ELECTRONICALLY CONTROLLED PNEUMATIC (ECP) CABLE-BASED BRAKE SYSTEMS—PERFORMANCE REQUIREMENTS

Standard
S-4200

Adopted: 1999; Revised: 2002, 2004, 2008

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IMPLEMENTED 02/2008

1.0 PURPOSE AND SCOPE

1.1 The following are the overall objectives of this standard:

1.1.1 Ensure that the functionality and performance of electronically controlled pneumatic (ECP) freight brake systems are uniform and consistent among equipment from different manufacturers.

1.1.2 Ensure that cars equipped with AAR-approved ECP brake systems from different manufacturers are interoperable.

1.1.3 Ensure that AAR-approved electronic brake systems meet a high standard of safety and reliability.

1.2 This specification defines the requirements for an AAR-approved freight train power brake using electronically controlled freight brake systems suitable for service in all-electronic braked trains. Operation of such systems in a conventionally (pneumatic-only) braked train is covered by *MSRP* Standards S-461, S-462, S-464, and S-467.

2.0 DESCRIPTION OF ECP BRAKE SYSTEM

2.1 An electronically controlled pneumatic (ECP) brake system is a train power braking system actuated by compressed air and controlled by electronic signals originated at the locomotive for service and emergency applications. The brake pipe is used to provide a constant supply of air to the reservoirs.

2.2 The "cable-based" ECP brake system provides power and communications to all ECP brake devices in the train via a two-conductor electric train line that spans the entire length of the train.

2.3 The system provides almost instantaneous response to braking commands, including graduated brake releases and reapplications. The system responds appropriately to undesired separation or malfunction of hoses, cabling, or brake pipe.

3.0 DEFINITIONS

For purposes of this standard, terms used herein are defined as follows:

Table 3.1 General definitions (page 1 of 5)

3.1 Car Control Device (CCD)	The CCD is an electronic control device that replaces the function of the conventional pneumatic service and emergency portions during electronic braking and provides for electronically controlled service and emergency brake applications. The CCD interprets and acknowledges the electronic signals and controls the service and emergency braking functions on the car. In a stand-alone system, the CCD also controls reservoir charging. The CCD also will send a warning signal to the locomotive in case any of the components cannot respond appropriately to a braking command. Each CCD has a unique electronic address that is keyed to car reporting marks and number. A CCD shall be activated by presence of train line power. Each CCD contains a battery, which is charged from train line power. There are a number of different types of CCD applications: • Overlay brake system—An overlay ECP brake system is capable of operating in either a conventionally or electronically braked train. A failure of the ECP overlay brake system would enable a train to continue to operate as a conventionally braked train using conventional control valves when the ECP brake system is placed in cutout mode. An electronically braked train must come to a complete stop before the ECP brake system can be placed into cutout mode and train operation continued with the pneumatic brake. When operating in the electronic mode, an overlay system and a pure ECP brake system must operate identically, as specified in forthcoming paragraphs of this standard. • Emulator CCD—A CCD may optionally emulate the function of the pneumatic control valve while in a conventionally braked train. A suitable power source shall be provided to allow the emulator CCD to function as specified at all train speeds for a minimum of 48 hours. The functions and performance of pneumatic brake emulation must adhere to the requirements of *MSRP* Standards S-461, S-462, S-464, and S-467. • Stand-alone CCD—A CCD that cannot operate in a conventional pneumatically braked train and must operate only in ECP equipped trains.

Table 3.1 General definitions (page 2 of 5)

3.2 Head End Unit (HEU)	The HEU is a brake system control device mounted within the locomotive and used to control the ECP brake system. The following are the specific functions of the HEU: • Provide a man/machine interface to operate the ECP brake system • Provide a data display to the engineer • Provide controls that allow the engineer to make brake commands • Monitor the end-of-train (EOT) beacon • Provide a control signal to turn off train line power whenever communications with the EOT is interrupted or discontinued • Provide a control signal to command a momentary train line power application to restart CCDs that are shut down • Provide mechanisms to conduct ECP brake system diagnostic tests • Interface with locomotive system signals that interact with the train braking system • Interface with the locomotive ID module in order to obtain locomotive-specific data • Provide an interface to other locomotive system(s) with the intent of being able to provide appropriate locomotive retardation in conjunction with ECP train braking.

Table 3.1 General definitions (page 3 of 5)

3.3 End-of-Train (EOT) Device	The EOT is a device that is connected to the train line at the end of the train that contains a means of communicating with the HEU, a brake pipe pressure transducer, and a battery that charges off the train line cable. The EOT is physically the last network node in the train and transmits a status message (EOT beacon) once per second. The status message includes the current brake pipe pressure that is displayed in the cab by the HEU. If the EOT does not require an emergency brake pipe vent valve, the hose to the EOT shall be a minimum of 3/8-in. ID. The EOT also shall contain an electric train line termination circuit. This termination circuit shall be a 50-ohm resistor in series with a 0.47-µF capacitor. The EOT shall be connected to the network and shall be transmitting status messages to the HEU before the train line power can be energized continuously. The EOT continually reports brake pipe pressure and train line voltage to the HEU. An EOT shall be activated by the presence of train line power. The requirements defined herein are those EOT functions required for ECP braked trains. The ECP EOT may be a device separate from the EOT device specified for pneumatically braked trains in the AAR *Communication Manual*, Part 12–15. For ECP trains capable of operating in a pneumatic mode (overlay or emulator brake systems), a pneumatic EOT function also shall be required. The ECP EOT functions may be combined in a single, dual-mode device with the pneumatic EOT functions. A dual-mode EOT device shall meet the requirements defined herein for ECP operation and the requirements for pneumatic EOTs specified in AAR *Communications Manual*, Part 12–15 and all applicable FRA rules. In trains that are operating with distributed power control per the AAR *Manual of Standards and Recommended Practices*, Standard S-4200, “Trailing Locomotive Control with ITC Specification,” latest revision, the ECP equipment on a locomotive at the end of the train may perform the ECP EOT function. Locomotive ECP equipment functioning as an EOT shall meet the requirements defined in paragraph 4.3.21.
3.4 Train Line	The train line is a two-conductor electric wire spanning the train that carries both train line power (to operate all CCDs and EOT devices) and communications network signals (superimposed on the power voltage). The train line shall meet the requirements of *MSRP* S-4210 “S-4210,” latest revision.
3.5 ECP Brake (Train Line) DC Power Supply	The ECP brake system power supply is a DC supply operating at nominally 230 Vdc to provide electrical power, via the train line, to all connected CCDs and EOT devices. The power supply is mounted within a locomotive and is controlled by a power supply controller (PSC), which is a network device. The power supply shall meet the requirements of *MSRP* S-4220 “ECP Cable-Based Brake DC Power Supply—Performance Specification,” latest revision. A single power supply shall be capable of supplying power to an ECP- equipped train consisting of a minimum of 160 CCDs and an EOT.

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Table 3.1 General definitions (page 4 of 5)

3.6 Power Supply Controller (PSC)	The power supply controller (PSC) shall interface with the train line communication network and control a train line power supply as commanded by the HEU. Multiple power supplies may be enabled by the HEU as described in paragraph 4.3.3. The PSC shall also comply with the requirements of *MSRP* S-4220 "ECP Cable-Based Brake DC Power Supply—Performance Specification," latest revision and S-4230 "S-4230," latest revision.
3.7 Head End Train Line Terminator	A terminator shall be attached to the front of the train line that provides an electrical termination of the train line at the lead locomotive to minimize impedance-related communications faults. This termination circuit shall be a 50-ohm resistor in series with a 0.47-µF capacitor. The HEU shall automatically confirm the presence of the head end train line termination. If the termination includes an ITC network device, it shall be incapable of transmitting.
3.8 Pneumatic Backup	A pneumatic backup (PB) system shall be required on each car to apply emergency brake cylinder pressure in the event of a vented brake pipe. The PB system also shall be capable of assisting in propagating pneumatic pressure signals through the brake pipe.
3.9 Car ID Module	Car-specific data shall be stored in a module on the car and provided to the CCD in such a way that the CCD always contains the correct characteristics, parameters (constants), and other information for the car or brake set on which it is placed. Therefore, car-specific data shall be mechanically tied to the car in such a way that it cannot be changed inadvertently in the field, even if CCDs are swapped. Format of the car specific data is given in S-4230, latest revision. The CCD shall maintain a copy of the car ID information. At a minimum, this information shall contain the following: • Vehicle reporting mark • AAR car type • Stretched length over pulling faces • Loaded weight • Empty weight • Default full-service net braking ratio (NBR) • Braking constant "C" • Reservoir constant "RC" • Minimum brake application cylinder pressure • Presence/type of pneumatic empty/load device • Presence of electronic empty/load device • Number of operable brakes controlled • Number of axles associated with CCD • Vehicle orientation reference

Table 3.1 General definitions (page 5 of 5)

3.10 Locomotive ID Module	Locomotive-specific data shall be stored in a locomotive ID module on the locomotive. The locomotive ID module shall provide data for the HEU and PSC in such a way that the HEU and PSC always contain the correct characteristics, parameters (constants), and other information for the locomotive on which they are placed. The locomotive-specific data shall be mechanically tied to the locomotive such that it cannot be changed inadvertently in the field even if the HEU or PSC is replaced. Format and resolution of the locomotive-specific data is given in S-4230, latest revision. At a minimum, this information shall contain the following: • Locomotive road number • Locomotive type • Stretched length • Nominal weight • Number of axles • Battery voltage fault threshold • Battery voltage fault clear threshold • Railroad default BBP setpoint • Default train full-service NBR • Suppression brake application • Nominal wheel diameter • Vehicle orientation reference
3.11 Operative Brake	An operative brake is two braked trucks.

4.0 FUNCTIONAL AND PERFORMANCE SPECIFICATIONS

This section describes the functional and performance requirements for an ECP brake system (which shall be designed for a minimum of 180 network devices spanning 12,000 ft), both in normal operation and in response to faults. The environmental conditions under which the system must operate are described in paragraph 5.0.

4.1 Primary Functions

4.1.1 The brake system shall provide the following primary functions:

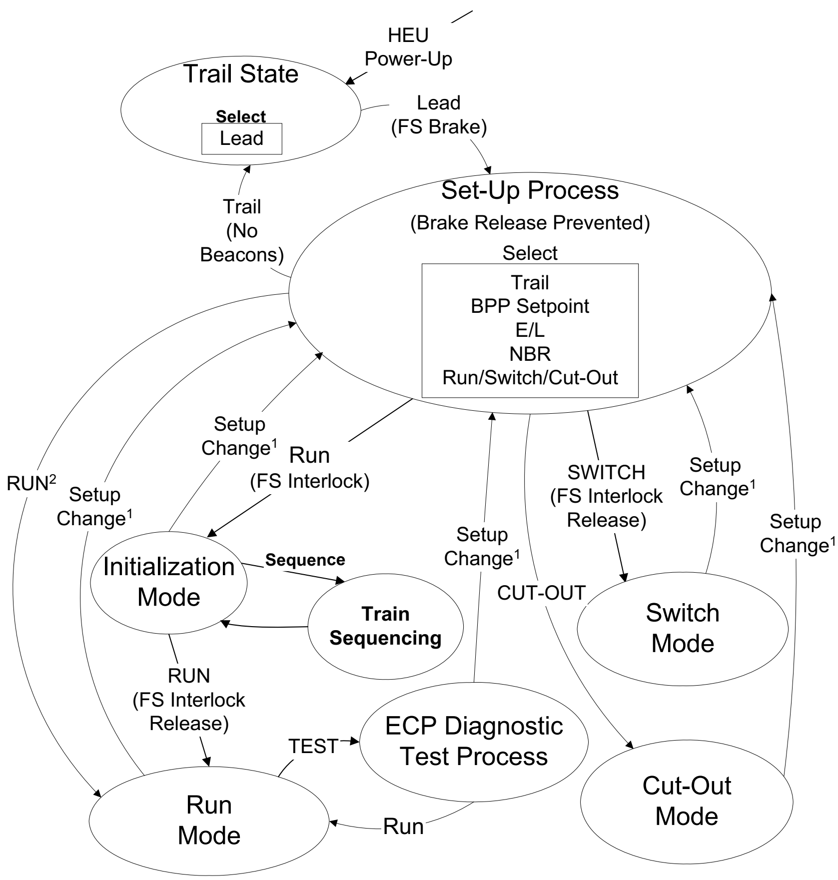
- Graduated brake applications and releases
- Continuous reservoir charging
- Adjustment of braking levels to car loading
- Continuous fault detection and equipment status monitoring
- Pneumatic backup

4.1.2 Paragraph 4.0 is divided into three major areas. The first area, (paragraph 4.2), covers system modes of operation, including pneumatic backup. The second area (paragraph 4.3) describes all normal operational functions performed by the system. The third area (paragraph 4.4) describes all the fault response functions of the system. The latter two areas describe in detail the functions and required performance of all major components and subsystems of the ECP brake system.

4.2 Operating Modes

Operating modes are the major categories of system operation. A particular set of procedures is followed and functions are performed in each mode. Four modes of operation are covered in this paragraph: initialization mode (paragraph 4.2.3), RUN mode (paragraph 4.2.5), SWITCH mode (paragraph 4.2.6), and CUTOUT mode (paragraph 4.2.7). An additional paragraph, 4.2.8 “All Modes,” lists procedures and functional references that apply to all ECP brake system operating modes. Also described in this area are the power- up HEU lead/trail selection procedure (paragraph 4.2.1), setup operations (paragraph 4.2.2), and ECP brake system diagnostic tests (paragraph 4.2.4). The modes and states diagram for the ECP brake system is given in Fig. 4.1.

The HEU shall broadcast the current operating mode to all CCDs as part of the HEU beacon.



Notes:

1. Set-Up changes are allowed only if the train is stopped or a full service brake application has been in effect for at least 120 seconds, with the exception of changing the empty/load state.
2. Transition to RUN mode without initialization is allowed ONLY IF the EOT beacon has not been lost for more than 3 seconds since the previous initialization.

Fig. 4.1 ECP system modes and states

4.2.1 HEU Lead/Trail Selection

4.2.1.1 Description of HEU Trail

The HEU, when powered up, shall default to trail state. When in trail state, the HEU shall not broadcast any HEU beacons or system commands.

4.2.1.2 Selection of HEU Lead

4.2.1.2.1 The engineer must select the HEU at the locomotive designated as “lead”; if any other HEU connected to the network has already been selected as lead, this HEU shall not assume lead state until all other HEUs have been placed in trail state. Multiple lead HEUs in the network shall be handled as described in paragraph 4.4.13.

4.2.1.2.2 Once lead is selected and prior to completing the setup process, the lead HEU broadcasts HEU beacon messages containing a full-service (100%) TBC, a train line power off command, and initialization mode. Then the HEU enters the setup process.

4.2.2 Setup

4.2.2.1 Description of Setup

Setup is an operation that allows the engineer to change the ECP brake system configuration. With the exception of changing the empty/load setting from empty to loaded and changing the train line power mode, setup changes shall not occur unless the train is stopped or until a full-service application has been in effect for 120 seconds. Any setup change shall require an operator confirmation to become effective.

4.2.2.1.1 Entering Setup from Trail State

Upon entering Setup from Trail state, all ECP brake system configuration information and operating mode may be selected. Setup shall not be exited until all configuration information is confirmed or the HEU is placed in the Trail state.

4.2.2.1.2 Entering Setup from RUN, SWITCH, Initialization, CUTOUT Mode, or Diagnostic Tests

Upon entering Setup from an operating mode, some or all ECP brake system configuration information and operating modes may be changed.

