

## SECTION 9 - TRACTION ELECTRIFICATION SYSTEM

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## SECTION 9 - TRACTION ELECTRIFICATION SYSTEM

### 9.1.0 GENERAL

The Traction Electrification System (TES) provides electrical power to a Light Rail Vehicle (LRV) by the means of Traction Power System (TPS) and the Overhead Contact System (OCS). The TPS consists of the Traction Power Substations (TPSS) and the Traction Power Feeder System (TPFS). The TPFS includes both the positive and negative feeder cables and their respective conduits. The LRV will collect current from the contact wire by means of pantographs and will return the current to the substations via the running rails.

The TPSS consists of traction power substations located along the Light Rail Transit (LRT) lines, which receives primary power from the local power utility company. The substations include all the equipment necessary to transform and rectify the primary AC three-phase power to DC traction power. Traction power will be supplied to the OCS via positive underground feeder cables. The negative return underground feeder cables shall be connected to the running rails via impedance bonds.

The OCS can be of two styles;

- Constant tensioned simple catenary style comprising a single messenger wire and single contact wire, including low profile simple catenary; or
- a variable tension single contact wire.

Unless directed otherwise by RTD simple catenary shall be used on mainline applications and single contact wire shall be used for all yards and shops. Single contact wire style shall be used in aesthetically sensitive areas such as city center streets and malls in which cases the single contact wire will be electrically reinforced by underground parallel feeder cables, with cable risers to the OCS every 300 to 400 feet. The use of a underground feeder to support a single contact wire is much more expensive then using a simple catenary style and therefore shall only be used where directed by RTD.

The traction power substations shall provide power to the OCS at sectionalizing points. The OCS shall normally operate as a dual multi-feed system for the full length of the main lines with each track being electrically separated from the other. The OCS for the maintenance facility and storage tracks shall operate independently from the main line OCS and shall have its own traction power substations. The mainline tracks will be isolated from ground and connected to the negative bus at the TPSS. The yard and shop tracks will be grounded and separated from the mainline tracks by insulated rail joints.

### 9.2.0 FUNCTIONAL REQUIREMENTS

The traction electrification system shall maintain the OCS voltage above the minimum allowable value. The spacing of the substations shall be established to prevent the temperature of the OCS conductors from exceeding the limit recommended by the conductor manufacturer. The OCS shall be designed to ensure that the LRVs operate with all pantographs in continuous contact with the contact wire up to the maximum allowable track speed. The design shall avoid sudden changes in contact wire height that would cause arcing during current collection.

All traction power and distribution system equipment shall be designed taking into account the effects of the harmonic content of the traction load, the highly fluctuating pattern of traction current, and system faults. The TES shall be designed for a minimum functional life expectancy of thirty (30) years. All traction power substations shall meet the harmonic requirements of IEEE 519.

### **9.3.0 DESIGN REQUIREMENTS**

#### **9.3.1 Traction Power System (TPS)**

The TPS includes the traction power substations and the pad mounted disconnects located adjacent to the substations from which the underground positive feeder cables run directly to the OCS feeder poles and the underground negative return cables run directly to the track rails in non-signalized territory and to the rails through impedance bonds in signalized territory.

##### **9.3.1.1 Substation Spacing and Location**

Traction power substation spacing shall be based on the system load flow simulation. The substations shall be located so that the distribution system voltage does not drop below the minimum level requirements, the temperature of the distribution system conductors does not exceed the maximum allowable value, and the rail voltages do not exceed the maximum permissible values.

##### **9.3.1.2 System Load Flow Simulation**

The design of the TES shall be based on a computer-aided load flow simulation. The simulator shall simulate operation of the trains along the alignment and calculate all necessary parameters for the electrification system design. Four car trains shall be simulated to operate on the system at the minimum projected headways, as specified by RTD, under normal and individual substation outage conditions, with the cars loaded to AW3. Under these operating conditions the TES design shall be shown to operate successfully within the required design parameters and the voltage at the trains shall not fall below 525 Vdc.

The input data shall include track gradients, track speed limits, passenger station locations and station dwell times, as well as the electrical and mechanical characteristics of the trains. Further, the input data shall represent the utility electrical system, the traction power substations, the distribution system and the power return system.

The output data shall include train operational data such as speed, distance traveled, power demand and energy consumption for each station-to-station run. For each substation, the results shall include average power output, energy consumption, rectifier current and current for each feeder breaker. For each substation to substation section of the, line the results shall include voltage profile and current flow in each OCS section. Calculations for maximum substation bus current, feeder

cable size, equipment temperature rating and OCS conductor temperature shall be performed.

### **9.3.1.3 Substation Incoming Service**

Incoming primary AC power to the TPSS may be supplied by the local power utility company at a nominal 13.2 kV, three phase, three wire, 60 hertz. The substations shall be connected by overhead lines or underground cables to the utility three-phase distribution network. The AC service and AC protection scheme shall be coordinated with the electrical utility.

One primary feeder shall supply each transformer rectifier. Each primary feeder shall originate from a different utility bus, and shall be as independent as possible. Feeders connected to the same utility bus shall not supply adjacent substations.

### **9.3.1.4 Substation Types**

Each mainline substation shall have one transformer/rectifier unit and four DC feeder breakers unless otherwise specified by RTD. Substations located in the vicinity of mainline junctions shall have six DC feeder breakers.

### **9.3.1.5 Substation Equipment Rating**

The continuous rating of the mainline substation equipment such as the traction transformer, rectifier, circuit breakers and cables shall be based on the system load flow simulation.

Each mainline and yard substation shall be capable of supplying the following load cycle in accordance with NEMA standards:

- Constant temperature of all equipment shall be reached following operation at 100% rated power for a minimum of 2 hours.
- Equipment shall then be able to sustain a 150% overload for 2 hours with five evenly spaced periods of one minute each at 300% of rated load and one 5 second period at 450% of rated load, followed by a maximum short circuit current with duration equal to substation protective device clearing time.
- Equipment shall be capable of sustaining such an overload twice a day, once in AM peak and once in the PM peak periods.

The shop substation shall be capable of supplying 100% rated load continuously, 150% rated load for two hours following temperature stabilization at 100% load or 300% load for one minute following temperature stabilization at the 100% load.

#### **9.3.1.6 TPSS Site Access, Grading and Drainage**

A minimum 12 foot wide access drive shall be provided to each substation from adjacent roadways. The access drive shall be surfaced with gravel or asphalt and shall not exceed a 6% grade. The surfacing material shall be as recommended by a Geotechnical Engineer or as required by local jurisdictions.

A minimum clearance of 10 feet shall be provided around the perimeter of each substation to permit access for RTD and maintenance vehicles and equipment. Clearance width may be reduced at one side of the substation with approval from RTD. A 72 inch high barbed wire chain link fence shall be provided around the perimeter of the substation and a 12 foot wide gate shall be provided at the access drive.

The fenced area shall be generally flat with finished grade sloping a minimum of 2% away from the building. Decorative stone (3/4 inch) shall be placed over geotextile weed barrier within the fenced area.

The Design Engineer shall analyze drainage at the substation and provide stormwater infrastructure as appropriate.

### **9.3.2 Traction Power Feeder System (TPFS)**

The TPFS shall be an underground feeder cable distribution system comprising positive feeder cables, negative return cables, transfer trip cables and high voltage AC power cables.

