CAT Electronics

LOCOMOTIVE ELECTRONIC SYSTEMS

TROUBLE SHOOTING GUIDE

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NOTICE

This document is intended to provide troubleshooting and diagnostic information utilizing the Caterpillar® Locomotive Control Module (LCM). Locomotives with single and multiple Engine Power Module (EPM) configurations are covered in this manual.

For the latest information on software, features, and release date(s) contact Cat Electronics via catelectronics@cat.com or visit the Cat Electronics web site at www.catelectronics.com

- Information in this document is subject to change as engine features, software, and requirements are revised and developed. Some of the features described in this document are not yet released.
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1 INTRODUCTION

1.1 SAFETY PRECAUTIONS

Most accidents that involve product operation, maintenance and repair are caused by failure to observe basic safety rules or precautions. An accident can often be avoided by recognizing potentially hazardous situations before an accident occurs. A person must be alert to potential hazards. This person should also have the necessary training, skills and tools to perform these functions properly.

IMPROPER OPERATION, LUBRICATION, MAINTENANCE OR REPAIR OF THIS PRODUCT CAN BE DANGEROUS AND COULD RESULT IN INJURY OR DEATH.

Do not operate or perform any lubrication, maintenance or repair on this product, until you have read and understood the operation, lubrication, maintenance and repair information.

1.2 WARNINGS

Safety precautions and warnings are provided in this manual and on the product. If these hazard warnings are not heeded, bodily injury or death could occur to you or to other persons.

The hazards are identified by the Safety Alert Symbol and followed by a Signal Word such as DANGER, WARNING or CAUTION. The Safety Alert WARNING label is shown below.

The meaning of this safety alert symbol is as follows:

Attention! Become Alert! Your Safety is Involved.

The message that appears under the warning explains the hazard and can be either written or pictorially presented.

NOTICE or **NOTE** labels on the product and in this publication identify operations that may cause product damage.

CATERPILLAR® CANNOT ANTICIPATE EVERY POSSIBLE CIRCUMSTANCE THAT MIGHT INVOLVE A POTENTIAL HAZARD.

The warnings in this publication and on the product are, therefore, not all inclusive. If a tool, procedure, work method or operating technique that is not specifically recommended by Caterpillar® is used, you must satisfy yourself that it is safe for you and for others. You should also ensure that the product will not be damaged or be made unsafe by the operation, lubrication, maintenance or repair procedures that you choose.

The information, specifications, and illustrations in this publication are on the basis of information that was available at the time that the publication was written. The specifications, torques, pressures, measurements, adjustments, illustrations, and other items can change at any time. These changes can affect the service that is given to the product. Obtain the complete and most current information before you start any job. **CATERPILLAR®** suppliers have the most current information available.

CAUTION: Do not use procedures that cause the product to be unsafe.

1.3 ELECTRICAL SAFETY

WARNING

Do not operate or work on an engine or generator set unless you have read and understand the instructions and warnings in the Operation and Maintenance Manual.

FAILURE TO FOLLOW THE INSTRUCTIONS OR HEED THE WARNINGS COULD RESULT IN INJURY OR DEATH.

Proper care is your responsibility. Contact any Progress Rail Services supplier for replacement manuals.

1.4 ELECTROSTATIC DISCHARGE AWARENESS

ECM control contains components that are sensitive to electrostatic discharge (ESD). An electrostatic charge can damage the control resulting in ECM breakdown or improper operation.

Take the following precautions while installing/removing/handling the control:

- Handle equipment correctly. Use ESD protective packaging and material handling containers that are anti-static and provide discharge protection and electric field suppression
- Use protective devices: ESD-protective workstations and/or work surfaces (grounding mat, anti-static wrist strap, etc)
- Keep all plastic items away from the devices. Any plastic item is a potential static generator. This includes candy wrappers, foam cups, synthetic carpet, foam cushions, etc.
- The anti-static bag cannot function as a static dissipating mat. Do not use the anti-static bag for any other purpose than to enclose a product.

CAUTION

The connectors on the top of the control are the most vulnerable area to ESD. Make sure extra attention is addressed to this area while handling the ECM. If extra care is not taken while handling this area of the control, the control may become damaged or inoperable.

Consult the Electrostatic Discharge Association (ESDA) regarding proper procedure for particular situations, (www.esda.org).

1.5 WELDING ON A MACHINE

Before welding on a product equipped with an electronic engine, the following precautions should be observed:

⚠ WARNING

- ☑ Turn the engine OFF.
- ☑ Depress and lock the EFCO button.
- ☑ If the unit is equipped with a battery disconnect switch, open the switch.
- ☑ Remove all electrical harness or wiring connections to any microprocessor. This includes but is not limited to, the engine ECM, LCM, TCM, PE Box, DVR/Interface Box, and any other electrically sensitive equipment.
- ☑ Disconnect the negative battery cable from the battery.
- ☑ If the unit is equipped with a battery disconnect switch, open the switch.
- ☑ DO NOT use electrical components in order to ground the welder.
- ☑ Do not use the ECM or sensors or any other electronic component in order to ground the welder.

