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NMRA STANDARD	
Electrical Interface & Wire Color Code for Digital Command Control	
All Scales	
May 2015	S-9.1.1

The purpose of this Standard is to simplify the installation and exchange of electronic devices (hereafter called "controllers") which are designed to control or modify the behavior of motors, lights, and other similar accessories installed in locomotives and other rolling stock by recommending:

- a color code for the wires used in these locomotives or cars, and
- a method to interface the controllers with the internal wiring or power-routing PCB of the locomotive or car.

This Standard applies to locomotives and cars of various sizes and scales, all kinds of controllers (digital command control decoders in particular), and 2-rail, 3-rail (central or trackside) and overhead wire power distribution systems. Refer to NMRA Data Sheet 9.1.1 for further information as it relates to this area.

A. General Interface Requirements

The primary purpose of an interface is to make it easy to insert a controller between the power pick-up system and the motor(s), light(s), and/or other similar accessories installed in the locomotive or car. The interface should assure an easy, precise, and error-free installation or exchange of a controller. When an interface and/or controller are installed in the locomotive or car by the manufacturer, this should be done in such a manner that it does not restrict the removal of the body from the chassis.

If no controller is installed by the manufacturer, that part of the interface that would be connected to a controller shall be replaced by a "dummy" part that should enable the locomotive or car to operate as if no interface had been present. Also, enough room must be available around the installed part of the interface to enable the replacement of the "dummy" part by one connected to a controller (i.e. enough room shall be available for the missing part and for its associated wiring to reach an area where a controller could be easily installed).

B. Locomotive Color Code of Wiring

If the manufacturer of model locomotives or cars uses wires within these to connect the power pick-ups to the motor(s) and/or light(s), the following is the recommended color assignment for these wires. All other wiring connections have no recommended color, but may not use one of the following colors. Also, the purpose of any other wiring connections has to be documented.

RED	from right-hand rail power pick-up (or center rail, outside third rail, traction/overhead wire) to motor or interface
ORANGE	from interface to motor brush (+) connected to right-hand rail (or center rail, outside third rail, traction wire)*
BLACK	from left-hand rail power pick-up to motor or interface
GRAY	from interface to motor brush (-) connected to left-hand rail *
WHITE	front headlight(s) power sink
YELLOW	rear headlight(s) power sink
BLUE	common (+) headlight(s)/function(s) power source
BLACK with WHITE stripe	common (-) power sink

* Present only when an interface is built-in the locomotive or car

C. Locomotive Interface Electromechanical Specifications

The interfaces can be of two kinds: basic service or extended service. The basic service interfaces only provide connections from the power pick-ups to one motor and to front and rear headlights, while the extended service interfaces also provide connections to additional motor(s), light(s) and/or other accessories¹.

¹The Medium design interface optionally allows the use of one of the basic service connections for an accessory control function.

When an extended service interface socket (or plug) is built-into a locomotive or car by a manufacturer, the manufacturer shall document very clearly which connection is wired to which built-in equipment. The extended service socket (or plug) should be made in such a way that it is possible to insert a basic service plug (or socket) only in those socket holes (plug pins) corresponding to the basic service socket (plug).

Three different interface designs (Small, Medium, and Large) are specified for different size and power applications. Their electromechanical characteristics are specified in Table 1, while the assignment of their connections is given in Table 2. Figures 2 and 3 illustrate the Medium interface socket and the Small interface socket, and the numbering of the connections on each one.

Locomotives or cars that have a built-in interface (socket or plug) shall be identified as having one of the specified designs by using the appropriate pictogram as shown in Figure 1. The same pictograms shall be used to identify the interface plug or socket design that is on the controller. These pictograms shall be clearly visible on the locomotive, car or controller packaging.

For the Small and Medium designs, connection 1 shall be identified clearly on both parts of the interface. In Figures 2 and 3 a small triangle is used to identify connection 1, but other symbols may be used. The connection layout for the Large design is left to the manufacturer but each connection shall be labeled such that its purpose can be identified easily. It is recommended that these connections be identified either with their number or their corresponding wire color.

For Medium Interface designs, a minimum distance of 0.180" (is required for decoder clearance above the socket).

