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RECOMMENDED PRACTICE

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Electrical Working Group

480 Vac Head End Power System

Abstract: This document defines the recommended practices for a head end power (HEP) system, including hardware component functional requirements, transmission, power distribution and load properties for use on locomotive-hauled passenger vehicles. Single bus and split bus forms are described to accommodate intercity and commuter-type operations.

Keywords: 480 Vac, head end power system, HEP, trainline, TLC, trainline complete

Summary: This recommended practice defines the functionality of the 480 Vac head end power trainline system, as well as its application to passenger cars and locomotives.

Foreword

The American Public Transportation Association is a standards development organization in North America. The process of developing standards is managed by the APTA Standards Program's Standards Development Oversight Council (SDOC). These activities are carried out through several standards policy and planning committees that have been established to address specific transportation modes, safety and security requirements, interoperability, and other topics.

APTA used a consensus-based process to develop this document and its continued maintenance, which is detailed in the manual for the APTA Standards Program. This document was drafted in accordance with the approval criteria and editorial policy as described. Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

This document was prepared by the Electrical Working Group as directed by the Passenger Rail Equipment Safety Standards Policy and Planning Committee.

This document represents a common viewpoint of those parties concerned with its provisions, namely transit operating/planning agencies, manufacturers, consultants, engineers and general interest groups. The application of any recommended practices or guidelines contained herein is voluntary. APTA standards are mandatory to the extent incorporated by an applicable statute or regulation. In some cases, federal and/or state regulations govern portions of a transit agency's operations. In cases where there is a conflict or contradiction between an applicable law or regulation and this document, consult with a legal adviser to determine which document takes precedence.

This document supersedes APTA PR-E-RP-016-99, Rev. 1, which has been revised. Below is a summary of changes from the previous document version:

- Updated working group roster; format updated to latest APTA standards format.
- Addition of Summary section.
- Addition of Foreword section.
- Added applicability language in the Introduction.
- Added power car as a vehicle type throughout document.
- Merged former sections 1.1, Scope, and 1.2, Purpose, into Scope and Purpose.
- Revised figures in former section 10, List of diagrams and illustrations. Redistributed revised figures in appropriate places within document.
- Moved former section 2, References, to the new sections Related APTA standards and References.
- Moved former section 3, Definitions, abbreviations and acronyms into new sections Definitions and Abbreviations and Acronyms.
- Former section 4, General, renumbered to new section 1.
    - Renumbered former section 4.3.3, Intermixing, to new section 1.3.3. Added recommendation that authority specify whether power configuration is single bus or split bus. Added recommendation that maximum tolerable fault current be specified by manufacturer but not below 35 kA.
    - Renumbered revision of former Figure 6, to new Figure 2.
    - Renumbered revision of former Figure 7, to new Figure 3.
    - Renumbered revision of former Figure 2, to new Figure 4.

  - Renamed and renumbered former Figure 3, Locomotive 480 VAC Trainline Power Schematic - Single Bus System, to new Figure 5, Locomotive/Power Car/MU 480 VAC Trainline Power Schematic - Single Bus System.
  - Renumbered revision of former Figure 4 to new Figure 6.
  - Renumbered former revision of Figure 5 to new Figure 7.
  - Renumbered former section 4.7, Environment, to new section 1.7. Reworded environment service rating, design, and manufacture recommendations.
- Renumbered former section 5, Application to vehicles, to new section 2.
  - Renumbered former section 5.1, End location (left/right), to new section 2.1. Added end of car design integration recommendations.
- Renumbered former section 6, Transmission system components, to new section 3.
- Renumbered former section 7, Trainline complete control (TLC), to new section 4.
  - Renumbered revision of former Figure 12 to new Figure 8.
  - Renumbered revision of former Figure 13 to new Figure 9.
- Renumbered former section 8, Load characteristics, to new section 5.
  - Renumbered former section 8.4, Phase balance, to new section 5.4. Added exceptions to achieving recommendations under very light load conditions and single phase loads with unpredictable duty cycles.
  - Renumbered revision of former Figure 14, to new Figure 10.
- Renumbered former section 9, Testing, to new section 6.
  - Renumbered and split former section 9.1, Wiring, into new sections 6.1, Production tests,6.1.1, Wiring, 6.1.1.1, Insulation, and 6.1.1.2, Continuity.
  - Added new section 6.1.1.3, Functional Tests. Added recommended functional tests.
  - Added new section 6.2.1, New vehicle tests. Added recommendation to test with all potential vehicle combinations with new and existing rolling stock.
  - Added new section 6.2.2, Functional tests. Added recommendations for verification of TLC circuits for all locomotive arrangements.
  - Added new section 6.2.3, Cable swing and interference. Added recommendations on cable swing and interference.
- Added APTA PR-CS-RP-019-12, "Pushback Couplers in Passenger Rail Equipment," APTA PR-M-RP-001-97, "End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers," and APTA PR-M-S-016-06, "Safety Appliances for Passenger Equipment" to Related APTA documents.
- Added 49 CFR, Part 231, Railroad Safety Appliance Standards, and PRIIA specifications to References.
- Removed Dead bus protection and Load box from definitions.
- Added new Appendix A containing revisions to former figures 8-11 and renumbered the revisions 11-14.

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Introduction

This introduction is not part of APTA PR-E-RP-016-99, "480 Vac Head End Power System."

This recommended practice applies to all:

- railroads that operate intercity or commuter passenger train service on the general railroad system of transportation; and
- railroads that provide commuter or other short-haul rail passenger train service in a metropolitan or suburban area, including public authorities operating passenger train service.

This recommended practice does not apply to:

- rapid transit operations in an urban area that are not connected to the general railroad system of transportation;
- tourist, scenic, historic or excursion operations, off the general railroad system of transportation;
- operation of private cars, including business/office cars and circus trains unless otherwise required by other standards or regulations;
- railroads that operate only on track inside an installation that is not part of the general railroad system of transportation; or
- vehicle-to-vehicle interfaces that are permanently or semi-permanently coupled within trainsets; however, the exposed ends are still subject to this recommended practice.

Scope and purpose

This document defines the recommended practices for HEP systems, including vehicle interface and the electrical source, transmission and load characteristics required to allow intermixing of cars, locomotives and MUs of varying designs. In addition, it defines minimum HEP system construction recommended practices for new equipment.

Equipment conforming to this recommended practice should be mutually compatible for HEP operation (with some limitations, as described in Section 1.3).

For the mechanical intercar and inter-locomotive jumper/receptacle interfaces for mounting receptacles on the end of the vehicles, see APTA PR-M-RP-001-97, "End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers."

For HEP jumper and receptacle hardware, see APTA PR-E-RP-018-99, "480 Vac Head End Power Jumper and Receptacle Hardware."

480 Vac Head End Power System

1. General

1.1 Purpose of head end power (HEP)

The concept of HEP provides a convenient means by which electrical power (typically up to about 1 MW but limited by transmission capacity) can be generated by a central source and transmitted to each car throughout a train consist to operate auxiliary equipment. Typical HEP loads consist of HVAC, lighting, battery charging/low-voltage power supply, food service equipment and water heating equipment.

The HEP system should be composed of the following:

- power source
- switchgear (on/off as well as overload and other protection)
- control system incorporating trainline complete (TLC) functions
- connections to vehicle HEP trainline

1.2 Power sources

There are four source configurations for HEP:

- alternator-driven from locomotive traction prime mover
- alternator-driven from dedicated engine
- locomotive inverter
- wayside power (stationary utility)

Refer to APTA PR-E-RP-015-99, "Head End Power Source Characteristics," for HEP source details.

1.3 HEP trainline configurations

Two alternative approaches for the HEP trainline system are available: single and split bus.

1.3.1 Single bus

Single bus is used on some commuter equipment and most intercity equipment. The single bus system is recommended, primarily on considerations of lower first cost, less complexity, more widespread usage and increased operational flexibility.

1.3.2 Split bus

Split bus allows the train to be fed from two independent HEP sources simultaneously, which may allow larger consist power demand. Split bus is used on some commuter equipment.

1.3.3 Intermixing

Individual railroad rules and operating practices govern the intermixing of single and split bus equipment. However, for the purposes of this document, the alternative approaches are semi-compatible as follows:

- Single bus source can feed a consist containing either single bus, split bus or a mix of both bus arrangements.
- Split bus source can feed only a split bus consist.
- Single bus and split bus equipment can be intermixed within a consist provided that the HEP source is single bus and that both split buses are utilized throughout the length of the consist.

It is incumbent upon the authority to specify which of the two following configurations the power source should take:

- single bus only
- split bus or single bus (the source is configured to provide power either way, depending upon the setup switch position)

The maximum tolerable short-circuit current contribution from the HEP source (symmetrical and asymmetrical) at the point of connection shall be specified by the carbuilder. This number shall not be below 35 kA. This number shall account for short-circuit ratings of carborne panels, circuit breakers, contributions of carborne motor loads, etc.

1.4 Single bus HEP system attributes

- One HEP bus the length of the train.
- 480 Vac, line-to-line (L-L), 3-phase, 3-wire, 60 Hz operation.
- Per APTA PR-E-RP-015-99, "Head End Power Source Characteristics," the source should have a neutral ground reference, but the distribution system and load do not.
- 1600 A continuous rating.
- Four jumpers across each car-car-locomotive connection (see **Figure 1**).
- All four jumpers in parallel.
- Control schematic as per **Figure 2** and **Figure 3**.
- Power schematic as per **Figure 4** and **Figure 5**.
- Jumper cable end arrangement on vehicle (see figures in Appendix A).
- Single HEP power junction box.
- Single HEP tap to feed each car.

