when switched off.
12	-	**Mars light** Signal-safety lights used in the United States.
13	-	**Flashlight (ping)** Ping/pong between the two.
14	-	**Flashlight (pong)** See above.
15	-	**Strobe #1** One 50ms strobe per second.
16	-	**Strobe #2** Two 50ms strobes per second.
17	-	**Strobe #3** Three 50ms strobes per second.
18	-	**Ditch (ping)** Purpose to make trains easier to spot, for safety. Primarily used in the US.
19	-	**Ditch (pong)** See above.
20	-	**Coupler output** The output will be active for a maximum of 1 second (to protect coupler hardware)

17.2 Automation

#	Parameter	Description
0	-	**OFF** The output is set permanently to OFF/Inactive.
1	-	**ON** The output is set permanently to ON/Active while the assigned FN is active.
2	-	**Headlight side 1 (DB)** Headlight automation according to the DB standard. • always OFF if parked is enabled • always ON if shunting enabled • ON if loco driving towards side-1 direction and nothing is coupled to side-1
3	-	**Headlight side 2 (DB)** Headlight automation according to the DB standard. • always OFF if parked is enabled • always ON if shunting enabled • ON if loco driving towards side-2 direction and nothing is coupled to side-2
4	-	**Taillight side 1 (DB)** Taillight automation according to the DB standard. • always ON if parked is enabled • always OFF if shunting enabled • ON if loco driving towards side-2 direction and nothing is coupled to side-1
5	-	**Taillight side 2 (DB)** Taillight automation according to the DB standard. • always ON if parked is enabled • always OFF if shunting enabled • ON if loco driving towards side-1 direction and nothing is coupled to side-2
6	-	**Driver cabin (centered)** Driver cabin light automation for centered cabins (e.g. V100). • randomly activated/deactivated if loco is in shunting mode • turns OFF (randomly delayed) if loco is driving faster
7	-	**Driver cabin (side 1)** Driver cabin light automation for side 1 cabin (e.g. V200). • randomly activated/deactivated if loco is in shunting mode heading in direction 1 • turns OFF (randomly delayed) if loco is driving faster
8	-	**Driver cabin (side 2)** Driving cabin light automation for side 2 cabin (e.g. V200). • randomly activated/deactivated if loco is in shunting mode heading in direction 2 • turns OFF (randomly delayed) if loco is driving faster
9	-	**Engine room** Engine room light automation (e.g. E10). • randomly activated/deactivated if loco is in shunting mode • turns OFF (randomly delayed) if loco is driving
10	-	**Coupler (side 1 + side 2)** Automation to decouple side 1 & 2 t.b.d
11	-	**Coupler (side 1)** Automation to decouple side 1 • Push towards side 1 / enable decoupler / back off / disable decoupler
12	-	**Coupler (side 2)** Automation to decouple side 2 • Push towards side 2 / enable decoupler / back off / disable decoupler
13	-	**Passenger car cabin** Automation cabin lights in passenger cars. • Randomly switches on/off at very low frequency to simulate passengers

#	Parameter	Description
14	-	**Passenger car lavatory** Automation lavatory lights in passenger cars. • Randomly switches on/off at very low frequency to simulate passengers
15	-	**Passenger car aisle** Automation aisle lights in passenger cars. • Permanently active but forced off if 'parked'
16	-	**Passenger car exit/passage** Automation for exit/passage lights in passenger cars. • Permanently active

17.3 Environment

Function key assignment to control environmental settings. Each mode can be assigned to any of the 68 function keys.

CV	Default FN#	Description
120	1	Coupling on side 1
121	2	Coupling on side 2
122	3	Shunting active
123	4	Parked active
124	5	Acceleration ramp disabled
125	6	Deceleration ramp disabled
126	7	Manual control mode
127	-	
128	-	
129	-	
130	-	
131	-	
132	-	
133	-	
134	-	
135	-	