4.2.2.2 Setup Operational Procedures

In Setup, the following information may be entered.

4.2.2.2.1 HEU Trail

If Trail state is selected, then no other information needs to be entered. The HEU enters Trail state.

4.2.2.2.2 Train Line Power Mode Selection

The engineer may select Automatic Power mode or Power Off mode at any time (see paragraph 4.3.3). The default is Power OFF.

4.2.2.2.3 Brake Pipe Pressure Setpoint

The engineer must select the BP pressure setpoint (BPP setpoint), or the engineer may accept the default setting. The BP pressure setpoint establishes the ECP brake system reference BP pressure. The minimum pressure setting for ECP brake systems shall be 60 psig and the maximum pressure setting shall be 110 psig, in increments of 1 psi.

4.2.2.2.4 Empty/Load

For trains with cars that do not have local load sensing capability, the engineer must designate if the train is empty or loaded prior to moving the train. The default setting on HEU power-up shall be loaded. This empty/load setting shall be selectable by the operator during train setup and under normal operating conditions (see paragraph 4.2.2.2.4.1). The engineer shall not be allowed to change the train's empty/load setting from loaded to empty while the train is in motion. After operator confirmation, the empty/load setting shall be transmitted to all CCDs. If the engineer does not change and/or confirm the current setting prior to moving the train, the HEU must, at a minimum, provide a visual indication to the operator as a reminder. Note that if cars have an on-board load sensor or empty/load device, or if car load data exists, the CCD shall ignore the HEU's "empty/load" command and use the other data (i.e., data on the car overrides data from the HEU for that car). See paragraph 4.3.9, "CCDs Determine Car Load Value."

4.2.2.2.4.1 Empty/Load Selection While Train Is Moving

The HEU shall provide an option for the operator to select the empty/load setting of the train. The train operator can accept the current empty/load setting or change it. The engineer may change the train's empty/load setting from empty to loaded at any time, but the train must be stopped with a full service brake application or a full service brake application must have been commanded for at least 2 minutes, in order to change the train's empty/load setting from loaded to empty. After the new empty/load setting is selected, the HEU shall request confirmation from the engineer before updating the train line empty/load command.

4.2.2.2.4.2 HEU Commands Train Empty/Load

The HEU shall provide two independent and redundant signals for commanding a train empty/load setting. These signals shall be transmitted once per second in the HEU beacon. CCDs shall use these commands as described in paragraph 4.3.9.

4.2.2.2.5 Train Net Braking Ratio

The requirements for a specific train net braking ratio (NBR) during ECP braking shall be railroad specific in that railroads do not want the ability for the engineer to make changes. If the optional ability to change the train NBR is provided, then the engineer will not be given the opportunity to change the setting. The change shall be implemented such that it is transparent to the engineer.

4.2.2.2.6 Configuration Confirmation

After values for brake pipe pressure setpoint and empty/load have been selected, the HEU shall display the entered values and request a confirmation from the engineer.

4.2.2.2.7 Operating Mode Selection

The desired operating mode (RUN, SWITCH, or CUTOUT) may be entered. If SWITCH mode or CUTOUT mode is selected, then the HEU shall release the brake application interlock and enter the desired mode. Transition to RUN mode without initialization is allowed only if the EOT beacon has not been lost for more than 3 seconds since the previous completion of initialization.

4.2.3 ECP Brake System Initialization

The ECP brake system must be initialized prior to entering RUN mode so that network devices and train conditions are registered. An EOT device is required to be connected for normal initialization of the train. When Initialization mode is entered, a full-service interlock is applied. The initialization sequence shall be performed by the HEU when RUN mode is selected by the engineer. Initialization involves establishing or confirming identity and position of all network devices in the train line communication network. It also involves assigning a network address to each network device and downloading operational data, including vehicle weight/load and brake pipe pressure setpoint and train net braking ratio for the train (see S-4230, latest revision). Specifically, the initialization procedure shall include the following:

1. Initial power-up to restart and cut in CCDs and EOT.

   In order to initialize the ECP system, CCDs and EOT shall be restarted via a train line power application if they have been shut down. The HEU shall prompt the engineer when entering Initialization to set train line power to AUTO when safe to do so. Within 2 seconds after the train line voltage has reached 100 Vdc at the device, any CCDs or EOT that were shut down restart (wake up) and begin to cut in. This procedure is necessary to prepare CCDs and EOT for ECP brake system initialization. This 2-second power-up function shall not depend on the existence of EOT or HEU beacons on the network. When the EOT is activated, it shall begin transmitting EOT beacon and status messages to the HEU. The EOT shall be activated by the presence of train line power.
2. The HEU shall establish the version compatibility level of the train per S-4230, latest revision.
3. The HEU shall poll the network to identify all network devices. When devices have been identified, they shall be assigned network addresses and shall be added to the HEU database.
4. The HEU database shall indicate the relative position of each network device within the train (correlated to reporting marks or road numbers). The relative position shall be determined as defined in paragraph 4.2.3.1
5. If additional CCDs are added to the database, the HEU shall configure the cars by downloading operational data to each additional CCD.
6. Car-specific data (paragraph 3.9) from the car ID module shall be retrieved from each CCD.
7. The HEU transmits train configuration data to all ECP train line devices. This information includes the train net braking ratio and brake pipe pressure setpoint.
8. Each CCD determines its car loading value in order to adjust brake cylinder pressures to car loading (see paragraph 4.3.9, “CCDs Determine Car Load Value.”
9. Locomotive-specific data (paragraph 3.10) from the locomotive ID module shall be retrieved from each trail HEU.
10. The HEU shall prompt the engineer to confirm or enter the total number of potentially operative brakes. If a discrepancy is found, the database must be cross-checked against the actual train configuration. After confirmation of the number of potentially operative brakes in the train, the HEU may begin the train sequencing process.

During Initialization mode, the network devices shall not transmit exception messages except for critical loss exceptions, PSC exceptions, and version compatibility exceptions per S-4230, latest revision.

The engineer may cancel the initialization procedure at any time. If the initialization procedure is cancelled, the HEU returns to the setup process and/or allows the engineer to restart the initialization process.

4.2.3.1 Sequencing

The ECP system shall provide the ability to sequence the train during ECP system initialization. The lead HEU, as part of the initialization procedure, shall determine the relative position and orientation of each vehicle within the train with respect to the locomotive on which the HEU designated as lead is installed.

4.2.3.1.1 General Sequencing Requirements

The following are general requirements for sequencing.

1. All network devices shall provide an indication of their capablility to perform the sequencing process during initialization.
2. The system shall be able to determine the sequential order of the vehicles in the train with an accuracy of ±0 vehicles.
3. When sequencing is completed successfully, each vehicle shall retain its position and orientation.
4. Successful sequencing shall not be required for normal train operation.
5. Any failures related specifically to sequencing shall not affect normal train operation.
6. Sequencing shall not in any way inhibit the car's ability to maintain the requested train brake command as long as the CCD's battery has sufficient charge to operate the CCD.
7. Sequencing shall not be affected by a low battery on a CCD (one that can still power the CCD electronics, but would normally cause the CCD to shut down to conserve the battery).

4.2.3.1.2 Locomotive Equipment Requirements for Sequencing

The sequencing requirements for locomotive equipment are met by the train line power supply and associated PSC, HEU, and locomotive ID device.

4.2.3.1.2.1 Train Line Power Supply Requirements for Sequencing

The train line power supply shall contain the hardware necessary to support train sequencing as defined in paragraph 4.2.3.1.4, "Hardware Requirements for Sequencing."

4.2.3.1.2.2 Lead HEU Requirements for Sequencing

The HEU shall contain the software necessary to support train sequencing as defined in paragraphs 4.2.3.1.5, "General Software Requirements for Sequencing," and 4.2.3.1.6, "Process Steps for Sequencing."

4.2.3.1.2.3 Trailing Locomotive Requirements for Sequencing

The HEU or the PSC on trailing locomotives shall contain the software necessary to support train sequencing as defined in paragraphs 4.2.3.1.5, "General Software Requirements for Sequencing," and 4.2.3.1.6, "Process Steps for Sequencing." If both the HEU and the PSC on a trailing locomotive indicates the capability to perform the sequencing process, the lead HEU shall select only one of the devices to perform the sequencing function for that vehicle.

4.2.3.1.2.4 Locomotive ID Requirements for Sequencing

The locomotive ID device shall contain the hardware and software necessary to support train sequencing as defined in paragraphs 4.2.3.1.4, "Hardware Requirements for Sequencing," 4.2.3.1.5, "General Software Requirements for Sequencing," and 4.2.3.1.6, "Process Steps for Sequencing."

4.2.3.1.3 Car Equipment Requirements for Sequencing

The sequencing requirements for rail car equipment are met by the CCD and car ID device.

4.2.3.1.3.1 CCD Requirements for Sequencing

The CCD shall contain the software necessary to support train sequencing as defined in paragraphs 4.2.3.1.5, "General Software Requirements for Sequencing," and 4.2.3.1.6, "Process Steps for Sequencing."

4.2.3.1.3.2 Car ID Requirements for Sequencing

The car ID device shall contain the hardware and software necessary to support train sequencing as defined in paragraphs 4.2.3.1.4, "Hardware Requirements for Sequencing," 4.2.3.1.5, "General Software Requirements for Sequencing," and 4.2.3.1.6, "Process Steps for Sequencing."

4.2.3.1.4 Hardware Requirements for Sequencing

4.2.3.1.4.1 Train Line Power Supply Requirements

The ECP train line power supply shall provide a nominal 24 Vdc output as defined in S-4220, "ECP Cable-Based Brake DC Power Supply—Performance Specification," latest revision. This voltage shall be applied to the conductors of the train line during the sequencing process.

4.2.3.1.4.2 Switchable Load Requirements

The ECP equipment on each car and locomotive shall provide a switchable load across the two conductors of the train line. The switchable load, when activated, shall cause a DC current of 0.65 A ± 0.1 A to flow between the load and the train line power supply with the train line voltage at 24 Vdc. The total AC impedance presented by the ECP equipment on a vehicle shall be nominally 2,000 ohms in the 100-KHz to 450-KHz frequency band when the load is not activated and shall not be reduced below 500 ohms when the load is connected. The default state of the switchable load shall be not activated. With no switchable load connected and the train line voltage less than 30 Vdc, train line current shall not exceed 0.17 mA per device.

4.2.3.1.4.3 Current Sensing Requirements

The ECP equipment on each car and locomotive (rail vehicle) shall be capable of sensing the train line current resulting from the activation of one switchable load as defined in paragraph 4.2.3.1.4.2, "Switchable Load Requirements," when that rail vehicle is between the train line power supply and the activated switchable load. No current shall be sensed when the sensing vehicle is not between the train line power supply and the activated switchable load. The ECP current sensor shall not be damaged by current up to 15 A.

4.2.3.1.4.4 Car Hardware Orientation

The default orientation of the current sensor and switchable load on each car relative to the A-end and the B-end shall be as shown in Fig. 4.2. If the opposite orientation is utilized, a parameter in the car ID shall be used to allow the CCD to invert the orientation data reported to the lead HEU.

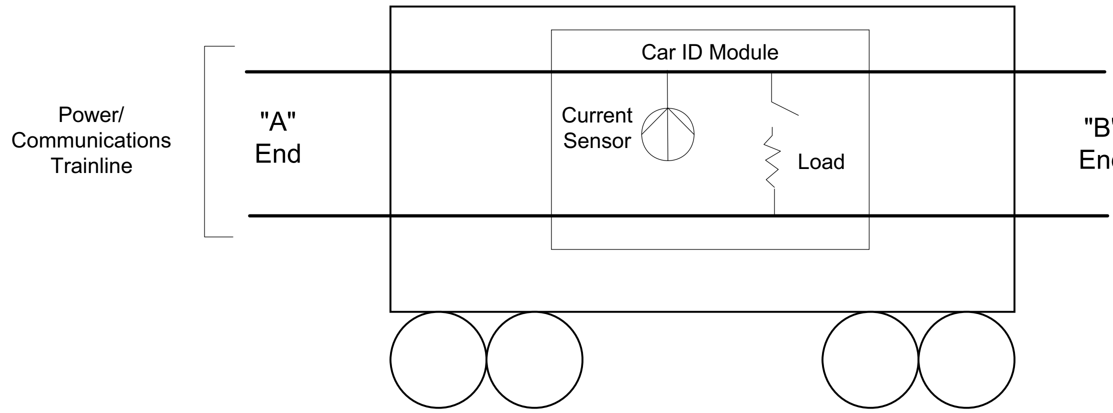


Fig. 4.2 Car orientation

4.2.3.1.4.5 Locomotive Hardware Orientation

The orientation of the current sensor, switchable load, and train line power supply on each locomotive relative to the front (short-hood) and the rear (long-hood) shall be as shown in Fig. 4.3. If the opposite orientation is utilized, a parameter in the locomotive ID shall be used to allow the locomotive equipment to invert the orientation data reported to the lead HEU.

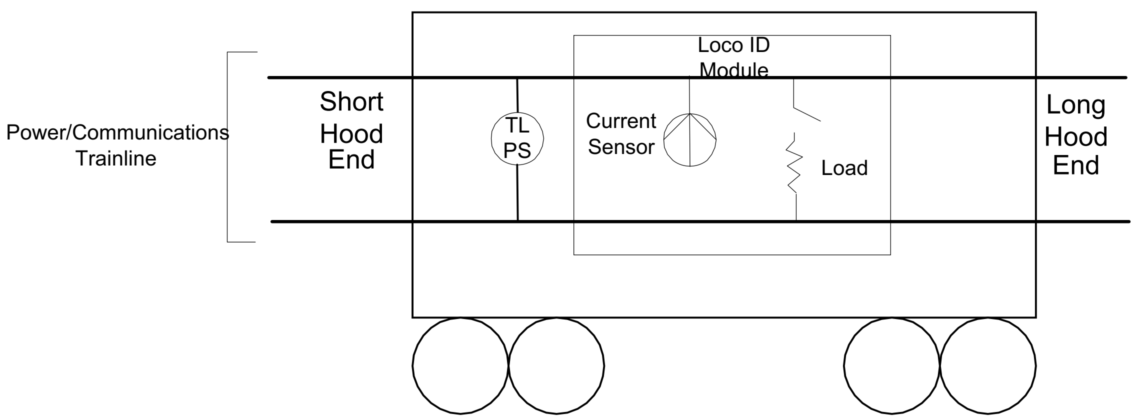


Fig. 4.3 Locomotive orientation

4.2.3.1.4.6 EOT Hardware Requirements for Sequencing

When the train line voltage is less than 30 Vdc, the current drawn from the train line by the EOT shall not exceed 0.17 mA.

