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Digital Trainline Hardware

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PRIIA Technical Subcommittee Member

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Originator

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## Revision Approval Sheet

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## Procedure Change Sheet

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1.0 Digital Train Line Specification Summary

1.1 Scope

This specification defines a high speed Ethernet data link “Digital Train Line” (DTL), which includes the physical hardware (e.g. jumpers, receptacles and cabling) and interfaces required onboard all passenger rail vehicles. The DTL can be either retrofitted to existing vehicles or incorporated into new vehicles being manufactured. This is a living document and will be modified and updated as new technologies become available. Changes will be backward compatible to the extent feasible as technology advances. This specification is intended to be used with PRIIA Specification 305-920: Digital Train Line Software.

1.2 Functionality

The DTL is used to control and transmit communication information throughout a passenger train consist of between 2 and 22 vehicles and locomotives. The DTL shall carry information along multiple paths between adjacent vehicles. The DTL and the 27 pin COMM will co-exist for the foreseeable future. The DTL will ultimately be capable of incorporating all the functions presently accommodated in the 27 pin COMM cables in the future, at present safety-critical functions will default to the 27 pin COMM. In the distant future, the DTL may be modified with additional interfaces to incorporate some additional functions from the 27 pin MU cables that cannot be incorporated elsewhere. For example, this may eventually include Electronically-Controlled Pneumatic Braking System (ECP), similar to what is presently under development by APTA.

1.3 System Capacity

The DTL is designed to have no less than 1Gbps of bandwidth when using the wired network for purposes of managing the traffic across its network. Current wireless bridge technology typically runs at approximately 100Mbps. In the future, possible additional functions may be added from those presently handled by the 27 pin MU cable.

1.4 Non-DTL-Equipped Vehicles

The DTL will allow intermixing of equipped and non-equipped vehicles and locomotives of varying designs while maintaining mechanical and electrical compatibility of the train line systems. When a non-DTL equipped vehicle is put into a train consist, the system will automatically revert to the 27 pin COMM cable and/or the wireless bridge to carry the signal between the DTL-equipped vehicle and the non-DTL-equipped vehicle. All safety functions will default to the 27 pin COMM in this situation. There may be some degraded functionality to DTL-equipped vehicles.
1.5 Assumptions

- There will be an existing WiFi system onboard each vehicle and a Wi-Fi control car in each consist, that includes a wireless bridge between vehicles which will provide redundancy in the event of a DTL failure. The 27 pin COMM will also provide redundancy.
- The DTL will connect directly to the onboard WiFi system.
- The WiFi system will provide a defined, open-standard, non-proprietary physical and IP interface.
- The WiFi system will provide the Internet capability on board the train.
- Once installed, the DTL will be utilized as the primary connection between vehicles.
- The DTL will support an Onboard Information System (OBIS).
- In the future the DTL will facilitate the technological migration of onboard equipment monitoring systems from analog to digital controls and eventually will provide a means to duplicate all the functions of the current 27 pin COMM Cable.
- Internal Ethernet network in cars to which DTL will connect.

1.6 Equipment

All hardware, software and network architecture shall be non-proprietary.

The DTL equipment is required to provide high availability of the overall train network, so the system shall ensure that failure of a single active component or power failure within one vehicle shall not interrupt the DTL functionality for the remainder of the train.
2.0 General Digital Train Line Requirements

2.1 Definitions

27 Pin COMM Cable — A cable assembly, having a 27-conductor plug on one or both ends, which is used to provide a flexible electrical connection between two cars and/or locomotives.

27 Pin MU Cable — A cable assembly, having a 27-conductor plug on one or both ends, which is used to provide a flexible electrical connection between two cars and/or locomotives typically used for propulsion and engine-related functions.

Digital Train Line — An Ethernet data cable system that will transmit data over the entire length of a train, through cabling in the interior of each rail vehicle and also via jumper cables physically connected between vehicles.

Inter-Vehicle Jumper Assembly — A cable assembly comprised of a jumper cable and fixed receptacle attached to the ends of each vehicle which is used to provide a flexible data connection between two vehicles.

Managed/Failover Switch — A managed network switch is a multi-port computer networking device that links multiple network segments or network devices to process and route data. Failover capabilities can switch a circuit between two networks based on a manual or automatic trigger.

