15. APTA PR-E-RP-016-99 Recommended Practice for 480 VAC Head End Power System

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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 new locomotive-hauled passenger vehicles. Single bus and split bus forms are described to accommodate intercity and commuter type operations.

Keywords: head end power system, trainline, 480 VAC

Participants

The American Public Transportation Association greatly appreciates the contributions of the following individual(s), who provided the primary effort in the drafting of the *Recommended Practice for 480 VAC Head End Power System.*

Dick Bruss

At the time that this recommended practice was completed, the PRESS Electrical Committee included the following members:

Doug Warner, *Chair*

Gilbert L. Bailey
Brad Barkman
Ronald Bartels
Richard Benjamin
Dick Bruss
Daniel L. Davis
James Dietz
Dave Elliott
Hassan A. Fazli
Bert Gagne
Peter Hale
Carl C. Herrmann
Stephen Hilbert
LeRoy D. Jones
Brian Ley
Otto Masek
Rich Mazur
Chuck Olson
David Phelps
Craig Prudian
George Scerbo
Ike Tingos
Steve Zuiderveen

Contents

APTA PR-E-RP-016-99
Recommended Practice for 480 VAC Head End Power System

1. Overview

1.1 Scope

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 new locomotive-hauled passenger vehicles. Single bus and split bus forms are described to accommodate intercity and commuter type operations.

This document covers HEP Vehicle Recommended Practices; document *APTA RP-E-018-99 covers associated HEP Jumper and Receptacle Hardware Recommended Practices*.

1.2 Purpose

The purpose of this document is to define the recommended practices for HEP systems, including vehicle interface and the electrical source, transmission and load characteristics required to allow intermixing of cars and locomotives 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 4.3).

For special functions not already in general use, it is recommended that the specifying entity, be it an authority or railroad, approach APTA for a recommendation as to how to address the property-specific functions.

When new equipment specifications are under development, it is highly advisable that the writer(s) carefully review the trainline control system requirements (both electrical and mechanical) with the specifying entity (which will for convenience herein be called an "authority"; "railroad" will be used to indicate the operating, as opposed to specifying, entity) to identify any subtle issues that may not be contained in this document.

2. References

APTA SS-E-001-98, Standard for Insulation Integrity

APTA RP-E-002-98, Recommended Practice for Wiring of Passenger Equipment

APTA RP-E-009-98, Recommended Practice for Wire Used on Passenger Rolling Stock

APTA RP-E-011-98, Recommended Practice for Head End Power Load Testing

APTA RP-E-015-99, Recommended Practice for Head End Power Source Characteristics

APTA RP-E-018-00, Recommended Practice for 480 VAC Head End Power Jumper and Receptacle Hardware.

49 CFR 229.85 Doors and cover plates marked “Danger”

49 CFR 238.303.12 Marking of door and cover plate guarding High Voltage Equipment.

3. Definitions abbreviations and acronyms

3.1 Definitions

For the purpose of this recommended practice the following definitions apply.

3.1.1 car control: For the purposes of this recommended practice, car control is those trainlined communication functions associated with locomotive-hauled passenger cars, e.g. door control, public address, etc.

3.1.2 dead bus protection: Dead bus protection is a control system feature that confirms that the HEP bus is not energized (dead bus) before allowing the local HEP output contactor to close. This prevents inadvertently connecting two HEP sources to the same bus.

3.1.3 fixed jumper: A fixed jumper is 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 only present on one end rather than two.

3.1.4 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.

3.1.5 HEP jumper cable: A HEP jumper cable is 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.

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

3.1.7 HEP source: A source of Head End Power, contained in a locomotive, power car or from a wayside power connection.

3.1.8 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.

3.1.9 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.

3.1.10 HEP system, split bus: Split bus is 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 and isolated from each other so as to take some power from each bus.

3.1.11 HEP trainline: The HEP trainline is an electrical cable system which 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.

3.1.12 load box: A load box is a piece of wayside equipment used to provide a test load for an HEP source to allow its performance to be measured. The equipment consists of a variable resistance load, cooling fan, load control switching, control panel and instrumentation.

3.1.13 looping: Looping is the process of connecting a jumper cable between two adjacent receptacles (or a fixed jumper and an 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.

When wayside power is applied via the end of the consist, the opposite, far end of the train is looped in the normal fashion. At the near end, a loop is put between left and right sides of the train and the wayside power is connected with one jumper to the right and one jumper to the left side of the train.

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

3.1.15 portable jumper: A portable jumper is 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.

3.1.16 power car: For purposes of this document, a power car is 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.

3.1.17 short looping: Short looping is 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.

3.1.18 trainline complete (TLC): The trainline complete circuit is a series 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 well being of passengers.

3.1.19 wayside power: Wayside power is an installation which 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.

4. General

4.1 Purpose of HEP (Head End Power)

The concept of HEP provides a convenient means by which electrical power (up to about 1 Megawatt) 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.

4.2 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)

The HEP system source should be comprised of:

- Power source
- Switchgear (on-off as well as overload and other protection)
- Control system incorporating Trainline Complete (TLC) functions
- Connections to vehicle HEP trainline

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

4.3 HEP trainline configurations

Two alternative approaches for the HEP trainline system are available: Single and Split Bus.

4.3.1 Single bus

Single Bus is used on some commuter equipment and all intercity equipment. (Except on VIA which uses Split Bus.) The single bus system is recommended, primarily on considerations of lower first cost, less complexity, more widespread usage, and increased operational flexibility.

4.3.2 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.

4.3.3 Intermixing

Individual railroad rules and operating practices govern the intermixing of single and split bus equipment. However, for 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 only feed a Split bus consist
- Single Bus and Split Bus equipment can be intermixed within a consist provided the HEP source is Single Bus and both Split Buses are utilized throughout the length of the consist.

4.4 Single bus HEP system attributes

- One HEP bus the length of the train
- 480 VAC, 3 Phase, 3-wire, ungrounded system, 60 Hz operation
- (The source may have a neutral ground reference, but the distribution system and load do not.)
- 1600 Amp continuous rating
- 4 jumpers across each car-car-locomotive connection (see Figure 1)
- All 4 jumpers in parallel
- Power schematic (see Figures 2 and 3)
- Control schematic (see Figures 6 and 7)
- Jumper cable end arrangement on vehicle (see Figures 8 through 11)
- Single HEP power junction box
- Single HEP tap to feed each car

4.5 Split bus HEP system attributes

- Two HEP buses the length of the train, one on each side
- 480 VAC, 3 Phase, 3-wire, ungrounded system, 60 Hz operation
- (The source may have a neutral ground reference, but the distribution system and load do not.)
- 800 Amp continuous rating per bus
- 4 jumpers across each car-car-locomotive connection (see Figure 1)

- 2 jumpers in parallel for left bus, 2 jumpers in parallel for right bus
- Power schematic (see Figures 4 and 5)
- Control schematic (see Figures 6 and 7)
- Jumper cable end arrangement on vehicle (see Figures 8 through 11)
- Two HEP power junction boxes
- Two HEP taps to feed each car, one from each bus

4.6 Transmission capacity

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

Single bus: 1600 Amps

Split bus: 800 Amps per each bus

To minimize voltage drop, cable resistance, including jumper cables and no more than four (4) bolted connections, should not exceed:

Single bus: equivalent to 125% of car length of 12-4/0 cables, 4 per phase

Split bus: equivalent to 125% of car length of 6-4/0 cables, 2 per phase.

4.7 Environment

The equipment should be suitably rated for the mechanical conditions experienced on the vehicle, especially shock, vibration and ambient temperatures. As these conditions are site and vehicle specific, they should be specified by the authority in contract specification documents. The following are examples of conditions which may occur and should be the subject of such detailed specifications:

- Heavy rain, driven by wind or water from a hose
- Hail, ice, powdered snow
- Blown sand, dust, ballast and rocks
- Vehicle speeds to 125 mph (200 km/hr)
- Wind gusts to 90 mph (145 km/hr)
- Salt (sea spray or from roads during winter months)
- Impact from airborne road debris
- Car washing chemicals and wash rack operations

5. Application to vehicles

5.1 End location (left/right)

The location of the receptacles on the end of the vehicle should conform to Figures 8 through 11.

5.1.1 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.

5.1.2 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.

5.1.3 Cars

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.

5.2 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 carbody components.