4.2.3.1.5 General Software Requirements for Sequencing

The CCD/car ID, HEU/locomotive ID, and optionally the PSC/locomotive ID shall provide the following functions to support sequencing:

1. Connect load across the train line in response to lead HEU commands.
2. Provide a timing function to automatically disconnect the load after train line current has reached and maintained a level as specified in paragraph 4.2.3.1.4.2, “Switchable Load Requirements,” for a minimum of 200 ms and a maximum of 300 ms of continuous connection.
3. Detect a valid sequencing train line current pulse when sequencing is active. A valid current pulse shall be detected if train line current is at or above the limit as specified in paragraph 4.2.3.1.4.2, “Switchable Load Requirements,” for a minimum of 100 ms and a maximum of 400 ms continuous.
4. Maintain a lead locomotive sense status that is initialized to false and set to true if a valid sequencing train line current pulse is detected during the lead locomotive sense phase.
5. Maintain a pulse counter that is initialized to zero and incremented by one during the sequencing phase each time a valid train line current pulse is detected when this vehicle is not the one connecting its load.
6. Maintain a vehicle orientation status relative to the lead locomotive that is determined by detecting the presence/absence of train line current when this vehicle’s load is connected, comparing it to a car/locomotive ID parameter that identifies how the current sensor was installed on the vehicle, and reversing it if the lead locomotive sense status is set to true .
7. Determine the vehicle position based on the total number of vehicles sequenced, pulse count and lead locomotive sense status. If the lead locomotive sense status is set to true, the vehicle position shall be calculated as (pulse count + 1); otherwise the vehicle position shall be calculated as (number of vehicles sequenced – pulse count).
8. Report the sequencing results as defined in S-4230, latest revision, to the lead HEU when requested.

4.2.3.1.6 Process Steps for Sequencing

The lead HEU shall control the sequencing process via network commands to a PSC, trailing locomotives, and all cars. Prior to beginning the sequencing process, the HEU must have completed the process of identifying all network devices in the train and assigning them unique network addresses. The general process involves a preparation phase, a lead locomotive sense phase if necessary, a vehicle sequencing phase, and a data collection phase.

4.2.3.1.6.1 Sequencing Preparation Phase

The preparation phase is used to initialize devices for sequencing. The lead HEU shall use the following steps during this phase:

1. The HEU shall broadcast a Prepare for Sequencing command on the train line to initialize all participating devices for sequencing. In response to this command, the CCDs and EOT disable their normal low battery shutdown logic and participating devices reset their position count and orientation status to unknown and lead locomotive sense status to false.
2. The HEU shall command 230 Vdc train line power to off.
3. After verifying that train line power is off, the HEU shall command a single PSC to energize 24 Vdc train line power.
4. After a minimum of 5 seconds, the HEU shall verify that 24 Vdc is present on the train line.
5. After verifying that 24 Vdc is present on the train line, if the enabled PSC is on the lead locomotive, the HEU shall begin the vehicle sequencing phase; otherwise it shall begin the lead locomotive sense phase

4.2.3.1.6.2 Preparation Phase Message Summary

1.	HEU -> All Vehicles	Prepare for Sequencing
2.	HEU -> All PSCs	Deactivate 230 Vdc
3.	HEU -> One PSC	Activate 24 Vdc

4.2.3.1.6.3 Lead Locomotive Sense Phase

This phase is required if a non-lead locomotive train line power supply and associated PSC are used for providing the train line voltage for sequencing. The lead HEU shall use the following steps during this phase:

1. The HEU shall broadcast an Enable Lead Sense command on the train line to enable the lead sense function on all participating devices.
2. The HEU commands the load on the lead locomotive to be connected across the train line.
3. The load on the lead locomotive shall be connected and removed as defined in paragraph 4.2.3.1.5, “General Software Requirements for Sequencing.”
4. All participating trailing devices shall read their current sensor and update their lead locomotive sense status as defined in paragraph 4.2.3.1.5, “General Software Requirements for Sequencing.”
5. Steps 2. through 4.) may be repeated up to two times to minimize the possibility of errors.

4.2.3.1.6.4 Vehicle Sequencing Phase

During this phase, each car and locomotive determines its relative position and orientation. The lead HEU shall use the following steps during this phase:

1. The HEU commands all participating devices to start counting current pulses.
2. The HEU commands a trailing device to connect its load across the train line.
3. The load on the trailing device shall be connected and removed as defined in paragraph 4.2.3.1.5, “General Software Requirements for Sequencing.” The associated network device shall respond with a Load Connected message.
4. All trailing devices participating in sequencing shall read their current sensor and update their sequencing information as defined in paragraph 4.2.3.1.5, “General Software Requirements for Sequencing.”
5. A minimum of 50 ms and a maximum of 150 ms after the load has been disconnected, the device shall send a Load Removed message to the HEU.
6. The HEU waits a minimum of 50 ms.
7. The HEU repeats steps 2. through 6. for each vehicle in the train database.
8. The HEU commands all train line devices to stop counting pulses.

4.2.3.1.6.5 Vehicle Sequencing Phase Message Summary

1. HEU -> All Vehicles Start Pulse Count
2. For each Vehicle(i) where (i=1,# of vehicles in train database):
   a. HEU -> Vehicle(i) Connect Load
   b. HEU <- Vehicle(i) Load Connected
   c. HEU <- Vehicle(i) Load Removed
3. HEU -> All Vehicles Stop Pulse Count

4.2.3.1.6.6 Data Collection Phase

The last phase is where each car and locomotive reports its sequencing results to the lead HEU. The HEU shall use the following steps during this phase:

1. The HEU shall query each vehicle for its position count, orientation, and other sequencing information as defined in S-4230, latest revision.
2. After all vehicles have been queried for their sequencing results, the HEU shall broadcast an End Sequencing command to all train line devices. In response to this command, the CCDs and EOT enable their normal low battery shutdown logic.
3. After sequencing is complete, the HEU can resume normal control of train line power.

Note: The lead HEU may, at the option of its manufacturer, resume normal control of train line power prior to sending the queries to each vehicle for its sequencing data.

4.2.3.1.6.7 Data Collection Phase Message Summary

1.	For each Vehicle(i) where (i=1,# of vehicles in train database):
	a. HEU -> Vehicle(i) Query Sequencing Results
	b. HEU <- Vehicle(i) Position Count and Orientation
2.	HEU -> All Vehicles End Sequencing
3.	HEU -> PSC Turn Off 24 Vdc
4.	HEU -> Any PSC Activate 230 Vdc

Note: The lead HEU may, at the option of its manufacturer, resume normal control of train line power prior to sending the queries to each vehicle for its sequencing data.

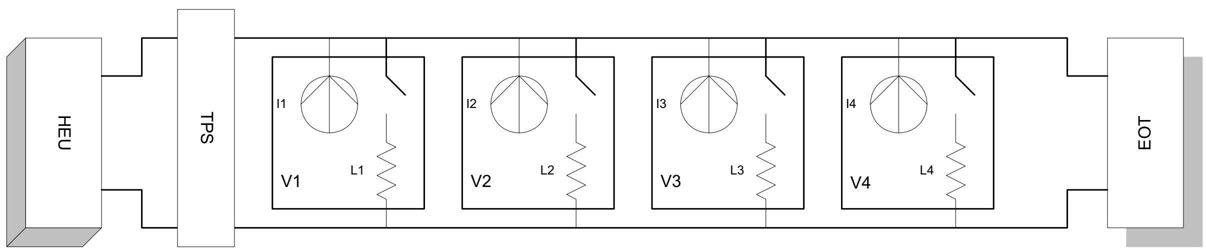


Fig. 4.4 Example train sequencing

Consider a sample train consist as shown electrically in Fig. 4.4. This train has four vehicles. The HEU performs four iterations during the vehicle sequencing phase. During each iteration, only one vehicle connects a load across the train line. All vehicles detect the presence or absence of current and keep count of the number of times current was detected. This information is stored in "Pulse Count" at each vehicle. The vehicle's actual position is based on the value of "Pulse Count" and the total number of vehicles in the train consist.

Table 4.1 Train sequencing example

Load Connected / Iteration	I1 / V1	I2 / V2	I3 / V3	I4 / V4
L4	present(1)	present(1)	present(1)	Note 1
L3	present(1)	present(1)	Note 1	absent(0)
L2	present(1)	Note 1	absent(0)	absent(0)
L1	Note 1	absent(0)	absent(0)	absent(0)
Pulse Count	3	2	1	0
Position (#Vehicles–Count)	1	2	3	4
Note 1: Vehicle that connected its load does not update its pulse count.				

4.2.3.2 Completion of Initialization Mode

When the BPP read by the EOT is greater than 0.74 × BPP setpoint, the system may enter RUN mode. Before the full-service interlock is allowed to clear, the HEU shall attempt to query the status of all CCDs. If the HEU detects, based on status information, that a CCD has a problem, then the HEU shall warn the engineer and the engineer may cut out the CCD. To clear the full-service interlock and operate in RUN mode, the engineer's brake controller must be in the full-service position; for trains with cars that do not have local load sensing capability, the train empty/load setting must be confirmed by the engineer.

4.2.4 ECPB System Diagnostic Test

A ECPB system diagnostic test may be requested by the engineer interacting with the HEU during RUN mode. Functions of the ECPB system diagnostic test include the following:

4.2.4.1 Train Line Power Supply Tests

4.2.4.1.1 During the ECP system diagnostic test, the HEU shall command that train line power be supplied by each train line power supply in the train on an individual basis. The test sequence shall be as follows:

1.	Enable a train line power supply.
2.	Wait at least 15 seconds for the train line voltage/current to stabilize.
3.	Poll the PSC that was enabled for status.
4.	Poll the PSC on the lead locomotive for status, if different.
5.	Record the EOT measured voltage.
6.	Disable the PSC under test.
7.	Wait at least 15 seconds.
8.	Repeat the above sequence for all PSCs.

4.2.4.1.2 The HEU shall record any exception messages related to train line power supplies under test for use by the HEU in automatically selecting power supplies and warn the engineer accordingly.

4.2.4.2 CCD/EOT Battery Tests

During the ECP diagnostic test, the HEU shall command the train line power OFF for at least 30 seconds while the ECP system is holding a full-service brake application. The HEU shall record any exception messages related to low battery charge and warn the engineer accordingly.

4.2.5 RUN Mode

4.2.5.1 Description

RUN mode is the main mode of operation of the ECP brake system and is selected when the train consist is fully configured and ready for normal road operations. As such, all fault detection modes (except for special SWITCH mode limits) are enabled to permit safe operation of long trains at full speed.

4.2.5.2 Normal Operational Procedures

The following describes the normal sequence of operation in RUN mode. paragraph 4.2.5.3, "Fault Detection and Response Procedures," describes fault detection and response operations.

4.2.5.2.1 RUN Mode Brake Control

RUN mode brake control provides the full functionality of the ECP brake system for road operations. The RUN mode brake control includes the following:

1. The engineer's brake command is read from the man-machine interface, translated by the HEU to train brake commands (TBCs), and broadcast to all network devices as part of the HEU beacon message.
2. HEU shall broadcast a "configuration" message containing BPP setpoint, train NBR, and other information (reference S-4230, latest revision), as follows:
   - every time "setup" is changed
   - once every 120 seconds
3. If an emergency command (TBC = 120%) is made, a 120-second emergency interlock timer is started.
4. If an emergency command is in effect, the HEU shall not release it until the 120-second interlock has expired. If the emergency brake application is in response to a fault condition, it shall additionally be maintained until the fault condition is removed or cleared or the operating mode changed.
5. If a release from emergency is requested, the engineer must place the control to the full-service position. Once the emergency interlock has expired, release from emergency shall be enabled unless a fault condition still exists. Release from emergency shall go directly to full service.
6. If a full or partial release from the current brake application is selected, the TBC transmitted shall reflect the control input unless a penalty brake application, an emergency, or a full-service interlock is active.
7. HEU train brake commands (TBC) are expressed as a percentage [0% (release), 10% (minimum service) to 100% (full service), in increments of 1%] of full-service braking force, plus 0% for full release and 120% for emergency. They are transmitted by the HEU once per second as part of the priority HEU beacon message. An emergency brake command shall be transmitted immediately when required and repeated once per second thereafter.
8. The HEU beacon is broadcast and includes the current operating mode, TBC, train line power on/off, train empty/load setting and network device status query (paragraph 4.3.18.1.2),. Other HEU commands or information may be transmitted, as well. See paragraph 4.3.18.8, "Control Messages."
9. A CCD may automatically cut out/in under the conditions described in paragraph 4.3.13.
10. CCD BCP control: CCDs use their preprogrammed braking constant C (and other parameters that may be required) with the accepted load data to give the proper BCP in response to each TBC. See paragraphs 4.3.4 through 4.3.11 for performance requirements of BCP response.
11. EOT transmits beacon to HEU: The EOT status beacon shall be transmitted to the HEU once per second and shall include BPP, percentage of full battery charge, and other data. See paragraph 4.3.18.4, "EOT Beacon/Status Message."

4.2.5.3 Fault Detection and Response Procedures

The following describes the sequence of operation for detecting and responding to various component and system faults in RUN mode:

4.2.5.3.1 General Fault Classification

4.2.5.3.1.1 Faults are categorized according to type and severity of fault and according to which major component is responsible for its detection and handling.

4.2.5.3.1.2 General fault types are outlined in paragraph 4.2.5.3.1.3 in order of severity. They comprise three basic classes of faults:

- The first class of faults is the most severe, and includes those faults that are likely to jeopardize safety. These faults must result in an immediate automatic emergency brake application.
- The second class of faults is somewhat less severe, and must result in an immediate automatic full service (or penalty brake application).
- The least severe fault class must result in a warning to the engineer, but must not significantly interfere with the normal operation of the brake system.

4.2.5.3.1.3 Note that some faults are compound faults (meaning a coincidence of two or more faults).

Automatic Emergency
- Critical system loss (loss of BPP or communication)

Automatic Full Service
- Less than 85% operative brakes, causes for which include low battery charge, low reservoir charge, CCD shut down, CCD cutout, and other disabling faults
- Low EOT battery charge
- Less than 90% operative brakes and either (a) low train line voltage or (b) train operating in low power mode
- Use of locomotive pneumatic brake control
- Multiple lead (active) HEUs

Warning Only
- Low train line voltage
- High train line voltage
- Incorrect BCP
- Low EOT BPP
- Percentage of operative brakes falls below 95% or 90%

4.2.5.3.2 HEU Fault Detection, Response, and Recovery

The HEU shall perform fault detection and response procedures as described in paragraph 4.4.

4.2.5.3.3 CCD Fault Detection and Response

CCDs shall perform fault detection and response procedures as described in paragraph 4.4.

4.2.5.3.4 EOT Fault Detection and Response

The EOT shall perform fault detection and response procedures as described in paragraph 4.4.

4.2.5.3.5 PSC Fault Detection and Response

The PSC shall perform fault detection and response procedures as described in paragraph 4.4.

4.2.6 SWITCH Mode

4.2.6.1 Description

4.2.6.1.1 SWITCH mode provides a means to allow operation of the ECP brake system when the EOT is not communicating with the HEU or when the train is separated during road switching operations. Many of the ECP brake system's fault detection/response procedures are suspended during SWITCH mode (see paragraph 4.2.6.3).

4.2.6.1.2 Operating in SWITCH mode differs from RUN mode in two ways:

- The EOT device is not required.
- The train configuration may be changed (cars added or removed).

4.2.6.2 Normal Operational Procedures

The following describes the normal sequence of operation in SWITCH mode. Paragraph 4.2.6.3 describes fault detection and response operations.

4.2.6.2.1 SWITCH Mode Power-Up to Restart and Cut In CCDs and EOT

During SWITCH mode, CCDs and EOT may be restarted via a train line power application if they have been shut down. Within 2 seconds after the train line voltage has reached 100 Vdc at the device, any CCDs or EOT that were shut down restart (wake up) and begin to cut in. This 2-second power-up function shall not depend on receiving HEU beacons. See paragraph 4.3.3, "Train Line power control."

4.2.6.2.2 SWITCH Mode Brake Control

Normal brake control functions in SWITCH mode shall be identical to those in RUN mode, with the following exceptions.