Receptacle — The fixed receptacle(s) mounted on the ends of rail vehicles into which the inter-vehicle jumper assemblies mate.

Wireless Bridge — is the hardware component which is used to connect two or more network segments which are physically separated. Specifically, it is the hardware that connects the network segments located in each vehicle.

2.2 Abbreviations

APTA: American Public Transportation Association
COMM: Communication
DTL: Digital Train Line
ECP: Electronically-Controlled Pneumatic Brake
EMI: Electromagnetic interference
ESD: Electrostatic discharge
FRA: Federal Railroad Administration
Gbps: Giga-bits per second
Mbps: Mega-bits per second
OBIS: Onboard Information System
IP: Internet Protocol
IP Components: Applications or systems that utilize Internet Protocol (IP).
MDBSF: Mean Distance Between Service Failure
MTBF: Mean Time Between Failure
MTBSF: Mean Time Between Service Failure
MU: Multiple Unit
TOR: Top of Rail
VLAN: Virtual Local Area Network
VOIP: Voice over Internet Protocol
WiFi: Wireless Fidelity

2.3 Reference Documents

The DTL shall be designed to meet the latest revision of the following:

- PRIIA Specification 305-912: *Operational and Environmental Conditions for Rail Rolling Stock*
- PRIIA Specification 305-915: *High Performance Wire and Cable*
- PRIIA Specification 305-920: *Digital Train Line Software*
- Amtrak Specification 328-1: *Materials and Workmanship*
- Amtrak Specification 854-1: *Vehicle Design – Build Components*
- Amtrak Specification #1: *Components to be installed on High Speed Train Sets*
- 49CFR 238 Appendix B: *Test Methods and Performance Criteria for the Flammability and Smoke Emission Characteristics of Materials Used in Passenger Cars and Locomotive Cabs Test Procedures and Performance Criteria for Flammability and Smoke*
- Rail Environmental:  EN 50155, EN 50121-4
- ANSI TIA/EIA Cat 7
- NFPA 130: *Standard for Fixed Guideway Transit and Passenger Rail Systems*
3.0 Digital Train Line General Architectural Overview

The DTL is comprised of two sub-system elements; an exterior network link between vehicles and a physical interface to the interior WiFi system.

3.1 Exterior Vehicle-to-Vehicle Network Link

The components of the exterior vehicle-to-vehicle network are the fixed receptacles, receptacle housings, bulkhead connectors and jumper cables.

Figure 1: Exterior Vehicle-to-Vehicle Network

Figure 2: End of Car Drawing
3.2 Bulkhead Connectors

Each Fixed Receptacle will be pre-wired with two Category 7 cables (one as a spare) that are designed in accordance with the technical specification described below. Each of the cables shall be terminated with an eight way A-Coded bulkhead M12 connector. Cables have to be routed in such a way that they are protected from EMI.

3.3 Jumper Cables

The inter-vehicle jumper assembly has two primary components; two fixed receptacles mounted to the end corners of each vehicle and a jumper, which is a flexible cable assembly. The fully removable jumper connects to the fixed receptacles on two facing vehicles and contains the Ethernet cable that links the two vehicles.

![Figure 3: Jumper Cable](image)

The jumpers are composed of two Category 7 cables and are 60 in. long. One of the cables will provide the Ethernet link between vehicles and the second is a provision for future expansion. Each cable will provide bandwidth that is at least 1 Gbps. The cables will populate position 1 and 3 of the receptacle. Each end of the jumper cable is designed to allow free movement, with a horizontal 270 degree arc of the mating face, in relation to the cable jumper to prevent excessive force on the jumper either when being mated to the vehicle or during normal vehicle movement. The jumper pulling failure force should be no greater than 110 kg-ft which shall be less than the strength of the attachment of the receptacle housing to the carbody.

In order to prevent damage to the receptacle internal connectors, the jumpers are designed with keyways to ensure that there is only one way to fit the jumper. The jumper plug is to be designed to allow removal from the fixed receptacle without causing strain to the internal cables or damage to any part of the jumper or connector face.