FIGURE 1

Typical Consist HEP Jumper Cable Arrangement

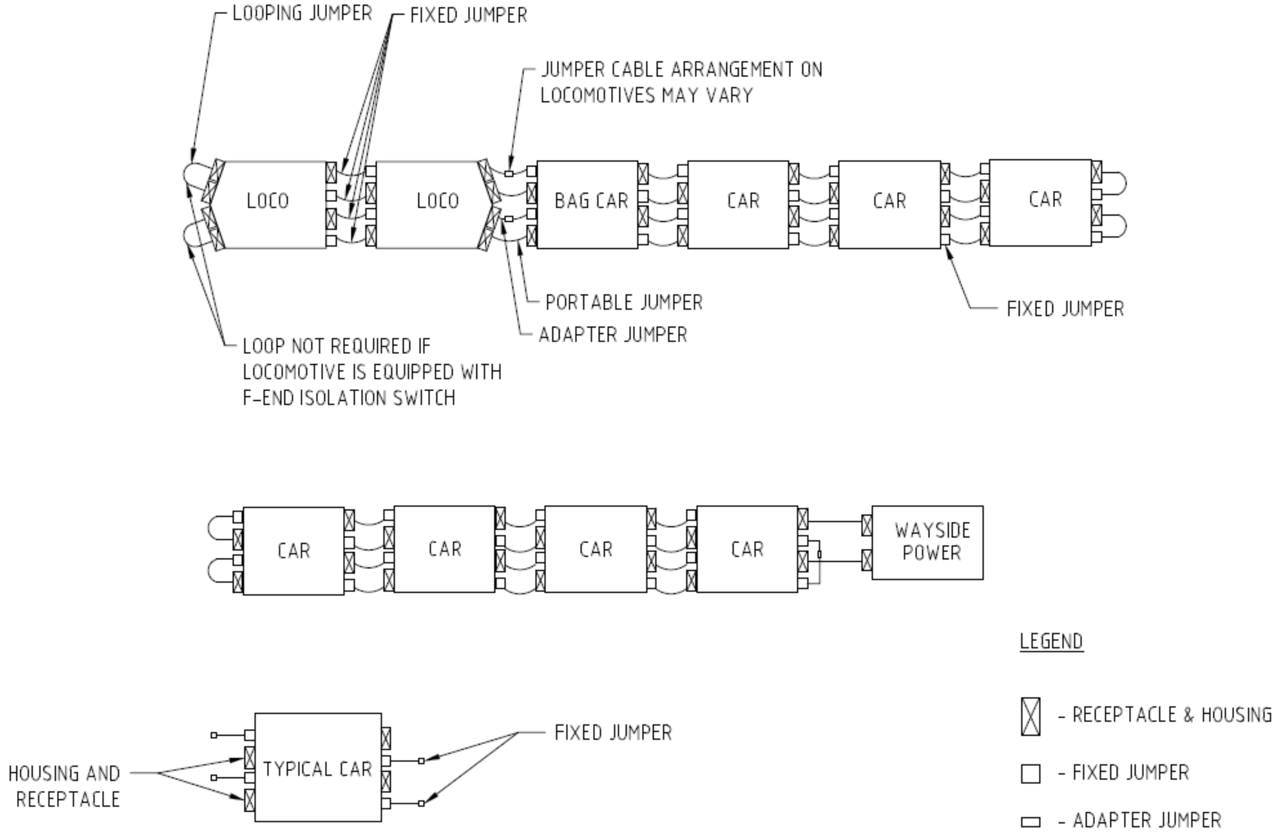


FIGURE 2

Car 480 Vac Trainline Control Schematic

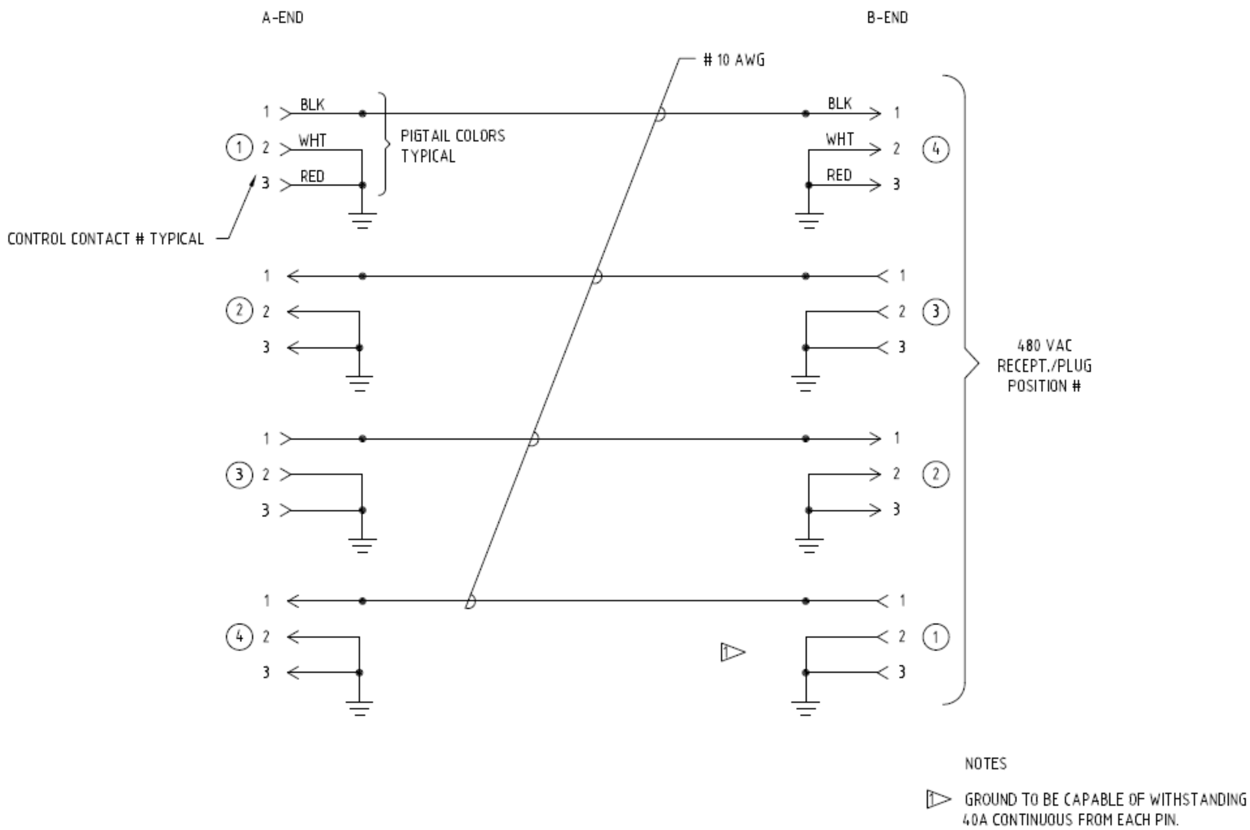


FIGURE 3

Simplified Locomotive/Power Car/MU 480 Vac Trainline Control Schematic

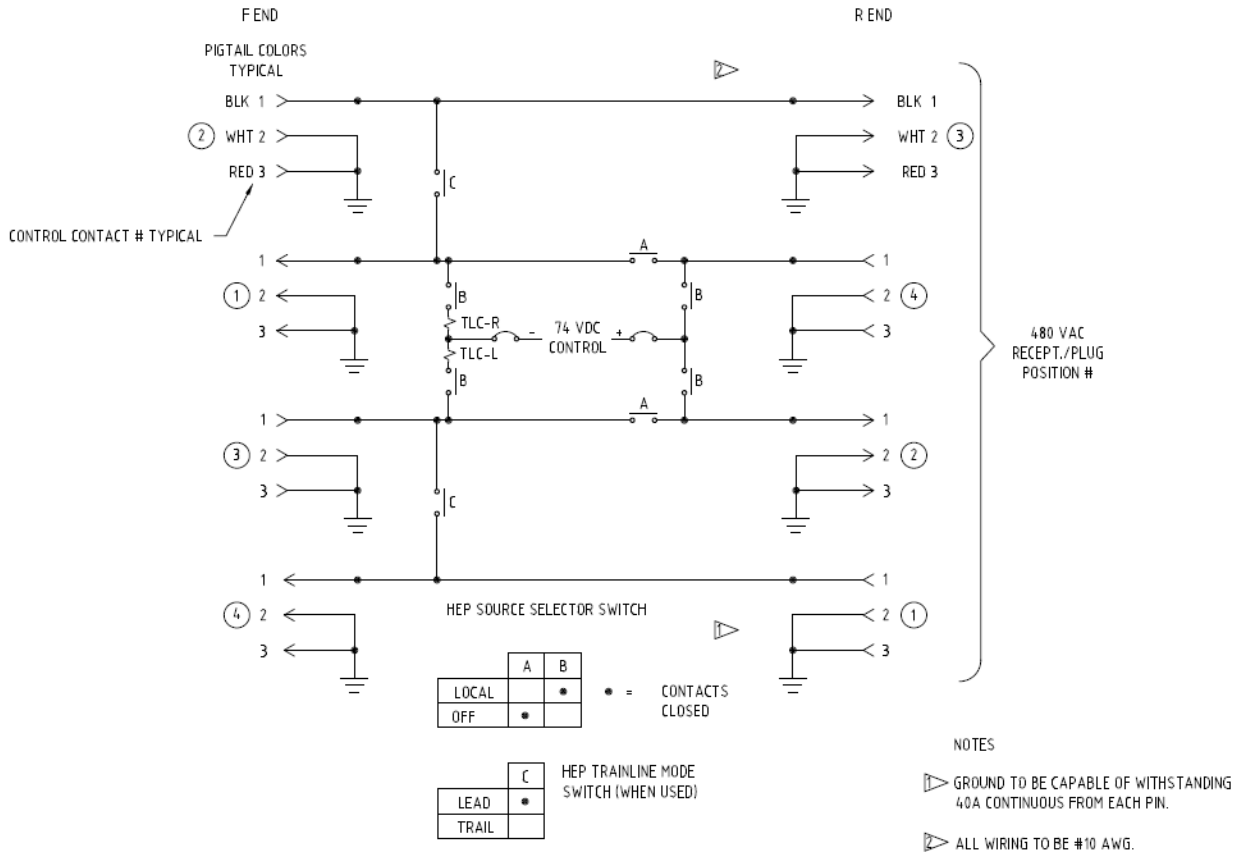


FIGURE 4

Car 480 Vac Trainline Power Schematic – Single Bus System

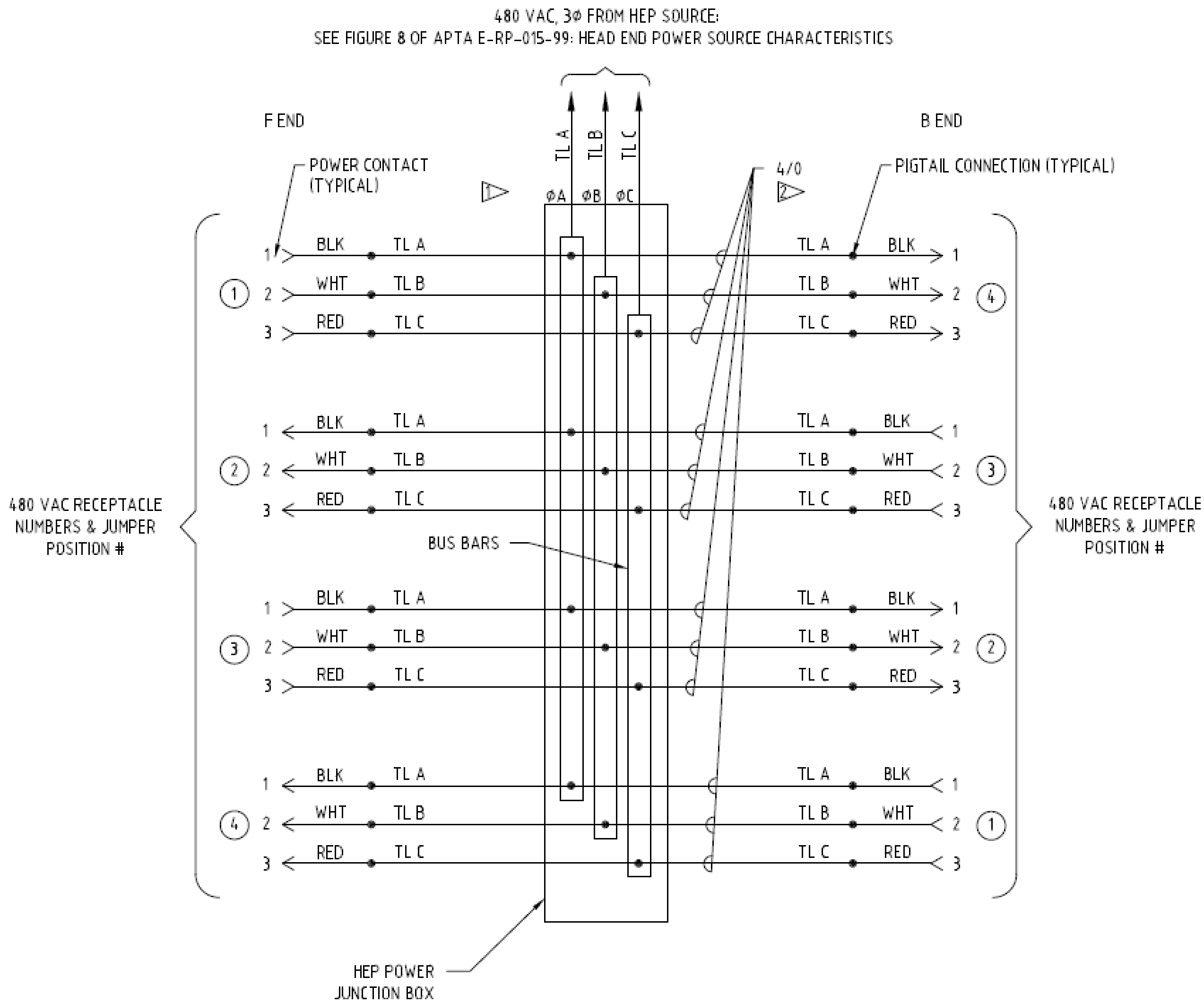
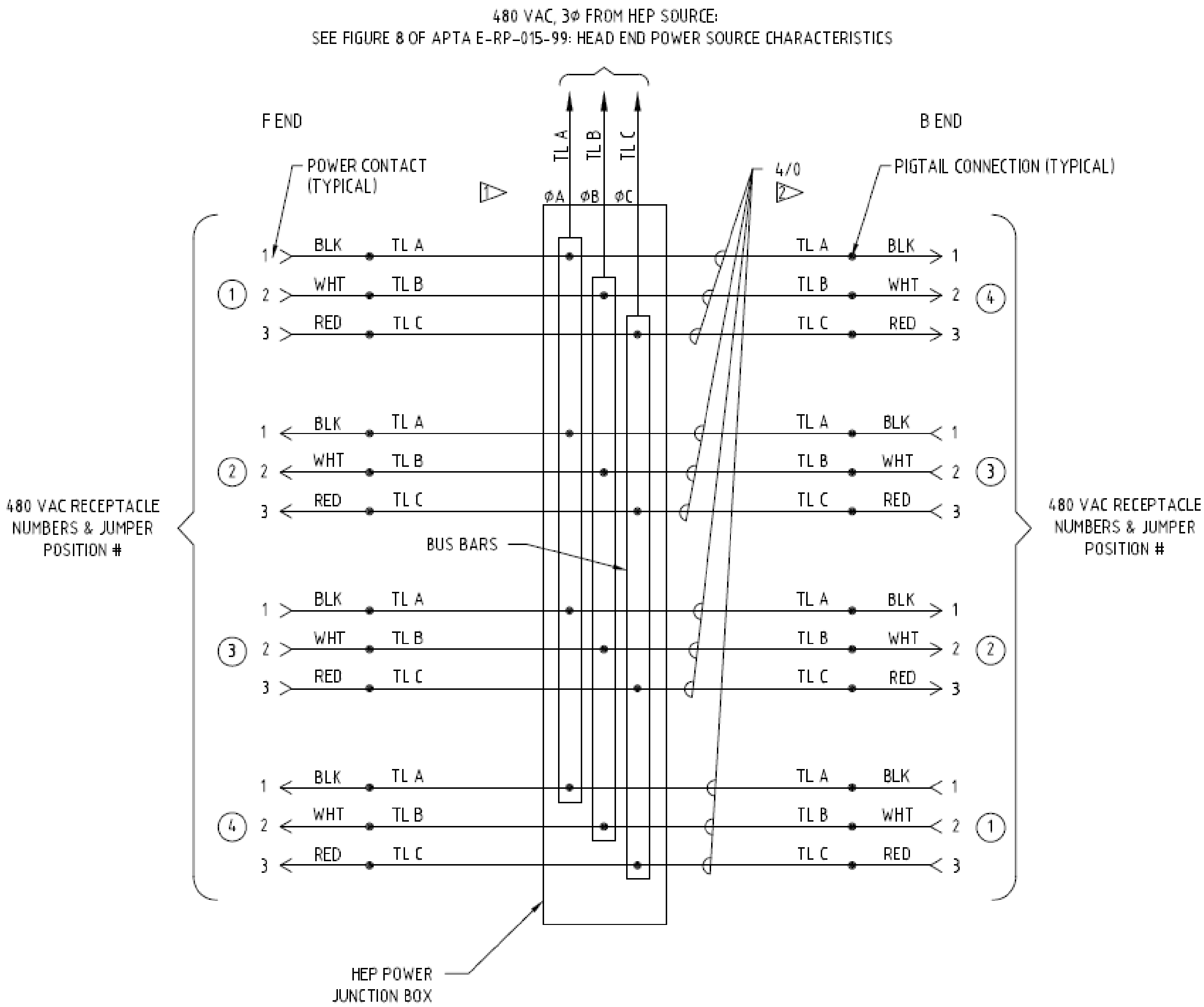


FIGURE 5

Locomotive/Power Car/MU 480 Vac Trainline Power Schematic – Single Bus System



1.5 Split bus HEP system attributes

- Two HEP buses the length of the train, one on each side.
- 480 Vac, line-to-line (L-L), 3-phase, 3-wire, 60 Hz operation.