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

- Coupler motion horizontally and vertically
- Relative motion to adjacent vehicle, in curve, passing through crossover, in buff and draft, etc.
- Whether jumper is inserted into receptacle or not

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

5.3 Identification

As an identification aid, receptacle housings should be color-coded red and labeled as follows:

"Danger 480 V"

Warning labels should be provided, consistent with FRA regulations *49 CFR 229.085* and *49 CFR 238.303.12*[1].

[1] For references in Italics, see Section 2.

5.4 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 carbody wiring.

5.5 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 split bus trainline system may have two such boxes, or a single box having both sets of bus bars.

5.6 Wire routing

Wire routing should comply with *APTA PR-E-RP-002-98, Recommended Practice for Wiring of Passenger Equipment*, with additional recommended practices as follows:

5.6.1 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 EMI.

5.6.2 Phases grouped

The power wiring should be run with all three (3) 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.

5.6.3 Undercar routing

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

5.6.4 Cable protection

Guards should be provided to shield 480-volt 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 on a bi-level car. If conduit is used for this purpose, it is necessary for cables to be grouped with the 3 phases from a given receptacle/plug together as they pass through the conduit.

5.6.5 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.

5.6.6 Cable support

Insulated cable cleats should be provided every four (4) feet (1.22 meters) or closer for power cable support.

5.6.7 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.

6. Transmission system components

6.1 Receptacle and jumper cable recommended practices

Refer to *APTA PR-E-RP-018 for recommended practices for 480VAC Head End Power Jumper and Receptacle Hardware.*[2]

6.2 Car cabling

6.2.1 End to end

Cable installation should be in compliance with *APTA PR-E-RP-002-98, Recommended Practice for Wiring of Passenger Equipment,* with the following additional recommended practices:

The carbody wiring should be open (i.e., not in conduit) and should connect the receptacles/jumpers to the 480 volt power junction box(s). It is recommended that 12-4/0 cables be used. This results in four (4) conductors per phase on single bus systems and two (2) conductors per phase on each trainline bus on the split bus system. Other cable arrangements may be used provided they meet or exceed the ampacity and meet or improve upon the impedance compared to the 4/0 approach.

6.2.2 Cable rating

Cable should be per *APTA PR-E-RP-009-98, Recommended Practice for Wire Used on Passenger Rolling Stock*, however it should have a double wall, .055 + .050 in. (1.4 + 1.3 mm) insulation, with a rating of a minimum of 600 VAC.

6.2.3 Cable cleats

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

6.2.4 Splices to receptacle wiring

Hydraulically crimped, bolted joint lugs employing two bolts should be used to splice the pigtails of the 480 volt jumpers/receptacles to the carbody 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.

[2] For references in Italics, see Section 2.

6.3 HEP power junction box

6.3.1 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-volt trainline conductors.

6.3.2 Bus bars

Three (3) 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 amp single bus, 800 amp split bus. The bus bars should be mounted via standoff insulators.

6.3.3 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 galvanized steel rigid, dedicated conduit.

6.4 Control junction box

6.4.1 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 carbody wiring.

6.4.2 Associated recommended practice

The installation should be consistent with *APTA PR-E-RP-002-98, Recommended Practice for Wiring of Passenger Equipment.*

6.4.3 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.

6.4.4 Terminations

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

7. Trainline complete control (TLC)

7.1 General

The 480 VAC HEP jumper cables/receptacles are composed of three (3) power and three (3) 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 Figures 6 and 7. The #1 control contact is used for the trainline complete continuity check, while #2 and #3 are used for electrically bonding the carbodies 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.

7.2 TLC trainline function of a train

The TLC control functions as follows: (Refer to Figure 12.)

The control system of the active (see below) HEP source applies control voltage to 480 volt 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-RP-E-015-99, HEP Source Characteristics*[3], for further details.)

An identical circuit on the right hand 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.

7.3 Active sources

Since several HEP sources (locomotives and or power cars) 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.

[3] For references in Italics, see Section 2.

7.4 Indicator lights

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

7.5 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 7.2, above, with a few differences. Refer to Figure 13.

a) Only one TLC circuit is provided for both sides of the consist, rather than two.

b) 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.

c) No "through" trainline feed switching is provided, since the wayside is always the only active HEP source for the consist.

8. Load characteristics

Loads fed from an HEP source should meet the following recommended practices:

8.1 Load type

480 VAC, 3 phase, ungrounded, 60 Hz

8.2 Maximum load

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

8.3 Phase rotation

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

8.4 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 so that the phase balance remains within 5% even during partial load conditions.

8.5 Voltage range

Loads should operate continuously without damage or shortening of life over a 480 VAC +/- 10% range.

8.6 Frequency range

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

8.7 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%.

8.8 Secondary loads

Secondary loads should be isolated and derived from the 480VAC 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-volt 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.

8.9 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, 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 zero to three (3) minutes. It is recommended that the delay be provided through the car temperature control system.

8.10 Power interruption

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

8.10.1 Momentary interruption

Momentary (0 to 10 seconds typical), such as those caused by pantograph bounce, phase breaks, 3rd rail gaps, etc when operating with an electric or dual-mode locomotive.

8.10.2 Short term interruption

Short Term (up to ½ hour typical), such as those experienced during the transfer between wayside and locomotive power, during locomotive changes or when adding cars to a train en route.

8.10.3 Long term interruption

Long Term (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.

8.11 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 14,000 Amps symmetrical, 15,000 amps asymmetrical at 480 volts.

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

8.12 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 14). All phases should be interrupted by the circuit breaker.

8.13 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.

9. Testing

9.1 Wiring

Continuity, insulation resistance and dielectric tests should be conducted in accordance with the requirements of *APTA PR-E-S-001-98, Standard for Insulation Integrity*, as well as the following, on each vehicle to ascertain that:

– Continuity exists between all intended contacts of all receptacles

– Continuity exists between trainlines and each vehicle connection to the trainline circuits

– No wires are unintentionally grounded

– No wires are shorted nor cross-connected to unintended circuits

9.2 Proof-of-design

An engineering Proof-of-Design test should be conducted on the new vehicles. 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. This is in addition to testing with all types of existing vehicles with which the new equipment is to be operated.

The testing should include:

- Measurement of end-to-end voltage drop at full rated load
- Current balance among jumper cables at full rated load (all should carry equal current)
- Phase balance of loads at full load as well as "typical" load conditions.

The test should include operating each trainline to demonstrate proper function. In addition, receptacle and jumper location and potential interference with coupler, uncoupling rods, diaphragm/ buffer, couplers, air hoses, etc. should be checked while:

- Manipulating jumpers into and out of receptacles
- Swinging coupler
- Curve test of two (or more) coupled vehicles through minimum radius curve and sharpest crossovers in both buff and draft.