#### **9.3.2.1 Positive Feeder Cables**

The positive feeder cables shall be insulated with low smoke, flame retardant, ozone resistant, non-shielded, single multi-strand flexible conductors. Class B stranded copper conductor with ethylene propylene (EP) rubber compound insulated rated 5 kV, and heavy-duty chlorosulfonated polyethylene (CP) jacket. The cables shall be suitable for installation in an underground conduit or duct, for use in wet and dry locations. The maximum operating conductor temperature shall be 90°C for normal operation and 110°C for hot spot. The cable construction shall comply with ASTM D2802 and ICEA S-58-516. The feeder design shall be coordinated with the OCS pole foundations.

#### **9.3.2.2 Negative Return Cables**

The negative return cables are the same as in Section 9.3.2.a, and shall be installed from the substation negative bus to the running rails. The negative return conduit location shall be outside the track, not between two rails, and shall be coordinated with the design of the substation foundation.

### **9.3.2.3 Transfer Trip Cables**

The transfer trip cables shall be fiber optic cables. Material and workmanship of all fiber optic cables shall be of the highest quality assuring durability for a 40 year design life. All cables shall be suitable for both wet and dry installations. The cable shall be suitable for direct field termination with most standard optical connectors. The outer jacket material shall be suitable for long-term exposure to sunlight and weather with a life expectancy in excess of 40 years. Suitability shall be determined in accordance with MIL-STD-810, method 505.

### **9.3.2.4 High Voltage AC Power Cables**

The high-voltage AC power cables shall comply with all of the local utility requirements.

### **9.3.2.5 Ductbank, Manholes and Hand Holes**

Positive and negative cables shall be run in separate ducts, manholes and handholes.

## **9.3.3 Overhead Contact System (OCS)**

### **9.3.3.1 Basic Design**

The design of the OCS for the mainline, the yard and the shop facilities shall be based on engineering studies.

#### **9.3.3.1.1 Maximum Tension Lengths**

The maximum tension length shall be determined based on:

- Along track movement of in running cantilevers
- Stagger Change
- Balance Weight Movement
- Loss of Tension (4%)

#### **9.3.3.1.2 Pantograph Security**

The pantograph security study shall include calculations which take into account all factors that contribute to displacement of the contact wire with respect to the pantograph. This study is required for different contact wire heights as needed and shall include:

- Climatic condition: wind and temperature

- Conductor dimensions and tensions
- Conductor stagger
- Stagger changes due to along track conductor movement
- Stagger effect
- Mast deflection due to live loads such as wind and conductor tension change due to temperature change
- OCS erection tolerances
- Vehicle roll and lateral displacement, or 50% maximum roll into 'operating' wind
- Pantograph width
- Pantograph sway
- Track maintenance tolerances
- 'Wind' and 'no-wind' operating conditions

The results of this study shall include:

- a) Maximum structure spacing as a function of track curvature
- b) Conductor blow-off
- c) Permissible midspan static offset for spans in 5 foot increments of length for tangent and curved tracks.
- d) Conductor along track movement and stagger variation.
- e) Maximum tension section length to the last in-running steady arm.
- f) Pantograph security

### **9.3.3.1.3 Conductor Tension Calculations**

Conductor tension calculations shall be made for various equivalent spans based upon the following:

- a) Conductor normal tension at 60°F
- b) Conductor temperatures
  - i) Minimum -25°F
  - ii) Maximum 125°F
- c) Conductor ice loads

i) Operational loading conditions

½ inch ice on the messenger

¼ inch ice on the contact

ii) Non-operational loading conditions

½ inch ice on the messenger

½ inch ice on the contact

d) Maximum tension length to the last in-running steady arm. The results of the tension calculations shall include the following for various equivalent spans:

Maximum and minimum messenger and contact wire tensions and factors of safety for:

- Conductors with no ice loading
- Conductors with 'operational' ice loading
- Conductors with 'non-operational' ice loading

**9.3.3.1.4 Catenary Hanger Tables**

Catenary hanger tables shall be prepared with a maximum hanger spacing of 30 feet for:

- a) Standard span with 5-foot increments of length
- b) Overlap spans
- c) Anchor spans

**9.3.3.1.5 Catenary (messenger) Sag**

Catenary messenger sag shall be calculated for various spans at 60°F, in 2-foot increments of span length.

Rise and fall of the contact wire shall be calculated for various spans in 5-foot increments of span length. The rise or fall of the wire is the increase or decrease of wire height as compared to the height of the wire at 60° F due to the following:

- Rise
  - Conductors with no ice loading at minimum wire temperatures

- Fall
  - Conductors with 'non-operational' ice loading with a wire temperature of 32°F
  - Conductors at maximum wire temperature

#### **9.3.3.1.6 Catenary Vertical Loads**

Catenary vertical loads for 5-foot increments of span length shall be calculated for:

- a) With no ice loading
- b) With 'non operational' ice loading

#### **9.3.3.1.7 Messenger Wire and Contact Wire Radial Loads**

Tangent Track:

Messenger wire and contact wire radial loads due to maximum tension for 5-foot increments of span length shall be calculated for tangent track with maximum staggers.

Curved Track:

Messenger wire and contact wire radial loads shall be calculated for every degree of angle deviation, in one degree increments, between 1 degree and 15 degrees. Radial loads greater than 15 degrees are not acceptable.

#### **9.3.3.1.8 Maximum Stagger Calculations**

Maximum stagger calculations shall be prepared using 50% of all allowances made for pantograph security calculations. Maximum stagger shall be determined by subtracting the 50% allowance total from the half width of the pantograph carbons.

#### **9.3.3.1.9 Pantograph Clearance Envelope**

A pantograph clearance envelope shall be developed for application on all tracks including superelevation, for worst case track conditions and full vehicle roll plus a 6 inch mechanical clearance. No equipment, except OCS steady arms attached to the contact wire, shall intrude into the pantograph clearance envelope.

### 9.3.3.2 Pole Clearances

Minimum pole lateral clearances to track are specified in Section 4 - Trackwork.

### 9.3.3.3 OCS Styles

Two OCS styles are standard on the RTD System:

- simple catenary style including low profile simple catenary; and
- single contact wire style.

A simple catenary system shall consist of a messenger wire supporting a contact wire by the means of hangers. The contact wire shall be without sag at the normal temperature of 60°F. The catenary conductors shall be auto-tensioned by means of counterweights, which shall be mounted on anchor poles located at the ends of each tension length. The anchor pole, counterweight and associated hardware constitute a balance weight assembly (BWA). As the conductors contract and expand with temperature variation, the counterweights will rise and fall and thus maintain a constant conductor tension throughout the specified temperature range. Suitable anchor arrangements shall be used in the center of each tension length to prevent along track movement of the catenary system at that point. The catenary system shall be supported and registered by means of hinged cantilevers attached to steel poles located between the tracks wherever possible. At special locations such as track crossovers and turnouts, the catenary system may be supported by cantilevers mounted on poles located on the outer sides of the track or attached to head-span arrangements. The contact and messenger wires shall be offset (staggered) at registration points. This style is referred to as Auto Tensioned Simple Catenary (ATSC).