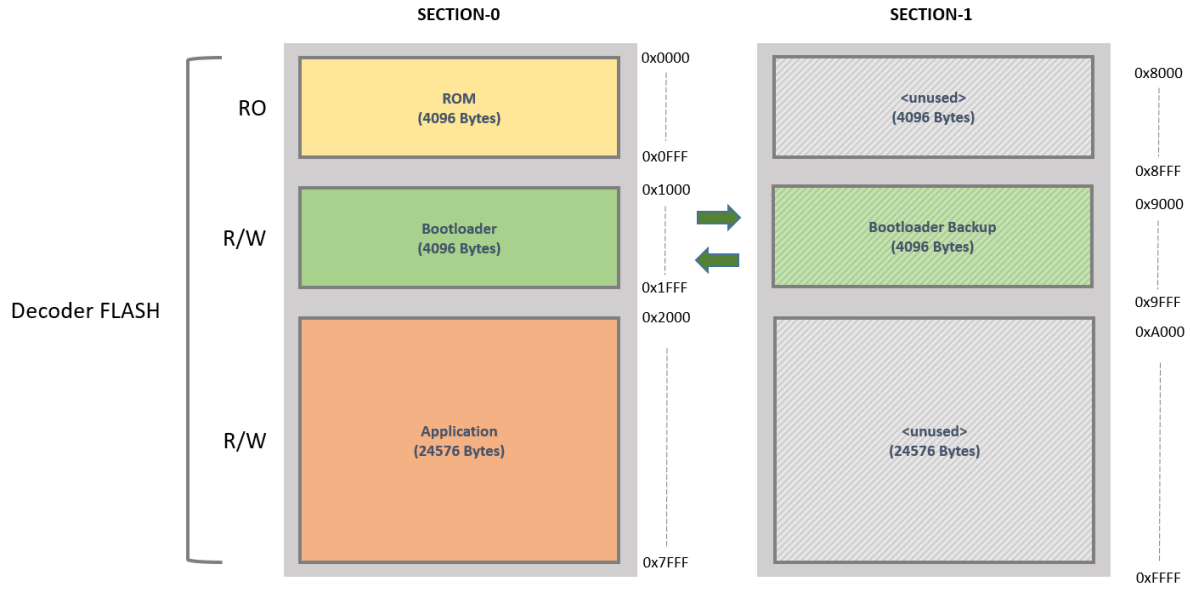
18 Decoder architecture

All Decoder share the same code base, thus the same high-level architecture.

18.1 Flash memory organization

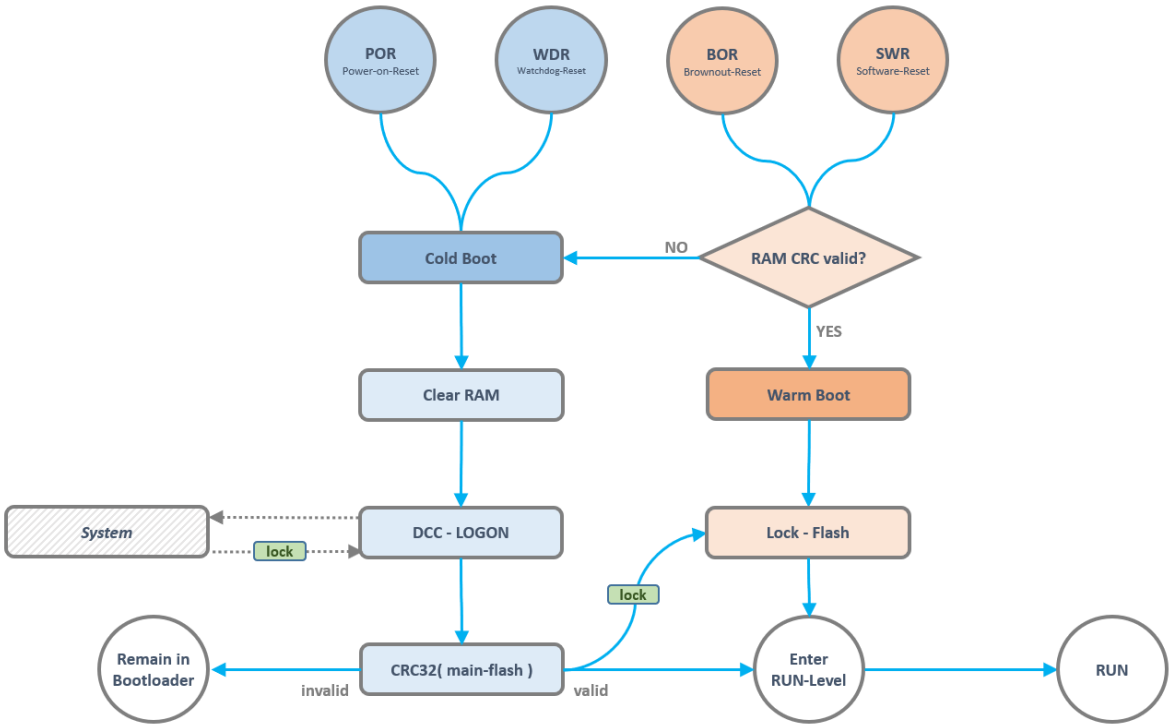
Decoder flash memory is organized as follows.