10. List of diagrams and illustrations

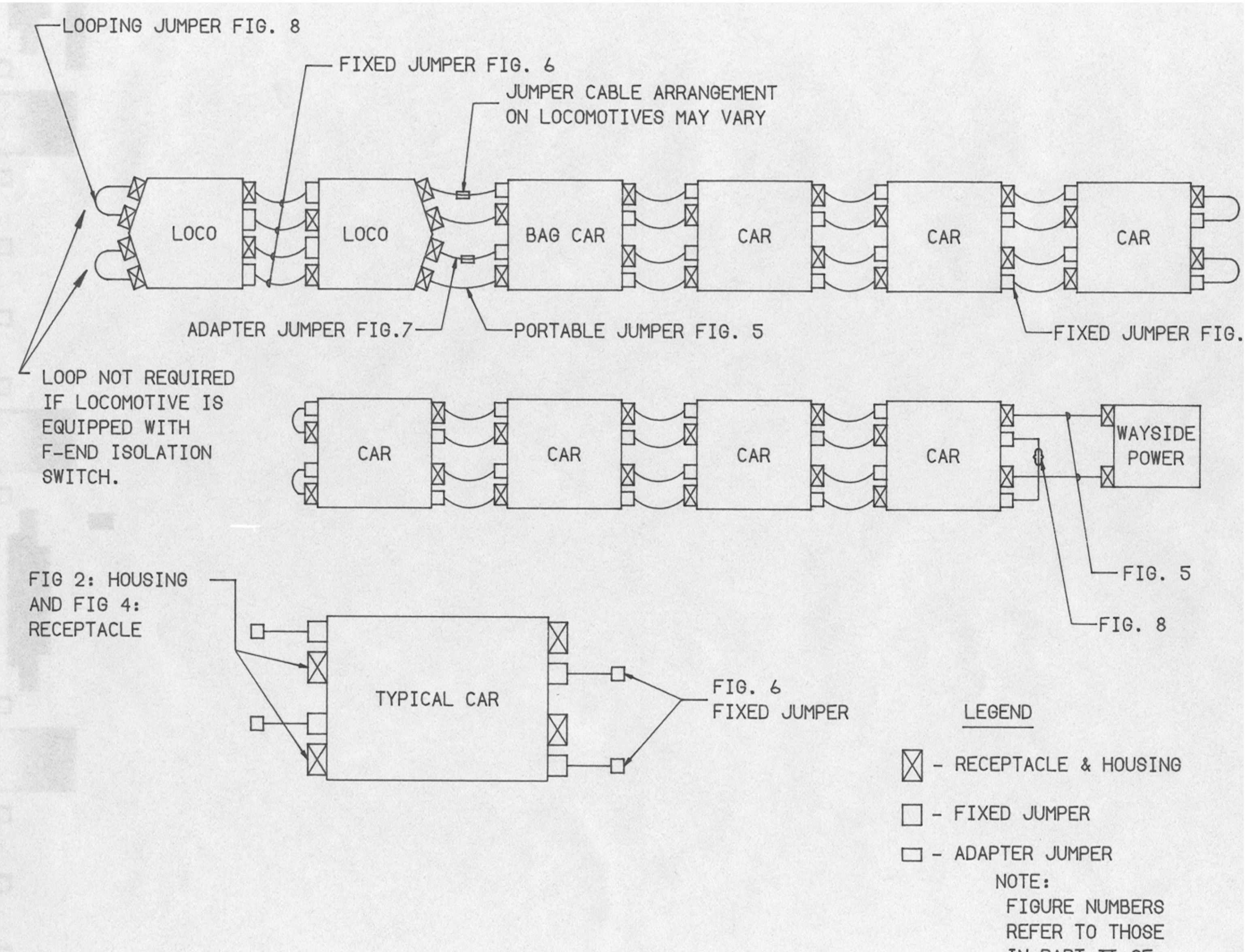


FIGURE 1
TYPICAL CONSIST HEP JUMPER CABLE ARRANGEMENT

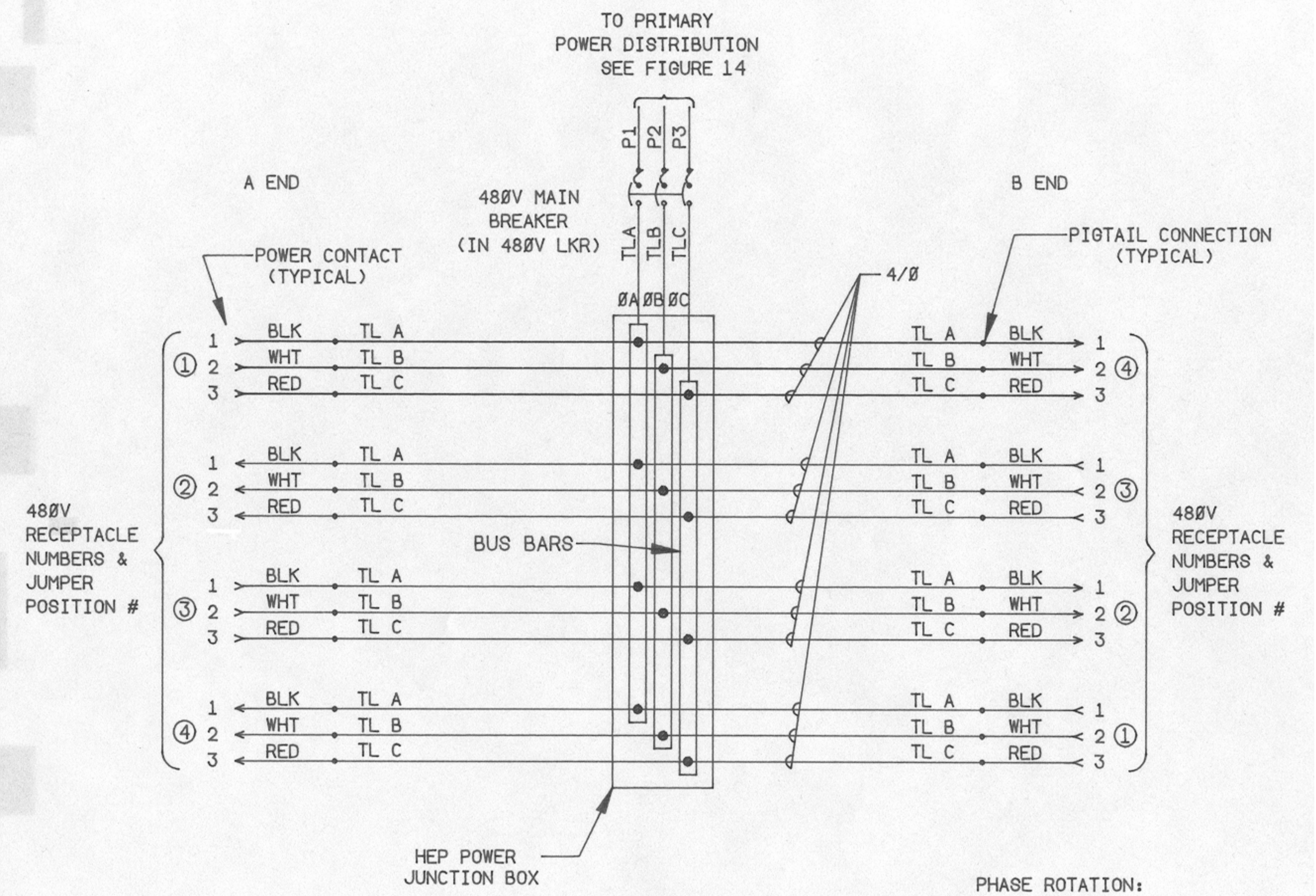


FIGURE 2: CAR
480V TRAINLINE