- Per APTA PR-E-RP-015-99, “Head End Power Source Characteristics,” the source should have a neutral ground reference, but the distribution system and load do not.
- 800 A continuous rating per bus.
- Four jumpers across each car-car-locomotive connection (see **Figure 1**).
- Two jumpers in parallel for left bus, two jumpers in parallel for right bus.
- Control schematic per **Figure 2** and **Figure 3**.
- Power schematic per **Figure 6** and **Figure 7**.
- Jumper cable end arrangement on vehicle (see figures in Appendix A).
- Two HEP power junction boxes.
- Two HEP taps to feed each car, one from each bus.

FIGURE 6

Car 480 Vac Trainline Power Schematic – Split Bus System

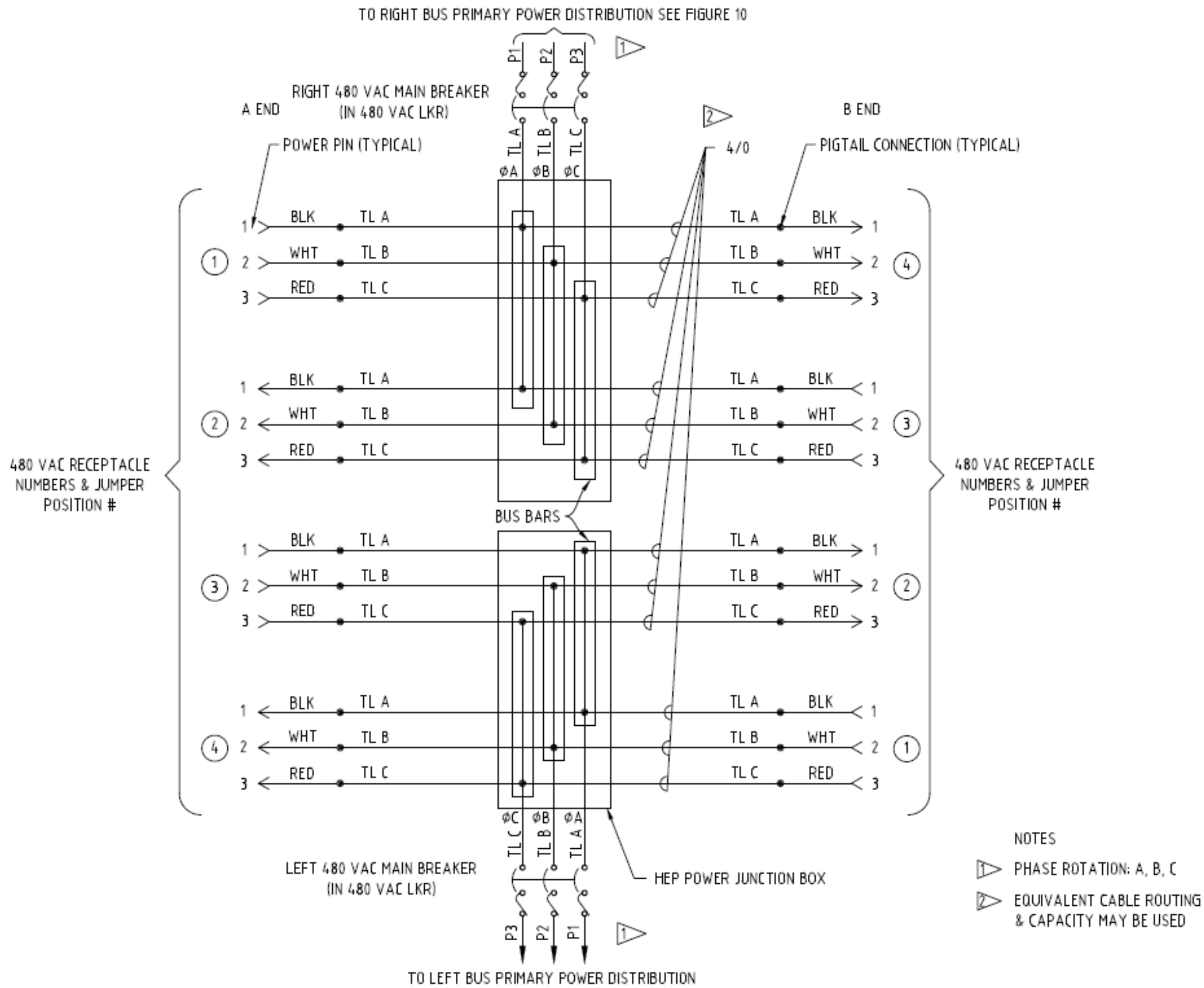
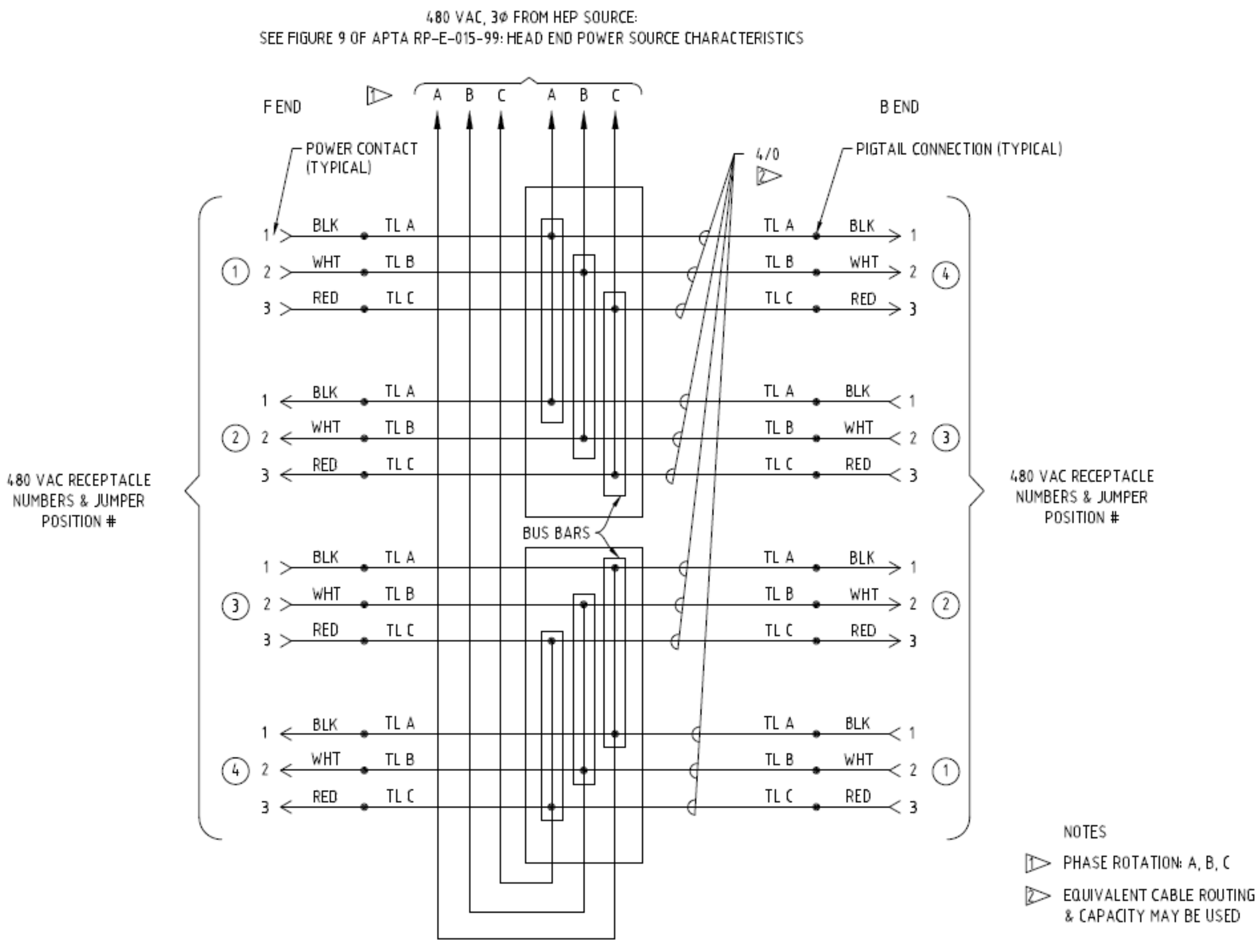