- ROM
- Bootloader
- Application
- Bootloader Backup (golden copy)



18.2 Decoder restart

- POR: Power on Reset (cold start)
- WDR: Watchdog Reset (in case the decoder freezes)
- BOR: Brown out Reset (if the decoder lost power for a very short time)
- SWR: Software Reset (triggered by the firmware)

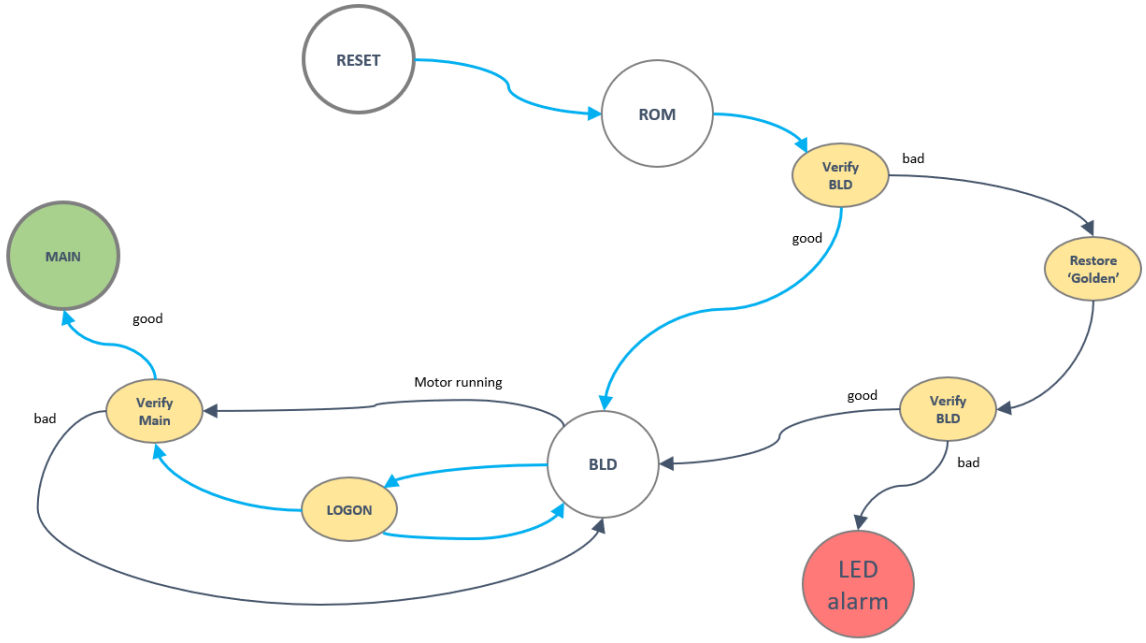


POR/WDR will always start ‘cold’. A cold start will take about 200ms for the startup. BOR/SWR may start ‘warm’ if RAM-CRC is valid allowing the decoder to warm-start within a few milliseconds.