- No status query operation is required during SWITCH mode, per paragraph 4.3.18.1.2.
- No EOT (beacon) is required during SWITCH mode.
- Train speed shall not exceed 20 mph.

4.2.6.3 Fault Detection and Response Procedures

HEU fault detection and response functions enabled in SWITCH mode:

- HEU transceiver generates uncontrolled signal transmissions (see paragraph 4.4.2.7.1)
- HEU receives critical loss messages from at least two network devices (CCD or EOT) within 5 seconds (see paragraph 4.4.4.3)
- HEU detects the use of pneumatic brake while train is moving (see paragraph 4.4.8)
- HEU receives CCD incorrect BCP exception (see paragraph 4.4.12)
- HEU detects multiple lead HEUs on network (see paragraph 4.4.13)
- Train speed exceeds 20 mph (see paragraph 4.4.9)
- HEU recovery from loss of BPP in SWITCH mode (see paragraph 4.4.3.5)
- HEU receives PSC or EOT detects greater than 30 V when power off exception (see paragraph 4.4.11.2)

CCDs, EOTs, and PSCs have the same fault detection and response in SWITCH mode as in RUN mode.

4.2.7 CUTOUT Mode

4.2.7.1 Description

CUTOUT mode is used to shut down the entire ECP brake system, either when the train is parked, when the train is reverting to the conventional pneumatic brake system (in a overlay or emulator equipped train), or when the engineer wishes to cut out all the CCDs and release air brakes prior to switching operations.

4.2.7.2 Normal Operational Procedures

CUTOUT mode shall be characterized by the following:

1. The lead HEU shall command train line power to off in the HEU beacon. Train line power shall not be available while in CUTOUT mode.
2. The HEU shall command all CCDs, trailing HEUs, and the EOT to cut out as described in paragraph 4.3.13 by entering CUTOUT mode.

4.2.8 All Modes

4.2.8.1 Description

This section lists functions and features that must be present in all ECP brake system modes of operation when applicable. Refer to paragraph 4.3 for detailed functional descriptions.

4.2.8.2 Functions and Features Applicable to All Modes of Operation

1. HEU cab displays and controls (engineer interface) include the following:
    - Normal displays (see paragraph 4.3.1.1)
    - Warnings and indications (see paragraph 4.3.1.2)
    - Engineer controls (see paragraph 4.3.1.3)
2. Manual brake cylinder and reservoir venting (see paragraph 4.3.12)
3. Pneumatic backup (see paragraph 4.3.19)
4. Multiple lead HEUs on the network (see paragraph 4.4.13)
5. A CCD shall be activated by presence of train line power.
6. An EOT shall be activated by the presence of train line power.
7. Continuous reservoir charging (see paragraph 4.3.20)

4.3 Normal Operation Functions

4.3.1 Cab Displays and Controls

The ECP brake system engineer interface (controls, displays, and alarms) may be provided directly by the HEU or via the locomotive system integration interface, and shall include the following features and functions:

4.3.1.1 Normal Displays

Information normally displayed in the lead locomotive shall include the following:

1.	Percentage brake command (current TBC)
2.	Current EOT BPP (transmitted by EOT beacon), updated once per second
3.	Percentage operating brakes
4.	Train line power on or off
5.	Total potentially operative brakes
6.	Car status data for any car requested
7.	Operating mode
8.	Train empty/load command (when available)

4.3.1.2 Warnings and Indications

Warnings are generally not required when an individual CCD has malfunctioned or ceases operation. Warnings and indications shall include the following:

1.	Warn of absence of EOT beacon (paragraph 4.4.2.1)
2.	Low battery charge on EOT (paragraph 4.4.10.4)
3.	Warn of overlay system presence on a car with HEU loss of communication to CCD without stuck brake protection feature (paragraph 4.3.13). This is an acknowledged warning.
4.	Warn of less than 95%, 90%, and 85% operative brakes in train (paragraph 4.4.5). This is an acknowledged warning.
5.	Warn of low brake pipe pressure at the end of the train (paragraph 4.4.3.1). This is an acknowledged warning.
6.	Warn of low train line voltage (paragraph 4.4.7). This is an acknowledged warning.
7.	Warn of critical loss reported by two or more network devices (paragraph 4.4.4)
8.	Warn of use of pneumatic brake while train is moving (paragraph 4.4.8)
9.	Warn of HEU shutdown resulting from uncontrolled signal transmissions from a transceiver (paragraph 4.4.2.7)
10.	Warn of multiple lead (active) HEUs in the network (paragraph 4.4.13))
11.	Warn of presence of more 30 Vdc on the train line when power is off. This is an acknowledged warning. (paragraph 4.4.11)
12.	Warn of CCD with incorrect BCP. This is an acknowledged warning. (paragraph 4.4.12.2)
13.	Warn of incorrect empty/load setting. (paragraph 4.4.14.2)

4.3.1.3 Engineer Controls

4.3.1.3.1 HEU brake control shall provide the following brake commands and functions. Each function must be available or accessible in one operator motion from any other function.

- Minimum service (10% application)
- Full service (100% application)
- Emergency (120% application)
- Full release (0% application)
- Graduated applications and releases in 1% increments between 10% and 100% full-service application.
- Suppression (when applicable)
- Acknowledgement (when applicable)

4.3.1.3.2 Means of implementation of other required inputs shall be manufacturer specific.

4.3.1.4 Interaction with Locomotive Systems/Signals

The HEU should be capable of responding to or generating the following locomotive system signals:

1.	Alerter (see paragraph 4.3.1.4.1)
2.	PCS /PCR (see paragraph 4.3.1.4.2)
3.	Cab Signal / Over Speed (see paragraph 4.3.1.4.3)
4.	Suppression (see paragraph 4.3.1.4.3)

4.3.1.4.1 Alerter (Safety Control Magnet Valve)

The HEU shall be capable of detecting a conventional penalty brake application initiated from the safety control magnet valve or similar device if the locomotive is so equipped. On detection of a penalty brake application from this device, the HEU shall increase the current electronic brake application to at least 100% brake command for as long as the penalty remains in effect.

4.3.1.4.2 PCS/PCR

The HEU shall be capable of sending the locomotive a signal that will unload the engine. This signal shall be asserted on any electronic emergency and ECPB automatic electronic penalty application and shall remain asserted until the application has been released.

4.3.1.4.3 Cab Signal /Over Speed

4.3.1.4.3.1 The HEU shall be capable of detecting a conventional penalty brake application initiated from the cab signal magnet valve or similar device if the locomotive is so equipped. On detection of a penalty brake application from this device, the HEU shall increase the current electronic brake application to at least 100% brake command for as long as the penalty remains in effect.

4.3.1.4.3.2 In addition, the HEU shall provide a means of providing to the locomotive cab signal equipment (if the locomotive is so equipped) a signal indicating that an electronic suppression application has been made by the engineer.

4.3.1.4.3.3 The suppression signal to the cab signal equipment shall be a fault tolerant system, since a false suppression signal from the HEU will render the cab signal system unable to stop the train in the event of a fault.

4.3.1.4.3.4 The HEU shall have a provision to sense that the cab signal system of an equipped locomotive has been cut out by the engineer. The HEU shall not respond to any cab signal penalty activation as long as this cutout signal remains in effect.

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4.3.1.5 Locomotive Retardation During ECP Braking

4.3.1.5.1 The requirements for locomotive retardation during ECP braking shall be railroad specific in that not all railroads may want automatic locomotive brake cylinder pressure control or dynamic braking during ECP brake applications (e.g., railroads that always bail off automatic brake applications). The requirement to provide the ability to have locomotive retardation during ECP brake applications shall not preclude manufacturers and railroads from developing other braking systems that meet the intent of providing appropriate locomotive retardation in conjunction with ECP train braking as long as these systems allow for interoperability between locomotives equipped with different manufacturers' ECP equipment.

4.3.1.5.2 The requirements for control of locomotive retardation during ECP braking will normally apply to the ECP equipment on the lead locomotive and to the controlling locomotive in a remote, distributed power locomotive consist. All other locomotives normally will be controlled via existing locomotive multiple-unit (MU) cables and pipes.

4.3.2 Communication Network Test

Testing of network communication integrity may be performed during RUN mode and at other times at the discretion of the manufacturer. The test may include evaluation of error rates and/or analysis of signal attenuation through the network.

4.3.2.1 To aid in system diagnostics, CCDs, PSCs, and EOTs shall maintain a count of CRC errors detected by the communication network controller. This count shall be reset to zero at power-up and once per hour by the HEU. Each CCD/PSC/EOT shall set a flag in its status report if the CRC error count exceeds a threshold broadcast by the HEU. The HEU may use this information to identify malfunctioning network devices or groups of network devices.

4.3.2.2 To aid in system diagnostic services, the HEU may provide a means to measure the communication signal voltage level at its interface to the communication medium. If provided, the HEU shall make this measurement with a relative resolution of ±0.5 dB over a minimum 50 dB dynamic range. The hardware that provides this measurement shall have no adverse effect on the communication signal. Determination of train line faults shall be manufacturer specific. A special "quiet" state shall be available when the train is stopped and holding a full-service interlock as defined in S-4230, latest revision.

4.3.3 Train Line power control

Train Line Power shall be controlled by the HEU via commands to the PSCs and a power control flag in the HEU beacon. The HEU power control shall be derived from a combination of engineer input and other mode and fault data as defined in this section.

4.3.3.1 Train Line Power Mode Control

The engineer shall be permitted to select the train line power mode at any time. There shall be two engineer-selectable train line power modes: OFF and AUTOMATIC. The default train line power mode shall be OFF. The HEU may change the train line power mode from AUTOMATIC to OFF as defined in paragraph 4.3.3.1.2.

4.3.3.1.1 Power OFF Mode

When the Power OFF mode is selected or entered automatically, the HEU shall disable all power supplies in the train by setting the power control flag in the HEU beacon to the OFF state. All PSCs shall disable their associated train line power outputs when the power control flag in the HEU beacon is set to OFF.

4.3.3.1.2 AUTOMATIC Power Mode

When AUTOMATIC power mode has been selected, the action performed by the HEU shall be as defined below:

1. If the head end termination is not detected and/or the HEU has not received EOT beacons for a minimum of 3 seconds and train is stopped:
    - A. The HEU shall provide a warning indicating train line power will be applied.
    - B. After the engineer has acknowledged the warning, the HEU shall request a confirmation that all personnel are clear from the train line.
    - C. After receiving this confirmation, the HEU shall command train line power to be activated. If the head end termination and EOT are not detected within 8 seconds after train line voltage has exceeded 30 Vdc at the activated PSC, the HEU shall automatically command that power be disabled.
2. If the head end termination is present and the HEU has received one or more EOT beacons in the last 3 seconds, it shall command that train line power be on continuously until a fault or engineer command requires power to be commanded OFF.
3. If train line power is disabled due to a fault condition, the HEU power mode may continue to be AUTOMATIC and power may be re-enabled depending on whether the train is in motion.
    - A. If the fault condition is cleared and the train is not stopped, the HEU may automatically set the HEU beacon power control flag to ON and enable one or more PSCs to provide train line power.
    - B. As long as the fault condition remains and the train is not stopped, the HEU may continue to indicate AUTOMATIC power mode with train line power disabled.
    - C. If the train is stopped, the HEU shall automatically disable train line power and the HEU may change the power mode to OFF.
4. If the ECP system is in RUN or SWITCH mode and the train is not stopped, the HEU may enable train line power continuously even though the head end termination is not present and/or the HEU has not received one or more EOT beacons in the last 3 seconds:
    - A. The HEU may automatically set the HEU beacon power control flag to ON and enable one or more PSCs to provide train line power.
    - B. If the train is stopped, the HEU shall automatically disable train line power. The HEU may remain in AUTOMATIC power mode or the HEU may change the power mode to OFF.

4.3.3.2 Train Line Power Supply Controller (PSC) Interface to HEU

The PSC shall provide a control and status interface to the HEU via the train line in accordance with the requirements of S-4220, "ECP Cable-Based Brake DC Power Supply—Performance Specification," latest revision, and S-4230, "S-4230," latest revision. This interface shall provide the functions identified in this section.

4.3.3.2.1 Enable Train Line Power as Primary Power Supply

1. A PSC shall determine and indicate to the lead HEU that it is available as a primary train line power supply only if all of the following conditions are true:
   A. Train line voltage measured at the PSC is less than 10 Vdc with either polarity.
   B. The PSC has received one or more HEU beacons in the last 3 seconds.
   C. The PSC has not detected a disabling fault (e.g., very low input voltage from the locomotive).
   D. The PSC has not been commanded to a cut-out state by the HEU.
2. A PSC shall enable its associated train line power supply as the primary train line power supply when the following conditions are true:
   A. A PSC has determined that it is available as a primary train line power supply.
   B. The last HEU beacon received has the power control flag set to ON.
   C. The PSC has received an individual command from the HEU to enable the train line power supply as a primary after the HEU beacon power control flag was set to ON.

4.3.3.2.2 Enable Train Line Power as Secondary Power Supply

1. A PSC shall determine and indicate to the lead HEU that it is available as a secondary train line power supply only if all of the following conditions are true:
   A. Train line voltage measured at the PSC is greater than 50 Vdc with a detectable DC polarity.
   B. The PSC has received one or more HEU beacons in the last 3 seconds.
   C. The PSC has not detected a disabling fault (e.g., very low input voltage from the locomotive).
   D. The PSC has not been commanded to a cut-out state by the HEU.
2. A PSC shall enable its associated train line power supply as a secondary train line power supply when the following conditions are true:
   A. A PSC has determined that it is available as a secondary train line power supply.
   B. The last HEU beacon received has the power control flag set to ON.
   C. The PSC has received an individual command from the HEU to enable the train line power supply as a secondary after the HEU beacon power control flag was set to ON.

4.3.3.2.2.1 Load-Sharing Capable Train Line Power Supply

All train line power supplies shall be load-sharing capable.

4.3.3.2.3 Disable Train Line Power

1. A PSC shall automatically disable its associated train line power supply output if any of the following conditions are true:
   A. The PSC has received no HEU beacons in the last 3 seconds.
   B. The HEU beacon has the power control flag set to OFF.
   C. The PSC receives a command from the HEU to disable train line power.
   D. The PSC detects a disabling fault (e.g., uncontrolled signal transmissions, very low input voltage from the locomotive). The PSC shall then send an exception message to the HEU.
   E. The PSC detects less than 100 Vdc ± 4% at its output while supplying its maximum rated current output (i.e., shorted train line). The PSC shall then send an exception message to the HEU.
   F. The PSC upon being enabled as primary detects less than 110 Vdc at its output within 10 seconds after receipt of the enable command. The PSC shall then send an exception message to the HEU.
   G. The PSC upon being enabled as secondary detects that it is not properly sharing the train line load at its output within 10 seconds after the receipt of the enable command. The PSC shall then send an exception message to the HEU.

4.3.3.2.4 PSC Status Flags for Power Management

1. A PSC shall provide the following flags in its status response to allow the HEU to manage train line power:
   A. Available for use as the primary train line power supply (see paragraph 4.3.3.2.1).
   B. Available for use as a secondary train line power supply (see paragraphs paragraph 4.3.3.2.2 and paragraph 4.3.3.2.2.1).
   C. Train line power supply input voltage below locomotive specific threshold. This shall be a threshold voltage defined in the locomotive ID module to indicate the inability of the locomotive electrical system to continuously operate a train line power supply at rated output. The locomotive ID module shall also include a second, higher threshold value to provide hysteresis for this flag. The default values for these threshold voltages shall be 50 V and 60 V.
2. The remaining PSC status response data shall be as defined in paragraph 4.3.18.5.