Table 1: Basic Interface Electromechanical Characteristics

	Small	Medium	Large
Connections (layout)	6 (1x6)	8 (2x4)	4 (none)
Part in Locomotive/car	female	female	male
Pitch	0.050"	0.100"	None
Pin Section	circular(1)	circular(1)	Circular
Pin Length	0.118"	0.155"	0.300"
Tolerance	0.001"	0.010"	0.030"
Pin Diameter	0.017"	0.022"	0.050"
Tolerance	0.002"	0.002"	0.003"
Power Rating (2)	0.50A	1.50A	4.00A
Peak Power Rating	0.75A	3.00A	6.00A
Suitable for Scales	N or larger	HO or larger	O or larger

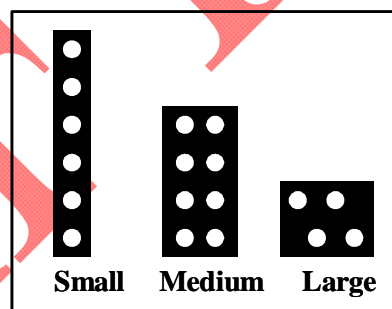


Figure 1: Pictograms

(1) Pins with a square or rectangular section are an acceptable alternative provided they offer similar power rating and physical contact quality as pins with a circular section.

(2) This power rating value applies to the individual connections of the interface - it does neither reflect a controller's power capacity nor a locomotive's motor or light power requirements. Because most controllers provide less current on the light(s) & function(s) connections, it is recommended that locomotive manufacturers clearly document the required power for each light/function. Similarly, controller manufacturers should clearly document the power rating for the light/function connections.

Table 2: Basic Interface Connection: Wire Assignments

Pin No.	Small		Medium		Large	
	Color	Use	Color	Use	Color	Use
1	Orange	Motor Right	Orange	Motor Right	Gray	Motor Left
2	Gray	Motor Left	Yellow	Rear Headlight	Orange	Motor Right
3	Red	Right Rail	(1)	(1)	Black	Left Rail
4	Black	Left Rail	Black	Left Rail	Red	Right Rail
5	White	Front Headlight	Gray	Motor Left		
6	Yellow	Rear Headlight	White	Front Headlight		
7			Blue	Common (V+)		
8			Red	Right Rail		

(1) This connection on the socket (in the locomotive) may be left unconnected or may be connected to an accessory. If connected to an accessory, the accessory must be protected by a diode, if it is polarity sensitive, to avoid any damage in case the plug is inserted the wrong way into the socket. On the plug, this connection may be left unconnected or may be connected to connection 7 or may be connected to a decoder's function output. In all cases, the use of this connection must be documented by the manufacturer.

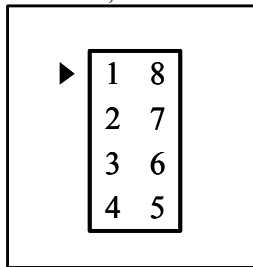


Figure 2: Top View Medium Interface

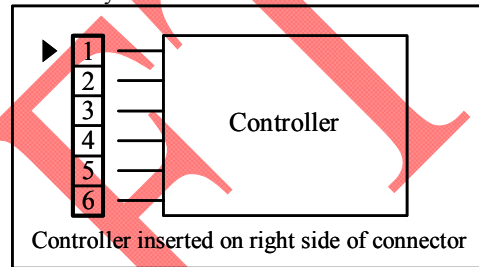


Figure 3: Top View Small Interface

Note: There must be no electrical connection on the locomotive side of the interface between either of the motor leads and either of the track leads. In addition, a direct connection must not be made between pins 3 and 7 on the locomotive side of the interface for the medium plug. Either type of connection can lead to decoder damage.

D. Controller Electromechanical Specifications

Controller circuit boards may contain a socket for the wiring harness. This socket / harness combination is currently manufactured by JST. The socket part number is S 9B-ZR-SM2-TF for the surface-mount version.