18.3 Code verification

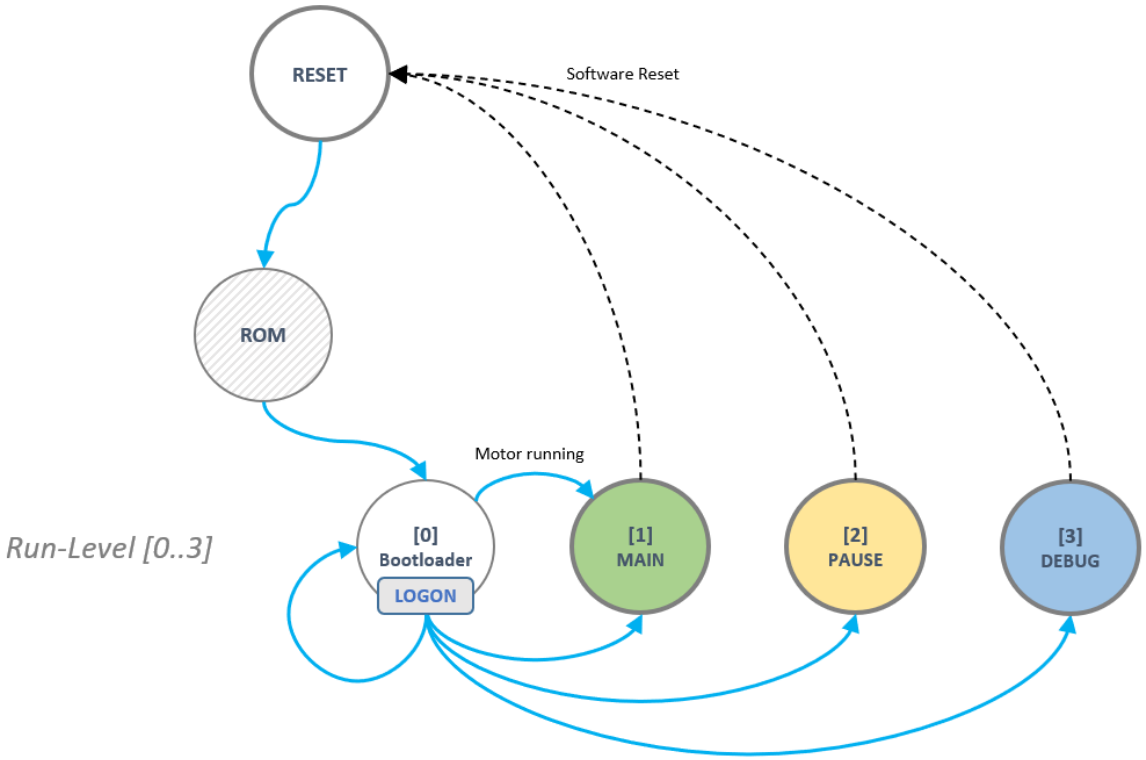
For improved reliability, the decoder validates each code section (ROM, Bootloader, Main) during start-up via CRC32 checksums. The decoder will prevent execution of invalid code.

Validation during decoder starts.



18.4 Decoder run level

The decoder implements 4 different run levels.



18.5 Firmware update

All decoders enable firmware over the main tracks via the DCC-R protocol. Therefore, no special service track is required. While the firmware update is running, regular DCC operation continues.

The update process is quick: In “Quick Mode”, a decoder update takes less than 10 seconds over main tracks. In “compatibility mode” an update takes about 60 seconds but ensures compatibility with old legacy decoders on the tracks.

The update is reliable: The transfer of firmware data is protected by CRC32. Additionally, the decoders do not activate corrupt or incompatible firmware to protect their hardware.

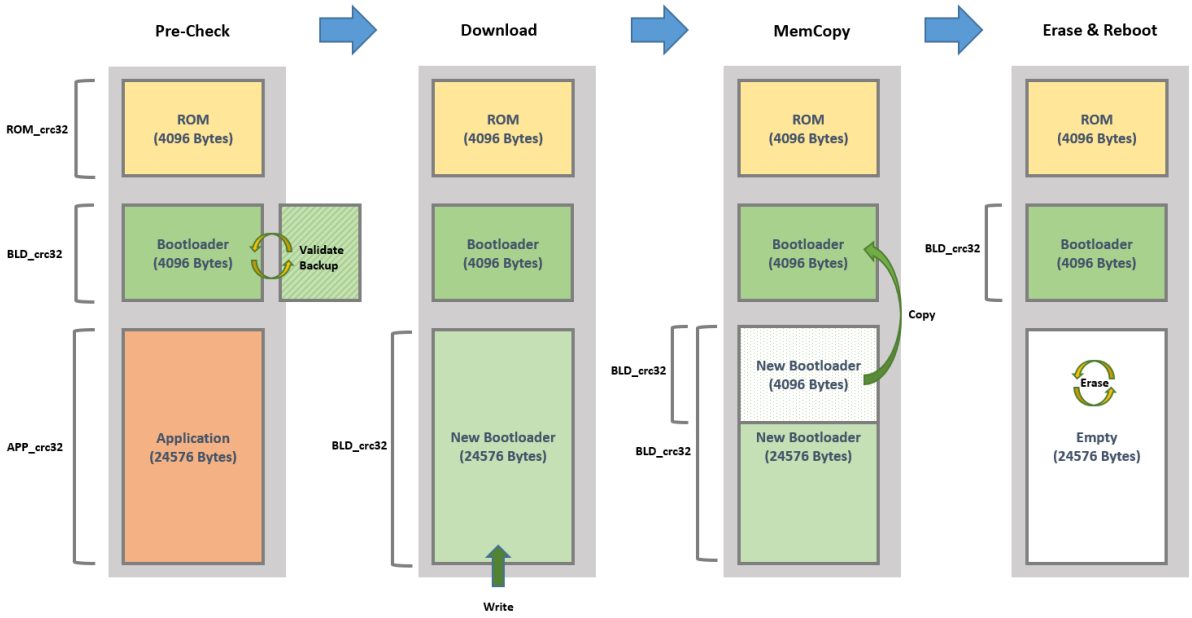
Example update of a decoder with UID 000dd160-da1980b9,

```
P:\>rtbclient --update 000dd160-da1980b9 --file D16F0001.hex
[000dd160-da1980b9] Sending firmware
Success: 9429[ms]

P:\>
```