1.6 REPLACEMENT PARTS

Caterpillar recommends using Caterpillar replacement parts or parts with equivalent specifications including, but not limited to:

- Physical Dimensions
- Type
- Strength
- Material

WARNING

WARNING: When replacement parts are required for this product Caterpillar recommends using Caterpillar replacement parts or parts with equivalent specifications including, but not limited to, physical dimensions, type, strength and material.

Failure to heed this warning can lead to premature failures, product damage, personal injury or death.

For safety's sake, it is necessary to follow certain precautions before inspecting equipment or operating the locomotive. General areas of concern are:

- High voltage that is present on PR22B locomotives that are running
- High voltage that may be present on PR22B locomotives that are shut down

1.7 DC BUSS VOLTAGE

The DC buss consists of all connections between the traction alternator and the traction inverters.

WARNING

WARNING: DC buss voltage is present on **all** equipment connected to the traction alternator output, including: traction alternator output terminals, cabling, connections, capacitor cabinets (when equipped), and switchgear.

CAPACITORS AND THE DC BUSS

The High Voltage Control (HVC) and Low Voltage Control (LVC) cabinets (both above deck and below deck) can be equipped with banks of large capacitors. They operate at DC buss voltage, which can be as high as 3000 VDC.

High DC buss voltage is a severe safety hazard to operating and maintenance personnel. Normally, within ten seconds after a locomotive shuts down, DC buss voltage automatically discharges. However, if anything prevents automatic discharging, the capacitors retain their charge for a long time after locomotive shutdown, holding the entire DC buss at high voltage. During normal locomotive operation, it is not necessary to discharge the DC buss.

1.8 ATTENTION LOCOMOTIVE CREW

Only qualified maintenance personnel, are permitted full access to electrical control cabinet(s) and equipment.

WARNING

WARNING:

Whether or not the engine is running, DO NOT TOUCH any electrical equipment in the electrical control cabinet, except for devices used in normal operation, such as switches, circuit breakers, etc.

1.9 WORKING WITH ELECTRONIC CONTROLS

"A COMMON SENSE APPROACH TO TROUBLESHOOTING"

1. Read the Service Manual.
2. **Avoid preconceived ideas**. Just because the machine has electronic controls does not mean that the electronics are at fault (i.e. don't change the LCM / ECM if the engine has run out of fuel).
3. **Look at the facts.** If you have an active fault, repair that fault. If it is logged, try and repeat the fault. Ask the operator to make it happen, and then do parts surgery till it is fixed. If the new part didn't fix it put the old part back on.
4. **The LCM / ECM rarely fails** or causes the trouble, but it can.
5. **Check *ALL* connectors for corrosion.** Pull them apart to look at the pins and sockets. Always change **both halves** of the connector if there is corrosion (pins, sockets and the plastic connector). Clean the battery terminals. Terminal nuts and bolts may break or be corroded. See, Section 1.10: PULL TEST on page 19.
6. **A new LCM / ECM is blank**. It will not communicate with the service tool (Cat ET) or any other LCM / ECM on the machine. It will not run the engine. **It must be flashed first**.
7. **If the LCM / ECM has been previously fitted to a machine**, a re-rate will have to be done after it has been flashed (factory passwords are required to change the interlock code).
8. **Injector codes**. Don't forget that the engine may have injector codes. When fitting a new injector or ECM, don't forget the codes (or use ET function "LCM / ECM Replacement."
9. **Electronics only do what they are told to do**. You must use manual gauges to verify that the LCM / ECM is reading the sensors correctly (HEUI oil press, fuel press, boost press, inlet air temp). There may be a problem but not an active or logged fault. This just means that the trip point for an active code has not been reached yet +(i.e. boost sensor stuck on 0 psi).

10. **Remember the things an engine needs to start**. ***GOOD POSITIVE POWER WHILE CRANKING,*** a good negative (ground), engine speed, air, fuel, HEUI pressure, and nothing telling it to shut down.
11. **When it all doesn't make sense,** switch everything off and start again. Always shut the computer down correctly.
12. **If Cat ET will not communicate with an LCM / ECM**, power up the LCM / ECM separately and use WinFlash and try and communicate. If WinFlash will communicate then Flash the LCM / ECM and go back and try Cat ET again. This means the flash file is damaged and not complete.