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4.3.3.3 HEU Train Line Power Management

The HEU shall provide a control and status interface to the PSC via the train line in accordance with the requirements of S-4230, "S-4230," latest revision. This interface shall provide the functions identified in this section.

4.3.3.3.1 Train Line Power On/Off Control

The HEU shall control the on/off state of the train line power supplies via the power control flag in the HEU beacon and individual commands to PSCs. The power control flag in the HEU beacon when set to the OFF state shall disable all PSCs as a group and prevent them from responding to enable commands. A command to disable individual PSCs also shall be available. Individual commands shall be used to enable a PSC when the power control flag in the HEU is set to the ON state. An enable command to secondary PSC(s) shall be sent only after the primary was successfully activated.

4.3.3.3.2 Locomotive Power Management

The HEU may optionally utilize the PSC status responses to select PSCs to operate the ECP train line while minimizing the effect of the ECP system on the locomotive power system. The HEU may utilize the following criteria in determining PSCs to enable:

1. If a PSC indicates that its input voltage is below the locomotive specific threshold, it shall not be enabled if there is any other PSC available with input voltage above the threshold.
2. If multiple PSCs indicate input voltage above the locomotive specific threshold, the HEU may select PSCs based on the results of the ECP diagnostic test or other data. The criteria could include the following:
   - A. PSC located on a locomotive other than the lead. This accounts for the likelihood that the lead locomotive has a larger electrical load for other than the ECP system.
   - B. PSC that provided the highest average EOT and lead locomotive measured train line voltage during diagnostic tests. This minimizes the train line cable losses.
   - C. Multiple PSCs may be enabled by the HEU if they meet the requirements of paragraphs 4.3.3.2.2 and 4.3.3.2.2.1. HEU logic in selecting multiple PSCs to enable may be manufacturer specific.
3. If all available PSCs indicate input voltage below the locomotive specific threshold, the HEU may enable one or more PSCs using a manufacturer-specific algorithm. After operating for 15 minutes with PSC(s) indicating low input voltage, the HEU may command the CCDs on the train line to limit their input power to less than 5 W average as defined in paragraph 4.3.14. The HEU shall warn the engineer of this condition. If a PSC indicates that its input voltage is above the locomotive specific threshold, it shall be enabled, PSCs with low input voltage shall be disabled, and the CCDs shall be commanded back to their normal power input mode.

4.3.4 Train Brake Commands

4.3.4.1 The HEU brake controller shall provide the engineer with a means for making the following braking commands:

- Full brake release
- Graduated brake release
- Minimum service brake application
- Graduated service brake application
- Full-service brake application
- Emergency brake application
- Suppression

4.3.4.2 The train brake commands (TBC) determine the level of brake application for electronically controlled brake systems and shall be expressed as a percentage from 0% to 100% of full-service braking force in 1% increments. A 100% TBC shall be for full service, and 0% shall be for full release. Minimum service shall be at 10%, and an emergency brake application (whether intentional or the result of a fault or penalty) shall result in a TBC of 120% (i.e., 120% of the full-service brake cylinder pressure setting).

4.3.4.3 A suppression brake application shall be railroad specific and programmed into the locomotive ID module. The default suppression brake application shall be full service.

4.3.5 Minimum Service Application

The minimum service brake application shall be at TBC = 10%. The minimum service brake cylinder pressure (MSP) is a preset value programmed in to the car ID module. Minimum service brake cylinder default is 7 psig if no other value is provided in the car ID module.

4.3.6 Net Braking Ratio

4.3.6.1 The CCD will provide the full-service brake cylinder pressure necessary to provide a train net brake ratio that is transmitted by the HEU.

4.3.6.2 The CCD shall have a default target NBR of 12.8% until a value is received from the HEU.

4.3.7 Full-Service Brake Cylinder Pressure

4.3.7.1 The formula for full-service brake cylinder pressure (FSP) is as follows:

$$FSP = \frac{NBR \times W}{C}$$

where

NBR = Net braking ratio
C = (Ap × LR × EFF)
where

Ap = Area of the brake cylinder piston
LR = Lever ratio
EFF = Brake rigging efficiency

W = Weight
FSP = Full-service brake cylinder pressure

4.3.7.2 The constant C is programmed into the car ID module.

4.3.7.3 The CCD uses the above formula to calculate its full-service brake cylinder pressure. However in order to ensure that a sufficient amount of full-service BCP is available, a minimum full-service BCP limit is needed. The minimum full-service BCP limit under any load condition shall be 30% of its maximum gross rail load full-service BCP or 20.0 psig, whichever is higher.

4.3.7.4 The CCD uses the above formula to calculate its full-service BCP. However a maximum full-service BCP pressure limit is needed. It is needed in the event that the above FSP calculation provides an unobtainable full-service BCP target and to ensure that a sufficient supply of air exists for the CCD to provide emergency BCP defined in paragraph 4.3.8. The maximum full-service BCP limit shall be determined by the following formula:

$$FSPmax = BPP\ setpoint \times RC$$

where

BPP setpoint = Brake pipe pressure set in the locomotive and transmitted by the HEU
RC = Reservoir constant programmed into the car ID module. For a conventional two-compartment reservoir, RC = 0.71.

4.3.7.5 Other algorithms may be used to determine actual and maximum FSP, provided the values obtained do not cause the actual net braking ratio to exceed 25%, thereby ensuring operational compatibility.

4.3.8 Emergency Brake Cylinder Pressure

Emergency brake cylinder pressure target = 1.2 × FSP

4.3.9 CCDs Determine Car Load Value

When the ECP brake system is initialized during the initial terminal inspection and at another location where the train is loaded or emptied, each CCD shall be told its percentage of car load, either by a message from the HEU or by an on-board self-weighing device. While each CCD is active, it shall update the car load value in its memory if the best (highest priority) source of load data changes at any time. This accommodates changes in load during normal road operations. Sources of load data, and the priority given to them by the CCD, are as follows:

1. If a mechanical empty/load device is installed, the CCD's car parameter database shall indicate its presence. The CCD shall then use only the device's indication of load or shall provide fully loaded BCP and rely on the empty/load device to adjust BCP for empty load.
2. If no mechanical empty/load device is installed, the CCD shall give the following priority to load data:
   - A. On-board electronic load sensor data (note that this shall take precedence over the HEU database value).
   - B. Empty/load command from HEU to an individual CCD, if it has been downloaded since Initialization mode was last entered. CCDs shall reset individual car load data back to the default value (car load data invalid) defined in S-4230, "S-4230," latest revision, upon entering Initialization mode. A change in the train E/L command shall override the individual command to a CCD.
   - C. Train empty/load command from the HEU. (CCDs downloaded with individual, valid, load data, in the 0% to 100% range from item B above shall ignore train-wide "empty/load" commands unless a change in the train E/L command has occurred.)
   - D. Default: assume full load (100% of car load).
3. A manual load data override shall not be provided.

4.3.9.1 CCD Response to HEU Train Empty/Load Commands

When responding to train empty/load commands, the CCD shall compare the two empty/load command signals received in the HEU beacon to properly set its empty/load state. If the commands match, the CCD shall update its local setting to reflect the current empty/load commanded state. If the two commands do not match, the CCD shall default its local setting to LOADED and shall report an invalid empty/load command status to the HEU when polled (reference paragraph 4.4.14). If a CCD detects a loss of HEU beacon, it shall remain at the last commanded empty/load setting.

4.3.10 Adjustment of BCP to Train Brake Command

4.3.10.1 The brake cylinder pressure curve for TBC vs. BCP is determined based on the Min-Service and the calculated Full-Service and Emergency BCP(s) for a given car weight. The following formulas are used to determine this BCP curve.

Train Brake Command (TBC)	Brake Cylinder Pressure (BCP)
0%	BCP = 0 psi
0 < TBC <= 10%	BCP = MSP (Min-Service BCP, per paragraph 4.3.5)
10 < TBC <= 100%	BCP = m(x) + b where m = (FSP – MSP) / (100 – 10) b = FSP – m(100) x = TBC
TBC = 100%	BCP = Full-Service BCP, per paragraph 4.3.7
TBC > 100%	BCP = Emergency BCP, per paragraph 4.3.8

4.3.10.2 Other algorithms may be used to derive service BCP on less than fully loaded cars, provided such BCP does not produce an actual NBR exceeding 25% using the actual weight of the car.

4.3.11 Brake Cylinder Pressure Control

CCDs shall control brake cylinder pressures according to the following performance requirements based on a standard AAR single car test rack with 50 ft of brake pipe:

1. Steady state BCP pressure regulation shall be within ±3 psi of target (final commanded) pressure.
2. The BCP control shall be as follows:
   - A. Minimum Service Application: BCP shall reach target pressure from a full release, within ±3 psi, in no more than 2.0 seconds.
   - B. Full-Service Application: BCP shall reach target pressure from a full release, within ±3 psi, in no more than 10.0 seconds nor less than 6.0 seconds.
   - C. Emergency Application: BCP shall reach target pressure from a full release, within ±3 psi, in no more than 12.0 seconds nor less than 7.0 seconds.
3. Full-Service Release performance, from the time each CCD receives the new brake command, shall be as follows: BCP shall reduce to 5 psi or less in no more than 15.0 seconds nor less than 6.0 seconds.

4.3.12 Mechanical Brake Cylinder and Reservoir Venting

A method shall be available to manually vent brake cylinder pressure and reservoir pressure at every CCD location from both sides of the car without reliance on electronic activation or electronic control. It shall be possible to vent the brake cylinder pressure independently of the reservoir pressure, but not vice versa.

Note: It is important to recognize that the brakes may still apply on a car that has its dirt collector cutout cock in the closed/isolated position when operating in ECP, and that the reservoirs must also be drained before a maintenance action is initiated.

The following requirements are listed in no particular sequential order:

1. The brake cylinder release valve shall be capable of releasing air pressure from all brake cylinders of air brake equipment regardless of the charge state of the brake pipe.
2. The brake cylinder release valve shall be capable of being manually actuated to release position by a single momentary pull of a release rod, from either side of the car, without requiring that the rod be held until brake cylinder pressure has been depleted.
3. When electrically cut in, a CCD in the brake cylinder venting state shall generate an incorrect brake cylinder exception in accordance with paragraph 4.4.12.
4. The reservoir air pressure shall be released by holding the release rod in the activated position. When electrically cut in and the reservoir has vented, the CCD shall become inoperable and shall generate a low reservoir exception in accordance with paragraph 4.4.6.
5. The brake cylinder release valve shall not release brake cylinder pressure during any brake application except under the circumstances of actuation by the release rod.
6. When activated while the brakes are applied, the brake cylinder release valve shall prevent the further flow of air from the reservoir to the brake cylinder.
7. The car's pneumatic backup shall remain functional in accordance with paragraph 4.3.19 when the brake cylinder release valve has been activated.
8. When the manual release is activated while the brake pipe is charged and the brakes are applied, the following events will occur:
    - Brake cylinder pressure will not reapply if the brake pipe remains charged and TBC remains non-zero.
    - Brake cylinder pressure will reapply when the brake pipe is vented due to pneumatic backup.

    The brake cylinder release valve shall reset automatically to reestablish the normal operating connection to the brake cylinder once brake pipe pressure has been restored and the CCD has been restored to a full release condition (CCD electrically cut in and commanded to release by the HEU or electrically cut out).
9. The brake cylinder release valve shall not permit air to flow from the reservoir to the brake cylinder while resetting.
10. The brake cylinder release valve may automatically reset upon depletion of reservoir pressure by leakage or otherwise but it shall not permit development of brake cylinder pressure sufficient to set all brake shoes against the wheels of the car.

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4.3.13 CCD Cutout/Cut-In

4.3.13.1 Under certain conditions, a CCD may cut out on its own or be commanded to cut out by the HEU. When a CCD is cut out, it releases its ECP brake application and relinquishes control of brake cylinder pressure to the pneumatic backup. If brake pipe is charged and a pneumatic application is not in effect, brake cylinder pressure will release; otherwise it will remain at the level commanded by the pneumatic backup. When cut out, the CCD continues to charge its reservoir. If capable, a cutout CCD will continue to transmit its status to the HEU in response to the polling cycle;, however, it will not respond to the brake command. A CCD that reports a status of cut out will be considered inoperative by the HEU. A CCD that is cut out is only polled once per polling cycle by the HEU.

4.3.13.2 A CCD shall cut out for the following reasons:

1. HEU commands a single CCD to cut out. This command is initiated by the engineer or the HEU.
2. HEU sets train operating mode to CUTOUT in the HEU beacon.
3. CCD detects a critical loss and determines that it is isolated.
4. Other CCD faults.
5. CCD detects that its transceiver is generating uncontrolled signal transmissions.
6. CCD detects low battery charge and train line power is not available.

4.3.13.3 Except when the train operating mode is set to CUTOUT, when a CCD cuts out, it shall transmit an exception message to the HEU if capable. If the CCD is operating on an overlay-equipped car without stuck brake protection, a visual and audible warning shall be given to the train engineer any time a CCD is cut out or cuts out for any reason. This warning shall be acknowledged. While cut out, a CCD shall suppress exception messages.

4.3.13.4 Once a CCD is cut out, it shall remain cut out until one of the following occurs:

1. HEU commands a single CCD to cut in. This command is initiated by the engineer or the HEU.
2. CCD cuts in if it detects (via HEU beacon) that the operating mode was changed from CUTOUT to another mode.
3. A CCD with fault detects that the fault condition is cleared. However, the HEU still considers such a CCD as cut out and inoperative until the HEU determines that the CCD is cut in.
4. HEU reinitializes train.

4.3.14 CCD/EOT Power System

4.3.14.1 The power on each car shall be maintained through a rechargeable battery system (refer to S-4220, "ECP Cable-Based Brake DC Power Supply—Performance Specification," latest revision. Batteries are continuously charged from the train line while it is energized via an on-board battery charger. In case of train line power failure, CCDs and EOT with fully charged batteries shall be capable of operating on battery backup power for at least 4 hours. The battery backup system within a CCD may be configured to allow the device to operate normally from train line power with a fully discharged, failed, or missing battery. A CCD in this condition may be considered as operative for the calculation of percentage operable brakes until the combined total of CCDs in this condition and other inoperative CCDs exceeds the penalty brake threshold. Refer to paragraph 4.4.10, "CCD or EOT Detects Low Battery Charge" for fault response.

4.3.14.2 Power consumed by each battery charger/CCD/EOT shall be limited to 10 W peak. The CCD also shall have a low power consumption mode. This low power mode shall limit the average power consumption from the train line by the CCD to 5 W over any 15-minute period. The CCD shall enter this low power mode on initial power-up and when commanded to by the HEU. If within 2 minutes of initial power-up a CCD does not receive a low power mode command from the HEU, it shall revert to normal power consumption mode. The CCD also shall revert to normal power consumption mode when commanded to by the HEU.

4.3.15 Network Device Input Characteristics

The input impedance of any network device shall be nominally 2,000 ohms in the 100-KHz to 450-KHz frequency band in receive mode.

4.3.16 Network Device Output Conducted Emissions

Output conducted emissions on the train line shall generally meet the requirements of FCC Section 15.107. Specifically, the conducted emissions as measured on the train line in differential mode may not exceed 106 dBµV from 9 kHz to 40 kHz; 86 dBµV from 40 kHz to 125 kHz; 36 dBµV from 125 kHz to 140 kHz; 56 dBµV from 140 kHz to 450 kHz; and 48 dBµV from 450 kHz to 30 MHz.

