

This Recommended Practice received final approval from the NMRA Board of Trustees in January 1995, March 1997, July 2003 and January 2008. Please note there are significant additions starting with paragraph E in this version. No change bars are provided.

NMRA RECOMMENDED PRACTICES

Electrical Interface & Wire Color Code for Digital Command Control

All Scales

Approved January 2008

RP-9.1.1

The purpose of this Recommended Practice 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 Recommended Practice 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

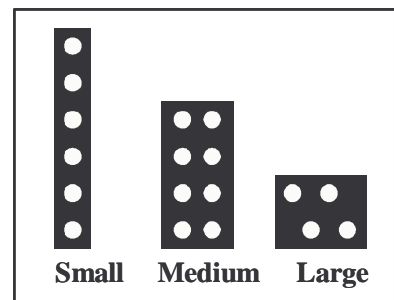


Figure 1: Pictograms

(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.

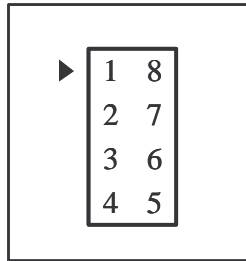


Figure 2: Top View Medium Interface

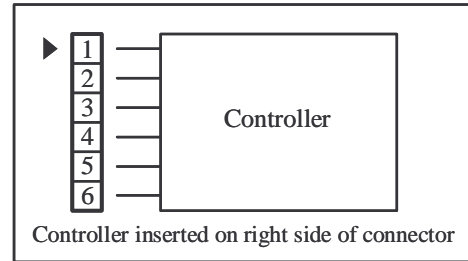


Figure 3 Top View Small Interface

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.

70 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.

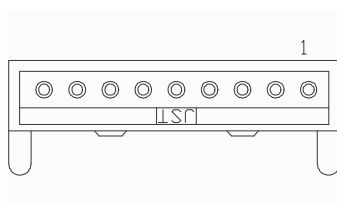


Figure 4:
View looking into end of Decoder

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.

75 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. Mechanical Specification

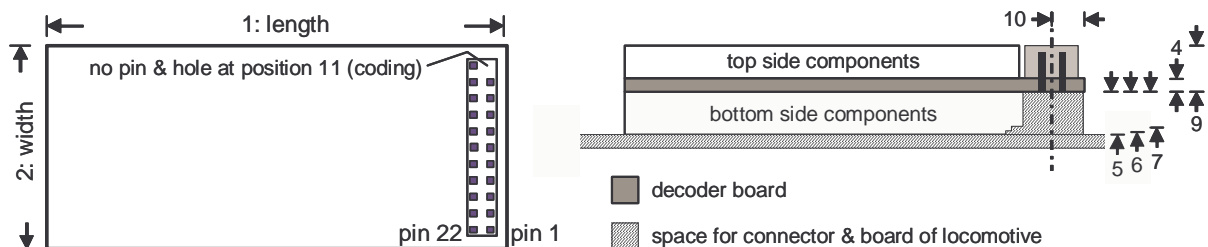


Figure 5: Top and Side View of 21MTC

80 The pins of the connector are plugged through the board into the socket on the controller. The side of the controller with the connector is defined as the top side. There are three mechanical setups:

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.

#	Controller Maximum / Space Minimum	Size 1	Size 2	Size 3
1	Controller length	20.5 mm	42.5 mm	30.0 mm
2	Controller width	15.5 mm	15.5 mm	22.0 mm
3	Total controller height	6.5 mm	6.5 mm	6.5 mm
4	Board thickness	1.0 mm	1.0 mm	1.0 mm
5	Bottom side component height	3.3 mm	3.3 mm	3.3 mm
6	- ditto within 5.85 mm from board edge 3	3.2 mm	3.2 mm	3.2 mm
7	- ditto within 5.45 mm from board edge 3	2.8 mm	2.8 mm	2.8 mm
8	- ditto within 4.6 mm from board edge 3	0.0 mm	0.0 mm	0.0 mm
9	Top side component height incl. board	3.2 mm	3.2 mm	3.2 mm
10	Connector center position from board edge	2.6 mm	2.6 mm	2.6 mm