A low profile simple catenary system is similar to a simple catenary system in all respects except that the distance between the messenger and the contact wire is reduced to 1.5 feet at supports and support of the contact wire shall be from a single cross span wire. This style is referred to as Low Profile Simple Catenary (LPSC).

A single contact wire style system shall be used in streets where the environmental impact of simple catenary construction is not acceptable. This style shall also be used in the storage yard and shop areas. The system shall use fixed conductor terminations. In the fixed-terminated system, the conductor tension will vary with temperature variation. This style is referred to as Fixed Terminated Single Contact Wire (FTSCW).

The system in the streets and in the yards shall be supported and registered by means of cantilevers and where cantilevers are not appropriate by means of cross-spans. In the shop, the system shall be attached to the building structure. The contact wire shall be staggered except in the shop where no stagger is needed.

When used in the streets the FTSCW shall be supplemented by along-track paralleling feeders connected to the contact wire at approximately equal intervals. The feeder shall be an insulated cable placed in an underground conduit.

#### **9.3.3.4 Structure Spacing**

Structure spacing for the OCS shall be as great as possible consistent with specified system height and maximum midspan offset criteria.

#### **9.3.3.5 Tension Length Design**

For ATSC the OCS shall consist of a number of overlapping tension sections. Each tension section shall be designed as long as practical considering the mechanical constraints of the overhead system design, such as along track movement of the last in running cantilever, tension loss along the system, counterweight travel and manufacturing limits of conductor length. Where practical, overlaps shall take into account the sectioning requirements.

Tension lengths shall be terminated at each end by auto-tensioning devices or fixed terminations, as necessary. A full tension length has an auto-tensioning device on each end of the tension length and a midpoint anchor midway between the two tensioning devices. A half tension length has a fixed termination on one end and an auto-tensing device on the other.

If over a half tension section the track is 20 or more feet lower at one end than the other the BWA shall be placed on the lower end.

#### **9.3.3.6 Wiring at Overlaps and Turnouts**

Overlaps shall be used between adjacent tension lengths to provide mechanical continuity of the OCS and to permit passage of the LRV pantographs from one tension section to another. Turnout arrangements shall be used at track special work locations where trains change tracks and where they leave or enter the mainline.

The contact wire heights at overlaps and turnouts shall be designed considering the mechanical properties of the OCS. The design shall enable a smooth transition between adjacent contact wires without hard spots, by equalizing the contact wire heights over approximately 10 to 15 feet of track.

Sufficient electrical and mechanical clearances shall be maintained between adjacent cantilevers and between the cantilever frames and adjacent conductors of the auto-tensioned catenaries at all temperatures.

The overlap and turnout wiring shall be designed using single poles with twin cantilevers. Alternatively, two poles with one cantilever each may be used on exclusive ROW when economically justified. In areas where center poles are used, the overlaps shall be staggered along the track to accommodate the balance weight assemblies.

**9.3.3.7 Contact Wire Heights**

Different conditions may exist along the route, for which applicable wire height (measured from top of rail at 60° F and no wind) is shown below. Under no circumstances shall the contact wire height exceed 23.0 feet.

**TABLE 9A – CONTACT WIRE HEIGHT**

Condition	*Minimum Permissible Contact Wire Height at Midspan	*Normal Contact Wire Height at Support	
		Single Contact Wire	Simple Catenary
Exclusive ROW	16' - 0"	17' - 0"	16' - 0"
Semi-exclusive ROW (shared with road vehicles)	18' - 0"	19' - 0"	18' - 0"
Crossing railroad tracks	18' - 0"	19' - 0"	18' - 0"
Shared with railroad tracks	22' - 0"	22' - 10"	22' - 0"
Maintenance Building**	18' - 0" **	19' - 0" **	18' - 0"
Storage tracks	18' - 0"	19' - 0"	18' - 0"

\* No allowance is made in the above table for future track rising.

\*\* Less may be permitted on an as needs basis.

### 9.3.3.8 Contact Wire Gradient

The pantograph shall track smoothly under the contact wire at all times. Where the contact wire height needs to be changed, the change shall not cause bouncing and arcing of the pantograph.

The following table provides AREMA's recommendations for the maximum wire gradient versus LRV speed ranges. To allow for an installation tolerance, the design wire gradient shall be not exceed 90% of those listed here:

**TABLE 9B - MAXIMUM WIRE GRADIENT VERSUS LRV SPEED**

LRV Speed Range (mph)	Maximum Gradient (%)
1-15	2.3
15-30	1.3
30-45	0.8
45-55	0.6

### 9.3.3.9 Change of Contact Wire Gradient

The maximum change of contact wire gradient shall be equal to one-half the maximum gradient, from one span to the next.

### 9.3.3.10 Contact Wire Registrations

The largest acceptable stagger at registrations shall be determined from basic engineering calculations. The angle of deviation on a single steady arm shall not exceed 7 degrees or 500 pounds during operating conditions.

#### 1) In Running Conditions

- Light load < 200 lb pull off or 80 lb direct push off steady arm
- Medium load < 500 lb pull off or push-pull off steady arm
- Heavy load < 1000 lb double medium load steady arms with contact wire swivel clamps 1 foot apart

## 2) Out of Running Conditions

Medium load	< 500 lb pull off or direct push-off registration pipe
Heavy load	< 1000 lb double medium load steady arms

### 9.3.3.11 Sectioning

The system sectioning shall be designed to enable the electrical protective relays to disconnect faulted sections of the distribution system, to permit planned maintenance, and to permit flexible operation during system emergencies.

Sectioning at substations shall be performed by means of insulated overlaps. Section insulators shall not be used in mainline tracks or crossovers used for normal train operations. Sectioning in crossovers and turnouts shall be performed by the use of insulated overlaps. Sectioning for emergency crossovers or turnouts, defined as crossovers or turnouts not used during normal revenue service, shall be performed using high-speed section insulators or insulated overlaps.

The primary connection and isolation of the system sections shall be performed by the substation DC feeder circuit breakers and by disconnect switches which shall be located adjacent to substations.

Circuit protection and transfer trip features between substations shall be arranged so that a fault on either track shall remove power from the associated track. Activation of a substation emergency pushbutton shall also deactivate the tracks associated with that pushbutton and leave all other tracks unaffected.

### 9.3.3.12 Grounding for Stray Current Corrosion Control and Safety

See Section 10.3.0.

Pole grounding resistance shall be less than 25 ohms.

### 9.3.3.13 Grounding for Lighting Arresters

All lighting arresters shall be grounded by an independent ground cable directly attached to a grounding device such as ground rod(s) or ground mat with a ground resistance of less than 5 ohms. Pole grounds may be connected to lighting arrester grounding devices.