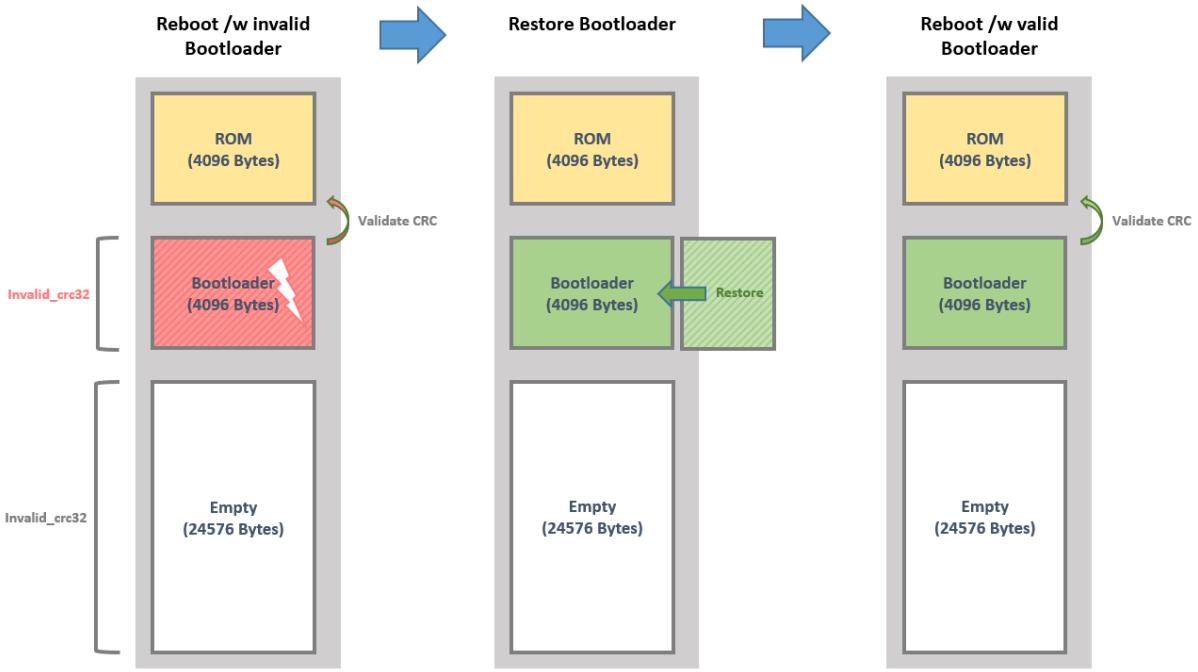
18.5.1 Bootloader update process

All decoders also allow bootloader updates. This should be a rare event as bootloader code has very limited functionality and typically remains stable throughout the lifetime of the device.