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

2. Electromechanical specification

Connector layout: 2 rows of 11 contacts, one position masked.
Part in locomotive / car: male
Pitch: 1.27 mm / 0.05"
Pin type & diameter: square 0.4mm / 0.016"
Pin length: 3 mm / 0.12"
Power rating: 1 A
Suitable for scales: H0 or larger



Figure 6: 21MTC Pictogram

Locomotives or cars that have a built-in a 21MTC interface shall be identified as such by using the pictogram shown above. The same pictograms shall be used to identify the interface socket design that is on the controller.

For sample connector manufacturer part numbers see TI-9.1.1

3. Pin Assignments:

Pin	Name	Pin Group	Description
1	Hall1	4	Hall Sensor #1
2	Hall2	4	Hall Sensor #2
3	Hall3	4	Hall Sensor #3
4	AUX4	5	Output 6 / Pick-up Control
5	TBCLK	7	Train Bus – Clock Line
6	TBDTA	7	Train Bus – Data Line
7	Rear Light	5	Output 2 / Rear Headlight
8	Front Light	5	Output 1 / Front Headlight
9	LS	6	Loudspeaker Terminal A
10	LS	6	Loudspeaker Terminal B
11	not mounted	n/a	Not used / Coding
12	VCC	2	Controller internal VCC
13	AUX3	5	Output 5
14	AUX2	5	Output 4
15	AUX1	5	Output 3
16	V+	2	Controller Plus (behind rectifier)
17	Motor 3	3	Motor Output 3
18	Motor 2 MR	3	Motor Output 2
19	Motor 1 MF	3	Motor Output 1
20	GND	2	Controller GND (behind rectifier)
21	Track Left	1	2 rail track: Left rail / 3rd rail track: Outside rails
22	Track Right	1	2 rail track: Right rail / 3rd rail track: Center rail

³ For size 3, this restriction applies only within the width of the connector of 14.4 mm centered to the maximum width of the controller.

4. Electrical Specifications:

Pin Group 1, track power pins:

- Track Right (pin 22) right track or center track in 3rd-rail systems.
- Track Left (pin 21) left track or outside tracks in 3rd-rail systems.

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

Pin group 2, secondary power pins:

- U+ (pin 16) 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.
- VCC (pin 12) internal logic supply voltage. This pin is not mandatory. The voltage is between 1.8 V and 5.7 V. The maximum current drawn depends on the controller. Controller manufacturers shall specify the maximum current to be drawn. Locomotive manufacturers shall specify the maximum current drawn on this pin. This pin is for reference and interfacing pin group 7 Train Bus only. External units should be supplied from U+ instead of VCC.
- GND (pin 20) 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.

Pin group 3, motor pins

There are three different motor configurations supported: DC motors, AC motors with two field coils and brushless DC motors. Brushless DC motors need a controller to work. AC motors need at least a direction switch device. DC motors may be operated without controller in analog mode using a locomotive manufacturer supplied plug. There is no support of AC motors with separate field coil connection for load regulation.

- Motor 1 (pin 19) first motor connection or field coil "A" terminal of AC motors. If no controller is used, it is connected to Track Right.
 - Motor 2 (pin 18) second motor connection or field coil "B" terminal of AC motors. If no controller is used, it is connected to Track Left. (DC motor only)
 - Motor 3 (pin 17) third motor connection, not used with DC and AC motors.
- If not used for the motor, this pin may be used as additional function output like the pins of group 5. Caution must be taken when wiring this function in a locomotive, as this pin may be pulled to U+.

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

The rotor terminal of AC motors will be connected to U+

Pin group 4, input pins:

These pins are primarily designed to read the Hall sensors of brushless DC motors. When another motor type is used these pins may be used for other types of inputs from the locomotive to the controller.