#### **9.4.0 STANDARDS AND CODES**

All design work and material selection shall conform to or exceed the requirements of the latest editions of standards and codes issued by the following organizations:

- Association of American Railroads (ARR)
- American Railway Engineering and Maintenance Association (AREMA)
- American National Standards Institute (ANSI)
- American Society for Testing & Materials (ASTM)
- Institute of Electrical & Electronics Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)
- Insulated Cable Engineers Association (ICEA)
- American Society of Mechanical Engineers (ASME)
- Underwriters Laboratories (UL)
- National Fire Protection Association (NFPA)
- National Electrical Testing Association (NETA)
- National Electrical Code (NEC), where applicable
- National Electrical Safety Code (NESC)
- Applicable State, Local, and County Codes

#### **9.5.0 PRODUCT REQUIREMENTS**

##### **9.5.1 Traction Power Supply System**

###### **9.5.1.1 Equipment Description**

The traction power supply system shall consist of all equipment between the interface points with the power utility, the distribution system and negative return impedance bonds. The equipment includes AC cables, AC switchgear assemblies, transformer/rectifier units, DC switchgear assemblies, busbars, positive and negative cables, cable ductbanks, conduits and raceways, negative return and drainage assemblies, substation housings, foundations, grounding systems, protective systems, auxiliary power supply systems, HVAC systems, batteries and chargers, fire and intrusion systems, lightning arresters, annunciation and control systems, metering equipment, supervisory control equipment, portable fire extinguishers, circuit breaker test cabinet, special tools for maintenance, operating and maintenance manuals and training of RTD personnel.

The electrical equipment shall be housed in traction power substations which shall be of the package type, except where conditions do not

permit. Each package substation shall be factory pre-wired, assembled and tested and housed in a self supporting, transportable enclosure suitable for outdoor installation. Each package substation shall be a completely self-contained and integrated unit installed on the previously prepared foundation designed to accommodate a 30 - inch crawl space and connected via suitable feeder cables to the utility interface point and to the traction power distribution and return systems. Where substations cannot be provided as packaged units, equipment shall be individually installed and tested in separately constructed buildings or rooms.

Entry doors shall be provided. The entry doors shall be of sufficient size for installation or removal of any piece of equipment if no other access is provided. All equipment shall be designed and arranged such that all repair, maintenance and cable connections can be accomplished from within the substation enclosure or through access panels at the rear of equipment lineups.

#### **9.5.1.2 Incoming AC Feeders**

The incoming substation service shall be by underground cables. Cable ductbanks, conduits, raceways and manholes inside the substation property line shall be designed from the point of utility interface to the traction power substation. The design shall be fully coordinated with the utility requirements and interfaced with the utility overhead or underground facilities. The feeder rating shall permit the substations to supply the specified load cycle and short circuits without exceeding the allowable equipment temperatures.

#### **9.5.1.3 AC Switchgear**

The AC switchgear assembly shall provide the means to deliver, control and measure the substation power requirements. The assembly shall be housed in dead-front enclosures containing AC disconnect switch, AC circuit breaker, metering equipment and auxiliary power supply.

The equipment shall conform to ANSI C37.20.2 "IEEE Standard for Metal Clad and Station Type Cubicle Switchgear", and shall be UL listed and labeled, or certified by an independent testing laboratory to meet ANSI and UL standards. Working space shall be provided to gain access to components from the front and the rear of the switchgear.

#### **9.5.1.4 Rectifier Transformer**

The rectifier transformer shall be 12 pulse, self-cooled, with primary voltage to be consistent with utility supply, and equipped with appropriate taps.

The transformer/rectifier shall be designed so that the maximum overall regulation rate is not greater than 6% ± 0.5% between 1% rated load and 450% rated load.

The transformer/rectifier design and component selection shall minimize harmonic distortion and shall comply with IEEE 519.

#### **9.5.1.5 Rectifier**

The rectifier shall be silicon diode type, natural convection-cooled. Thyristor rectifiers will be considered where necessary to provide improved voltage regulation or reduce overall traction electrification costs. The rectifier shall be a complete operative assembly consisting of the diodes, heat sinks, internal buses, connections, diode fuses and all other necessary components and accessories. It shall consist of full-wave bridges providing 12-pulse rectification.

The rectifier shall be capable of withstanding the duty cycles specified in Section 9.3.1.5 without exceeding the manufacturer's allowable diode junction temperature and without damage to any component:

The rectifier shall also be capable of withstanding the maximum theoretical short circuit current on the rectifier until cleared by the fault clearing devices.

#### **9.5.1.6 DC Switchgear Assembly**

The DC switchgear assembly shall consist of the positive and negative switches, rectifier, bus work, and DC circuit breakers. It shall form a lineup of dead-front metal clad switchgear built to ANSI C37.20.2 "IEEE Standard for Metal Clads and Station Type Cubicle Switchgear", except that the positive and negative switch and rectifier cubicles may alternately be constructed to ANSI C37.20.3 "IEEE Standard for Metal Enclosed Switchgear". The DC circuit breakers shall be high-speed, stored energy, draw-out, single-pole units and shall have bottom feeder cable entry.

#### **9.5.1.7 Negative Return and Drainage Assembly**

The negative return assembly shall include negative disconnect switches, negative busbar, terminations for negative return cables and other associated equipment. All equipment shall be rated at the system maximum rated voltage.

#### **9.5.1.8 Programmable Logic Controller (PLC)**

This section sets forth the minimum acceptable requirements for a Programmable Logic Controller (PLC) and associated modules as described below for the specified control, processing, and monitoring

system and to interface with the Traction Power Substation equipment and the SCADA System. The Contractor shall be required to provide a full featured, integrated, modular operational PLC system. The modules shall be capable of being inserted at the site, with no factory re-wiring required.

Contractor shall provide a Programmable Logic Controller (PLC) relay interface system. All functional requirements specified shall be met or be exceeded by the PLC system. PLCs, associated network and interfaces shall be rated to utility standards for substation environment.

At a minimum, the PLC system shall consist of the following components:

- Electronic terminators shall replace the normal auxiliary and interposing relays. These shall be placed at the A/C switchgear cubicle, rectifier unit, rectifier DC disconnect switch unit, at each DC feeder circuit breaker unit and at each remote DC disconnect switch group.
- A stand alone modular programmable controller, or protective relay, shall be designed to provide the breaker reclosure relay, long time overload relay, frame fault protection relaying and lockout relays. Running rail voltage monitoring shall be furnished at each DC feeder breaker.
- "Transfer Tripping" of DC breakers adjacent to the section where a fault is detected will be provided by an optical fiber link and associated interface equipment.
- A local area network providing communication from the feeder breakers modular programmable controllers to the substation master programmable controller shall be furnished.
- A master PLC designed and programmed to integrate and control all interpanel connections and to provide substation monitoring and data logging shall be furnished at each traction power substation. The master PLC in combination with the above-described local area network shall result in the elimination of majority of the inter-panel wiring where applicable.
- A man/machine interface (operator panel) capable of providing substation status annunciation and local/remote control of substation operations (e.g. opening and closing of circuit breakers) shall be furnished at each traction power substation.

The PLC system and equipment shall be designed to operate in the environment and conditions specified by the requirements of the LRT

system. All electrical interfaces, including relaying, voice and data, shall meet ANSI/IEEE surge withstand requirements. The system shall be immune to Radio Frequency Interference and shall be designed to meet the requirements of ANSI/IEEE C37.90.2 and ANSI/IEEE 281. The presence of transients on the communication interfaces shall not cause misoperation or blocking of any of critical communications. The system shall be failsafe.

The systems shall also be capable of integrating with the SCADA system using Ethernet for communication. A SCADA points list will be developed with RTD staff that includes alarms, status and supervisory control functions. Alarms will consist of all locally annunciated alarm points discussed in 9.5.1.9. Status points will consist of circuit breaker position, and other necessary points selected to give information about the condition of the remote station to Operations Control Center. The selection of a "local" control mode at the substation shall inhibit remote SCADA control of specific functions, but shall not prevent the monitoring of all substation parameters via the SCADA system.