4.3.17 CCD or EOT in Shutdown Mode

Shutdown mode (or "battery conservation" mode) shuts off the CCD or EOT to minimize battery drain. When shut down, the CCD or EOT is turned off. When a CCD shuts down, it releases its ECP brake application and relinquishes control of brake cylinder pressure to the pneumatic backup. If the brake pipe is charged and a pneumatic application is not in effect, brake cylinder pressure will release; otherwise it will remain at the level commanded by the pneumatic backup. When an EOT shuts down, it stops transmitting EOT beacons. Once train line power is lost, the CCD or EOT either continues to operate off of battery power until its battery runs low or enters into a timed shutdown mode. The intent of this logic is to allow the train to operate as long as possible after a loss of train line power and to conserve batteries if the device is disconnected from the train line, the train is parked, or the ECP brake system is CUTOUT. The CCD or EOT shall shutdown 1 hour after both train line power is lost and no HEU beacon has been received. The CCD or EOT shall shut down after the train line power is lost and the train operating mode is set to CUTOUT.

4.3.18 Messaging Requirements

These requirements are covered in detail in S-4230, "S-4230," latest revision. The following paragraphs are intended to give a brief description.

4.3.18.1 HEU Beacon

The HEU beacon shall be a priority message broadcast by the HEU once per second (1.0 Hz) and shall contain a train brake command (TBC), train empty/load setting, and a network device status query, among other information, as described in S-4230, "S-4230," latest revision.

4.3.18.1.1 Train Brake Commands

A TBC shall be broadcast as part of the HEU beacon and shall be a percentage of full-service braking force: 0% shall be full release;, 10% shall be minimum service application; 11% to 99% shall be graduated service; 100% shall be full service; and 120% shall be emergency braking.

4.3.18.1.2 Network Device Status Query

Each HEU beacon shall include a status query for an individual network device (trail HEU, PSC, or CCD) during RUN mode. The network device status query shall be used by the ECP brake system to periodically verify communications and control between the HEU and all network devices on the train. It also shall gather data for diagnostic and event recording purposes. Network devices shall be queried for their operating status on a round-robin basis by the HEU. During each round-robin cycle, all CCDs, all active PSCs, and at least one inactive device (trail HEUs and standby PSCs) shall be queried. Status queries to all inactive devices shall be completed on successive round-robin polling cycles. With the transmission of each HEU beacon once per second, the HEU will query a different network device by transmitting its address and a request for its status. There is no polling cycle required in SWITCH mode.

4.3.18.2 Train Configuration Command

Once every 120 seconds and upon setup changes, the HEU shall broadcast a configuration command message. This message shall contain the current BPP setpoint, train NBR, and other information as defined in S-4230, latest revision.

4.3.18.3 CCD Status Messages

When a CCD is queried, it shall transmit the following quantities:

1. BPP
2. Percentage brake applied (BCP relative to full-service application)
3. Reservoir pressure
4. Percentage of full load
5. Cut-in/cutout status
6. Other information as identified in S-4230, "S-4230," latest revision.

Some of this information may be recorded by the locomotive's event recorder and/or made available for display to the engineer. To give "percent brake applied" status, the CCD shall compute the percentage of full-service BCP applied during each status query.

4.3.18.4 EOT Beacon/Status Message

The EOT beacon shall be a priority message transmitted to the HEU once per second (1.0 Hz) and shall contain a status message that includes the brake pipe pressure, percentage of full battery charge, train line voltage, and other information as identified in S-4230, “S-4230,” latest revision. This information may be recorded by the locomotive’s event recorder and/or made available for display to the engineer. The brake pipe pressure at the EOT shall be displayed continuously to the engineer via the HEU.

4.3.18.5 PSC Status Message

When a PSC is queried, it shall read and transmit the following quantities:

1.	Status data
2.	Train Line voltage
3.	Other information as identified in S-4230, “S-4230,” latest revision
4.	Input voltage
5.	Output current

Some of this information may be recorded by the locomotive’s event recorder and/or made available for display to the engineer.

4.3.18.6 Trailing HEU Status Message

When a trailing HEU is queried, it shall read and transmit the following quantities:

1.	Status data
2.	Other information as identified in S-4230, “S-4230,” latest revision

Some of this information may be recorded by the locomotive’s event recorder and/or made available for display to the engineer.

4.3.18.7 Exception Messages

A network device shall generate an exception message when and as required by paragraph 4.4 of this document and by S-4230, “S-4230,” latest revision.

4.3.18.8 Control Messages

Control messages are generated by the HEU to command CCDs, PSCs, or EOT to operate in certain ways. They include the following:

- CCD cut-in/cutout
- Operating mode
- Train initialization and sequencing
- Car load
- PSC enabled/disabled
- Version compatibility

(Other messages concerning car health monitoring and distributed locomotive control are covered in S-4230, “S-4230,” latest revision.)

4.3.19 Pneumatic Backup

4.3.19.1 Each car shall have a means of propagating a pneumatic emergency and of pneumatically applying emergency brake cylinder pressure (i.e., requiring no electrical power). The pneumatic backup system shall always be capable of providing emergency brake cylinder pressure (assuming reservoirs are adequately charged) in the event of a pneumatic emergency whether or not the CCD is operational.

4.3.19.2 The pneumatic backup (PB) system shall include an AAR-approved (or equivalent) pneumatically controlled brake pipe emergency venting device that shall be required on all ECP-equipped cars, whether a “pure” ECP or an overlay system is used. Said emergency venting device(s) shall always be active (enabled) when connected to the brake pipe; however, they shall not undesirably vent BPP in response to typical service fluctuations of BPP, either when the ECP is operational or during pneumatic operation in an overlay system. The pneumatic backup equipment shall conform to existing AAR specifications for emergency venting devices as follows:

- Spacing in accordance with the paragraph entitled “Additional Equipment for Cars with Brake Pipe Length in Excess of 75 ft” in *MSRP* Standard S-401, “Freight Car Brake Design Requirements.” (**Note:** the words “control valve” refer to the emergency venting device for ECP operation.)
- Triggering (by the rapid venting of BP to zero) compliant with the paragraph entitled “Emergency Test,” in *MSRP* Standard S-486, “Code of Air Brake System Tests for Freight Equipment—Single Car Test.”

4.3.19.3 When possible, electronic CCD operation shall take precedence over or assist the pneumatic backup in controlling BCP. Operating CCDs shall sense loss of BPP (see paragraph 4.4.3.3) and respond accordingly. CCDs that may not be able to completely take precedence over pneumatic backup (e.g., overlay CCDs, CCDs not communicating with the HEU but still powered by the train line) shall assist in controlling BCP to the emergency pressure appropriate to car loading (see paragraph 4.3.9).

4.3.19.4 The pneumatic backup must remain active when a CCD has been cut out, disabled, or shut down or has stopped receiving the HEU beacon. A pneumatic emergency brake application shall be released when the brake pipe pressure has increased between the initial application threshold and the remaining reservoir pressure or when electronic CCD operation has taken precedence.

Note: Cars at any load not equipped with a pneumatic empty/load device will apply emergency brakes at the loaded car pressure when the pneumatic backup applies the brakes.

4.3.19.5 Pneumatic Backup Brake Performance

4.3.19.5.1 The pneumatic backup (PB) application shall always be available irrespective of the existing state of ECP operation, providing no mechanical isolation of the brake pipe signal by means of dirt collector cutout cocks has been established.

4.3.19.5.2 The pneumatic backup signal transmission rate shall exceed 750 ft/sec on an AAR standard 150-car test rack.

4.3.19.5.3 The pneumatic backup brake cylinder build-up time shall meet the requirements of an ECP emergency application as specified in paragraph 4.3.11.

4.3.19.5.4 With any group of five consecutive PB-equipped, 50-ft cars pneumatically cut out, an emergency reduction of brake pipe pressure shall cause the remainder of the PB-equipped cars to operate in emergency.

4.3.20 Continuous Reservoir Charging

4.3.20.1 Car reservoirs shall be charged continuously. Reservoir charging shall be accomplished only by conducting BP air to the reservoir (i.e., BC air is never used). Air flow from the BP to the reservoir is never interrupted; however, a mechanism shall be provided to prevent reversal of flow from the reservoir into the BP, especially in case of pneumatic emergency.

4.3.20.2 Reservoir charging chokes shall be sized so that both chambers of an AAR standard 6,000-in.^{3} combined reservoir reach 85 psi in 410 to 480 seconds when charged from a 90-psi brake pipe pressure.

4.3.21 Locomotive ECP Equipment as the EOT

4.3.21.1 The ECP equipment on the last locomotive in the train, if it is also the last vehicle in the train, may perform the functions of the EOT as defined in this document and in S-4230, “S-4230,” latest revision.

4.3.21.2 The ECP equipment on a locomotive shall automatically enable the EOT function if the following conditions are met:

1. The locomotive ECP equipment is capable of measuring brake pipe pressure.
2. The locomotive ECP equipment is capable of measuring train line voltage.
3. The locomotive ECP equipment detects the presence of the train line termination.
4. The locomotive ECP equipment is not on the lead locomotive.
5. The locomotive ECP equipment is receiving HEU beacons.
6. The locomotive ECP equipment is not receiving EOT beacons.

4.3.21.3 Once the EOT function has been enabled for a locomotive ECP device, that device shall continue to perform the EOT function until one of the following conditions is met:

1. Train line power is lost and no HEU beacons are detected for more than 1 hour.
2. Train line power is lost and the train operating mode is set to CUTOUT.
3. EOT beacons from another ECP network device, an EOT, or another locomotive ECP device are detected on the train line.

4.3.21.4 The purpose of the requirements in this section is to support a train that is operating with distributed power control in accordance with AAR *Manual of Standards and Recommended Practices*, Standard S-4250, “Trailing Locomotive Control with ITC Specification,” latest revision, when the last vehicle in the train is a locomotive. To provide locomotive brake control for critical loss penalties, the locomotive functioning as the EOT shall be capable of detecting an ECP critical loss and providing local brake cylinder control.

4.3.21.5 Locomotive ECP equipment functioning as the EOT shall perform the normal EOT fault response and recovery as specified in paragraphs 4.3.21.6 and 4.4.

4.3.21.6 Locomotive as ECP EOT Loses Train Line Termination

If the locomotive ECP equipment functioning as the EOT detects the removal or loss of its train line termination, it shall stop transmitting EOT beacons.

4.4 Fault Response and Recovery Functions

The following fault modes (response functions) apply to both pure ECP and overlay operation. All fault-induced brake applications must remain in effect for 120 seconds or until the train has stopped before recovery procedures (see paragraph 4.4.16) can be initiated. Operating mode changes can be made only after the train is stopped or after the 120-second timer has expired (see paragraph 4.2.2.1).

When a CCD, PSC, or EOT (including locomotive ECP equipment functioning as an EOT) experiences multiple faults, only the most serious fault shall initially be reported and acted upon. Only when this fault is cleared shall the lower priority faults be acted upon. The hierarchy of fault severity shall be as shown in Table 4.2.

The HEU, upon receiving CCD, PSC, Trailing HEU, or EOT exception messages and/or generating its own exceptions, shall prioritize them as shown in Table 4.3. When the HEU detects a fault condition, the highest priority condition is acted upon first. Lower priority faults are handled only after high-priority faults are cleared.

When an emergency brake application is active, a CCD shall suppress all exception messages except for Critical Loss exception messages. Recovery from an emergency brake application shall cause all CCD, trailing HEU, and EOT fault logic to be reset and/or enabled.

Exception-Clear messages shall be allowed when the HEU is commanding an emergency. Exception messages from a PSC shall be allowed in any mode.

Table 4.2 CCD, PSC, and EOT fault hierarchy and exception priority

Fault-Degree	Type of Fault	Fault
1	Fault that may immediately disable the entire ECP control network	• CCD/EOT/PSC Transceiver Generates Uncontrolled Signal Transmission
2	Fault that may cause a penalty or emergency brake application	• CCD/EOT Detects Critical System Loss • PSC Detects Multiple HEUs • EOT Detects Low Battery Charge
3	Fault that may cause system degradation	• EOT Detects Low BPP • PSC Detects Loss of HEU Beacon • EOT or PSC Detects Low/High Train Line Voltage • PSC Detects Train Line Short Circuit • PSC Detects Low Input Voltage • PSC Detects Enable Fault
4	Fault that may disable a single CCD, PSC, or EOT	• CCD Detects Incorrect BC Pressure • CCD Detects Low Reservoir Pressure • CCD Detects Low Battery Charge • CCD, PSC, or EOT Detects Other Manufacturer-Specific Self-Diagnostic Fault

Table 4.3 HEU fault hierarchy and exception priority

Fault Degree	Type of Fault	Fault
1	Fault that may immediately disable the entire ECP control network	• HEU Transceiver Generates Uncontrolled Signal Transmission
2	Fault that requires an emergency brake application	• Two CCD/EOTs Report Critical Loss within 5 seconds • HEU Misses EOT Beacon when in RUN mode • Crew Commands an Emergency Brake Application
3	Fault that requires a full-service brake application.	• <85% Operative Brakes Detected • Low Train Line Voltage with <90% Operative Brakes • EOT Reports Low Battery Charge • Penalty Brake Application • Use of Pneumatic Brake while Train Is Moving • Train Exceeds 20 mph in SWITCH Mode • EOT Reports Critical Loss • PSC Reports Detection of Multiple Lead HEUs
4	Fault that indicate multiple brakes may eventually be disabled.	• <95% Operative Brakes Detected • <90% Operative Brakes Detected • CCD Reports Low Reservoir Pressure • CCD Goes Off Line (or Cuts Out) • CCD Reports Low Battery Charge • EOT or PSC Reports Low or High Train Line Voltage • EOT Reports Low Brake Pipe Pressure • PSC Reports Other Disabling Fault
5	Individual device faults	• CCD Detects Incorrect BC Pressure • PSC or Trail HEU Fails to Respond to Status Query • CCD/EOT/PSC/trail HEU Detects Other Self-Diagnostic Fault

4.4.1 System Fault-Initiated Brake Applications

4.4.1.1 Conditions causing fault-initiated emergency (as differentiated from penalty and intentional) application are described in the following paragraphs:

- HEU transceiver generates uncontrolled signal transmission (see paragraph 4.4.2.7)
- HEU misses EOT beacon when in RUN mode (see paragraph 4.4.2.1)
- HEU receives at least two Critical Loss exception messages from CCDs or EOT (see paragraph 4.4.4.3)
- CCDs may self-initiate an emergency brake application in response to multiple CCDs and/or EOT detecting a critical loss (see paragraph 4.4.4.1)

4.4.1.2 Conditions causing a fault-initiated full-service application are described in the following paragraphs:

- HEU registers less than 85% operative brakes (see paragraph 4.4.5.2)
- HEU detects low train line voltage with less than 90% operative brakes (see paragraph 4.4.7.5)
- EOT low battery charge (see paragraph 4.4.10)

4.4.1.3 Conditions causing a penalty full-service brake application are described in the following paragraphs:

- HEU receives "Critical Loss" message from EOT (see paragraph 4.4.4.5)
- HEU detects use of pneumatic brake while train is moving (see paragraph 4.4.8).
- Train speed exceeds 20 mph in SWITCH mode (see paragraph 4.4.9)
- PSC reports detection of multiple lead HEUs (see paragraph 4.4.13)

4.4.2 Signal Transmission Faults

4.4.2.1 HEU Misses EOT Beacon (RUN Mode Only)

If the HEU fails to receive the EOT beacon for 3 seconds, the engineer shall be given an audible and visible warning and the HEU shall automatically command an emergency brake (TBC=120%) command and transmit a "train line power-off" command (see paragraph 4.3.3.1.2).