18.5.2 Recovery after failed Bootloader update

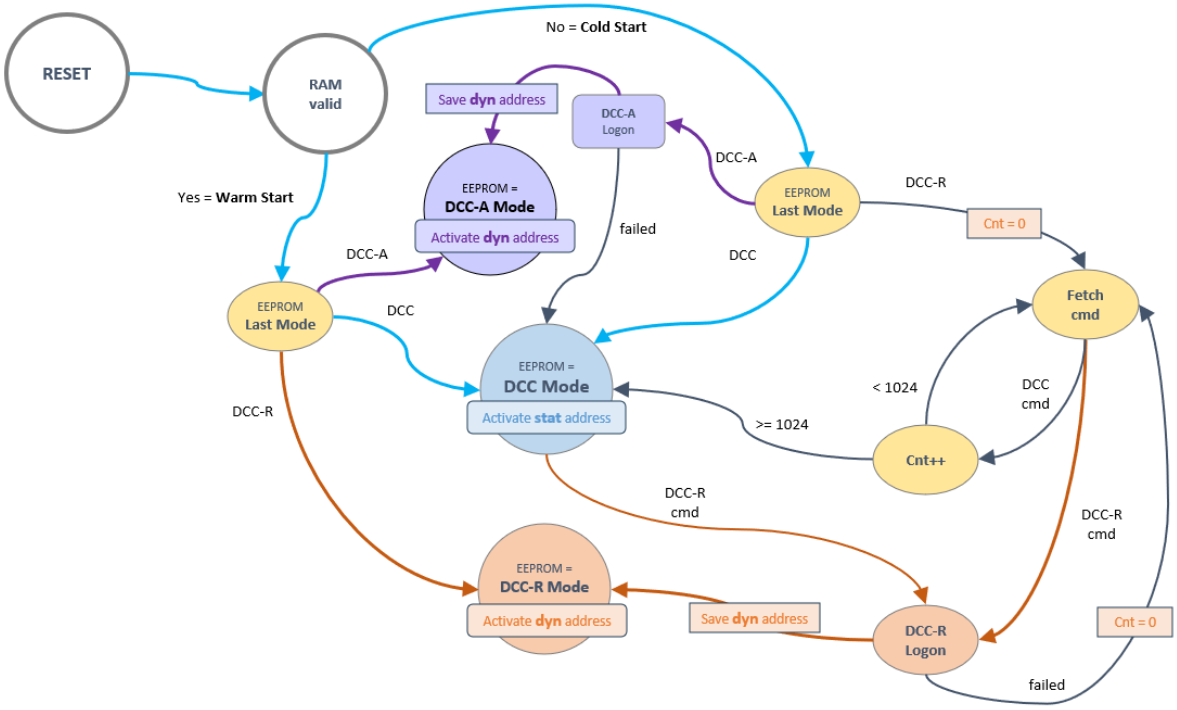
The decoder maintains a so called ‘golden copy’ of the boot loader. If the boot loader should ever become corrupted e.g., during an aborted bootloader update, the decoder will automatically reload the code from the backup.


Reboot /w invalid Bootloader
Restore Bootloader
Reboot /w valid Bootloader
ROM (4096 Bytes)
Validate CRC
Invalid_crc32
Bootloader (4096 Bytes)
Restore
Invalid_crc32
Empty (24576 Bytes)

18.6 DCC Address Selection Flow

Process flow during decoder startup for selecting its DCC address.

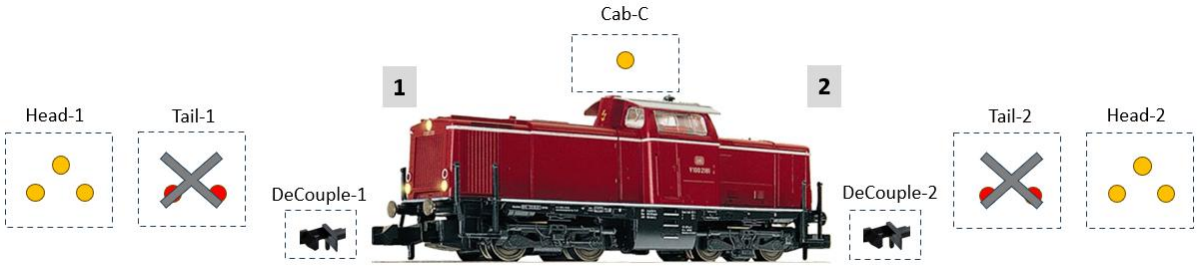
Decoder startup



19 Example Configurations

19.1 D12

The #7230 model physically does not have taillights. Therefore AUX1/2 ports remain unused.