#### **9.5.1.9 Local Annunciation**

The substations shall be equipped with an internal annunciation system. The annunciator shall be of modular design, programmable and may be integrated with the PLC described in 9.5.1.8, if provided. The annunciator shall consist of LED indicating lamps, audible alarm, test, silence, acknowledge and reset switches, as well as other associated equipment.

A flashing blue light shall be installed on the exterior of the substation, visible from the LRT trackway. The blue light shall be illuminated whenever a DC breaker is open or the DC output is not available.

An electrical alarm "points list" shall be developed listing electrical alarms to be annunciated. These alarms will be annunciated locally and by the blue light which shall be visible from the trackway.

#### **9.5.1.10 Auxiliary Power**

Each substation shall be furnished with AC and DC distribution panel boards. The AC panel board shall supply the substation lighting, HVAC, convenience receptacles and battery charger. The DC panel board shall supply circuit breaker and other control power and annunciation.

#### **9.5.1.11 Busbars and Bus Connectors**

Busbars and bus connections shall be designed to withstand, without damage to the bus or enclosure, the thermal and mechanical stresses

occurring during the specified load cycle and the rated short circuit currents.

Busbars shall be made of rigid high electrical conductivity copper and shall be adequately insulated and braced with high strength insulators. Bus connections shall be bolted and furnished with silver-plated surfaces. Each joint shall have conductivity at least equal to that of the busbar.

#### **9.5.1.12 Equipment Arrangement**

Substations shall have adequate area to accommodate all the electrical equipment and ancillary components. Relative spacing and positioning of each item of equipment shall permit maintenance, removal and replacement of any unit without the necessity of moving other units. The arrangements of the equipment shall permit doors to be opened, panels to be removed, and switchgear to be withdrawn without interference to other units. Ceiling heights and structural openings shall permit entry and removal of the largest components installed in the housing.

Wall space for future growth will be provided. Minimum working clearances will be provided per the NEC. A minimum of 6 feet of space in front of high voltage switchgear shall be provided. Two exit doors with panic hardware, one from each end of the switchgear, shall be provided.

#### **9.5.1.13 Grounding**

Each traction power substation shall be furnished with a ground mat and provisions for equipment grounding. The ground mat shall be contained within the substation property lines and shall be designed so that the step and touch potentials at the rated short circuit current do not exceed the recommended safety limits of IEEE Standard 80. All grounding connections shall be capable of carrying the rated short circuit current.

Substation high voltage DC equipment enclosures shall be low resistance grounded.

#### **9.5.1.14 Negative Return System**

The substation negative bus shall be connected to the running rails. The rails shall be welded in continuous lengths. Any bolted rail joints shall be electrically bonded. At locations requiring insulated rail joints, the continuity of the negative circuit shall be maintained by the use of impedance bonds.

In areas of double track equipped with double-rail AC track circuits, cross bonding between tracks for negative return equalization shall be

accomplished by impedance bond center tap connections at each substation return connection location. In areas of double track equipped with single rail AC track circuits, cross bonding between tracks shall be accomplished by direct connections between the negative traction return rails only. Single rail negative return segments shall not exceed 60 feet in length. In areas of trackage not equipped with track circuits, cross bonding between tracks shall be provided throughout the system, with a spacing of cross bonds of 1000 feet or at every second tracks circuit boundary.

#### **9.5.1.15 Operations Facility Electrification**

See Section 11.

### **9.5.2 Overhead Contact System (OCS)**

#### **9.5.2.1 Equipment Description**

The OCS consists of all equipment between the interface with the DC traction power supply equipment and the vehicle pantograph. The equipment shall include foundations, poles, cantilevers, bridge arms, shop building supports, system conductors, feeders, hangers, jumpers, terminations, tensioning devices, sectioning equipment and all other necessary equipment.

The overhead system shall be designed to be environmentally acceptable. Within the mechanical and structural design constraints, the system structures and associated equipment shall be as lightweight as possible and shall use visually unobtrusive fittings. The system shall be double-insulated with each level of insulation compatible with the system insulation class. A minimum of 4 foot separation between energized components and grounded structure shall be provided. In areas where the grade separation or other means may allow bystanders close proximity to the OCS, at least 10 feet separation and a physical barrier e.g. chain link fence shall be provided to prevent access to any energized component. In cases where any energize component is less than 10 feet separation from the edge of the ROW, a solid barrier or panel must be placed between the energized component to prevent access to the energized component.

#### **9.5.2.2 Foundations**

The design of foundations for supporting structures and guy anchors shall be based on the structure loading calculations and soil data. The supporting structure foundations shall be designed to accept bolted base poles and shall have provision for feeder conduits and structure grounding. The size and placement of the OCS foundation anchor bolts

shall be in accordance with RTD's standard OCS foundation designs. Deviation from the standard plans requires prior approval from RTD.

#### **9.5.2.3 Poles and Supporting Hardware**

All poles shall be designed as free standing except for termination poles for auto tensioned catenary. All poles shall have a base plate drilled to fit the foundation bolt pattern and shall have provision for grounding or bonding conductors.

For open track, the poles shall be galvanized wide flange beams mounted between the tracks except where special conditions require side poles. For operations in paved track where aesthetics are important, tapered tubular steel poles, side-mounted, ranging from 9 to 17 inches in diameter depending on the application will be used. Structures shall be designed so that the normal operating across-track live load deflection of any structure shall not exceed 2 inches, i.e. one inch in either direction laterally.

#### **9.5.2.4 Cantilevers**

The cantilevers shall be designed for a range of loads, pole-to-center track distances, and for a range of system heights considering the system installation tolerances. The cantilever members shall be designed for easy installation and adjustment.

#### **9.5.2.5 Bridge and Shop Building Supports**

Bridge and shop building supports shall be used where sufficient clearance to accommodate a cantilever-type assembly is not available. The supports shall be designed to restrict the uplift of the contact wire when subjected to pantograph pressure and shall be capable of providing vertical and across-track adjustment. The bridge supports shall permit the longitudinal movement of contact wire.

#### **9.5.2.6 Insulators**

Insulators shall provide electrical insulation in accordance with the system insulation class and shall have the mechanical safety factors specified.

The insulators shall have resistance against deterioration from exposure to sunlight and airborne chemical pollution. The insulators shall be a light gray, sky tone color and their life expectancy shall be compatible with that of the rest of the equipment.

### **9.5.2.7 Conductors and Associated Items**

Contact wire shall be 350 kcmil solid, grooved, bronze-80 alloy conductor. The messenger wire shall be stranded, hard-drawn copper conductor. All feeder and connecting cables shall be insulated, stranded copper conductors with sufficient flexibility to prevent fatigue failure of the cable due to vibration of the overhead conductors.

All conductor connections, attachments, hangers and clamps shall be copper or bronze fittings and shall be designed for ease of replacement and maintenance.

Continuity and equalizing jumpers shall be flexible copper conductors. The spacing of the jumpers shall be determined based on the required current conductivity. However, a minimum of one jumper per span shall be used. In addition to the jumpers, current carrying hangers of stranded copper wire can be used. All conductive copper or bronze hardware to terminal and hardware to wire connections shall be coated with grease on the mating surface.