Each cable is protected externally with an industrial woven, close fitting, sleeve that ensures mechanical protection from abrasion along the length of the cable's jacket. The sleeving selected meets the FRA requirements (NFPA 130) for fire performance. The cables also incorporate an internal EMI screen over the length of the cables and the screen is continuous over the connector. The screen connection is not continuous over the full length of the assembly to prevent providing a common earth connection between adjacent vehicles. The screen of each cable is capable of being connected to the vehicle body at one point only. All other connectors and parts of the assembly are constructed to prevent multiple earth points on the cable screen.

Jumper (and associated mating half on the receptacle) position 1 shall be used for the DTL connection. Jumper (and associated mating half on the receptacle) position 3 shall be used for the spare connection; positions 2 and 4 shall be plugged. Within the car the free end of the cable from the fixed receptacle shall be clearly marked with a heat shrunk cable label with either a 1 or a 3 related to the receptacle position as defined above.

The cable jumper shall not be handed, i.e. it will allow a secure connection regardless of which end is presented to the fixed receptacle.

The DTL connectors are colored orange (Pantone 166C) to differentiate them from other connectors on the vehicle.
The connectors are twist lock bayonet style with visual and tactile indexing. The jumpers will be designed with keyways to ensure that there is only one correct way to fit the jumper to prevent damage to the internal connectors. The jumper plug will be capable of being removed from the fixed receptacle without causing strain to the internal cables or damage to any part of the jumper or connector. In the case that the jumper has not been disconnected between two vehicles that are separating, the jumper has been designed to break away before any damage to the fixed junction box or vehicle body has occurred.

3.4 Fixed Receptacles and Receptacle Housings

Each vehicle has four receptacles, two per end of the vehicle. Each of the receptacles is wired into the vehicle and connected to the Ethernet switch inside the end of the vehicle.

The switch / jumper arrangement shall be wired to ensure that the network takes advantage of both sets of DTL cables to provide redundancy and also is protected against individual device failure. The Fixed Receptacle shall be secured to the vehicle to ensure that the Ethernet Jumper attaches at an angle of approximately 15 degrees from vertical. The center line of the Fixed Receptacle mounting junction box shall be 60 in. from TOR and 31.25 in. outward from the vehicle longitudinal center line. The body end sheet is assumed to be 17.15 in. from the coupler face. An installation tolerance of 2 in. is acceptable for any of these dimensions in any direction. The Fixed Receptacle will incorporate two connectors to align with the two cables inside the jumper cable. The receptacle will have alignment markers to ensure correct orientation of the jumper. The covers of the receptacles are designed to automatically hinge shut, providing an IP67 water resistant seal to prevent water ingress into the electrical contacts.
Figure 5: The DTL Exterior Junction Box
4.0 Interior Vehicle Network Architecture

4.1 Switches

A managed Ethernet switch (Figure 6) will be installed in each end of the vehicle. The switches are capable of allowing the Ethernet signals from adjacent vehicles to pass through them when they fail or lose power. The Ethernet switches used shall conform to the protocols and standards defined in the software specification.

Two Ethernet switches inside the end of the vehicle are to be mounted close to the location where the jumper receptacle cables enter the vehicle. A length of Category 7 Ethernet cable shall be connected to the end of the receptacle cable and attached to the Ethernet switch.

![Figure 6: Managed Ethernet Switch (Typical)](image)

4.1.1 Switch Design

The switch design includes (at a minimum):

- 8 Fast Ethernet ports (100Mb)
- 4 GigE ports
- 2 Fiber ports
- Failover contacts, if switch fails then GigE Ethernet ports automatically bridge passing signal through switch to next vehicle
- Direct connection to train power

The switches must be able to withstand the operating environment, vibration and shock found in the rail environment as defined in the standards defined in section 2.3 above, have both predictable failure modes and MTBF and MDBSF data calculated according to MIL-HDBK-217 and from real world test experience. They accept a wide power input range. They are designed to tolerate power surges and Electrostatic Discharge (ESD). They utilize M12 connectors designed for harsh environments.
4.1.2 Switch Interfaces

- Fast Ethernet Front cabling 10/100BaseT(X) using an M12 connector (D-Coded)
- Gigabit Ethernet Down cabling using 8 way (A-Coded) 1000 BaseT(X)
- Where implemented any fiber connections will use Q-ODC connections

4.1.3 Switch Failover Contacts

- The failsafe position of the switch is closed
- Gives wired vehicle-to-vehicle communication priority
- Switches to wireless vehicle-to-vehicle communications when wired communication is lost