FIGURE 7
Locomotive 480 Vac Trainline Power Schematic – Split Bus System



1.6 Transmission capacity

The entire HEP trainline system should be rated for continuous service over the outside ambient temperature of −40 to 110 °F (−40 to 43 °C), unless otherwise specified by the authority.

Single bus	1600 A
Split bus	800 A per each bus

To minimize voltage drop, cable resistance, including jumper cables and no more than four bolted connections, should not exceed the following values:

Single bus	equivalent to 125% of car length of 12-4/0 cables, four per phase
Split bus	equivalent to 125% of car length of 6-4/0 cables, two per phase

1.7 Environment

The equipment should be rated, designed and manufactured to operate reliably with or without degradation under the following environmental conditions or with any additional requirements as specified by the authority. Of particular concern are shock, vibration and ambient temperature. The following are examples of conditions that may occur and should be the subject of such detailed specifications:

- heavy rain, driven by wind or water from a hose
- direct sun
- hail, ice, powdered snow
- blown sand, dust, ballast and rocks
- vehicle speeds to 125 mph (200 km/h)
- wind gusts to 90 mph (145 km/h)
- salt (sea spray or from roads during winter months)
- impact from airborne road debris
- car washing chemicals and wash rack operations

2. Application to vehicles

2.1 End location (left/right)

The design of the ends of the vehicles shall be integrated early on in the design to comprehensively and holistically meet the following requirements for the HEP, as well as 27-point assemblies and DTL trainlines (if equipped):

- Location and clearance requirements of APTA PR-M-RP-001-97, "End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers." This companion document defines receptacle mounting locations and clearance criteria to prevent mechanical interference between different cable systems, couplers, etc., as well as identifying issues that affect the inter-vehicle end-to-end relationships dynamically.
- This must take into account all practical combinations of vehicles that may be intercoupled: car-to-car, car-to-locomotive (both locomotive ends) and locomotive-to-locomotive (on both ends).
- Moreover, this must take into account not only the new vehicles, but also how the new vehicles will interface with existing rolling stock with which it may operate.

The location of the receptacles on the end of the vehicle is shown for reference in Appendix A.

2.1.1 Locomotives

Receptacles or fixed jumpers with receptacles should be provided on all four corners of each vehicle. Fixed jumpers should be provided at the non-cab end.

2.1.2 Power cars

Receptacles or fixed jumpers with receptacles should be provided at all four corners of each vehicle. Fixed jumpers should be provided at the non-cab end(s).

2.1.3 Cars and MUs

Receptacles and fixed jumpers should be provided at all four corners of each vehicle, with fixed jumper cables installed in positions #1 and #3 at both ends.

2.2 Mounting

The plate to which the receptacles (and fixed jumper flanges, if used) are mounted should be reinforced to resist, without bending, forces produced from pulling the locked jumper out of the receptacle, such as by an unintended uncoupling. The jumper cable should be sacrificial relative to the car body components to avoid damage to the internal wiring of the vehicle.

Receptacle mounting should be such that there is adequate clearance between jumpers, receptacles and uncoupling rods, diaphragm/buffer, coupler, air hoses, etc.

For details of these requirements, refer to APTA PR-M-RP-001-97, "End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers."

There should be no interference that restricts opening the receptacle cover fully to allow insertion or withdrawal of jumpers.

2.3 Identification

As an identification aid, receptacle housings should be color-coded red and labeled "Danger 480 Vac."

Warning labels should be provided, consistent with FRA regulations 49 CFR §229.085 and 49 CFR §238.303(e)(12).

2.4 Control junction boxes

A junction box should be provided near each end of the vehicle to provide for the connecting of the receptacle and fixed jumper control wire pigtails with the vehicle car body wiring.

2.5 Power junction boxes

A power junction box should be provided near the center of the vehicle to provide a point for the trainline cables of each phase to be connected to a common bus bar (one per phase). In addition, the box provides a point for the car wiring to connect to the trainline wiring, either as a tap to feed power to the car loads or from the HEP source to the trainline. A vehicle with a split bus trainline system may have two such boxes, or a single box having both sets of bus bars.

2.6 Wire routing

Wire routing should comply with APTA PR-E-RP-002-98, "Installation of Wire and Cable on Passenger Rolling Stock," with additional recommended practices as described in this section.

2.6.1 Mechanical separation

The power wiring for the HEP trainline system should be mechanically separated from other sensitive vehicle wiring so as to minimize the risk to other equipment from electromagnetic interference.

2.6.2 Phases grouped

The power wiring should be run with all three phases grouped together at all times. Conductors should be located to avoid local induction heating, which includes but is not limited to avoiding resting cables on magnetic materials such as undercar equipment enclosures.

2.6.3 Undercar routing

Beneath the car body, trainline cables should be routed as high as possible to minimize exposure to road impact damage.

2.6.4 Cable protection

Guards should be provided to shield 480 Vac undercar power cables from mechanical damage in exposed areas at a minimum, such as above the trucks, the transition between areas over the truck and the low floor area. If conduit is used for this purpose, it is necessary for cables to be grouped with the three phases from a given receptacle/plug together as they pass through the conduit.

2.6.5 Cable impedance

Power cable lengths should be kept as equal as possible between the end of the vehicle and the HEP power junction box. This is to keep the impedance of each cable nearly equal in order to force current-sharing among all jumpers.

2.6.6 Cable support

Insulated cable cleats should be provided every 4 ft (1.22 m) or closer for power cable support.

2.6.7 TLC circuit

The TLC circuit conductors should run in a separate conduit, terminating at each end of the vehicle in the control junction box. Only the TLC wires may occupy this conduit.

3. Transmission system components

3.1 Receptacle and jumper cable

Refer to APTA PR-E-RP-018-99, "480 Vac Head End Power Jumper and Receptacle Hardware," for recommended practices for 480 Vac head end power jumper and receptacle hardware.

3.2 Car cabling

3.2.1 End to end

Cable installation should be in compliance with APTA PR-E-RP-002-98, "Installation of Wire and Cable on Passenger Rolling Stock," with the following additional recommended practices:

- The car body wiring should be open (i.e., not in conduit) and should connect the receptacles/jumpers to the 480 Vac power junction box(es).
- It is recommended that 12-4/0 cables be used. This results in four conductors per phase on single bus systems and two conductors per phase on each trainline bus on the split bus system.
- Other cable arrangements may be used, provided that they meet or exceed the ampacity and meet or improve upon the impedance compared with the 4/0 approach.

3.2.2 Cable rating

Cable should be per APTA PR-E-RP-009-98, "Ampacities for Wire and Cable Used on Passenger Rolling Stock with Flame, Smoke and Toxicity Considerations." However, it should have a double wall, 0.055 + 0.050 in. (1.4 + 1.3 mm) insulation, with a rating of a minimum of 600 Vac.

3.2.3 Cable cleats

Neoprene cable cleats should be provided to support the trainline power cable. Cleat design should prevent crushing cables from overtightening the mounting hardware, such as by incorporating spacers within the mounting holes.