### **9.5.2.8 Terminations and Midpoint Anchors**

Strain-type termination assemblies shall be light weight and of aesthetically pleasing appearance. Wire wrap, straight line, cone or wedge type designs are acceptable. Turnbuckles shall be included as appropriate and shall have adequate adjustability.

A mid-point anchor arrangement shall be used at or near the mid-point of each tension length of auto-tensioned equipment to restrict movement of the conductors at that point.

### **9.5.2.9 Tensioning Devices**

The auto-tensioned system conductors shall be tensioned using cast iron or steel counterweights. At wide flange beam poles, the counterweights shall be positioned in the pole web to be as unobtrusive as possible. The poles with counterweights shall be fitted with guides that will prevent the counterweight from binding or jamming over the entire range of movement. The top and bottom of the weight shall be engaged by the guides at all times. The guide shall prevent the weights from falling away from the anchor pole during a broken wire condition. In areas frequented by passengers or pedestrians, the counterweights shall be provided with a protective shield. The tensioning devices shall accommodate conductor expansion and contraction and shall be provided with broken wire arrangements. All operating cables shall be of flexible stainless steel wire.

Pneumatic, spring or hydraulic tensioning devices may be used in public streets or for short tension lengths such as at crossovers.

#### **9.5.2.10 Sectioning Equipment**

Section Insulators shall not be installed in mainlines or crossovers in regular revenue service. High-speed section insulators may be used in emergency crossovers and in yards. Section insulators without skirts shall be installed in the yards, except for test tracks.

No load disconnect switches shall be used to electrically connect and disconnect line sections. The disconnect switches shall be rated to withstand the system worst-case overload and short circuit conditions without overheating. The switches shall be capable of breaking the maximum load current under emergency conditions.

#### **9.5.2.11 Lightning Arresters**

Over-voltage protection for the OCS shall be provided by lightning arresters. The arresters shall be rated to withstand the maximum system voltage and anticipated voltages induced from any paralleling high-voltage transmission lines onto the system conductors. The arresters shall be capable of discharging the energy resulting from lightning strikes to the system.

All feeder riser cables shall be protected by lightning arresters. Arrester design and installation shall prevent grounding of the energized circuit during catastrophic failure.

At a minimum, arresters shall be located adjacent to each substation and in all areas of reduced clearances, such as at overhead bridges, midway between substations and high points in the alignment such as flyovers.

#### **9.5.2.12 Protective Screening**

When the LRT is constructed below a bridge, building, or structure, screening and fencing shall be erected to physically separate the catenary wires from human reach. Furthermore, the overpass screening and/or fencing shall be constructed to protect LRVs from vandals dropping objects from above. The design of the overpass screening and/or fencing shall be compatible with the local architecture and landscaping. All fencing passing over the LRT shall be grounded. Fence grounding resistance shall be less than 25 ohms.

## 9.6.0 DESIGN PARAMETERS

**TABLE 9C – DESIGN PARAMETERS**

Climatic Conditions	
Maximum Ambient Temperature:	100 °F
Minimum Ambient Temperature:	-25 °F
Radial Ice Loading:	1/2 in
Maximum Wind Speed:	
Structural design	80 mph
Pantograph Security	55 mph
CS Conductor Sizes and Material	
Messenger Wire: Copper. Alternative sizes require RTD approval	500 KCMIL HD
Contact Wire:	350 KCMIL Bronze 80
Factors of Safety -- Conductors and Wires	
Operating:	2.0
Non-operating:	1.6
Contact Wire Wear for Mechanical Design	30%
Factors of Safety -- Hardware	
Operating:	2.5
Non-operating:	2.0
Minimum Electrical Clearances	
Static Clearance:	4 in
Passing Clearance:	3 in (in addition to the static clearance)
Minimum Contact Wire Heights Above Top-of-Rail	See Section 9.3.3.7. RTD approval is required for any deviation in the minimum contact wire height (e.g. tunnels and overpasses)

Maximum Contact Wire Gradients	
Constant Gradient:	See Section 9.3.3.8
Gradient Change:	See Section 9.3.3.9
Pantograph Security	
Minimum Pantograph Security:	6 in
Loss or gain of tension within a tension section shall not exceed:	4%
Track maintenance Tolerances	
Ballast Track	
Alignment:	1 in
Cross level:	1 in
Embedded Track	
Alignment:	0.5 in
Cross level:	0.5 in
Track Gauge	
Widening:	0.625 in
Vehicle Data	
Maximum Roll (broken springs)	4%
Pantograph Data	
Width:	74.75 in
Separation of Carbons:	12-13 in
Length of Carbons:	52 in
Maximum Carbon Wear:	
40 mm x 25 mm Carbons	1 in
75 mm x 15 mm Carbons	0.625 in
Maximum Reach	23.51 ft

Maximum Operating Height	23 ft
Minimum Operating Height	13.78 ft
Lockdown Height	12.42 ft
Contact Wire Height	
Maximum Wire Height	23.00 ft

## **9.7.0 CONDUIT AND DUCTBANKS**

The following parts apply to all conduit and ductbanks for traction power, signals, communications and high voltage (15 KV) AC.

### **9.7.1 Raceway and Ductbank System**

This section describes the design criteria necessary to provide raceway and ductbank systems to protect all power wiring and system cables on RTD's LRT facilities. The systemwide electrical raceway and ductbank system includes conduits, ductbanks, cable trays and cable trough installations and related manhole, handhole and pullbox equipment. Generally there are two ductbank systems used within the trackway, parallel to the mainline track, namely the signal/communication (SC) mainline ductbank, and the traction electrification (TE) ductbank in addition there are various lateral ductbanks.

#### **9.7.1.1 Scope**

Systemwide Electrical Raceway and Ductbank System applies to all traction power electrification systems, communication systems, signal systems, fare collection equipment and electrical facilities including system buildings and rooms, maintenance facilities, passenger station platforms, park and ride lots, parking structures, lighting systems, pedestrian and LRT bridges, and AC low voltage and high voltage electrical systems.

#### **9.7.1.2 System interfaces**

Systemwide Electrical Raceway and Ductbank System engineering shall be coordinated with the other disciplines, including architectural, mechanical, utility, electrical, civil, structural, trackwork, electrification, signal and communication designs.

#### **9.7.1.3 Codes and standards**

Raceway and ductbanks design shall conform to the latest edition of the following codes where applicable:

- National Electrical Code (NEC)
- National Electrical Safety Code (ANSI/IEEE C.2)
- Electrical Codes or amendments of the local authority having jurisdiction
- American National Standards Institute (ANSI)
- National Electrical Manufacturers Association (NEMA)
- Institute of Electrical and Electronics Engineers (IEEE)
- National Fire Protection Association (NFPA 70, 101 & 130)
- The Occupational Safety and Health Act (OSHA)

#### **9.7.1.4 Products**

Raceway products used shall in all cases be listed and labeled by a nationally recognized electrical safety testing organization.

#### **9.7.1.5 Functional Requirements**

All power wire and systems cables shall be protected by conduit, cable tray, or cable trough per this section, except for low voltage signal or communication wiring where protected from physical damage within traction power substations, signal or communication buildings and rooms, bungalows, or cases. Installations shall comply with the NEC and local county and city codes.