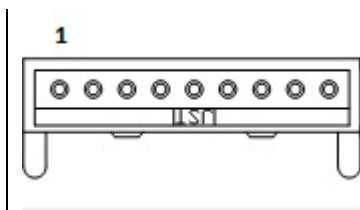


Figure 4:
View looking into end of Decoder

Color	Use	Pin Number
Violet or Brown	Output 4	1
Black	Track – Left Rail	2
Gray	Motor (-)	3
Yellow	Output 2 (Rear Headlight)	4
White	Output 1 (Front Headlight)	5
Blue	+V	6
Orange	Motor (+)	7
Red	Track – Right Rail	8
Green	Output 3	9

E: 21 Pin Connector Interface².

As an alternative to the connectors in sections C and D a 21MTC pin connector may be used. The controller will be plugged directly on top of the pin header in the locomotive / car.

1. Interface - Description

- 5 This interface is usable for AC-Motors (2 field coils), DC-Motors or bell rotor DC-Motors. 8 outputs are provided for functions and 2 inputs are provided for sensors. The required room for installation of the decoder and its dimension are integral part of this standard.

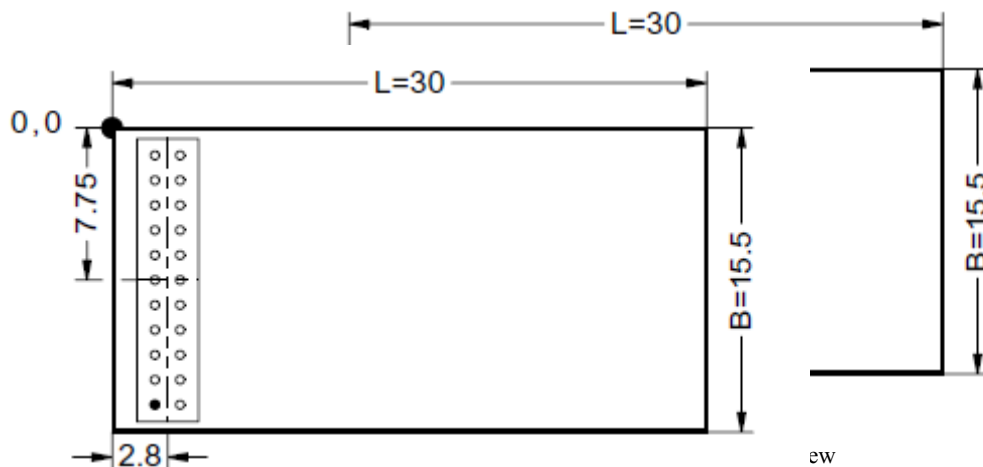
2.1 Mechanical Characteristics

- 10 The interface on the system PCB (printed circuit board) consists of a 22 pin male plugs arranged in two rows with 1.27 mm interval. The dimension of the decoder are at the most 30 (L) x 15.5 (W(B)) x 6.5 (H) mm. The system PCB must provide sufficient room in order to plug in the decoder without any problem on the PCB.

Male and female plugs form a ridge consisting of 11 contacts in two rows. Preferred is a soldering of the plugs on the system PCB. Not installing pin 11 insures the correct insertion on the PCB (index pin).

2.1.1 Decoder

15 The decoder is provided with a ridge of female plugs. The plugs are oriented on the small side of the decoder PCB as shown in picture 1.



- 20 The ridge of plugs must be located from the edge of the PCB as shown in picture 1. The decoder may be shorter than L = 30 mm. The position of the ridge of plugs in reference to 0.0 must be guaranteed.
- 25 The maximum height of the decoder is given and must be observed. Picture 2 shows the assembly. For the components the side with the plugs allows a maximum height of 2.2 mm. The other side allows a height of 3.3 mm. The PCB itself has a height of 1.0 mm.

² Starting Jan. 1st 2010, this connector will not be recommended for new locomotive designs. This will not invalidate the conformance of existing designs. Controllers for these connectors will continue to conform, as controllers for this connector will be required as long as locomotives with this connector exist.