4.2 Connectors

The Ethernet terminations on both the Ethernet switches and on the ends of the cable receptacles shall be fitted with M12 connectors utilizing D-Coding for fast Ethernet connection and 8 way A-Coded for gigabit Ethernet. (see Wiring table below for reference)

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<tr>
<th>Core</th>
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<tbody>
<tr>
<td>Green</td>
<td>TRD 3 +</td>
<td>1</td>
</tr>
<tr>
<td>Brown</td>
<td>TRD 4 +</td>
<td>2</td>
</tr>
<tr>
<td>White Brown</td>
<td>TRD 4 -</td>
<td>3</td>
</tr>
<tr>
<td>White Blue</td>
<td>TRD 1 -</td>
<td>4</td>
</tr>
<tr>
<td>Orange</td>
<td>TRD 2 +</td>
<td>5</td>
</tr>
<tr>
<td>Blue</td>
<td>TRD 1 +</td>
<td>6</td>
</tr>
<tr>
<td>White Green</td>
<td>TRD 3 -</td>
<td>7</td>
</tr>
<tr>
<td>White Orange</td>
<td>TRD 2 -</td>
<td>8</td>
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Figure 7: M12 GigE Connector Pin Arrangement

4.3 Cabling

An Ethernet cable is installed along the length of the vehicle to connect the switch at each end of the vehicle together. Certain areas of specific rail vehicles can be sources of EMI so the position and routing of this Ethernet cable inside of the vehicle is done in such a way as to not impede the 1Gbps performance. A fiber optic cable assembly is placed alongside the Ethernet cable that connects the two switches together to future-proof the system. When a fiber optic vehicle-to-vehicle jumper and its mating receptacle assembly are available the Ethernet cable connecting the two switches will be disconnected and the fiber optic cable running alongside it will be utilized to connect the two switches together, thereby increasing the bandwidth and EMI immunity. The fiber optic cable can be used to connect the two switches together without a corresponding fiber optic vehicle-to-vehicle jumper and mating receptacle assembly but when the switches in a particular vehicle lose power they will not be able to pass data between the two adjacent vehicles coupled to it. Ethernet cable on each vehicle connects the exterior receptacles to the managed switches. Proper engineering practices shall be followed for terminating the shields.
4.4 Fiber Optic Cable

The fiber optic cable assembly runs the entire length of the vehicle and can be used to connect the managed switches together. Historically when electrical cables have been used for this portion of the digital train line electrical noise was sometimes induced into the line from the traction motors in the locomotive. This assembly is immune from EMI and can be used in such a way as to increase the bandwidth. Ideally it is used in conjunction with a fiber optic vehicle-to-vehicle jumper and its mating fiber optic receptacle assembly.

4.5 Failover Switch

A fiber optic or copper cable assembly is placed alongside the Ethernet cable that connects the two Ethernet switches together. When a fiber optic vehicle-to-vehicle jumper and its mating receptacle assembly are available the Ethernet cable connecting the two switches will be disconnected and the fiber optic or copper cable ran alongside it will be utilized to connect the two switches together thereby increasing the bandwidth and EMI immunity. The fiber optic cable can be used to connect the two switches together without a corresponding fiber optic vehicle-to-vehicle jumper and mating receptacle assembly but when the switches in a particular vehicle lose power they will not be able to pass data between the two adjacent vehicles coupled to it.

Figure 8: Typical Ethernet Switch
5.0 Wiring Topography

The existing wireless train components (Access Points) of the WiFi system will be connected to the Ethernet switches. This is done to provide a fall back connection method such that if a jumper connection fails then data will automatically be routed over the wireless network. The wired network will always be used in preference to the wireless network.

The switches will allow multiple VLAN assignment for the management of network traffic flow and shall support both port based VLAN assignment and also the passage of trunked VLAN traffic if required.

The DTL shall ensure that the network shall be maintained when a minimum of one of the Ethernet jumpers on each end of the vehicles are connected. If a single Ethernet jumper should fail then the failover contacts will ensure that the connection is maintained from the DTL receptacles to the next switch in the vehicle. If power fails within the car then the failover contacts will ensure that the Gigabit network is maintained between both working vehicles on each side of the failed car. The network shall be maintained with a maximum of three adjacent vehicles with complete power failure.
Figure 9: Ethernet Switch Wiring