Head-1	**CV**	**Setting**	**Description (FL-f)**	
	160	0	F0	Assigned function key
	161	2	light bulb (soft ON, soft OFF)	Type
	162	3	DB headlight side 1	Automation
	163	-	-	Optional parameter
Head-2	**CV**	**Setting**	**Description (FL-r)**	
	164	0	F0	Assigned function key
	165	2	light bulb (soft ON, soft OFF)	Type
	166	4	DB headlight side 2	Automation
	167	-	-	Optional parameter
Tail-1	**CV**	**Setting**	**Description (AUX-1)**	
	168	0	F0	Assigned function key
	169	2	light bulb (soft ON, soft OFF)	Type
	170	0	Disabled	Automation
	171	-	-	Optional parameter
Tail-2	**CV**	**Setting**	**Description (AUX-2)**	
	172	0	F0	Assigned function key
	173	2	light bulb (soft ON, soft OFF)	Type
	174	0	Disabled	Automation
	175	-	-	Optional parameter
DeCouple-1	**CV**	**Setting**	**Description (AUX-3)**	
	176	255	-	Assigned function key
	177	20	decoupler (1 sec max)	Type
	178	11	decouple side-1 orchestration	Automation
	179	-	-	Optional parameter
DeCouple-2	**CV**	**Setting**	**Description (AUX-4)**	
	180	255	-	Assigned function key
	181	20	decoupler (1 sec max)	Type
	182	12	decouple side-2 orchestration	Automation
	183	-	-	Optional parameter
Cab-C	**CV**	**Setting**	**Description (AUX-5)**	
	184	0	F0	Assigned function key
	185	2	light bulb (soft ON, soft OFF)	Type
	186	6	Cabin-Centered	Automation
	187	-	-	Optional parameter

Environmental information for the loco. This will influence the port automation defined above.

Env

CV	Setting	Description	
120	1	Coupled on side 1	Assigned function key (F1)
121	2	Coupled on side 2	Assigned function key (F2)
122	3	Shunting enabled	Assigned function key (F3)
123	4	Parked enabled	Assigned function key (F4)
124	5	Disable acceleration ramp	Assigned function key (F5)
125	6	Disable breaking ramp	Assigned function key (F6)
127	7	Manual driving	Assigned function key (F7)

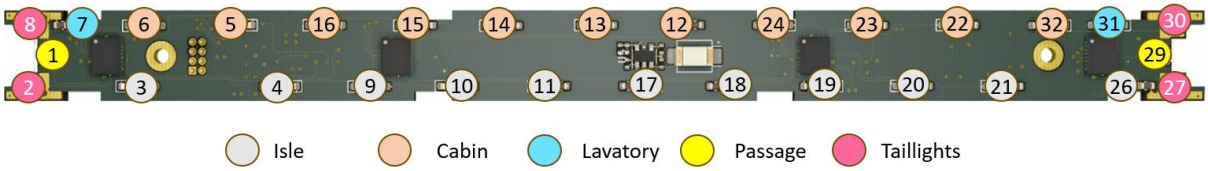
Functional matrix

Operation	F0	F1	F2	F3	F4	F5	F6	F7
solo	✓	⃠	⃠	⃠	⃠	⟲	⟲	⟲
coupled side 1	✓	✓	⃠	⃠	⃠	⟲	⟲	⟲
coupled side 2	✓	⃠	✓	⃠	⃠	⟲	⟲	⟲
coupled both sides	✓	✓	✓	⃠	⃠	⟲	⟲	⟲
shunting	✓	⟲	⟲	✓	⃠	⟲	⟲	⟲
parked	✓	⟲	⟲	⟲	✓	⟲	⟲	⟲

✓= active, ⃠ = inactive, ⟲ = don't care

19.2 D13

The D13 PCB decoder adds a total of 32 lights to the Minitrix (15795) 2nd class couchette. The taillights will be on a separate PCB; all other LEDs are positioned to fix exactly their required position. All 32 LEDs are independently programmable. By default, lights are enabled with F0.



The first CV number of a port is calculated with CV# = (port * 4 + 509)

Passage

CV	Setting	Description (port 0)	
513	0	F0	Assigned function key
514	4	Neon light (/wo shimmer)	Type
515	1	Permanent ON (except when parked)	Automation
516	-	-	Optional parameter

Same for port 29: 625-628

Taillight-1

CV	Setting	Description (port 2)	
517	0	F0	Assigned function key
518	2	light bulb (soft ON, soft OFF)	Type
519	4	DB taillight side 1	Automation
520	-	-	Optional parameter

Same for port 8: 541-544

Taillight-2

CV	Setting	Description (port 27)	
617	0	F0	Assigned function key
618	2	light bulb (soft ON, soft OFF)	Type
619	5	DB taillight side 2	Automation
620	-	-	Optional parameter