POWER SCHEMATIC-
SINGLE BUS SYSTEM

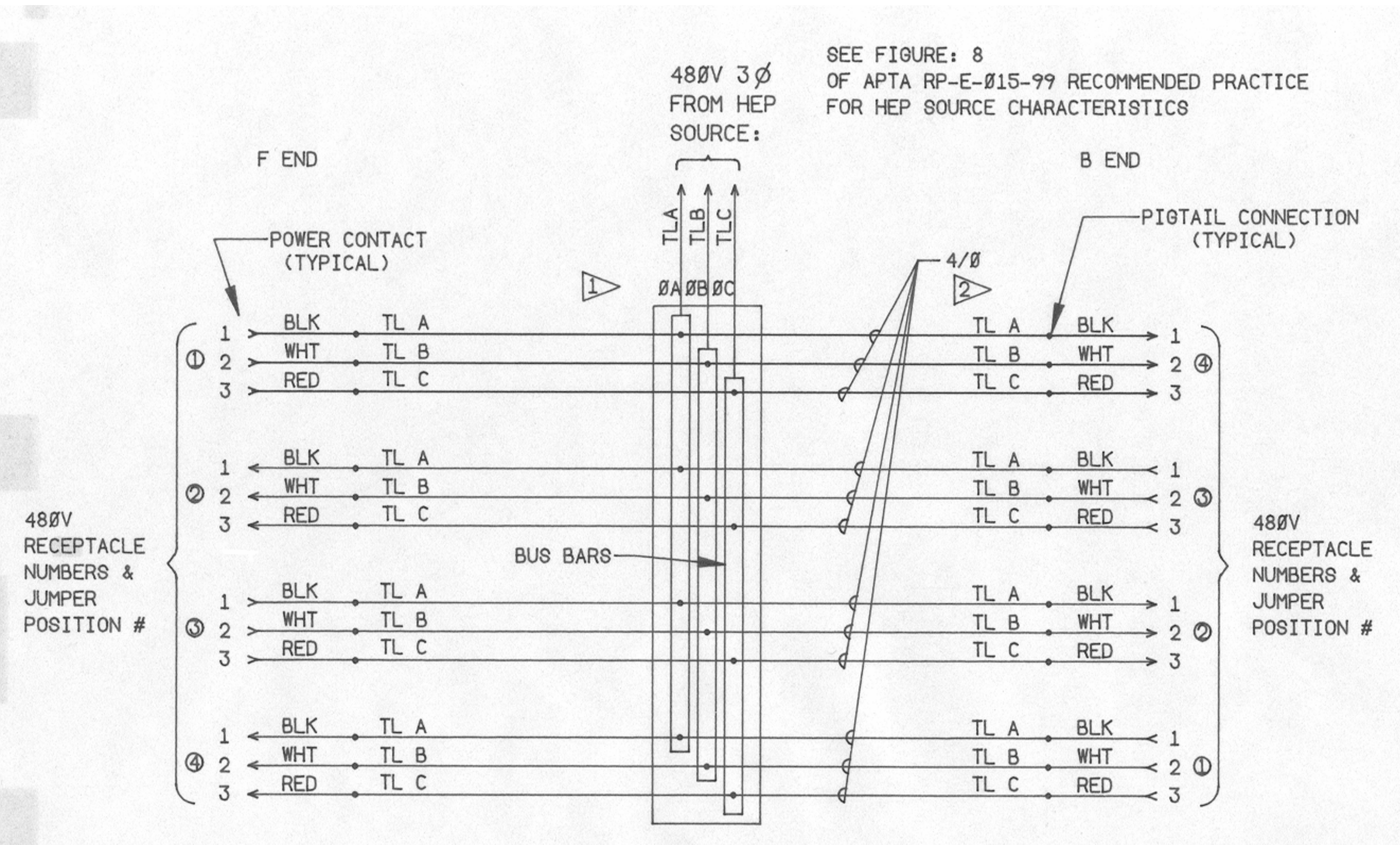


FIGURE: 3
LOCOMOTIVE
48ØV TRAINLINE
POWER SCHEMATIC
SINGLE BUS SYSTEM

NOTES

1. PHASE ROTATION: A,B,C