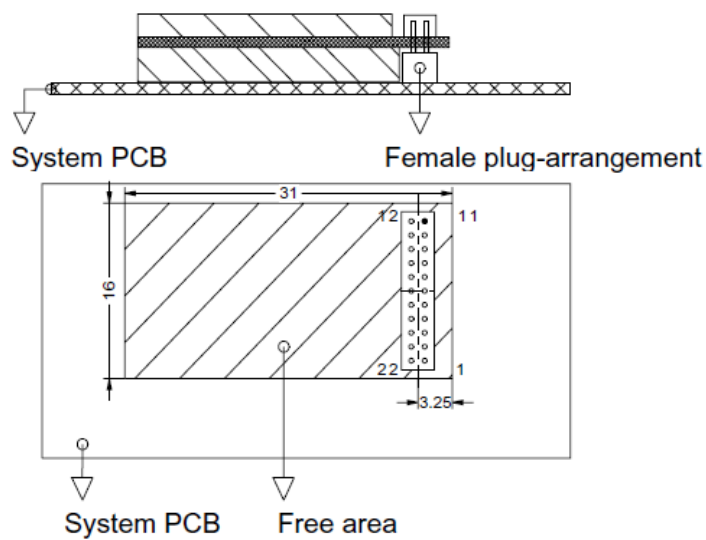


Figure 9: Compact Mounting

2.1.3.2 Up-side-down Mounting

In case it is enough room above the system PCB, but no free area on the system PCB, the decoder may be mounted in the up-side-down position. The Decoder will be plugged with the female plugs oriented down onto the system PCB. The pin orientation of system PCB must be mirrored at the axis of pin 6/17.

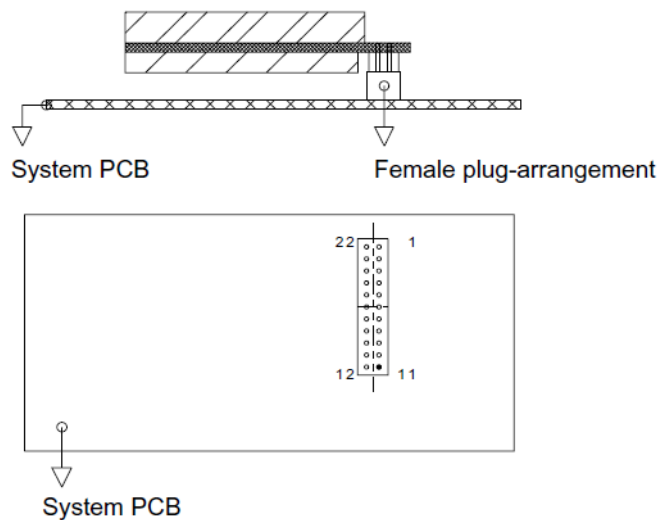


Figure 10: Up-side-down mounting

Locomotives with implemented interface according to this NEM shall be identified with the following logo on its package:



2.2 Electrical Characteristics

Manufacturer of this decoder must specify the maximum current allowed to draw for each output and input. In case the decoder must be placed in a different space and is connected with a flat ribbon cable the colors of the cables are not mandatory. The colors are required for single cables.

2.3 Pin Assignments

The pin assignments for 21MTC are defined in Table 1:

Table 1: Pin assignments and definition of function

Pin	Name	Color	Description	Group
1	Input1		Sensor-Input 1	4
2	Input2		Sensor-Input 2	4
3	AUX6		Output 6	8
4	AUX4		Output 4	8
5	ZBCLK		Train Bus Clock	7
6	ZBDTA		Train Bus Data (TxD, RxD)	7
7	F0r	yellow	Light direction rear	5
8	F0f	white	Light direction forward	5
9	LS/A	brown	Speaker Connection A	6
10	LS/B	brown	Speaker Connection B	6
11	Index		Not used, Orientation	
12	Vcc		Internal Decoder-Voltage 1.8 – 5.7 Volt	2
13	AUX3		Output 3	8
14	AUX2	violet	Output 2	5
15	AUX1	green	Output 1	5
16	V+	blue	Decoder Plus, referenced at rectifier, port storage capacitors	2
17	AUX5		Output 5	8
18	Motor2	grey	Motor-connection #2 minus / direction rear	3
19	Motor1	orange	Motor-connection #1 plus / direction forward	3
20	GND		Decoder GND, Referenced at rectifier	2
21	Track left	black	Track left in direction forward	1
22	Track right	red	Track right in direction forward	1

Annotation for Groups:

- Group 1:** When supplied with AC-Motors Pin 21 is connected to the outer rails und Pin 22 to the middle rail.
- Group 2:** Pin 12 is not mandatory. It is recommended to supply this pin in order to connect additional processors.
- Group 3:** Pin 19 is field coil A, Pin 18 is field coil B for AC-Motors..
- Group 4:** Pin 1 and 2 are Open-Collector-Inputs and will switch on against GND. The input resistance should be ca. 100 K-Ohm. Sensor-Input 1 shall be used to synchronize wheel movement and sound when steam engines are used.
- Group 5:** In case the rear lights are connected to the decoder separately, the rear lights of locomotive in forward direction 1 are switched from Pin 15 and those in rear direction 2 to Pin 14.
- Group 6:** The speaker impedance is defined by the manufacturer and is as such documented.
- Group 7:** The microcontroller-pins of the train bus are connected through a serial resistor with a maximum of 470 Ohm.
- Group 8:** Output load may not exceed 0.5 mA and has logic levels according table 2.

Table 2:

	Voltage Level Decoder Output	Voltage Level for switching element on the system PCB.
Function switched off	≤ 0.4 Volt	≤ 0.8 Volt
Function switched on	≥ 2.4 Volt	≥ 2.0 Volt

90 3. Operation without Decoder

By operation without Decoder it is required to use a female plug. At least the pins track right must be bridged with motor 1 and track left must be bridged with motor 2. If lights exist, the appropriate pins must be bridged to the appropriate pins.

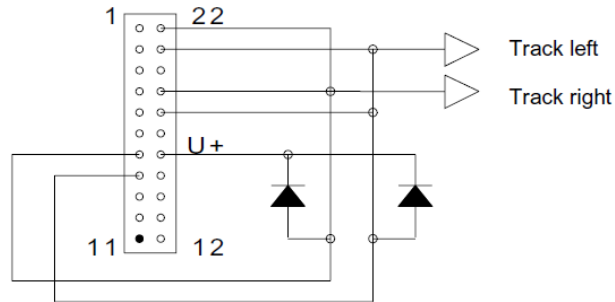


Figure 11: Typical female bridge plug

95 Depending of the connections of the various outputs, the manufacturer may generate a specific female bridge plug.

F: PluX8/16/22 Interface

Alternatively to the connectors in sections C to E a multiple pin connector may be used. The controller will be plugged with its pins directly into the female connector in the locomotive / car or, what is preferable, through the holes of a PCB into the female connector with bottom entry on the other side of the PCB. This Standard includes the descriptions of a connecting system with 8, 16 or 22 pins with the small connectors being subsets of the big ones.

1. Mechanical Specification

The pins of the controller are plugged through the board into the bottom of the female connector. The side of the controller with the pins is defined as the bottom side. There are five mechanical setups:

#	Controller Maximum / Space Minimum	PluX8	PluX8	PluX16	PluX16	PluX22
		N	HO/TT	no Sound	Sound	
1	Max. controller length	15.0 mm	20.0 mm	20.0 mm	28.0 mm	35.0 mm
2	Max. controller width	9.0 mm	11.0 mm	11 mm	16 mm	16 mm
3	Max. controller height without connector	3.5 mm	4.2 mm	4.2 mm	6.0 mm	6.0 mm
4	Min. pin length from controller bottom	3.0 mm	3.0 mm	3.0 mm	3.0 mm	3.0 mm
5	Connector center position from board edge	3.6 mm	3.6 mm	3.6 mm	3.6 mm	3.6 mm
6	Max. locomotive PCB thickness	1.0 mm	1.0 mm	1.0 mm	1.0 mm	1.0 mm
7	Height of female through hole connector	2.0 mm	2.0 mm	2.0 mm	2.0 mm	2.0 mm

Note 1: On the package of each controller with this connector the size of the matching controller should be stated.

Note 2: Board thickness, bottom side component height and top side component height don't need to be fixed.

Note 3: The minimum pin length is measured from the bottom of the controller, not from PCB.

2. Electromechanical specification

Connector layout: 2 rows of 4/8/11 contacts, one position masked (Index-pin).

Controller plug: male, loco plug: female

Pitch: 1.27 mm / 0.05"

Pin type & diameter: square 0.4 mm / 0.016"

Power rating 1 A

Suitable for scales: N, TT, H0

For sample connector manufacturer part numbers see TN-9.1.1.

Drawings see subsection 5.