4.4.2.1.1 Recovering from a Missed EOT Beacon Fault

4.4.2.1.1.1 If an HEU in this fault condition subsequently receives the EOT beacon, the fault is cleared and the HEU will enable system recovery as described in paragraph 4.4.16. Loss of the EOT beacon for more than 15 seconds while in RUN mode shall require a reinitialization of the train.

4.4.2.1.1.2 If the EOT beacon cannot be restored, then the engineer may change mode.

4.4.2.2 Failure to Receive HEU Beacon

4.4.2.2.1 CCD or EOT or Trailing HEU Misses HEU Beacon

If any CCD, trailing HEU, or EOT fails to receive the HEU beacon for 3 seconds, then the CCD or trailing HEU shall maintain the current brake application and the CCD, trailing HEU, or EOT shall broadcast a Critical Loss exception message (see paragraph 4.4.4).

4.4.2.2.1.1 Locomotive EOT Function Loses HEU Beacon

If the locomotive ECP equipment functioning as the EOT fails to receive the HEU beacon for 3 seconds, then the locomotive ECP equipment shall stop transmitting EOT beacons, transmit a Critical Loss exception message, and make an electronic emergency brake application (see paragraph 4.3.1.5).

4.4.2.2.2 Clearing a CCD or EOT or Trailing HEU Misses HEU Beacon Exception

If a CCD or EOT or trailing HEU subsequently receives the HEU beacon, it shall clear this exception, but shall not transmit an Exception-Clear message. If the TBC in the HEU beacon is less than 120%, all other critical exception logic shall also be reset. After communication with the HEU is restored, and the CCD or EOT or trailing HEU has no other faults, it shall resume normal operation.

4.4.2.3 HEU Does Not Receive CCD's Response to Status Query (RUN Mode Only)

If the HEU does not receive a response from a CCD logged as cut in to a Status Query message, the HEU shall repeat the status query (re-poll the CCD) up to two times. If the HEU does not receive the CCD's response by the third query, the CCD is logged as inoperative by the HEU, and the HEU transmits a cutout command to the CCD in accordance with paragraph 4.3.13.

4.4.2.3.1 Recovery of a CCD that Failed to Respond to Status Query

If a CCD that is cut out because it failed to respond to the HEU status query responds to subsequent HEU status queries and reports that it is cut-in, the HEU shall log this CCD as operative.

4.4.2.4 HEU Does Not Receive PSC's Response to Status Query

4.4.2.4.1 If the HEU does not receive a response from a PSC to a Status Query message, the HEU shall repeat the status query (re-poll the PSC) up to two times. If the HEU does not receive the PSC's response by the third query and it is an active PSC, the PSC shall be commanded to an inactive state and another PSC shall be commanded to an active state (if available) to power the train line.

4.4.2.4.2 If the HEU does not receive the PSC's response by the third query and it is an inactive PSC, the HEU shall log the PSC as inoperative for the purpose of being available for activation.

4.4.2.4.3 If the PSC later resumes responding to the status query and has no other faults, the HEU shall log the PSC as available for activation.

4.4.2.5 HEU Does Not Receive Trailing HEU's Response to Status Query

4.4.2.5.1 If the HEU does not receive a response from a trailing HEU to a Status Query message, the lead HEU shall repeat the status query (re-poll the trailing HEU) up to two times. If the lead HEU does not receive the trailing HEU's response by the third query, the lead HEU shall log that trailing HEU as inoperative.

4.4.2.5.2 If the trailing HEU later resumes responding to the status query and has no other faults, the lead HEU shall log the trailing HEU operative.

4.4.2.6 PSC Misses HEU Beacon

If a PSC fails to receive the HEU beacon for 3 seconds, it shall automatically de-energize its train line power output and enter a disabled state. A PSC shall not broadcast a Critical Loss exception.

4.4.2.6.1 Clearing PSC Misses HEU Beacon Exception

If a PSC subsequently receives the HEU beacon and the PSC has no other faults, it shall respond to subsequent status queries that it is available for activation.

4.4.2.7 Network Device's Transceiver Generates Uncontrolled Signal Transmissions

A means shall be provided within each network device on the train line network to detect if it is transmitting improper signals or noise onto the communications network and to disable its transmitter within 1 second. This method shall detect the presence of improper signals and ascertain that the local transceiver is the source. It shall then interrupt the transceiver by commanding an immediate shutdown of the transceiver.

The device with the faulty transceiver shall cut out and shut down its transmitter within 1 second. The device may attempt to re-enable its transmitter a maximum of two times, with a minimum retry interval of 30 seconds, before shutting it down permanently. (Removal and reapplication of power shall allow the device to re-enable its transmitter subject to another shutdown if uncontrolled signal transmissions are detected.)

4.4.2.7.1 HEU Transceiver Generates Uncontrolled Signal Transmissions

If the HEU's transceiver is the source of the fault, the HEU shall shut off its transmitter and, if it is the LEAD HEU, it shall then warn the engineer.

4.4.2.7.2 PSC Transceiver Generates Uncontrolled Signal Transmissions

If an enabled PSC's transceiver is the source of the fault, the PSC shall shut off its transmitter, disable its train line power output, and enter an inactive state.

4.4.2.7.3 CCD Transceiver Generates Uncontrolled Signal Transmissions

If a CCD's transceiver is the source of the fault, the CCD shall shut off its transmitter and cut out.

4.4.2.7.4 EOT Transceiver Generates Uncontrolled Signal Transmissions

If an EOT's transceiver is the source of the fault, the EOT shall shut down its transmitter. Normal HEU fault logic shall then respond accordingly to the loss of EOT beacon.

4.4.2.7.5 Recovery Procedure for Uncontrolled Signal Transmission

The faulty device must be cut out or otherwise disconnected from the network. In the case of the HEU, another locomotive must be used as lead locomotive or the HEU must be replaced. In the case of the EOT, the EOT must be replaced or the system mode must be changed.

4.4.3 Low Brake Pipe Pressure (BPP)

4.4.3.1 EOT Detects Low BPP

If an EOT detects BPP less than (0.67 × BPP setpoint), it shall transmit a Low BPP exception message to the HEU.

4.4.3.1.1 HEU Response to EOT Low BPP

The HEU shall detect low BPP at the EOT. On detection of low BPP at the EOT, the HEU shall give an audible and visual warning to the engineer. The HEU may detect low EOT BPP either by receipt of an EOT Low BPP exception message or based on information transmitted in the EOT beacon.

4.4.3.2 EOT Detects Loss of BPP

If the EOT detects BPP less than (0.56 × BPP setpoint), it shall broadcast a Critical Loss exception.

4.4.3.2.1 Clearing an EOT Low/Loss of Brake Pipe Pressure Exception

The Low BPP exception and/or Loss of BPP exception shall be cleared when the EOT detects that BPP rises above (0.74 × BPP setpoint). When the Low BP exception is cleared, the EOT shall transmit an EOT Low BPP Exception Cleared message to the HEU. When the Loss of BPP exception is cleared, the EOT shall transmit an EOT Loss of BPP Exception Cleared message to the HEU.

4.4.3.3 CCD or Trailing HEU Detects Loss of BPP

If a CCD or trailing HEU detects BPP less than (0.56 × BPP setpoint) it shall broadcast a Critical Loss exception message.

4.4.3.3.1 Clearing CCD or Trailing HEU Loss of BPP Exception

This exception shall be cleared when the CCD or trailing HEU detects that the BPP rises above (0.67 × BPP setpoint). When this exception is cleared, it shall not transmit a Loss of BPP Exception Cleared message to the HEU.

4.4.3.4 HEU Recovery from Loss of Brake Pipe Pressure in RUN Mode

The HEU shall not allow recovery from a loss of brake pipe pressure as described in paragraph 4.4.4.6 until it detects that the loss of BPP condition is cleared at the EOT.

4.4.3.5 HEU Recovery from Loss of BPP in SWITCH mode

If an EOT is present, recover per paragraph 4.4.3.4. Otherwise, 120 seconds after the emergency brake application was made, the HEU shall command all CCDs and trailing HEUs to reset their fault logic. If the CCDs or trailing HEUs do not re-initiate an emergency application, the HEU clears the loss of BPP fault and allows recovery as described in paragraph 4.4.4.6

4.4.4 System Critical Loss

A System Critical Loss is defined as a loss of HEU beacon or a loss of BPP.

Critical loss fault logic brake control specified in this section for trailing HEUs applies to ECP-equipped locomotives with the ability to provide locomotive retardation based on ECP brake applications as specified in paragraph 4.3.1.5.

4.4.4.1 Multiple CCDs, Trailing HEUs, or EOT Has Critical Loss

If a CCD or trailing HEU receives a Critical Loss exception within 5 seconds of experiencing a critical loss, or experiences a critical loss within 5 seconds of receiving a Critical Loss exception message, or receives Critical Loss exception messages from two other devices (CCDs or EOT or trailing HEU) within 5 seconds, then that CCD or trailing HEU, if applicable (see paragraph 4.3.1.5), shall make an electronic emergency brake application.

CCDs or trailing HEUs that go into self-initiated emergency shall maintain their emergency application, regardless of the TBC in the HEU beacon, until the System Critical Loss fault condition is cleared as described in paragraph 4.4.4.6.

4.4.4.1.1 Critical Loss Relay

If the HEU beacon is still being received, CCDs or trailing HEUs that go into self-initiated emergency shall monitor the TBC in the HEU beacon for a period of 60 seconds ± 10 seconds after it went into self-initiated emergency to ensure that the "critical loss" is propagated to the HEU.

If the TBC in the HEU beacon is not 120% within 5 seconds of self-initiating an emergency, the CCD or trailing HEU shall broadcast a Critical Loss Relay exception. This process shall repeat every 5 seconds until the TBC in the HEU beacon is 120%, the 60-second monitoring period ends, or the CCD and trailing HEU critical loss fault logic is reset by the lead HEU.

The unique IDs of the first two devices generating a critical loss message shall be included in the Critical Loss relay message.

4.4.4.1.1.1 HEU Receives Critical Loss Relay Message

If the HEU receives one or more Critical Loss Relay exception messages, it shall command an electronic emergency brake application (TBC=120%) and provide a warning to the engineer.

4.4.4.1.1.2 CCD or Trailing HEU Receives Critical Loss Relay Message

If a CCD or trailing HEU receives a Critical Loss Relay exception, then that CCD or trailing HEU shall make an electronic emergency brake application.

CCDs and trailing HEUs that go into self-initiated emergency shall maintain their emergency application, regardless of the TBC in the HEU beacon, until the System Critical Loss fault condition is cleared as described in paragraphs 4.4.4.6 and 4.4.4.6.1.

4.4.4.2 Isolated Critical Loss

If a CCD detects a critical loss (loss of HEU beacon or loss of BPP) and does not receive a Critical Loss exception message from any other device within 5 seconds, it will assume the fault is local to the CCD and shall cut out as described in paragraph 4.3.13.

4.4.4.3 HEU Receives at Least Two Critical Loss Messages

If the HEU receives Critical Loss exception messages from two or more devices (CCDs or EOT or trailing HEU) within 5 seconds, then it shall command an electronic emergency brake application (TBC=120%) and provide a warning to the engineer.

4.4.4.4 HEU Receives a Single CCD Critical Loss Message

If the HEU receives only one Critical Loss exception message (loss of HEU beacon or loss of BPP) within a 5-second time period and it is from a CCD, then the HEU shall command that CCD to cut out (see paragraph 4.3.13).

4.4.4.5 HEU Detects EOT Critical Loss Message (RUN and SWITCH Modes)

The HEU shall detect an EOT critical loss. On detection of an EOT critical loss, the HEU shall command a full service brake application and provide a warning to the engineer. The HEU may detect an EOT critical loss either by receipt of a single Critical Loss exception from an EOT or based on information in the EOT beacon. In SWITCH mode, only a Loss of BPP critical loss shall be acted upon.

4.4.4.6 Recovery from System Critical Fault

After the HEU has detected that the cause of the fault has been eliminated (as described in paragraphs 4.4.2.1.1, 4.4.2.2.2, 4.4.3.4 and 4.4.3.5), the HEU shall command the system to reset fault processing and allow recovery as described in paragraph 4.4.16.

4.4.4.6.1 Clearing a CCD or Trailing HEU System Critical Fault

CCDs and trailing HEUs shall reset their critical fault logic on detection of an HEU-commanded critical fault reset, transition out of INIT mode, receipt of the HEU beacon with a TBC less than 120% after an HEU beacon loss event, or on the detection of a transition in the train brake command from 120% to less than 120%.

4.4.5 Reduced Percentage of Operative Brakes

In RUN mode, the HEU shall register as inoperative any CCD that is disabled for any of the following reasons:

- Communication lost (CCD status query not answered)
- Low battery charge with no train line power
- Low reservoir charge
- CCD is cut out

The HEU shall then compute the percentage of operative brakes based on the total number of potentially operative brakes determined during initialization and the number of remaining operative brakes. Fractional percentage operative computation results shall always be truncated down to the next whole percentage point.

CCDs that have a low or missing battery but are functional when train line power is active may be considered operative by the HEU for the purpose of calculating percentage of operative brakes as long as the combined total of these and other inoperative CCDs does not exceed the threshold that causes the HEU to command a penalty full-service brake application.

The following fault responses shall occur if the percentage of operative brakes falls below certain thresholds.

4.4.5.1 HEU Registers Less Than 95% or 90% Operative Brakes (RUN Mode Only)

If the percentage of operative brakes falls below 95%, the engineer shall be audibly and visually warned and given the current percentage operable. If the percentage falls below 90%, the engineer shall likewise be warned and given the percentage. These warnings must be acknowledged by the engineer. See paragraph 4.4.7.5 for the response if the percentage of operable brakes falls below 90% with low train line voltage.

4.4.5.2 HEU Registers Less Than 85% Operative Brakes (RUN Mode Only)

If the percentage of operative brakes falls below 85%, the engineer shall be given a warning and the HEU shall command an electronic full-service brake application.

4.4.6 CCD Low Car Reservoir Charge

If a CCD detects that its reservoir charge is less than (0.63 × BPP setpoint), then it will transmit a Low Reservoir Charge exception message to the HEU.

4.4.6.1 Clearing the CCD Low Car Reservoir Charge Exception

When the CCD detects that its reservoir charge exceeds (0.74 × BPP setpoint) the fault is cleared and the CCD transmits a Low Reservoir Charge Exception Cleared message to the HEU.

4.4.6.2 HEU Receives CCD Low Reservoir Charge Message (RUN Mode Only)

When the HEU receives a CCD Low Reservoir Charge exception message, it shall record the occurrence and log the CCD as inoperative.

4.4.6.3 HEU Receives CCD Low Car Reservoir Charge Exception Cleared Message

When the HEU receives a CCD Low Reservoir Charge Exception Cleared message from a CCD, it shall record the occurrence and log the CCD as operative.

4.4.7 Low Train Line Voltage

When the train line voltage falls below 100 Vdc ±4%, the ECP brake system shall continue to operate, on battery power if necessary, as defined in paragraph 4.3.14.