2. EQUIVALENT CABLE ROUTING & CAPACITY MAY BE USED

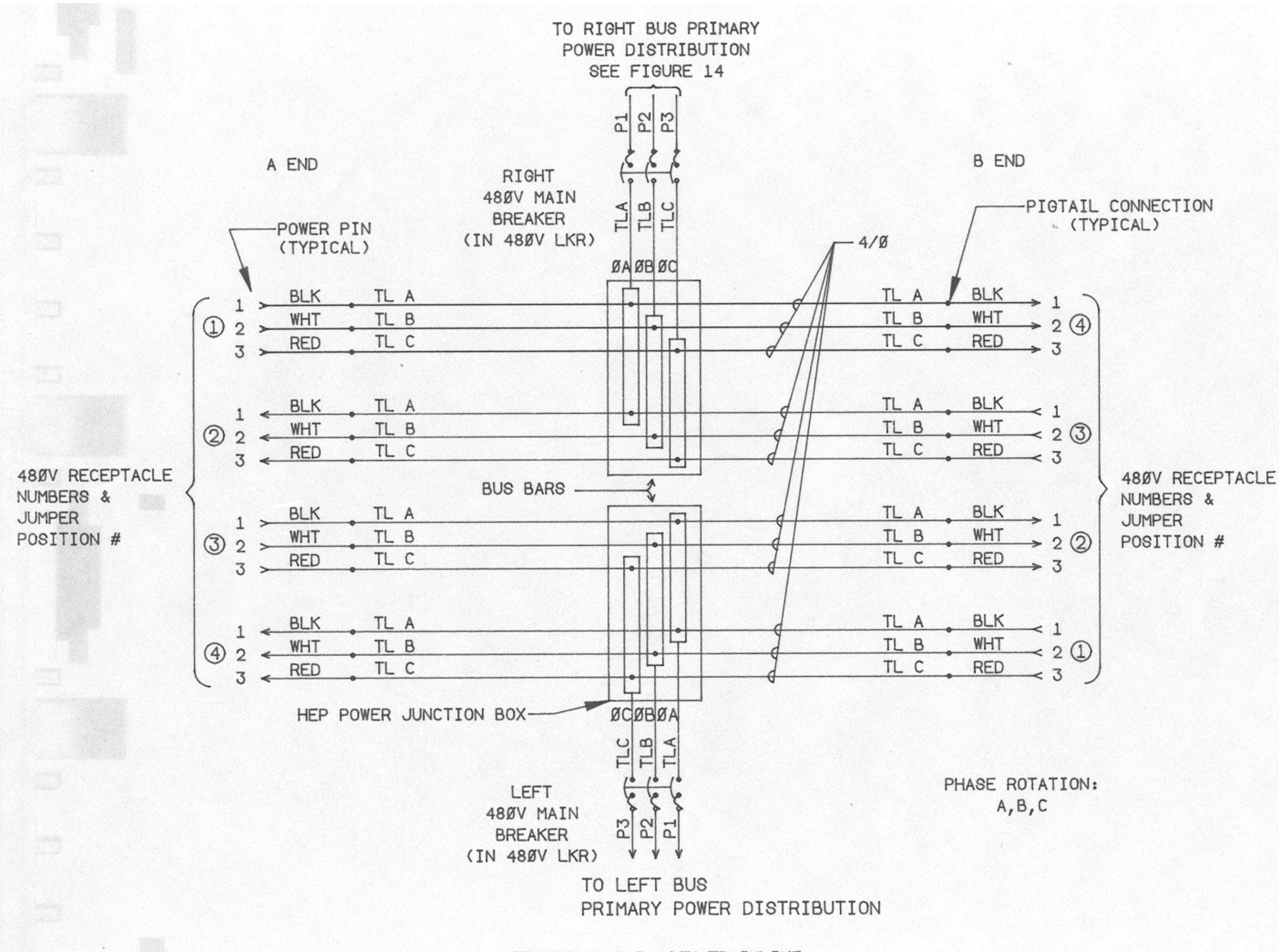


FIGURE 4: CAR 480V TRAINLINE
POWER SCHEMATIC
SPLIT BUS SYSTEM

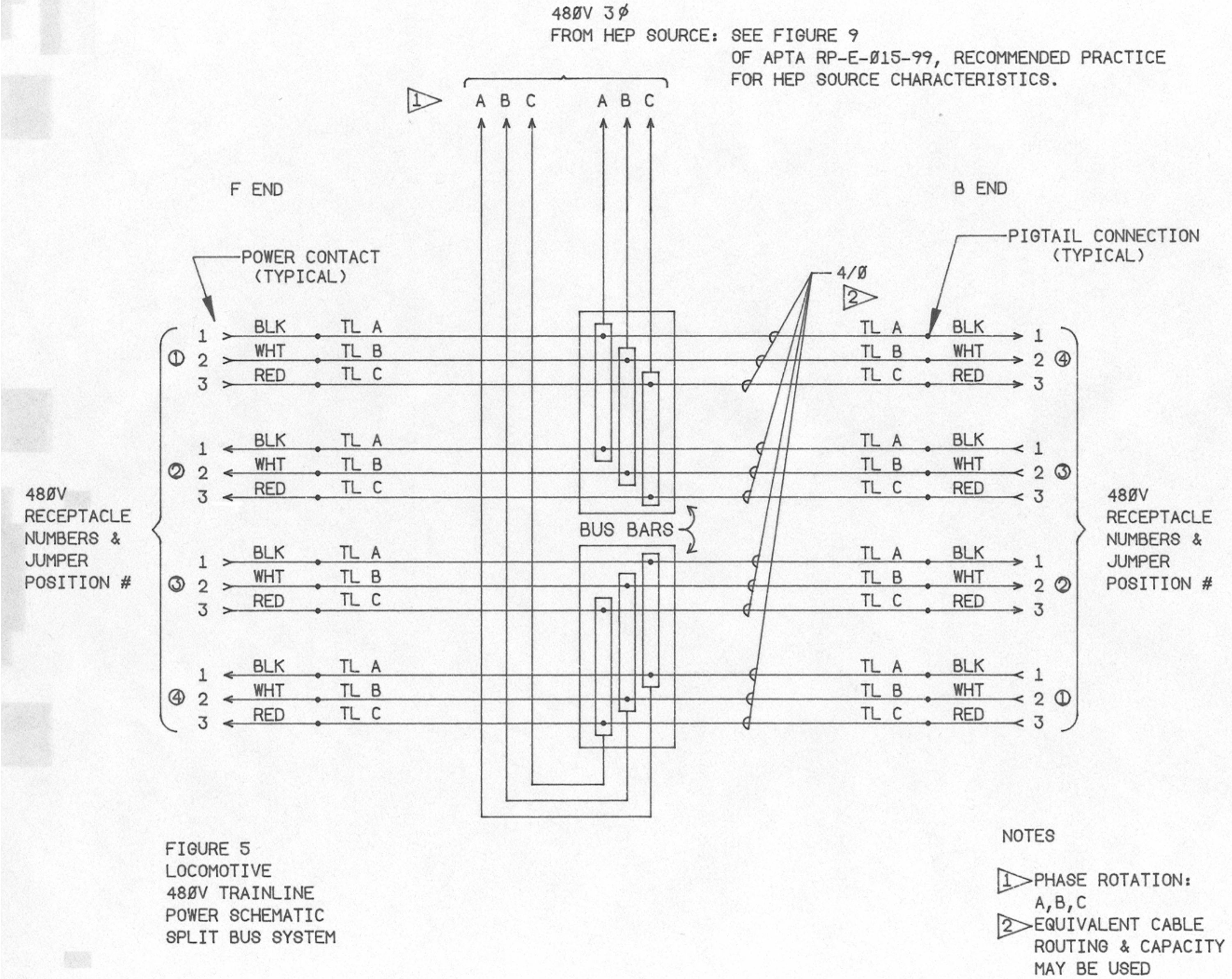


FIGURE 5
LOCOMOTIVE
48ØV TRAINLINE