Spare raceway capacity of 40% minimum shall be provided in the mainline SC ductbank, TE, HV, and lateral ductbanks or conduit runs including station platforms, except where determined by RTD. Spare cable tray or cable trough capacity shall be provided in all installations for future equipment. RTD may determine that the spare capacity is not necessary at various locations; due to the expense that would be incurred and this requirement could be reduced in capacity or eliminated.

Manholes shall be provided in the mainline SC ductbank, in TE ductbanks, in HV ductbanks, in lateral ductbanks, and in conduit runs at junction points and for cable pulling requirements in the cable system. Handholes shall be provided in various lateral ductbanks or conduit runs at junction points and for cable pulling requirements in the cable system. On LRT bridges, tunnels, or shafts where raceways are provided pullboxes shall be provided.

#### **9.7.1.6 Raceway products**

Raceways may be galvanized rigid steel conduit (GRS), PVC Schedule 40 conduit, PVC Schedule 80 conduit; PVC coated galvanized rigid steel conduit (PVC/GRS), rigid non-metallic fiberglass reinforced epoxy

conduit, electrical metallic tubing (EMT), liquid-tight flexible metal conduit or flexible metal conduit.

Cable trays shall be aluminum, fiberglass-reinforced plastic, welded or swaged steel hot-dipped galvanized after fabrication, ladder type with formed rungs and channel type side rails with inward or outward turned flanges. Special design circumstances may require physical protection of the cables, and solid or ventilated cable trays and covers may be used.

Cable trough and cover shall be a dielectric material, High Density Polymer Concrete, pre-fabricated, nonmetallic, rated for exterior below grade use, resistant to sunlight exposure and suitable for use in wet locations. Individual cable trough sections must interlock together to make a continuous cable trough without gaps. Covers shall sit inside the trough, be flush with the finished grade, be designed to withstand excessive loading and not shatter and be secured with stainless steel vandal proof hardware. The weight of each cover shall not exceed the allowable handling weight as per OSHA requirements.

#### **9.7.1.7 Systemwide Ductbanks**

Ductbanks are concrete-encased conduits using Schedule 40 PVC conduit, with GRS or PVC/GRS conduit ells, or Schedule 40 PVC conduit large radius elbows greater than 6 feet. Ductbanks with reinforced steel rebar are used for special utility and roadway crossings. The exact ductbank dimensions vary with the number and size of conduits. Plastic spacers shall be provided between conduits to allow for concrete-encasement around the conduits. The minimum spacing between conduits is 1.5 inches for signal/communication conduits and 3 inches for traction electrification and power conduits unless otherwise required by the NEC. The overall concrete-encasement around the outside conduits shall be 3 inches on all sides. Trench walls that are stable may provide the forms for the concrete encasement.

Ductbanks shall be located longitudinally along the length of the trackway and between the mainline tracks. Generally the ductbank is located below the end of the track ties at a depth of 36 inches so that conflict with OCS and signal foundations is avoided and the ductbank runs in a straight line between conduit transitions into manholes. If required, due to special circumstances, ductbanks located other than between the mainline tracks will be determined solely at the discretion of RTD. Ductbanks are to be set on a prepared and compacted bed.

When it is necessary, lateral ductbank crossings below the track are permitted as long as the ductbank meets the minimum depth requirements.

Where obstacles such as underground utilities or foundations are encountered the ductbank shall be gradually offset around them and must meet the concrete-encasement and conduit bending requirements. Ductbanks shall be located outside the envelope shown in Figure 9.1.

Ductbanks shall be located precisely on all plans and profile design drawings. Ductbanks shall be sloped to drain to manholes or handholes, be located to avoid interference with new or existing utilities, and be located at a minimum depth of 36 inches below finished grade. Conduits shall be limited to a maximum of 270° of bend between manholes, handholds, junction boxes, or termination points.

#### **9.7.1.8 Systemwide Raceways**

##### **Conduit**

Within the trackway, raceways may be direct buried and shall be PVC/GRS conduits if designs are encountered where concrete encasement cannot be achieved due to space restrictions.

The final signal raceway connections (normally the last 10 feet of the conduit run from last signal handhole or into bungalows and cases) to signal equipment maybe direct buried and shall be schedule 40 PVC conduit.

On LRT bridges, exposed raceways for signal, communication, traction electrification, and lighting shall be galvanized rigid steel conduit or rigid non-metallic fiberglass reinforced epoxy conduit and its use will be determined solely at the discretion of RTD. If raceways are concealed as an integral part of an emergency pedestrian walkway schedule 40 PVC conduit may be used, except for transitions at the end of the bridge, which shall be PVC/GRS conduit direct buried or ductbank with GRS conduit. Transitions at end of bridges require expansion couplings.

##### **Cable Tray**

The use of cable trays is restricted to use within system buildings, across pedestrian bridges and rooms. Cable trays and supports shall be designed to provide adequate strength to support the weight of the tray, cables, and future cables and meet the local seismic requirements. The use of fiberglass cable trays is generally used inside TP Substations for DC feeders and cables.

##### **Cable Trough**

The use of cable trough is restricted to existing trackways and its use will be determined solely at the discretion and approval of RTD. If required, due to special circumstances, cast-in-place type cable troughs may be located on LRT bridges as an integral part of an emergency

pedestrian walkway as determined solely at the discretion and approval of RTD. Covers for cast-in-place cable troughs shall be pre-fabricated High Density Polymer Concrete and be secured with stainless steel vandal proof hardware. The capacity of the approved cable trough shall be 200% of the feeding conduit system.

Cable trough may be used for signal, signal power and communication cables only. The cable trough shall have integral dividers to maintain separation between signal, signal power and communication cables. Cables shall only enter or exit the cable trough through cable trough handholes or pullboxes that are an integral part of the cable trough system.

The cable trough shall be located longitudinally along the length of the trackway and shall not be located between mainline tracks. Cable troughs shall not be located directly above longitudinal runs of track drains or other utilities. Where obstacles, such as OCS and signal foundations, or utility manholes are encountered, the cable trough shall be gradually offset around the structure. Cable trough shall be placed in a level trench, with the lids flush with finished grade.

Cable troughs shall not be used in station platform areas, road and pedestrian crossings, high rail accesses and any areas accessible to pedestrians.

#### **9.7.1.9 Manholes, Handholes and Pullboxes**

Manholes and handholes shall be of the pre-cast concrete type, complete with cable supports, pulling irons, and a ground rod, and all metallic parts shall be internally grounded. Manholes or handholes installed in streets shall be equipped with a cast iron cover and grade ring suitable for H-20 street loading and which can be adjusted for final grade. In other locations, covers shall be hot-dipped galvanized steel diamond plate suitable for H-20 street loading.

Pullboxes shall be welded hot-dipped galvanized steel boxes or cast-in-place boxes with hot-dipped galvanized steel diamond plate covers, for use on LRT bridges, in tunnels and in shafts. All manholes, handholes and pull boxes shall be identified with welded raised lettering, except platform handholes, which shall be cast integral with the cover.

#### **9.7.1.10 High Voltage Raceways and Ductbanks**

High voltage raceways and HV ductbanks that are maintained by RTD, and are used for AC feeders (greater than 600V) shall be GRS, PVC/GRS, or PVC conduits encased with red concrete, and the conductors separated from other systems per the NEC.

If required because of electromagnetic interference (EMI) high voltage AC conductors shall be installed in galvanized rigid steel conduit or other means shall be taken to mitigate the effects of the EMI.