3.2.4 Splices to receptacle wiring

Hydraulically crimped, bolted joint lugs employing two bolts should be used to splice the pigtails of the 480 Vac jumpers/receptacles to the car body wiring. These splices should be kept waterproof either through the use of insulated boots over the joint or by enclosing them in a non-magnetic stainless steel junction box. Spliced joints should be kept physically separated from each other to avoid crushing or abrasion of the insulated boot with the subsequent risk of loss of insulation.

3.3 HEP power junction box

3.3.1 Enclosure

The waterproof enclosure should be constructed of heavy gauge, non-magnetic, corrosion-resistant material (stainless steel or approved equal), with a gasketed cover. Metallic, corrosion resistant, waterproof strain relief bushing should be installed to provide cable entry for the 480 Vac trainline conductors.

3.3.2 Bus bars

Three copper bus bars should be provided, one per phase, to provide a connection point for the busing of the trainline cables. The cables should be connected to the bus bars through the use of bolted, hydraulically crimped lugs. The bars should be of adequate cross-sectional area for the trainline rating required: 1600 A single bus, 800 A split bus. The bus bars should be mounted via standoff insulators.

3.3.3 HEP tap

The bus bars should provide the connection point for any power tap to the car main HEP circuit breaker. These connections should also take the form of bolted, crimped terminals. Since they are unfused, the power conductors connecting the bus bars to the main circuit breaker should be routed within corrosion-resistant steel rigid, dedicated conduit.

3.4 Control junction box

3.4.1 Construction

A corrosion-resistant junction box constructed from stainless steel or approved equal, equipped with screw or stud type terminal blocks, should be provided near each end of the vehicle to provide for the connecting of the receptacle control and fixed jumper pigtails with the vehicle car body wiring.

3.4.2 Associated recommended practice

The installation should be consistent with APTA PR-E-RP-002-98, “Installation of Wire and Cable on Passenger Rolling Stock.”

3.4.3 Physical separation

If the box is shared with 27-point receptacle wiring, the terminal blocks for different functions—HEP control, MU, car control, etc.—should be physically separate.

3.4.4 Terminations

Individual terminals should be permanently labeled for each specific wire name. Termination should be with vibration-resistant, ring-tongue, crimp-type lugs.

4. Trainline complete control (TLC)

4.1 General

The 480 Vac HEP jumper cables/receptacles are composed of three power and three control contacts; thus, the control circuit is established in conjunction with the power circuit when plugs are mated.

Trainline complete (TLC) wiring should comply with **Figure 4** and **Figure 5**. The #1 control contact is used for the trainline complete continuity check, while #2 and #3 are used for electrically bonding the car bodies of adjacent vehicles. The #10 AWG wire size is used to ensure minimal voltage drop for TLC, since it can be several thousand feet long.

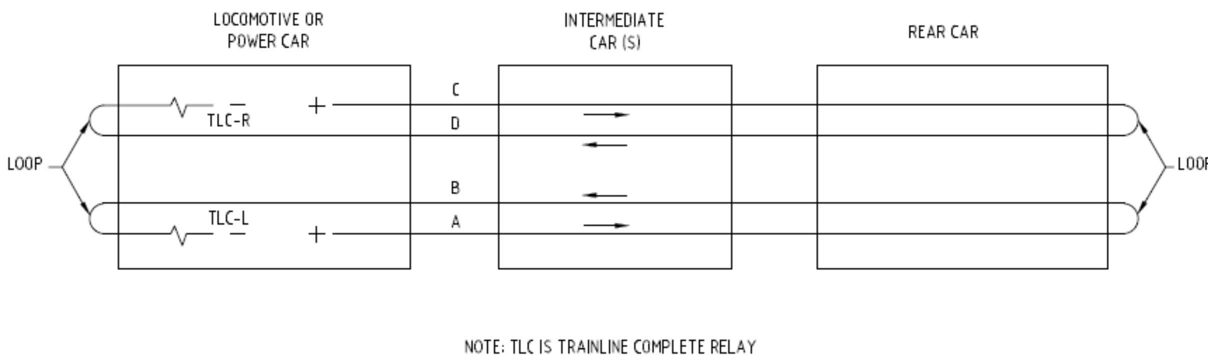
The control contacts are the “first to break” and “last to make” relative to the power contacts of the jumper/receptacle mating. Accordingly, this approach is used to provide the TLC function, where all HEP trainline jumper cables throughout the entire length of the consist must be plugged in fully and correctly before TLC is established and HEP can be energized.

Loss of the trainline complete signal should result in disconnection of the HEP source from the trainlines.

4.2 TLC trainline function of a train

The TLC control functions as follows as shown in **Figure 8**.

FIGURE 8
Simplified Trainline Complete Operation – Train



NOTE: TLC is trainline complete relay.

The control system of the active HEP source (see Section 4.3) applies control voltage to 480 Vac trainline “A” control contact #1. The resulting current flows rearward along the “A” trainline to the rear of the consist, where the looped jumper connects control contact #1 of trainline “A” to control contact #1 of trainline “B.” The current now travels forward on trainline “B” all the way to the front of the train, where it is similarly looped to trainline “A.” Finally, the current again flows rearward back to the active HEP control system, where it energizes the left TLC relay. This relay provides an indication to the operator of consist TLC status and establishes one of the prerequisites for closing the HEP power contactor. (Refer to APTA PR-E-RP-015-99, “Head End Power Source Characteristics,” for further details.)

An identical circuit on the right side of the consist is established via HEP trainlines “C” and “D,” with a corresponding TLC relay.

Should a locomotive be turned end-for-end in the train, as in an MU arrangement, the basic TLC function is maintained, although current routing rearward/forward may be altered.

4.3 Active sources

Since several HEP sources (locomotives and/or power cars and/or MUs) could be present in a consist at the same time, switching must be provided so that only the “active” HEP source (the one actually supplying HEP) is connected to the TLC trainlines. The TLC circuits revert to “pass-through” on inactive HEP source vehicles. Refer to **Figure 7**. This is essential to prevent false TLC indication that could otherwise result from the interaction of the HEP control systems of two separate HEP sources.

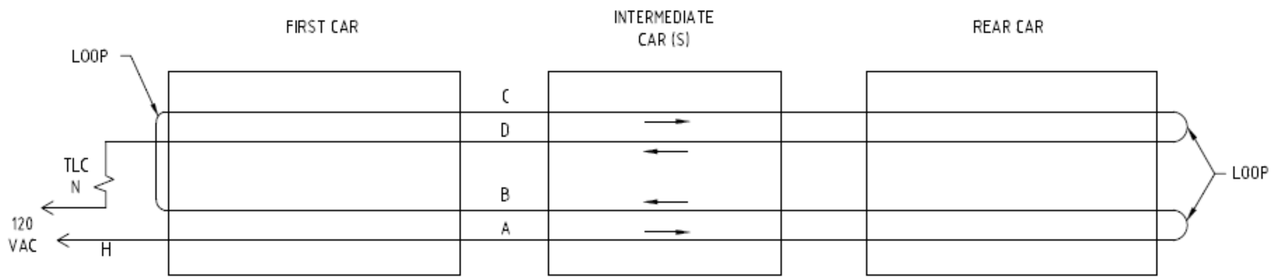
4.4 Indicator lights

The separate left and right indicator lights are important to the operator, because if TLC is not established, it identifies which side of the consist has the problem, reducing the sites to inspect by half.

4.5 TLC trainline function from wayside

The basic operation of TLC when HEP is fed from a wayside source is similar to that of a train as described in Section 4.2, with a few differences. Refer to **Figure 9**.

FIGURE 9
Simplified Trainline Complete Operation – Wayside



NOTE: TLC is trainline complete relay.

- Only one TLC circuit is provided for both sides of the consist, rather than two.
- The HEP feed end of the consist is also looped, between left and right sides of the consist. This results in the TLC current path through control trainlines "A" to "B" to "C" to "D" and then to the TLC relay.
- No "through" trainline feed switching is provided, since the wayside is always the only active HEP source for the consist.

5. Load characteristics

Loads fed from an HEP source should meet the recommended practices described in this section.

5.1 Load type

480 Vac, 3-phase, ungrounded, 60 Hz.

5.2 Maximum load

The maximum load imposed by a 10-car train should not exceed 1 MW, based on a power factor of at least 0.8. Individual railroads may limit this to a lower value.

5.3 Phase rotation

Phase rotation should be A, B, C with HEP power pins designated 1 = A, 2 = B, 3 = C.

5.4 Phase balance

Loads should be balanced to within 5% per car. This is at full rated load; however, all major car loads should each be balanced 3-phase, such as floor heat, overhead heat, etc. All loads should be configured with the goal that the phase balance remains within 5% even during partial load conditions. It is understood that under very light load conditions, such as when the HVAC system is neither heating nor cooling, it may be impossible to attain this goal. Likewise, it is difficult to balance galley electrical loads, since they are often single-phase with unpredictable duty cycles.

5.5 Voltage range

Loads should operate continuously without damage or shortening of life over a 480 Vac ±10% range.

5.6 Frequency range

Loads should operate continuously without damage or shortening of life over a 60 Hz ±5% range.

5.7 Primary loads

All motor loads above 1/2 HP and loads fed directly from the HEP voltage should be balanced 3-phase loads. The load on each branch circuit breaker exceeding 5 kW should be balanced within 5%.

5.8 Secondary loads

Secondary loads should be isolated and derived from the 480 Vac through the use of a 3-phase transformer arrangement with a delta-connected primary and ungrounded secondary. For equipment employing food-service appliances, a 120/208 Vac service with grounded neutral is acceptable. Typical voltages include 120, 240 and 120/208. Low-voltage power supply/battery charger voltages are typically 75 or 37.5 Vdc.

5.9 Staggered start

To avoid excessive step loads being applied to the HEP source when power is first applied, a time delay should be imposed on the starting of large car loads. This delay should include heating and HVAC condensing unit motors. Other car loads, such as lighting, battery charging and ventilation, are not subject to this delay.

The time delay should be imposed on a per-car basis, with the delay on each car randomly set at a fixed value ranging from 0 to 3 minutes. It is recommended that the delay be provided through the car temperature control system.

5.10 Power interruption

During normal operation of a car, power is often interrupted as follows:

- **Momentary interruption:** Momentary interruptions are typically 0 to 10 seconds, such as those caused by pantograph bounce, phase breaks, third rail gaps, etc. when operating with an electric or dual-mode locomotive.
- **Short-term interruption:** Short-term interruptions are typically up to 30 minutes, such as those experienced during the transfer between wayside and locomotive power, during locomotive changes, or when adding cars to a train en route.
- **Long-term interruption:** Long-term interruptions are typically up to several hours to several days, such as those experienced in yard switching, train spotting, and yard storage and service.

Electrical equipment should not be damaged in any way by HEP power interruptions of these types.

5.11 Isolation from HEP bus

Each car should be provided with a 3-phase main HEP circuit breaker to provide isolation from the HEP bus.