POWER SCHEMATIC
SPLIT BUS SYSTEM

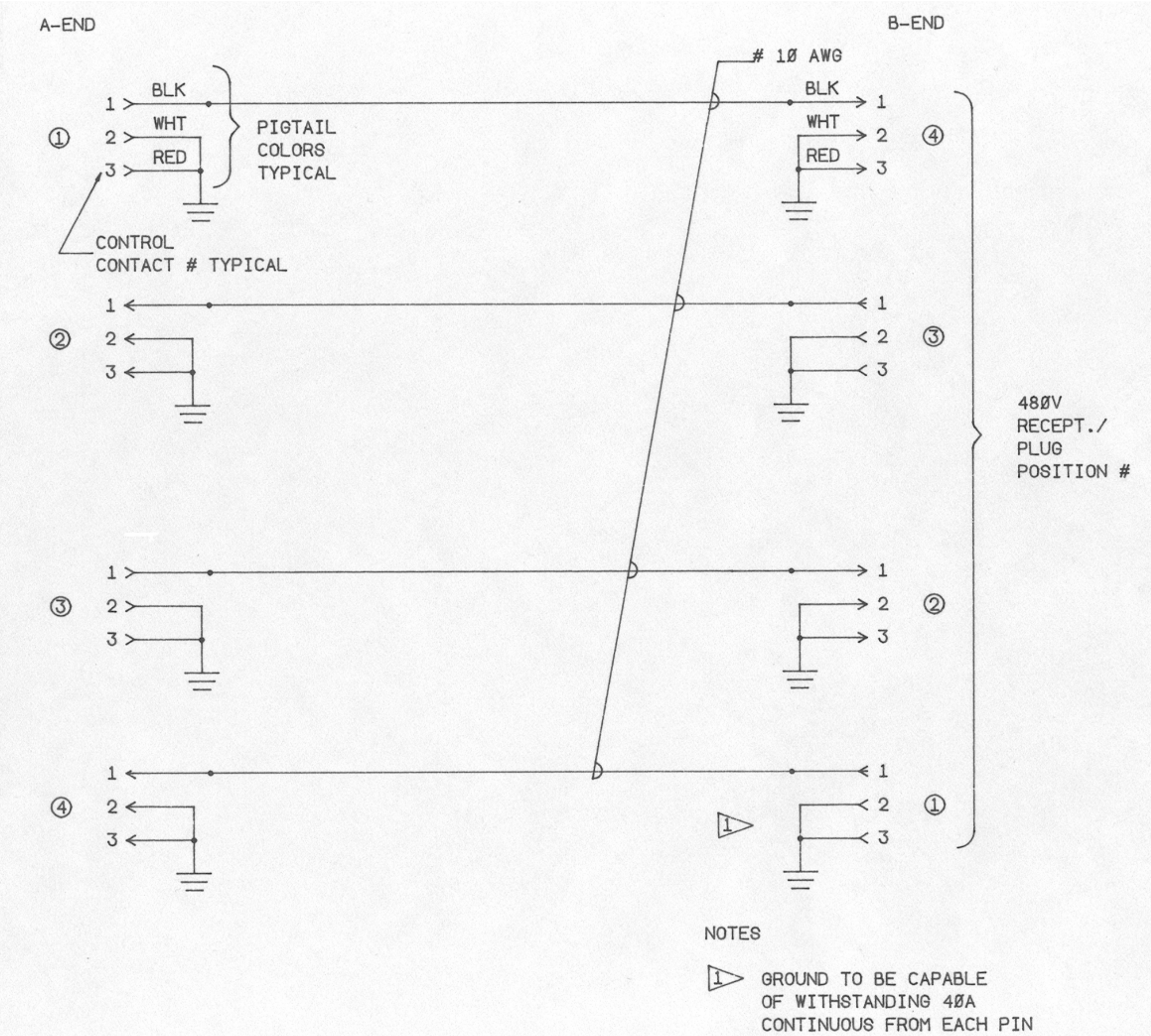


FIGURE 6
CAR 480V TRAINLINE CONTROL SCHEMATIC

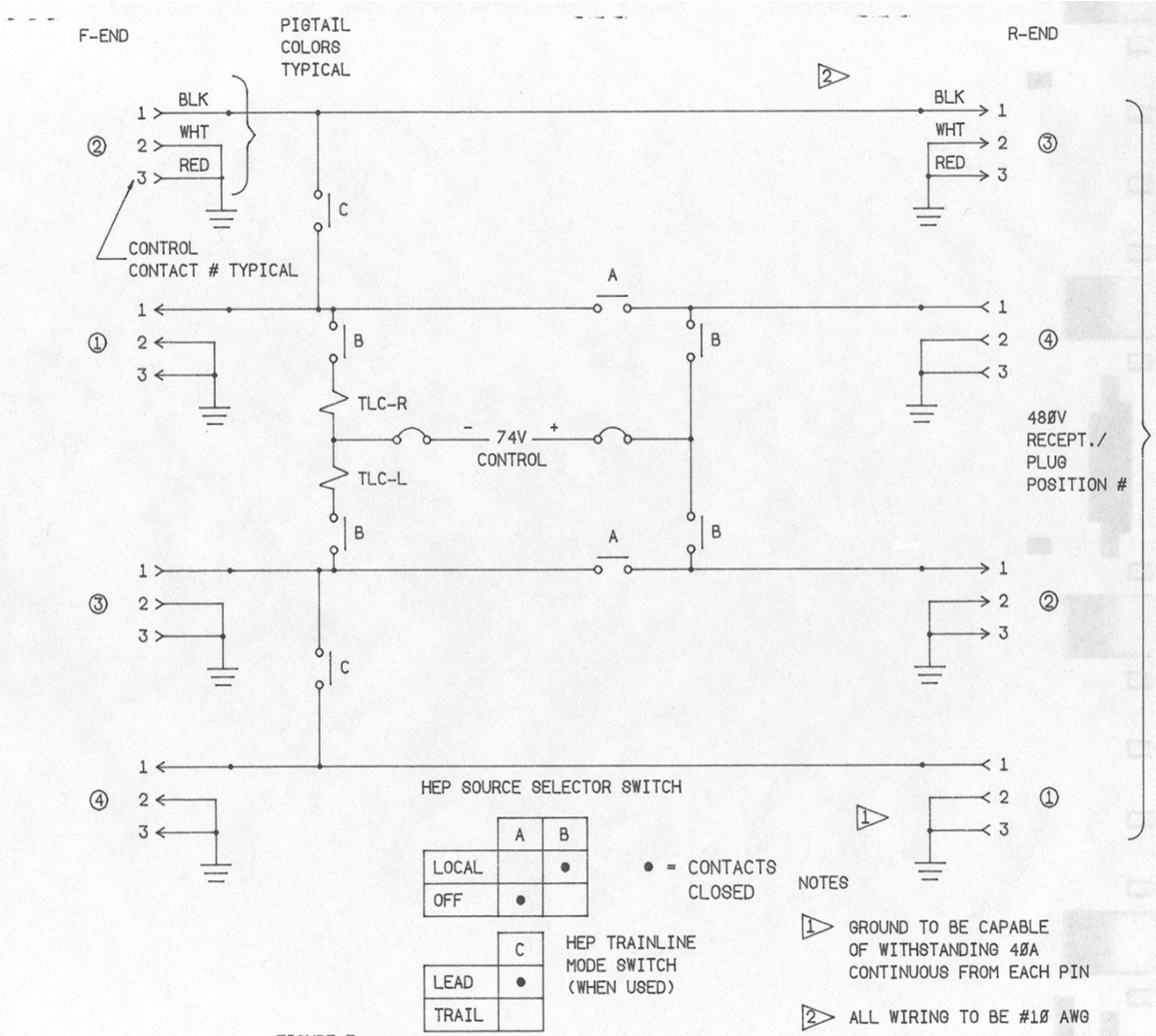
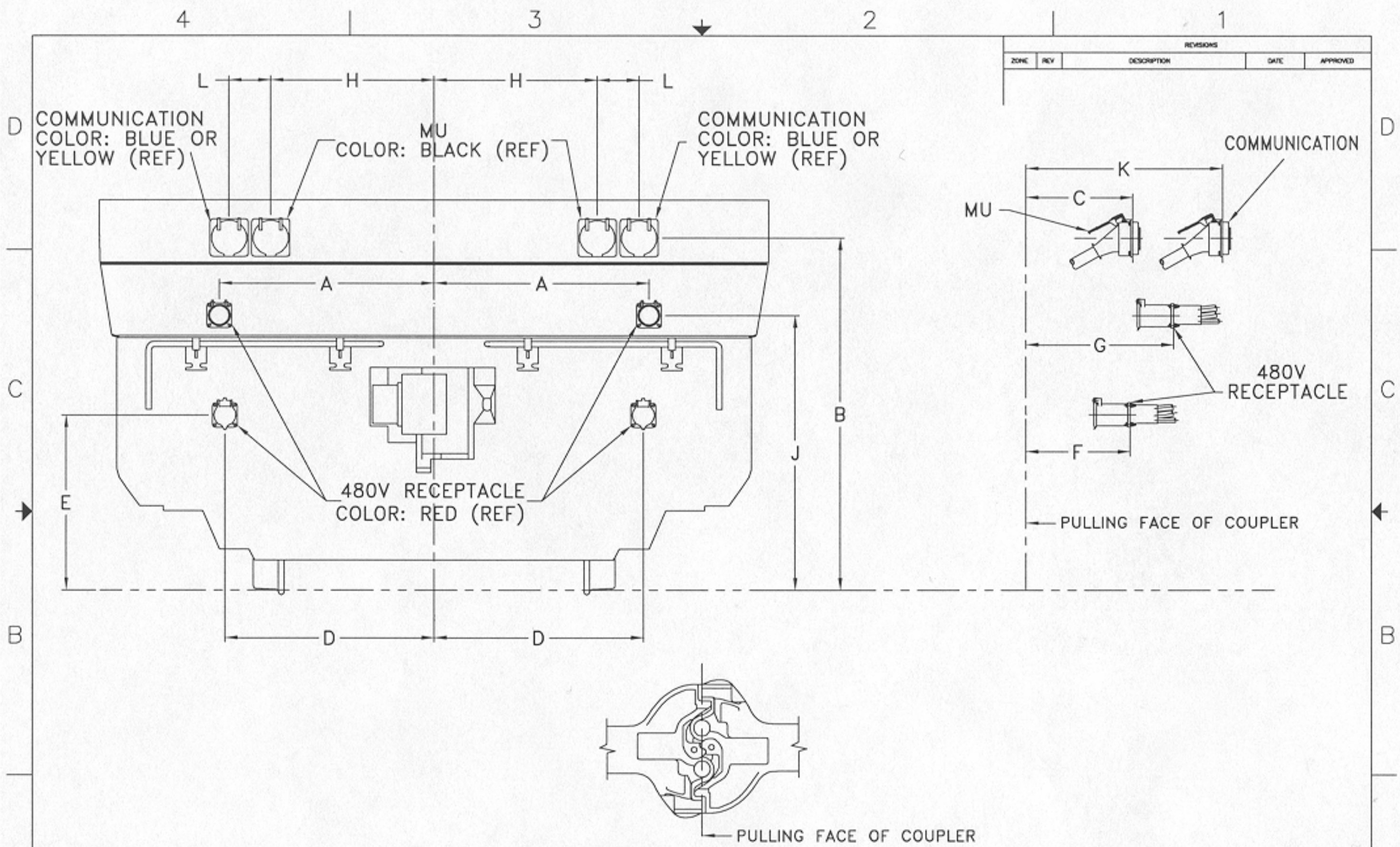