- Hall 1 (pin 1) first input, used for Hall sensor #1 for brushless DC motors.
- Hall 2 (pin 2) second input, used for Hall sensor #2 for brushless DC motors.
- Hall 3 (pin 3) third input, used for Hall sensor #3 for brushless DC motors.

Maximum voltage applied VCC+0.2V.

Pin group 5, output pins:

- Output 1 (pin 8) (front headlight + rear taillight)
- Output 2 (pin 7) (rear headlight + front taillight)
- Output 3 (pin 15)
- Output 4 (pin 14)
- Output 5 (pin 13)
- Output 6 (pin 4) (pick-up selector)

In case the red and white lights are connected separately they shall be connected as:

- Output 1 (pin 8) (front headlight)
- Output 2 (pin 7) (rear headlight)
- Output 3 (pin 15) (rear taillight)
- Output 4 (pin 14) (front taillight)
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With the default mapping only the white lamps will be directionally controlled by F0.

With a mapping 5, 10, 0, 0 in CVs 33 to 36 the same as lamps wired together is achieved.

With a mapping 4, 8, 1, 2 in CVs 33 to 36 the red lamps are directionally controlled by F0 and the white lamps are individually controlled via F1 (front) and F2 (rear), allowing all major prototype light settings.

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.

Pin group 6, loudspeaker pins:

- LS 1 (pin 9)
- LS 2 (pin 10)

The speaker will be wired between these Pins. The impedance shall be 100 Ohm.

Pin Group 7, Train Bus

- ZBCLK (pin 5) clock signal
- ZBDTA (pin 6) data signal

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

Note: There is no protocol defined in this RP. In the future Protocols may be defined in a separate RP.

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 RP 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

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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

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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 RP. In the future protocols may be defined in a separate RP.

5 Dimensions and Orientation

Space for decoder seen from top of decoder

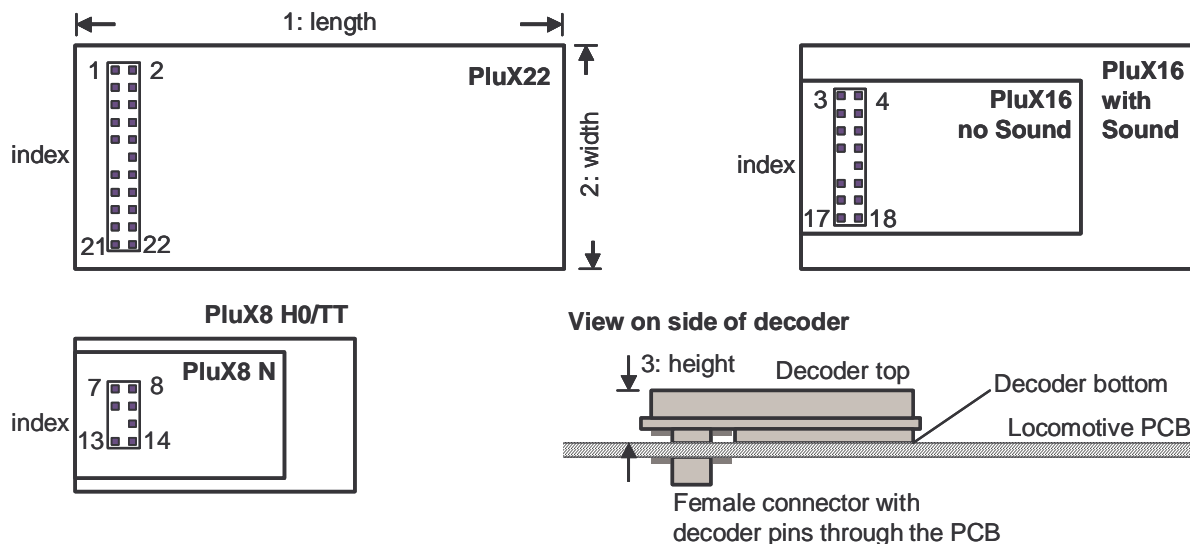


Figure 6: Top and Side Views of the PluX Interface

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