4.4.7.1 EOT or PSC Detects Low Train Line Voltage

If, after allowing a 25-second settling period after the HEU beacon power flag is set to ON, the EOT or any PSC detects that train line voltage is below 100 Vdc ± 4%, it shall transmit a Low Train Line Voltage exception message to the HEU.

4.4.7.2 Clearing an EOT or PSC Detects Low Train Line Voltage Exception

When the EOT or PSC that reported low train line voltage detects that the train line voltage increases to more than 110 Vdc ± 4%, it shall clear this exception and transmit a Low Train Line Voltage Exception Cleared message to the HEU.

4.4.7.3 HEU Receives Low Train Line Voltage Exception Message (RUN Mode Only)

The HEU shall provide an audible and visual warning to the engineer that an EOT or PSC detected that the train line voltage is less than 100 Vdc only when train line power is activated. The audible warning shall cease when the engineer acknowledges the warning.

4.4.7.4 HEU Receives Low Train Line Voltage Exception Clear Message

When all Low Train Line Voltage Exceptions have been cleared, the visual warning shall be removed.

4.4.7.5 Low Train Line Voltage or Train Operating in Low Power Mode with Less Than 90% Operative Brakes (RUN Mode Only)

If the percentage of operative brakes falls below 90% and any of the following conditions exist, the HEU shall provide a warning to the engineer and command a full-service brake application.

- Train line power is off
- Low train line voltage is detected
- HEU is commanding CCDs to operate in low power mode

The process of determining percentage operative brakes shall be as outlined in paragraph 4.4.5, “Reduced Percentage of Operative Brakes.”

4.4.8 HEU Detects Use of Pneumatic Brake While Train Is Moving

Whenever the ECP brake system is in RUN or SWITCH Mode and not in electronic emergency, and while the train is in motion, movement of the automatic (pneumatic) brake valve handle to any position in the service application zone shall result in a warning to the engineer indicating that the automatic brake valve handle was used in error. An ECP penalty full-service application shall occur after the handle is moved from the release position. The automatic brake valve handle may be moved without penalty, however, when the train speed is zero or the HEU is already commanding an emergency application. Moving the automatic brake valve handle back to RELEASE position shall clear the fault.

4.4.9 Train Speed Exceeds 20 mph in SWITCH Mode

If train speed exceeds 20 mph in SWITCH mode, the HEU shall command a penalty full-service brake application and give a warning to the engineer. This penalty may be reset once train speed falls below 20 mph or the system is placed in a different operating mode.

4.4.10 CCD or EOT Detects Low Battery Charge

If a CCD or EOT detects low battery charge with train line power off (threshold to be determined by its manufacturer), it shall transmit a Low Battery exception message to the HEU at least 5 minutes before commencing an orderly shutdown as described in paragraph 4.3.17. With train line power available, a CCD or EOT shall transmit a Low Battery exception message if it detects that its battery would be incapable of powering the device in the event of a loss of train line power. A CCD may continue to operate from train line power if its batteries are unable to power it.

4.4.10.1 Clearing the CCD or EOT Low Battery Charge Exception Message

When the CCD or EOT with a low battery charge fault detects that its battery has recharged to a sufficient level (defined by manufacturer), it shall transmit a Low Battery Charge Exception Cleared message to the HEU.

4.4.10.2 HEU Receives CCD Low Battery Charge Exception Message (RUN Mode Only)

The HEU shall include CCDs reporting low battery charge in its calculation of inoperative CCDs.

4.4.10.3 HEU Receives CCD Low Battery Charge Exception Cleared Message

The HEU shall include the CCD that cleared the Low Battery exception as an operative brake unless another fault prevents this.

4.4.10.4 HEU Detects EOT Low Battery Charge (RUN Mode Only)

The HEU shall detect an EOT low battery charge. On detection of an EOT low battery charge, the HEU shall command a full-service brake application and provide a warning to the engineer. The HEU may detect an EOT low battery charge either by receipt of a Low Battery Charge exception message from an EOT or based on information in the EOT beacon.

4.4.10.4.1 HEU Receives EOT Low Battery Charge Exception Cleared Message

The HEU clears the fault when an EOT Low Battery Charge Exception Clear message is received, the EOT beacon indicates charged battery, or the train mode is changed.

4.4.11 PSC or EOT Detects Greater Than 30 V When Power Is Off

Allowing for a 10-second settling period after the HEU beacon power flag is set to OFF, if the train line voltage monitored by a PSC or the EOT is greater than 30 Vdc ±4%, the PSC or EOT shall transmit a High Train Line Voltage exception message to the HEU.

4.4.11.1 Clearing PSC or EOT Detects Greater Than 30 V When Power Is Off

If the train line voltage detected by the PSC or EOT with an active High Train Line Voltage exception is less than 10 Vdc ±4% or the HEU beacon power flag is set to ON, the PSCs or EOT shall transmit a High Train Line Voltage Exception Cleared message to the HEU.

4.4.11.2 HEU Receives PSC or EOT Detects Greater Than 30 V When Power Is Off Exception

If the HEU receives a High Train Line Voltage exception message from a PSC or EOT, it shall visually and audibly warn the engineer that the train line voltage is not off. This shall be an acknowledged warning. An indication that the train line voltage is still on shall remain displayed until the PSCs or EOT clear the exception or the operating mode is changed.

4.4.12 CCD Detects Incorrect BC Pressure

If a CCD determines that it is unable to control the BCP for any of the following conditions, it will generate an Incorrect BC Pressure exception message.

- CCD detects a BCP that for non-zero TBC is 5 psig or more higher than the target BCP
- CCD cannot obtain a BCP of at least 5 psig after minimum service or greater is commanded. A CCD with this condition may automatically cut out.
- CCD cannot release BCP below 5 psig with a TBC=0
- Other conditions as determined by the manufacturer

The Incorrect BCP exception message shall include the actual BCP (in psig), the target BCP (in psig), current reservoir pressure, and an indication from the CCD of the reason for incorrect BCP. With the exception of the condition noted above, a CCD shall not automatically cut out as a result of detecting incorrect BCP.

4.4.12.1 Clearing CCD Detects Incorrect BC Pressure Exception

If a CCD determines that is has regained control of the BCP, it shall transmit an Incorrect BC Pressure Exception Cleared message. The engineer then has the option to cut in the CCD.

4.4.12.2 HEU Receives CCD Incorrect BCP Exception

Upon receiving an Incorrect BCP exception message from a CCD, the HEU shall warn the engineer (see paragraph 4.3.1.2) of this condition and indicate on which car the malfunction is occurring. If it is determined by the engineer or the HEU that the CCD has failed, then the HEU will command it to cut out. See paragraph 4.3.13, “CCD Cutout/Cut-In.”

4.4.13 Multiple Lead (Active) HEUs in Network

Multiple lead HEUs shall be detected by PSCs. The PSC shall count the HEU beacons received over a 5-second time period and report an exception if the count is 8 or more. Upon receipt of this exception message, all lead HEUs shall broadcast HEU beacons with the mode set to Initialization and a TBC of 100% and then transition to the trail state.

4.4.14 CCD Detects Train Empty/Load Command Mismatch

If a CCD detects a train empty/load command mismatch, it shall report an invalid empty/load command status to the HEU when polled. CCDs that are responding to the train empty/load command shall default to a LOADED state when a command mismatch is detected.

4.4.14.1 CCD Clears Train Empty/Load Command Mismatch

The CCD shall clear the train empty/load command mismatch when the two train empty/load command signals are the same.

4.4.14.2 HEU Receives Train Empty/Load Command Mismatch

The HEU shall monitor the train empty/load command status reported by each CCD during the polling process. If the CCD reports a train empty/load command mismatch, the HEU shall provide a warning to the operator.

4.4.15 Other Local Fault Detected

If a network device detects a fault not listed above, it may send an exception message to the HEU in accordance with *MSRP* S-4230, "Intratrain Communication Specification for Cable-Based Freight Train Control Systems," latest revision. The HEU shall log these exception messages for display on system diagnostic screens. High priority exception messages (e.g., hot bearing detected, wheels on the ground, severe truck hunting, severe harmonic rocking, stuck hand brake, etc.) as defined in *MSRP* S-4230, shall be displayed to the engineer.

Example exception messages that would appear only on diagnostic screens and be saved in an event recorder could include the following:

- CCD system self-diagnostic test fails
- Trailing HEU not sending status messages
- Car sensor detects worn brake shoes

4.4.16 Recovery from Emergency, Fault-Induced, or Penalty Brake Applications

In all cases, an ECP brake system fault-induced full-service or full-service-penalty application shall stay in effect for 120 seconds or until the train has stopped. An ECP electronic emergency shall remain in effect for a minimum of 120 seconds. After the cause has been eliminated, the HEU shall provide a means for the engineer to release the interlock. Releasing the interlock shall cause an HEU that has a 120% application to transition to 100% application, or an HEU that has a 100% application to remain at 100% application, where subsequent brake controller operation shall again be permitted.

5.0 ENVIRONMENTAL REQUIREMENTS

5.1 Vibration and Shock Environments

The CCD shall be designed and mounted on the base structure of the car to withstand continuous vibrations, in the three major axes, of 0.4 *g* rms with a frequency content from 1 Hz to 150 Hz, containing peak values of ±3 *g* in the 1-Hz to 100-Hz bandwidth. The CCD and its mounting shall also be designed to withstand a longitudinally oriented shock impulse (half sine wave) of 10-*g* peak with a ramp time of 20 msec to 50 msec. If the CCD is mounted on the car strength members (ribs, slope sheet support columns, etc.), then the bracket and mounting arrangements, together with the electronics packaging, shall be designed to provide protection from the amplification effects of any local vibration resonances. It should be noted that peak resonant acceleration levels in excess of 15 *g* in the 100–150 Hz range and values in excess of 50 *g* in the 200–500 Hz range have been measured on car strength members as a result of shock impulses sustained during yard impacts.

5.2 Temperature and Humidity Requirements

The CCD shall be designed to operate in temperatures from –46 °C to 66 °C in all humidity conditions.

6.0 APPROVAL PROCEDURE

Refer to Standard S-4240.

APPENDIX A
GLOSSARY OF TERMS

Battery	Device used to store and provide electrical power to each CCD and EOT, even when train line electrical power is unavailable; the battery is recharged by the "battery charger" when the train line is energized
Battery charger	Device that receives direct current electrical power from the train line and provides current to recharge batteries on a CCD or EOT
BCP	Brake cylinder pressure (usually in psig)
BP	Brake pipe; main pneumatic power transmission conduit in a train
BPP	Brake pipe pressure (usually in psig)
BPP setpoint	See "*BP pressure setpoint*"
BP pressure setpoint	The pressure point at which the HEU or equalizing valve maintains the brake pipe pressure at the locomotive (usually in psig)
Broadcast	A message simultaneously transmitted to all active devices on the communications network
C	Car braking constant that represents the relation between BCP and applied shoe force on a particular car
CCD	Car control device (see definition, paragraph 3.1)
CCD status query	A function by which the HEU periodically polls each CCD to obtain information on the CCD's operating status; CCD data such as BPP, BCP, percentage of battery charge, etc., is transmitted to the HEU in response to the query
Critical loss	A functional loss, such as loss of brake pipe pressure or loss of train line communications, that requires an emergency brake application
Cut in	Process whereby a CCD or EOT is activated and becomes fully functional and able to provide electronically controlled braking and fault detection and response functions; also see "*Cut out*"
Cut out	A command to deactivate a CCD such that it no longer performs electronically controlled braking functions; also see "*Cut in*"
Emergency interlock	A mechanism whereby an emergency brake application command is maintained by the HEU, regardless of the engineer's input, until certain conditions are satisfied
Empty/load command	A command initiated by the engineer to indicate the load condition of a train in a particular type of service where the train may be either loaded or empty during a given operation
Empty/load device	A mechanical-pneumatic device on a car that is used to reduce BCP for lightly loaded or empty cars
EOT	End-of-train device (see definition, paragraph 3.3)
Fault	A malfunction of the ECP brake system or one of its components; the ECP brake system is designed to safely handle typical individual faults ("Fault detection and response"); for example Fault: low battery charge at CCD
Fault detection and response	CCD reads battery charge and determines that the battery is about to fail; the CCD then issues an exception message, cuts out (goes off line), and shuts down in an orderly way
Failure	A failure occurs when the system or a component fails to adequately and safely handle a single or multiple (compound) fault, thereby compromising braking control or safety
Full-service interlock	A mechanism whereby a full-service brake application command is maintained by the HEU, regardless of the engineer's input, until certain conditions are satisfied
GRL	Gross rail load; the total design weight of a fully loaded car on the rail (usually in lb)

%GRL	Percentage of full gross rail load; the actual weight of the car divided by the GRL, expressed in percent
HEU	Head-end unit (see definition, paragraph 3.2)
Lead	Lead locomotive HEU at front of train, set to “lead” (or active) mode; the lead HEU initiates all train brake commands (TBCs) and performs all system diagnostic and control functions
Loss of beacon	See “*Loss of communications*”
Loss of communications	Indicated by any the following faults related to either the HEU or EOT beacon: • Beacon not received by another device • Beacon discontinued • Beacon masked by noise • Beacon corrupted by a malfunctioning transmitter such that it is not recognizable by a normally functioning transceiver
Loss of signal	See “*Loss of communications*”
NBR	Net braking ratio; the sum of the actual normal (perpendicular) brake shoe forces on all of the wheels on a car divided by the actual weight of the car on the rail; the term is used specifically in tread braking applications. In this standard, NBR refers to the loaded net brake ratio resulting from a full-service (100%) brake application from a 90-psi brake pipe pressure.
Noise (in communications network)	Presence of excessive electrical noise on the network that materially degrades or interferes with normal electronic communications
Operative brake	An individual brake set that is fully functional and that applies correct braking forces on two braked trucks in response to the engineer’s or HEU’s braking commands
Operating modes	Modes of system operation that depend on the type of train operation requirements
Packet	Network communications term; quantity of data
Percentage braking applied	The percentage of full-service braking that is applied at a given car
Percentage car load	The percentage of full-rated car load
Remote	A remote locomotive is one that is generally placed at a distance behind the lead locomotive in a train and is found in distributed (locomotive) power applications; a remote power supply is a train line power supply mounted within a remote locomotive
Restart	Process by which a CCD or EOT is “wakened” or turned on after having been shut down; if it has no internal faults, a restarted CCD or EOT is able to be cut in to resume normal braking functions
Shut down	Process by which a CCD or EOT shuts off to save its battery, usually in response to an extended train line power outage or disconnection
Stuck brake protection	A mechanism in an overlay CCD that significantly increases the probability that the pneumatic service portion is maintained in a release state when it would normally respond to fluctuations in brake pipe pressure that could cause the brake to become stuck in the applied state. Stuck brake protection is enabled in the CCD by the application of train line power.
TBC	Train brake command; the message transmitted by the lead HEU that indicates to the entire ECP brake system the current braking application to be made, if any
Trail	Trailing locomotive HEU behind lead unit, set to “trail” (or inactive) mode; trailing HEUs do not initiate train brake commands (TBCs) nor do they perform any system diagnostic and control functions
Train line	The electric power and signal conduit in a train (see definition, paragraph 3.4)
Vdc	Volts direct current
Zero speed	This is a locomotive specific zero speed setting

APPENDIX B
ECP DEVICE COMPATIBILITY

ECP Device	S-4200 Compatibility Version		Reasons for Current Compatibility Version
	Mandatory	Current	
HEU	2	2	Initial version
CCD	2	2	Initial version
PSC	2	2	Initial version
EOT	2	2	Initial version

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