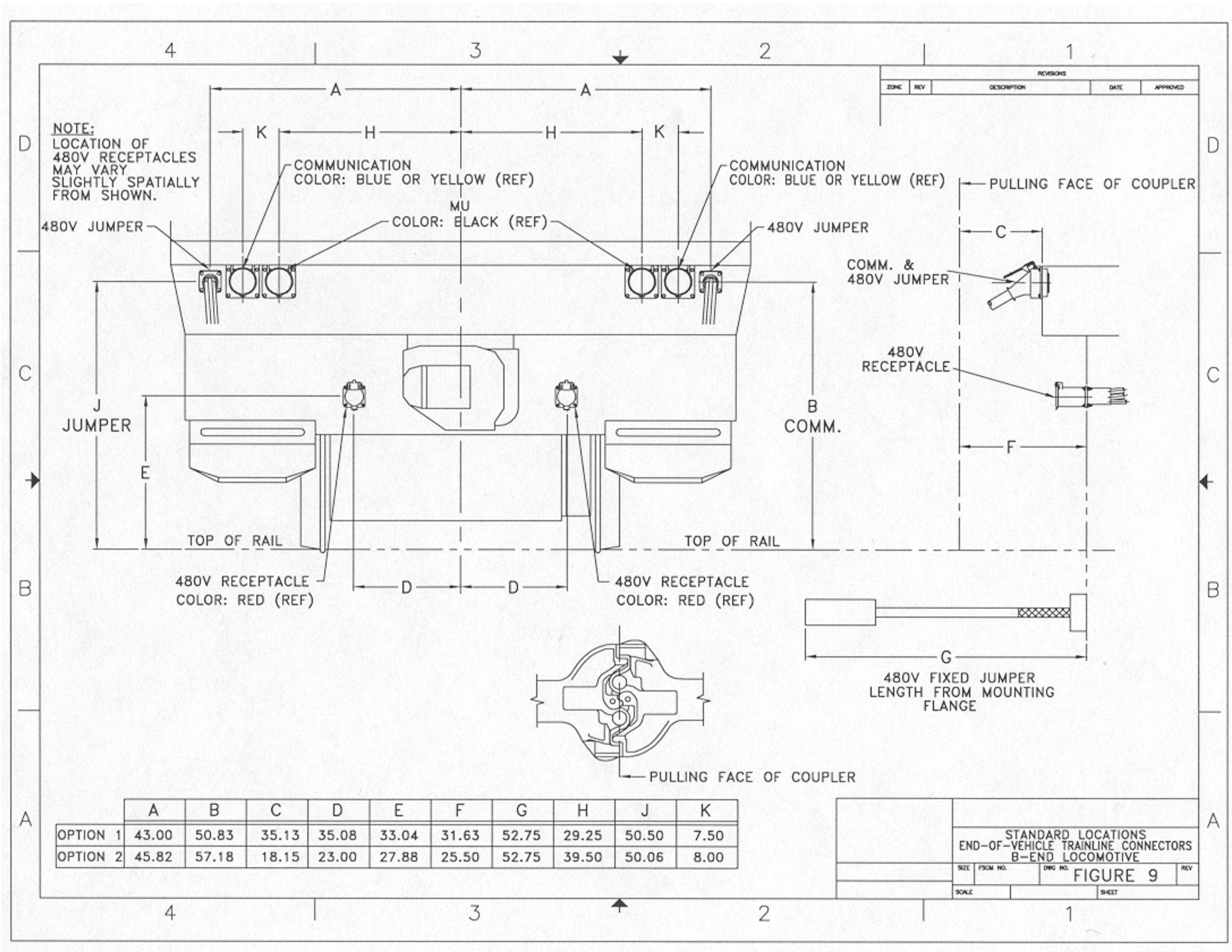
FIGURE 7
SIMPLIFIED LOCOMOTIVE 480V TRAINLINE CONTROL SCHEMATIC



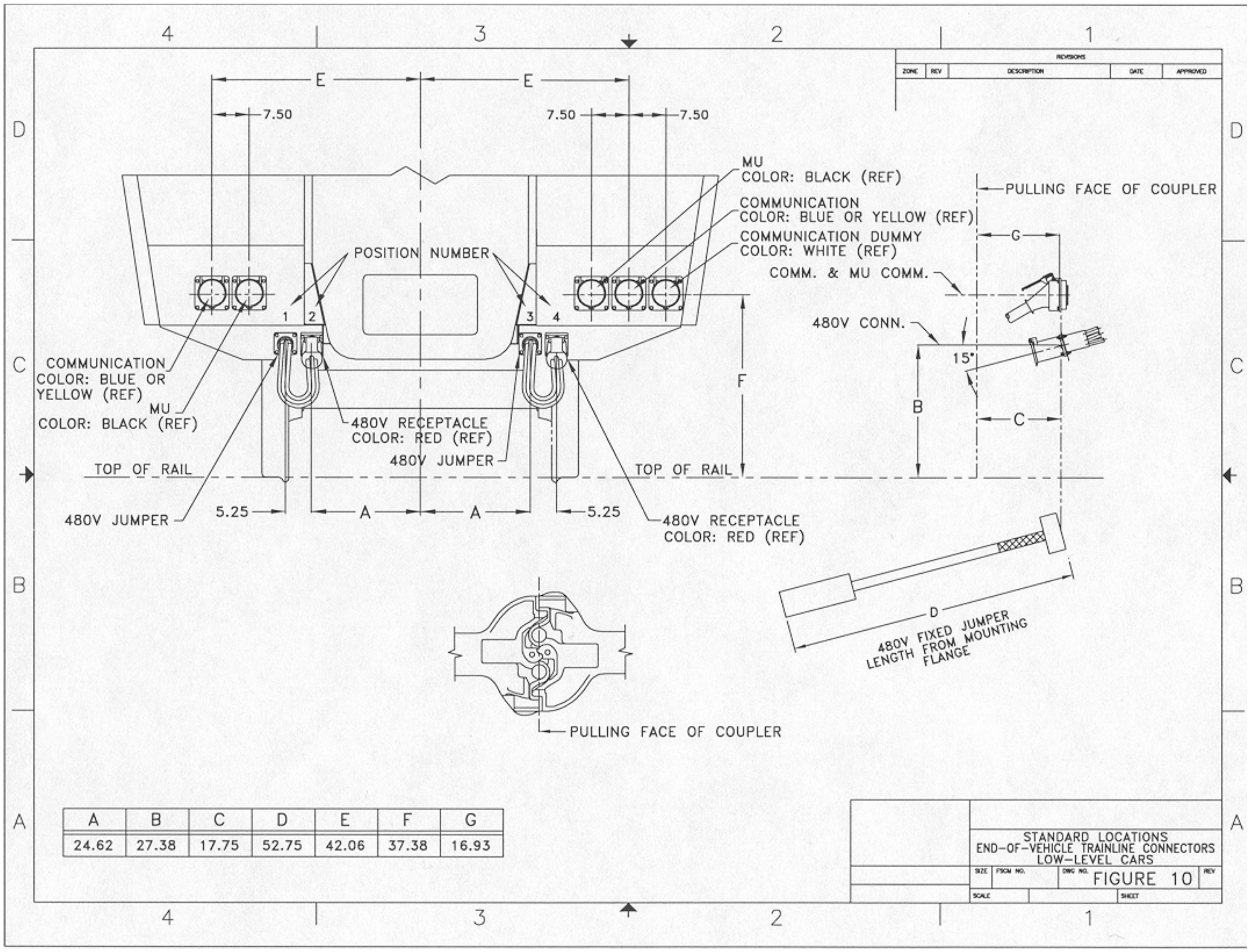
	A	B	C	D	E	F	G	H	J	K	L
OPTION 1	29.25	64.46	19.19	37.50	32.01	18.75	26.54	29.25	50.28	21.56	7.50
OPTION 2	39.00	53.00	25.50	38.63	33.25	33.25	21.75	19.12	40.75	25.50	7.12

STANDARD LOCATIONS
END-OF-VEHICLE TRAINLINE CONNECTORS
F-END LOCOMOTIVE

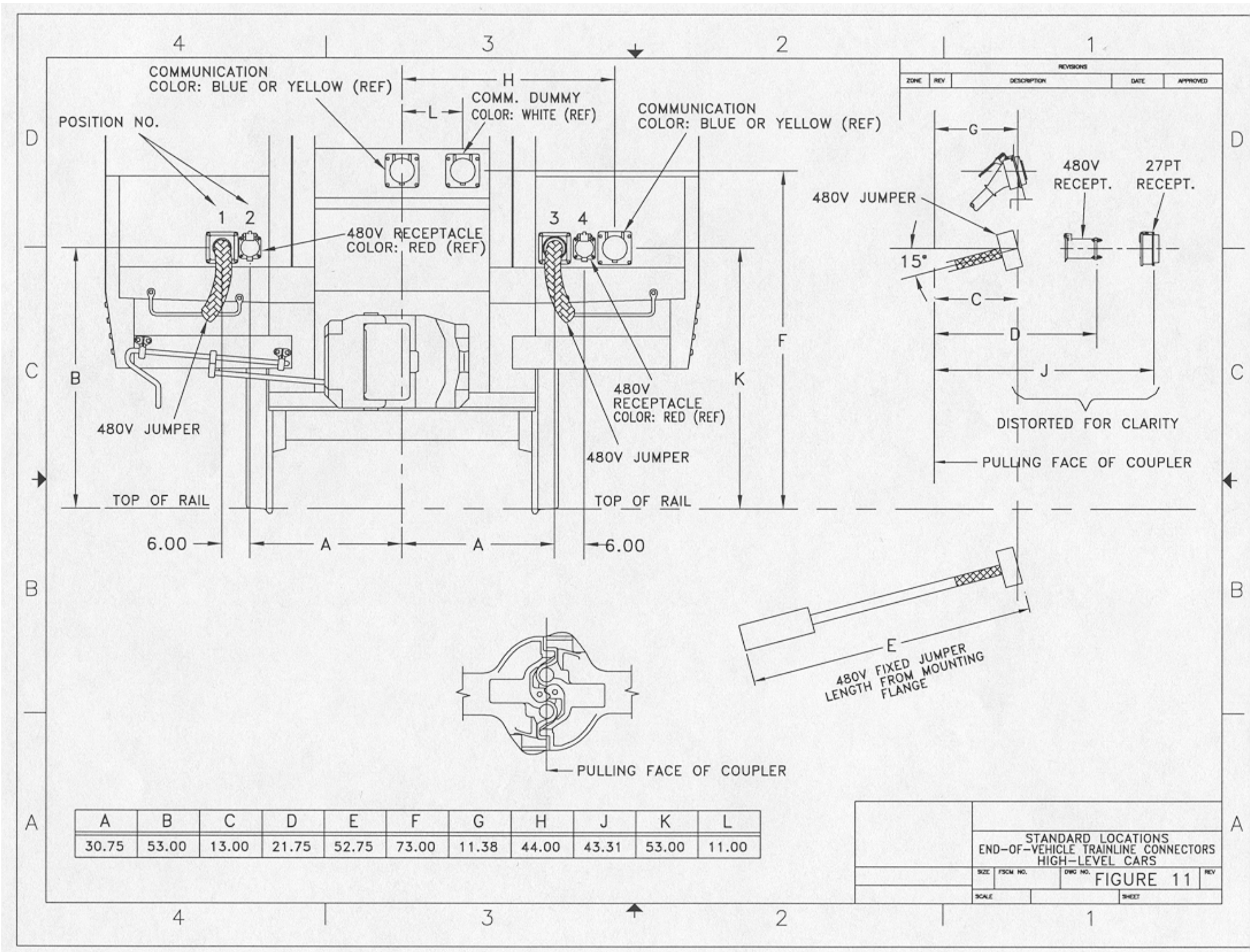
FIGURE 8



	A	B	C	D	E	F	G	H	J	K
OPTION 1	43.00	50.83	35.13	35.08	33.04	31.63	52.75	29.25	50.50	7.50
OPTION 2	45.82	57.18	18.15	23.00	27.88	25.50	52.75	39.50	50.06	8.00