3. Pin Assignments and Layouts:

Pin	Name	Corresponding wire color	Description
1	GPIO/C		General purpose input/output
2	AUX3		Output 3
3	GPIO/B		General purpose input/output, Train Bus – Clock Line
4	GPIO/A		General purpose input/output, Train Bus – Data Line
5	GND		Controller GND (behind rectifier)
6	V+ Cap.	blue	Controller Plus (behind rectifier)
7	f0f	white	Front Headlight
8	Motor	orange	Motor 1
9	V+	blue	Controller Plus (behind rectifier)
10	Motor	grey	Motor 2
11	Index	not mounted	n/a Not used / Coding
12	Track Right	red	Right rail
13	f0r	yellow	Rear Headlight
14	Track Left	black	Left rail
15	LS/A		Loudspeaker Terminal A
16	AUX1 or f0f	green	Output 1
17	LS/B		Loudspeaker Terminal B
18	AUX2 or f0r	violet	Output 2
19	AUX4		Output 4

20	AUX5		Output 5
21	AUX6		Output 6
22	AUX7		Output 7

For better understanding the pins and the names of the corresponding signals are the same for all plugs, because PluX8 is a subset of PluX16 and this one is a subset of PluX22. The usage and layout of the pins is as follows viewed from the decoder top, i.e. the direction the controller is plugged in:

- PluX22: Pins 1 – 22

GPIO/C	1	2	AUX3
GPIO/B	3	4	GPIO/A
GND	5	6	V+
f0f	7	8	Motor 1
V+	9	10	Motor 2
Index	11	12	Track Right
f0r	13	14	Track Left
LS/A	15	16	AUX1 or f0f
LS/B	17	18	AUX2 or f0r
AUX4	19	20	AUX5
AUX6	21	22	AUX7

- PluX16: Pins 3 - 18

GPIO/B	3	4	GPIO/A
GND	5	6	V+
f0f	7	8	Motor 1
V+	9	10	Motor 2
Index	11	12	Track Right
f0r	13	14	Track Left
LS/A	15	16	AUX1 or f0f
LS/B	17	18	AUX2 or f0r

- PluX8: Pins 7 - 14

f0f	7	8	Motor 1
V+	9	10	Motor 2
Index	11	12	Track Right
f0r	13	14	Track Left

Note: For special purposes a 12-pin-version with pins 7 to 18 is useful and conforming.

4. Electrical Specifications:

Track power pins:

- Track Right (pin 12) right track.
- Track Left (pin 14) left track.

The voltage is specified in S-9.1. The maximum current is given by the connector type.

Secondary power pins:

- U+ (pin 6, 9) raw controller plus, common power supply for the functions. The voltage corresponds to the track voltage. The maximum current is defined by the controller and/or the connector type. Controller manufacturers shall specify the maximum current to be drawn. Locomotive manufacturers shall specify the maximum current drawn on this pin.

Note: For locos with many accessories with high power consumption V+ (pin6) on the electronics side of the plug is necessary because of wiring reasons.

- GND (pin 5) controller ground, negative supply. All voltages are measured relative to this pin. The maximum current is defined by the controller and/or the connector type.

Motor pins

DC motors may be operated without controller in analog mode using a locomotive manufacturer supplied plug.

- Motor 1 (pin 8) first motor connection. If no controller is used, it is connected to Track Right.
- Motor 2 (pin 10) second motor connection. If no controller is used, it is connected to Track Left.

The maximum voltage applied is the track voltage. The maximum current is given by the controller and/or the connector type.

Output pins:

- Front Head (pin 7) (front headlight + rear taillight)
- Rear Head (pin 13) (rear headlight + front taillight)
- AUX1 (pin 16)
- AUX2 (pin 18)
- AUX3 (pin 2)
- AUX4 (pin 19)
- AUX5 (pin 20)

- AUX6 (pin 21)
 - AUX7 (pin 22)
- In case the red and white lights are connected separately they shall be connected as:
- Front Head (pin 7) (front headlight)
 - Rear Head (pin 13) (rear headlight)
 - AUX1 (pin 16) (rear taillight)
 - AUX2 (pin 18) (front taillight)

These pins are pulled to GND by the controller, if the function is on. The maximum voltage for the load is the track voltage. The maximum current is defined by the controller and/or the connector type. Controller manufacturers shall specify the maximum current to be drawn. Locomotive manufacturers shall specify the maximum current drawn on these pins. The noted usage in brackets is the default wiring in case the corresponding function exists in the controller.