Split bus equipment should have two main circuit breakers, one for each HEP bus.

Main circuit breakers should be the lockable molded case type so as to provide isolation from the HEP bus to protect it from faults on the car, as well as allowing car equipment to be isolated and tagged for servicing or other reasons.

The main circuit breaker should have an interrupting capacity of at least 35 kA symmetrical and asymmetrical at 480 Vac.

Cars equipped with split bus HEP trainline should be configured in such a way as to prevent any possibility of bridging between the two split bus systems in the switchgear that connects the trainline feeds to the car loads.

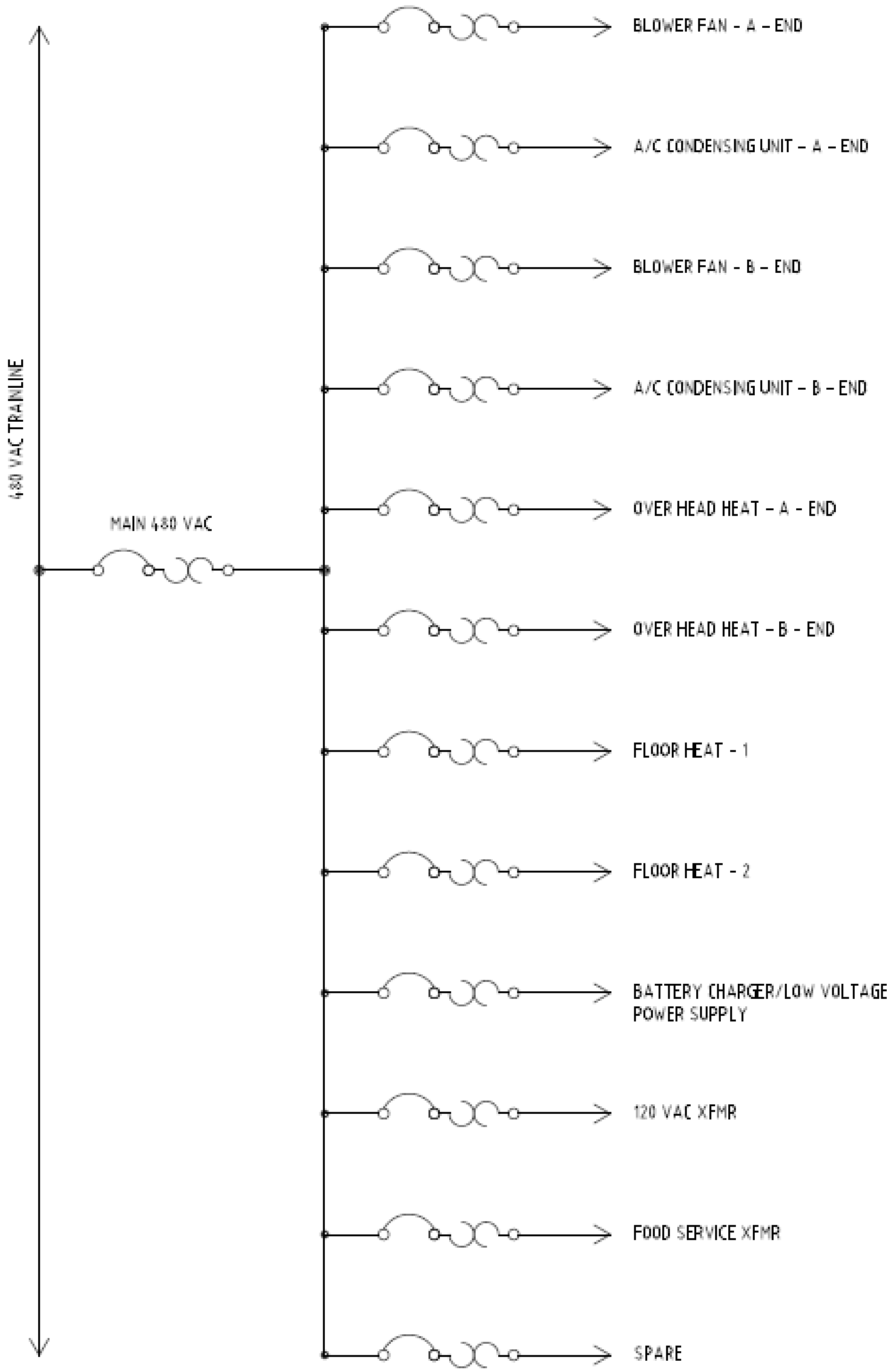
5.12 Primary power distribution

Car loads should be fed from the main circuit breaker through the use of branch circuit breakers, one for each major load (refer to **Figure 10**). All phases should be interrupted by the circuit breaker.

5.13 Branch circuit breakers

Branch circuit breakers, opening all phases of the circuit, should be molded case types, mounted on a suitable switchboard with protective cover. Circuit breakers should use screw-type fasteners to attach to bus bars or discrete car wiring, via ring tongue lugs.

FIGURE 10
Typical Car Power Distribution



6. Testing

6.1 Production tests

Each HEP system should undergo a complete set of tests on the entire system, including the functions in this section.

6.1.1 Wiring

6.1.1.1 Insulation

Continuity, insulation resistance, and dielectric tests should be conducted in accordance with the requirements of APTA PR-E-S-001-98, "Electrical Insulation Integrity."

6.1.1.2 Continuity

Tests should be undertaken to ensure the following:

1. Continuity exists between all intended contacts of all receptacles.
2. Continuity exists between trainlines and each vehicle connection to the trainline circuits.
3. No wires are unintentionally grounded.
4. No wires are shorted or cross-connected to unintended circuits.

6.1.1.3 Functional tests

Cars:

1. Verify correct phase rotation at the line side of the main circuit breaker on each car (after verifying correct phase rotation of the HEP power source).

Locomotives and power cars:

1. Verify correct phase rotation at one of the 480 Vac trainline receptacles or jumpers.
2. Verify that the TLC functions correctly on both ends and both sides of the locomotive. This includes, at a minimum, that:
    a. each TLC relay (or equivalent) causes HEP lockout; and
    b. left- and right-side TLC indications within the locomotive cab coincide with left and right sides of the locomotive relative to the engineer facing forward. This should be done from both ends of the vehicle, since left and right are reversed with orientation.

6.2 Vehicle proof-of-design tests

An engineering proof-of-design type test should be conducted on the new vehicles.

6.2.1 New vehicle tests

At a minimum, a pair of vehicles should be tested, but should there be more than one vehicle type, all types should be included in the test. In addition, all new vehicle types should be tested with all types of existing vehicles with which the new equipment is to be operated.

6.2.2 Functional tests

For locomotives, tests should verify the correct function of TLC circuits and indications under all the following conditions:

1. Two new locomotives (or power cars), coupled back to back:
    a. HEP from lead unit
    b. HEP from rear unit
2. Two new locomotives (or power cars), coupled elephant style (both facing the same direction):
    a. HEP from lead unit
    b. HEP from rear unit

Where the new locomotives (or power cars) will be used with a fleet of existing older locomotives, the above tests should be made with one each old and new coupled.

For cars:

1. Measure end-to-end voltage drop at full rated load (most easily done with a long consist).
2. Verify current balance among jumper cables at full rated load (all should carry equal current).
3. Verify phase balance of loads at full load as well as “typical” load conditions.

6.2.3 Cable swing and interference

Tests should be conducted with the new and all existing rolling stock with which it might operate, coupled to verify successful interfaces and freedom from interferences in actual track conditions. This must take into account all practical combinations of vehicles that may be intercoupled: car-to-car, car-to-locomotive (both locomotive ends) and locomotive-to-locomotive (on both ends).

1. Inspect to verify that the location and clearance requirements of the following are met:
    a. 49 CFR Part 231, “Railroad Safety Appliances”
    b. APTA PR-CS-RP-019-12, “Pushback Couplers in Passenger Rail Equipment”
    c. APTA PR-M-S-016-06, “Safety Appliances for Passenger Equipment”
2. Verify that receptacle mounting provides sufficient clearance between, as well as among, receptacles and jumper cables of Head End Power (HEP), 27-Point Communication (COMM), Multiple Unit (MU), ECP brakes and Digital Trainline (DTL – if applicable) so they do not rub or foul one another, nor the uncoupling mechanism, buffer/diaphragm, air hoses or coupler. Jumpers must not interfere with normal use of safety appliances (including uncoupling mechanism) or required clearances. Variables include the worst-case combination of the following:
    a. Relative motion to adjacent vehicle: resulting from operation on worst-case track conditions (i.e., FRA Class 1) in curving, lateral displacement passing through two facing point turnouts or crossovers (reverse curves), in buff and draft, vertical track curves (rises and dips) etc. This should be conducted at locations where the most demanding track geometry occurs.
    b. Coupler motion laterally and vertically.
    c. Diaphragm movement (both adjacent to another car and when unrestrained).
    d. Conditions of when jumpers are inserted into the receptacles, as well as when receptacles are empty or looped. There should be no interference that restricts the receptacle cover from fully opening to allow insertion or withdrawal of jumpers.
3. On the outside side of the coupling, verify that the jumpers are sufficiently long to reach without strain/pullout.
4. On the inside of the coupling, verify that the jumper low points do not violate the 2 in. above top-of-rail minimum, nor do they collide with each other.

NOTE: Depending on car design, the handbrake mechanism will need to be included in this review if it is located within the respective areas.

Related APTA standards

APTA PR-CS-RP-019-12, "Pushback Couplers in Passenger Rail Equipment"
APTA PR-E-S-001-98, "Electrical Insulation Integrity"
APTA RP-E-RP-002-98, "Installation of Wire & Cable on Passenger Rolling Stock"
APTA PR-E-RP-009-98, "Ampacities for Wire and Cable Used on Passenger Rolling Stock with Flame, Smoke and Toxicity Considerations."
APTA PR-E-RP-011-98, "Head End Power Load Testing"
APTA RP-E-RP-015-99, "Head End Power Source Characteristics"
APTA RP-E-RP-018-00, "480 Vac Head End Power Jumper and Receptacle Hardware"
APTA PR-M-RP-001-97, "End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers"
APTA PR-M-S-016-06, "Safety Appliances for Passenger Equipment"

References

Code of Federal Regulations:
- 49 CFR, Part §229.85, High voltage markings: doors, cover plates, or barriers
- 49 CFR, Part 231, Railroad Safety Appliance Standards
- 49 CFR, Part §238.303, Exterior calendar day mechanical inspection of passenger equipment, Subsection (e)(12) Marking of door and cover plate guarding High Voltage Equipment.