Same for port 30: 629-632

Lavatory

CV	Setting	Description (port 7)	
537	0	F0	Assigned function key
588	4	Neon light (/wo shimmer)	Type
539	14	Lavatory	Automation
540	-	-	Optional parameter

Same for port 31: 633-636

Aisle

CV	Setting	Description (port 3)	
521	0	F0	Assigned function key
522	4	Neon light (/wo shimmer)	Type
523	15	Aisle	Automation
524	-	-	Optional parameter

Same for port 4, 9, 10, 11, 17, 18, 19, 20, 21, 26: (port * 4 + 509)

Cabin

CV	Setting	Description (port 5)	
529	0	F0	Assigned function key
530	4	Neon light (/wo shimmer)	Type
531	13	Cabin	Automation
532	-	-	Optional parameter

Same for port 5, 6, 12, 13, 14, 15, 16, 22, 23, 24, 32: (port * 4 + 509)

19.3 D14

The #12402 model physically comes with head- and taillights. The PCB decoder adds cabin lights as well as ports for electrical couplers.

Head-1	**CV**	**Setting**	**Description (FL-f)**	
	160	0	F0	Assigned function key
	161	2	light bulb (soft ON, soft OFF)	Type
	162	3	DB headlight side 1	Automation
	163	-	-	Optional parameter
Head-2	**CV**	**Setting**	**Description (FL-r)**	
	164	0	F0	Assigned function key
	165	2	light bulb (soft ON, soft OFF)	Type
	166	4	DB headlight side 2	Automation
	167	-	-	Optional parameter
Tail-1	**CV**	**Setting**	**Description (AUX-1)**	
	168	0	F0	Assigned function key
	169	2	light bulb (soft ON, soft OFF)	Type
	170	5	DB taillight side 1	Automation
	171	-	-	Optional parameter
Tail-2	**CV**	**Setting**	**Description (AUX-2)**	
	172	0	F0	Assigned function key
	173	2	light bulb (soft ON, soft OFF)	Type
	174	6	DB taillight side 2	Automation
	175	-	-	Optional parameter
Cab-1	**CV**	**Setting**	**Description (AUX-3)**	
	176	0	F0	Assigned function key
	177	2	light bulb (soft ON, soft OFF)	Type
	178	7	Cabin 1	Automation
	179	-	-	Optional parameter
Cab-2	**CV**	**Setting**	**Description (AUX-4)**	
	180	0	F0	Assigned function key
	181	2	light bulb (soft ON, soft OFF)	Type
	182	8	Cabin 2	Automation
	183	-	-	Optional parameter
DeCouple-1	**CV**	**Setting**	**Description (AUX-5)**	
	184	255	-	Assigned function key
	185	20	decoupler (1 sec max)	Type
	186	11	decouple side-1 orchestration	Automation
	187	-	-	Optional parameter
DeCouple-2	**CV**	**Setting**	**Description (AUX-6)**	
	188	255	-	Assigned function key
	189	20	decoupler (1 sec max)	Type
	190	12	decouple side-1 orchestration	Automation
	191	-	-	Optional parameter

Environmental information for the loco. This will influence the port automation defined above.

Env

CV	Setting	Description	
120	1	Coupled on side 1	Assigned function key (F1)
121	2	Coupled on side 2	Assigned function key (F2)
122	3	Shunting enabled	Assigned function key (F3)
123	4	Parked enabled	Assigned function key (F4)
124	5	Disable acceleration ramp	Assigned function key (F5)
125	6	Disable breaking ramp	Assigned function key (F6)
127	7	Manual driving	Assigned function key (F7)

Functional matrix

Operation	F0	F1	F2	F3	F4	F5	F6	F7
solo	✓	⃠	⃠	⃠	⃠	⟲	⟲	⟲
coupled side 1	✓	✓	⃠	⃠	⃠	⟲	⟲	⟲
coupled side 2	✓	⃠	✓	⃠	⃠	⟲	⟲	⟲
coupled both sides	✓	✓	✓	⃠	⃠	⟲	⟲	⟲
shunting	✓	⟲	⟲	✓	⃠	⟲	⟲	⟲
parked	✓	⟲	⟲	⟲	✓	⟲	⟲	⟲

✓= active, ⃠ = inactive, ⟲ = don't care