High voltage AC conduits shall have a bending radius no less than 36 inches.

#### **9.7.1.11 Utility Raceways and Ductbanks**

Utility raceway and ductbank installations shall meet the construction and material requirements of the local utility if installed under an RTD contract.

#### **9.7.1.12 Station Platforms**

For station platform, raceways shall be schedule 40 PVC conduits embedded in fill and located at a minimum depth of 18 inches below the finished grade of the platform slab. All conduit stub-ups through the platform slab or foundations shall be PVC/GRS conduit. Platform pullboxes shall be located along the platform, generally towards each end and in the middle of the platform to provide junction points for the communication cables and power wiring. Pullboxes and covers shall be pre-cast high density polymer concrete type with split covers if used for communication cables and power wiring and the box sections shall be divided. For all mainline platform conduit penetrations into the pullboxes, that run the length of the platform, they shall enter the side of the pullbox and be provided with bell ends. All lateral conduit penetrations into pullboxes shall enter the bottom of the pullbox and be provided with bell ends.

Communication conduits shall be provided to all planned and future communication equipment on the station platforms. Spare conduits shall be provided to all mainline conduit runs along the length of the platform, and to all shelters including future shelters. All exposed conduits shall be painted to match the structure which to it is attached.

#### **9.7.1.13 Park-n-Ride Lots and Street Lighting**

For park and ride lot lighting and street lighting systems that are maintained by RTD, raceways shall be schedule 40 PVC conduit, and direct buried 30 inches minimum below grade. Raceways buried less than 30 inches below grade shall be concrete encased.

Communication conduits and pullboxes shall be provided to all planned and future communication equipment at the park and ride lots. Pullbox requirements are the same as listed for station platforms.

For all street lighting systems not maintained by RTD, but installed under an RTD contract, the raceways shall meet the construction and material requirements of the local authority having jurisdiction.

#### **9.7.1.14 Pedestrian Bridges**

For pedestrian bridges, raceways for signal, communication, traction electrification, and lighting conduits shall be GRS conduits, PVC/GRS conduits, or rigid non-metallic fiberglass reinforced epoxy conduit if exposed or concealed.

#### **9.7.1.15 Maintenance Facilities**

For maintenance facilities, interior installations of raceways shall be EMT, GRS, or flexible metal conduits at dry locations not subject to damage; GRS conduits at dry locations subject to damage; and PVC/GRS or liquid tight flexible metal conduits at wet or damp locations. All exterior installations of raceways shall be GRS, PVC/GRS, or liquid tight flexible metal conduits. All raceways installations under-slabs or in-slabs of structures shall be GRS, PVC/GRS or PVC conduit, and all conduit stub-ups through the building slab or foundations shall be PVC/GRS conduit.

For the yard and site areas of maintenance facilities, ductbanks with manholes and handholes shall be provided, see the systemwide ductbanks section for requirements. All street or yard lighting system raceways within the track areas of the maintenance facility shall be schedule 80 PVC conduit, and direct buried 36 inches minimum below grade. For parking lot lighting and street lighting systems, outside the track areas, the raceways shall be schedule 40 PVC conduit, and direct buried 30 inches minimum below grade.

System raceways shall be provided to all planned and future system equipment at the maintenance facility. Provide spare capacity in all system raceways for future equipment.

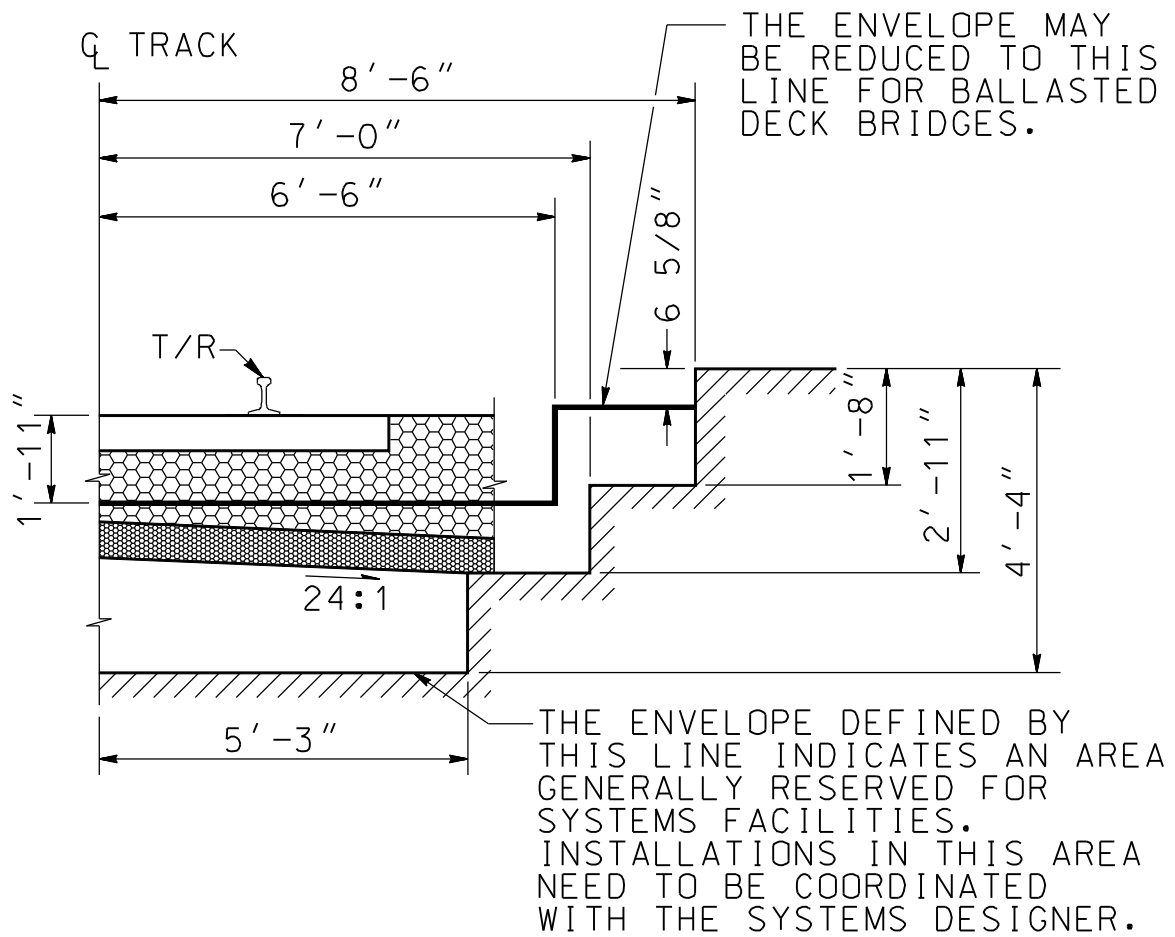
For communication, signal, or TP substation rooms within the maintenance building, cable trays may be used. Spare cable tray capacity shall be provided for future equipment.

#### **9.7.1.16 Parking Structures**

The raceways requirements for parking structures shall be the same as for maintenance facilities.

## LIST OF FIGURES

FIGURE 9.1 LRT ENVELOPE



DESIGN CRITERIA

TITLE: LRT ENVELOPE

FIGURE: 9.1