PRIIA specifications:
- 305-001: Specification for PRIIA Bi-Level Passenger Rail Car
- 305-003: Specification for PRIIA Single Level Passenger Rail Car
- 305-005: Specification for Diesel-Electric Passenger Locomotives
- 305-007: Specification for Trainset
- 305-009: Specification for Diesel Multiple Units (DMUs)
- 305-011: Specification for Dual Mode (DC 3rd Rail) Passenger Locomotives

Definitions

car control: Those trainlined communication functions associated with locomotive-hauled passenger cars (door control, public address, etc.).

fixed jumper: A variation of a HEP jumper cable in which only one end is provided with a plug, while the remaining end is provided with a flange for mounting on a vehicle. This approach is taken to permanently affix the jumper to the vehicle and reduce the number of contacts, since they are present on only one end rather than two.

head end power (HEP): A system by which 480 Vac 3-phase electrical power, to operate auxiliaries, is provided to railroad vehicles from a central source via a trainline system. The power source can be locomotive (hence "head end"), power car or wayside source.

HEP jumper cable: A cable assembly having the necessary power and control conductors and equipped with a plug on one or both ends, which is used to provide a flexible electrical connection between two cars and/or locomotives or wayside equipment.

HEP receptacles: The receptacles mounted on the ends of rail vehicles and wayside equipment into which the HEP jumper cables mate.

HEP source: A source of head end power, contained in a locomotive, power car or from a wayside power connection.

HEP switchgear: The contractors, circuit breakers, power switches, overload protection and associated control components used to connect the HEP power source to the trainline system.

HEP system, single bus: A form of HEP transmission system in which there is a single electrical bus running the length of the train. All four jumpers connecting adjacent vehicles are wired in parallel.

HEP system, split bus: A form of HEP transmission system in which there are two independent electrical buses running the length of the train, a train left and train right (relative to the forward direction of the train). The buses may be fed HEP independently from separate sources, such as two locomotives. Two of the jumpers connecting vehicles are wired in parallel to the left bus, and two to the right bus. Vehicle loads may be divided so as to take some power from each bus.

HEP trainline: An electrical cable system that allows HEP to be transmitted over the entire length of a train. It includes both power and control conductors. The trainline may provide power to equipment in each vehicle or may simply pass straight through, providing a power path between vehicles on opposite ends of that vehicle.

looping: The process of connecting a jumper cable between two adjacent receptacles (or a fixed jumper and adjacent receptacle) on the same vehicle. This is normally done on the exposed end of the first and last vehicles of a train and establishes the trainline complete circuit. Locomotives having the F-end HEP receptacles disconnected through the use of an isolation switch use an internal loop circuit and do not require an F-end loop.

> **NOTE:** When wayside power is applied via the end of the consist, the far end of the train is looped in the normal fashion, the wayside feed end is looped between left and right sides of the train, and the wayside power is connected with one jumper on each side of the train.

MU (multiple unit): A system of simultaneous control of all locomotive units in a consist from one master controller through the means of trainlines.

portable jumper: A form of a HEP jumper cable in which both ends are provided with plugs. This approach is taken to allow the jumper cable to be easily removed from the vehicle and moved elsewhere.

power car: A rail vehicle, other than a locomotive, containing a HEP source and control system. This generally takes the form of a baggage car or a car converted from a locomotive that has had the traction system removed. It can also be MU equipment.

short looping: The process of looping the HEP jumpers at points other than the ends of the train. This is used in an emergency situation such as overcoming a damaged jumper on the road, to bypass an open trainline complete circuit on one side of the train.

> **CAUTION:** When short looped, vehicles behind the short loop site do not have the TLC indication or control interlock at the HEP controls, even though the 480 volt circuits may be live.

trainline complete (TLC): A series circuit continuity check, originating at the HEP control system, used to determine that all HEP trainline jumper cables throughout the entire length of the consist are plugged in correctly. The circuit provides an indication at the HEP control panel and is interlocked with the HEP main contactor/circuit breaker to allow the trainlines to be energized only when the TLC circuit is established.

> **CAUTION:** The practice of short looping will negate the TLC protection and is generally prohibited except when absolutely necessary to protect the health and wellbeing of passengers.

wayside power: An installation that provides HEP from a ground-based source, used to provide power to the consist when the on-board source is unavailable, such as in a yard. Generally, utility power is used, though sometimes a diesel generator is provided.

Abbreviations and acronyms

A	amperes
AWG	American Wire Gauge
CFR	Code of Federal Regulations
DTL	digital trainline
ECP	electronically controlled pneumatic
FRA	Federal Railroad Administration
HEP	head end power
HVAC	heating, ventilation and air conditioning
kA	kiloamperes
kW	kilowatts
MU	multiple unit
MW	megawatts
PRIIA	Passenger Rail Investment and Improvement Act of 2008
TLC	trainline complete
V	volts
Vac	volts alternating current
Vdc	volts direct current

Document history

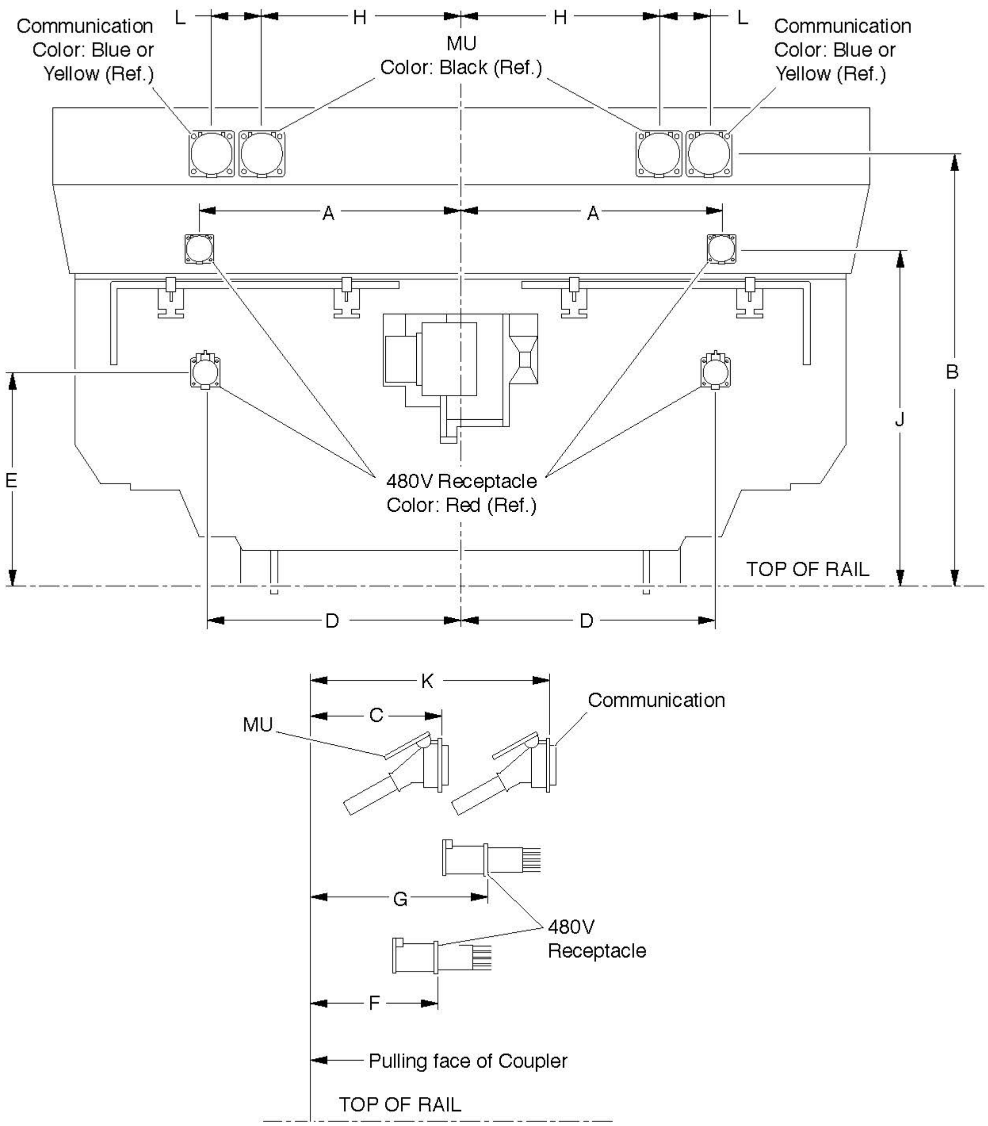
Document Version	Working Group Vote	Public Comment/ Technical Oversight	CEO Approval	Policy & Planning Approval	Publish Date
First published	—	—	—	March 4, 1999	Jan. 11, 2000
First revision	—	—	—	—	March 22, 2004
Second revision	Nov. 16, 2025	Jan. 30, 2026	April 19, 2026	May 5, 2026	May 13, 2026

Appendix A

The figures in this appendix are part of APTA PR-M-RP-001-97, “End-of-Car Connections with Tightlock and Interlocking Knuckle-Type Couplers,” and are provided here for reference only to assist in the understanding of the locations of receptacles and jumper cables located on the ends of cars and locomotives. For details affecting the mounting, refer to that document.