Loudspeaker pins:

LS A (pin 15)
LS B (pin 17)
The speaker will be wired between these Pins.

Note: The impedance of Controllers LS pins and speakers is not defined; it has to be given in the manual.

General Purpose Input / Output

GPIO/A (pin 4) – Train Bus Data Line
GPIO/B (pin 3) – Train Bus Clock Line
GPIO/C (pin 1) – Hall in

The voltages, currents and series resistors at these pins depend on the type of bus supported. Both controller and locomotive manufacturers shall specify the electrical characteristics of the input/output interface. The electrical characteristics are needed to allow a possible use of controllers in locomotives with a different bus without destruction.

Note 3: There is no protocol defined in this Standard. In the future protocols may be defined in a separate Standard.

5 Dimensions and Orientation

Space for decoder seen from top of decoder

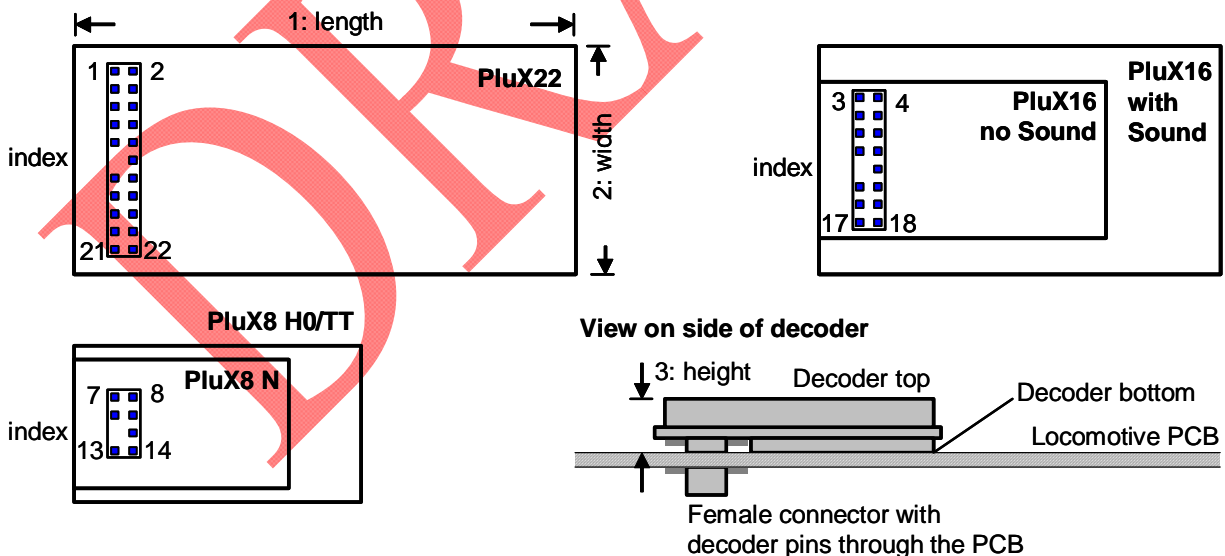


Figure 12: Top and Side Views of the PluX Interface

G. Controller Color Code of Wiring

If the manufacturer of a controller uses wires for the connection of the controller to the locomotive, the following color scheme must be used. All other wiring connections besides those described below have no recommended color-code. The purpose of any other wiring connections and color-codes must be clearly documented.

RED	from right-hand rail power pick-up (or center rail, outside third rail, traction/overhead wire) to motor or interface
ORANGE	from interface to motor brush (+) connected to right-hand rail (or center rail, outside third rail, traction wire)*
BLACK	from left-hand rail power pick-up to motor or interface
GRAY	from interface to motor brush (-) connected to left-hand rail *
WHITE	front headlight(s) power sink
YELLOW	rear headlight(s) power sink
BLUE	common (+) headlight(s)/function(s) power source
BLACK with WHITE stripe	common (-) power sink
GREEN	Output 3 power sink
VIOLET or BROWN	Output 4 power sink