A	B	C	D	E	F	G
24.62	27.38	17.75	52.75	42.06	37.38	16.93



A	B	C	D	E	F	G	H	J	K	L
30.75	53.00	13.00	21.75	52.75	73.00	11.38	44.00	43.31	53.00	11.00

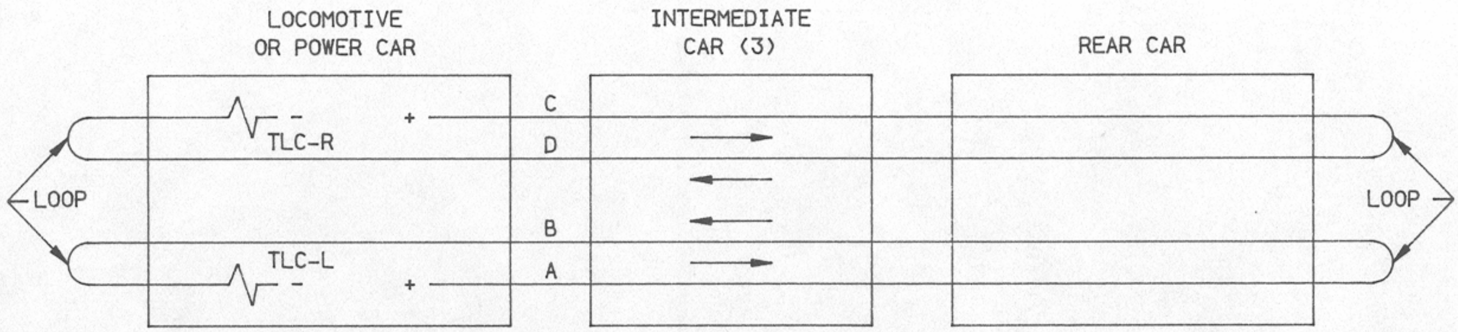


FIGURE:12 SIMPLIFIED TRAINLINE COMPLETE (TLC) OPERATION - TRAIN

NOTE: TLC IS TRAINLINE COMPLETE RELAY

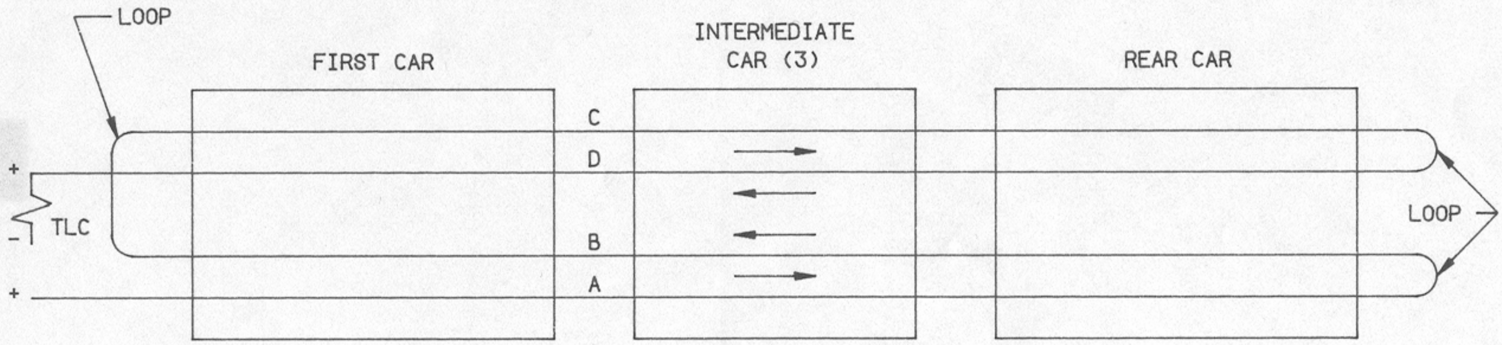


FIGURE:13 SIMPLIFIED TRAINLINE COMPLETE (TLC) OPERATION - WAYSIDE

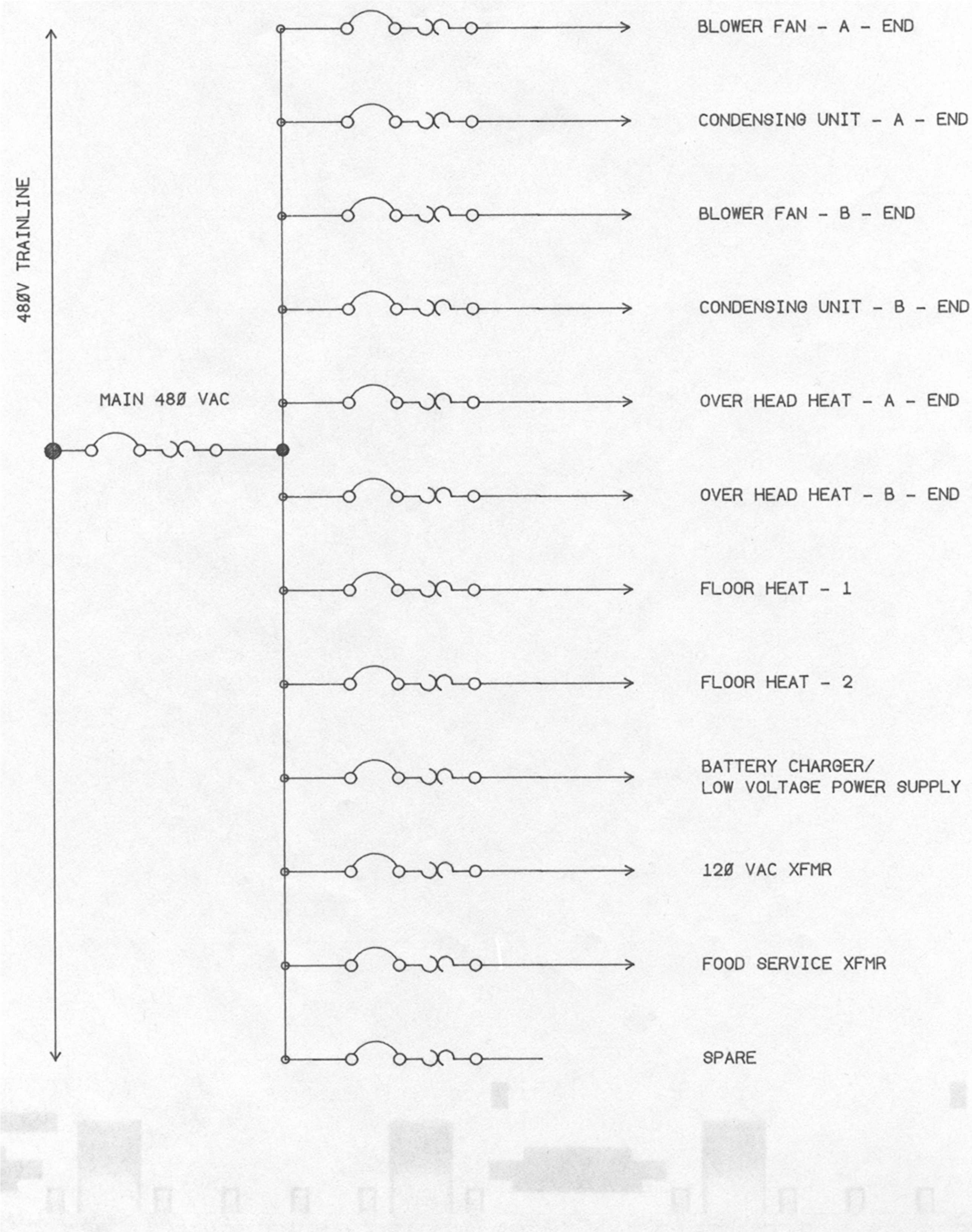


FIGURE 14
TYPICAL 480VAC POWER DISTRIBUTION