FIGURE 11

End of Vehicle Trainline Connector Typical Location: Locomotive F-End

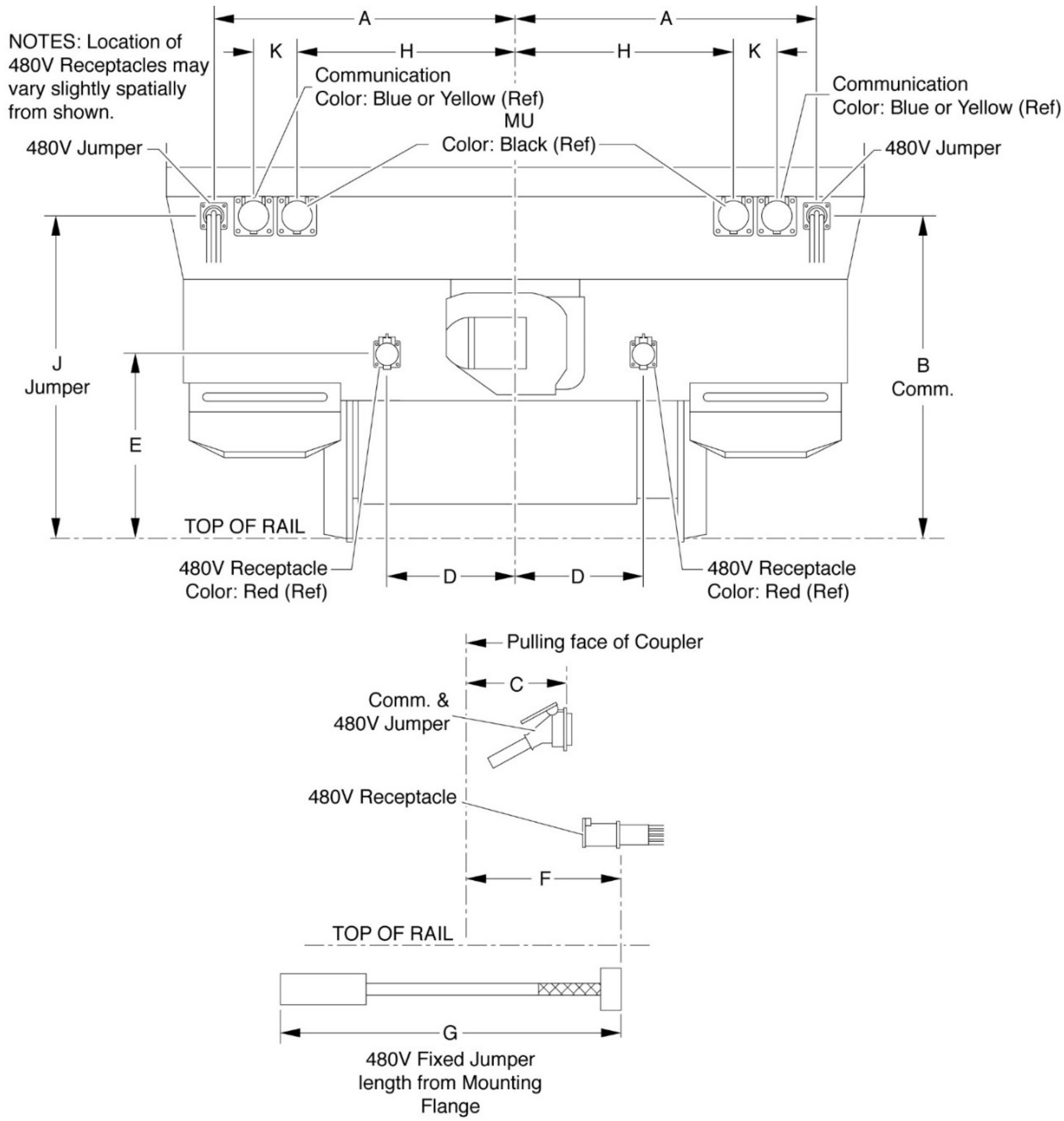


	A	B	C	D	E	F	G	H	J	K	L
Option 1	29.25	64.46	19.19	37.50	32.01	18.75	26.54	29.25	50.28	21.56	7.50
Option 2	39.00	53.00	25.50	38.63	33.25	33.25	21.75	19.12	40.75	25.50	7.12

NOTE: This can also represent the B-end of a dual cab locomotive. Dimensions are in inches.

FIGURE 12

End of Vehicle Trainline Connector Typical Location: Locomotive B-End



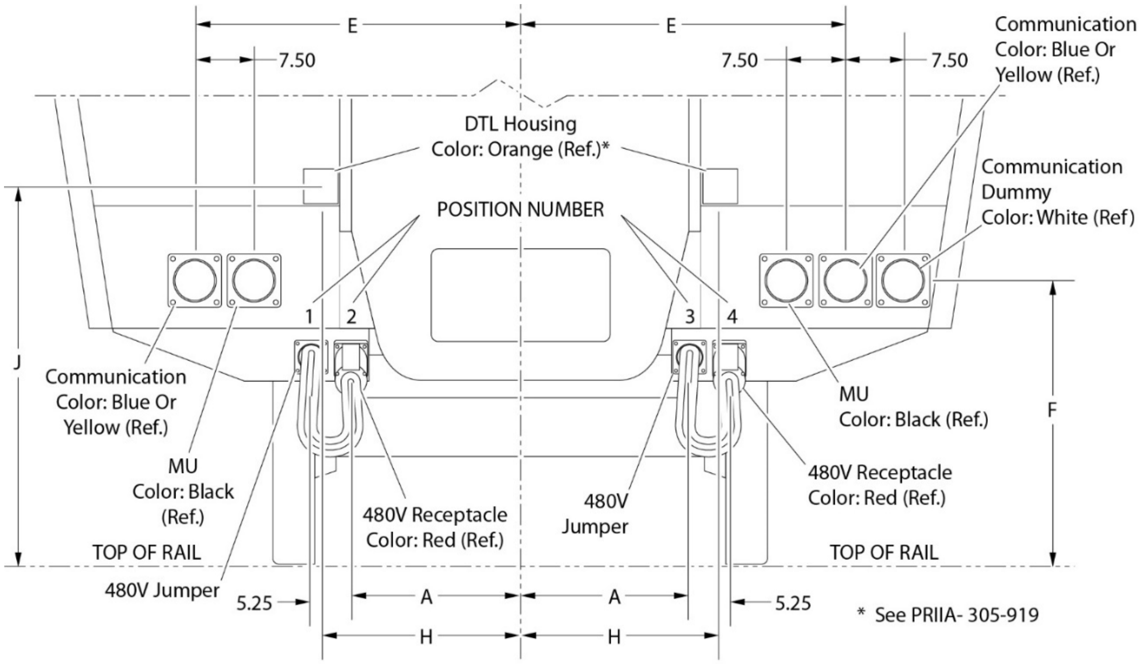
	A	B	C	D	E	F	G	H	J	K
Option 1	43.00	53.83	35.13	35.08	33.04	31.63	*	29.25	50.50	7.50
Option 2	45.82	57.18	18.15	23.00	27.88	25.50	*	39.50	50.06	8.00

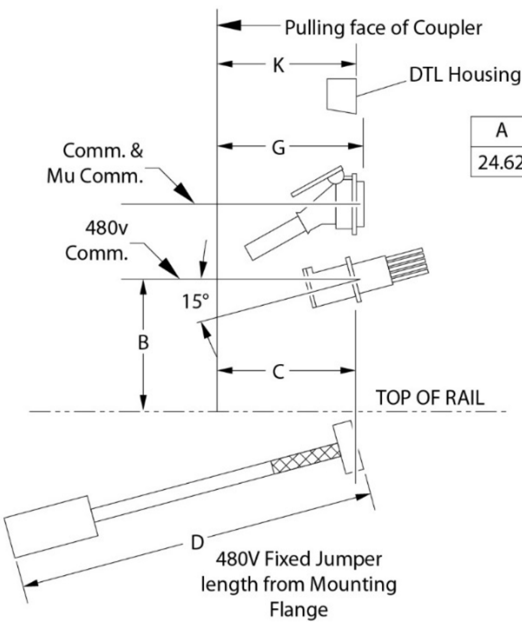
* Refer to APTA PR-E-RP-018 for Column "G."

NOTE: Dimensions are in inches.

FIGURE 13

End of Vehicle Trainline Connector Typical Location: Low-Level Car End





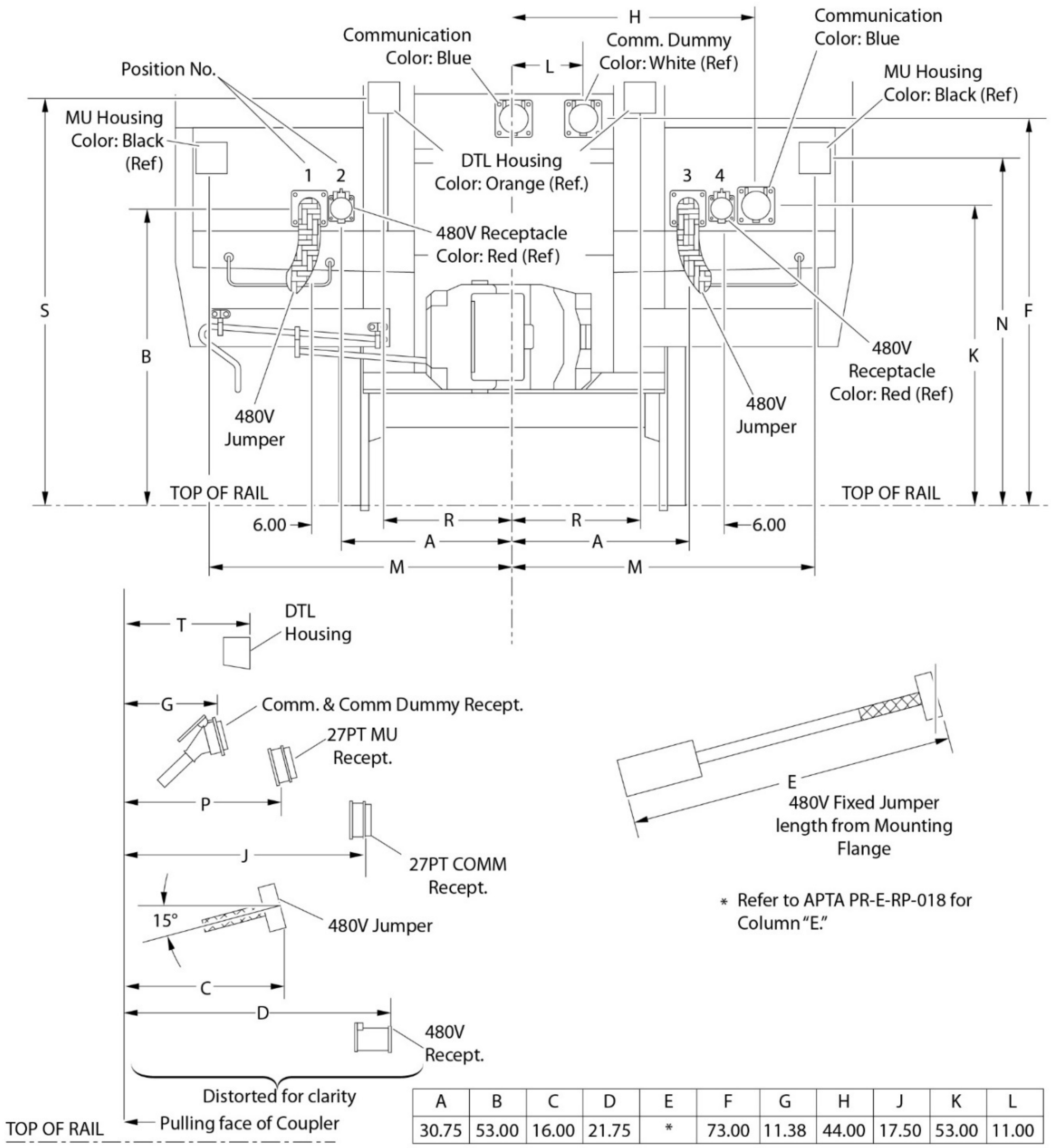
A	B	C	D	E	F	G	H	J	K
24.62	27.38	17.75	**	42.06	37.38	16.93	31.25	60.00	17.15

** Refer to APTA PR-E-RP-018 for Column "D."

NOTE: Dimensions are in inches.

FIGURE 14

End of Vehicle Trainline Connector Typical Location: High-Level Car End



A	B	C	D	E	F	G	H	J	K	L
30.75	53.00	16.00	21.75	*	73.00	11.38	44.00	17.50	53.00	11.00

M	N	P	R	S	T
51.50	60.50	15.00	31.25	60.00	13.00

NOTE: Dimensions are in inches.