1.10 PULL TEST

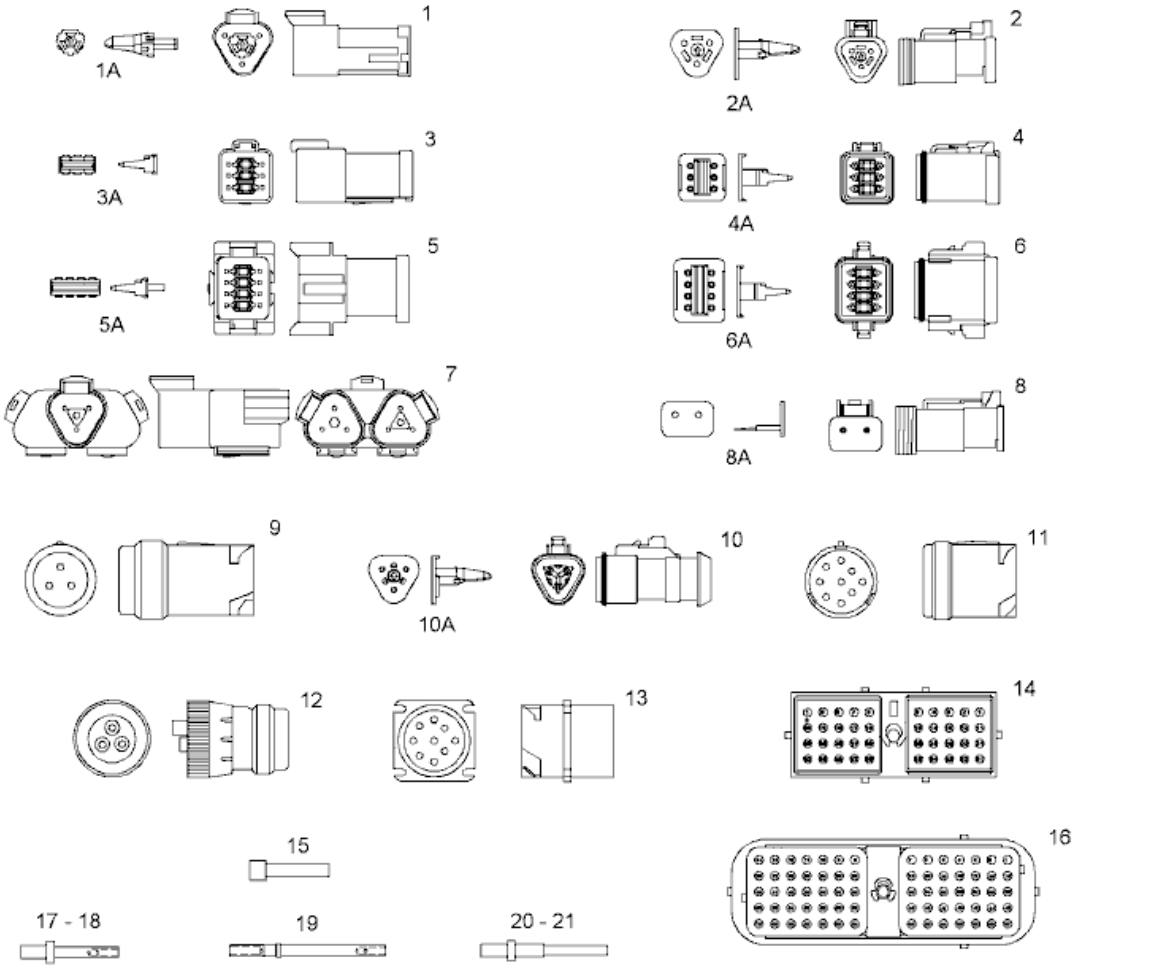
Several types of connectors are used as illustrated in Figure 1-1. Many problems can occur from improperly crimped and seated connectors. Before assuming a circuit or device may be defective always perform a 10 pound PULL TEST on each wire in that circuit.

Locomotive circuits are subject to vibration, changes in temperature, and defective terminals and pins.

10 LB PULL TEST

The pull test is used to verify that the wire is properly crimped in the terminal and the terminal is properly inserted in the connector. Perform the pull test on each wire. Each terminal (socket or pin) and each connector should easily withstand 45N (10lb) of pull and each wire should remain in the connector body.

Connectors



(1) 102-8803 Receptacle Kit
(1A) Receptacle wedge
(2) 155-2260 Connecting Plug Kit
(2A) Receptacle wedge
(3) 102-8805 Receptacle Kit
(3A) Receptacle wedge
(4) 155-2274 Connecting Plug Kit
(4A) Receptacle wedge
(5) 102-8806 Receptacle Kit
(5A) Receptacle wedge
(6) 155-2265 Connecting Plug Kit
(6A) Receptacle wedge
(7) 133-0970 Receptacle As
(8) 155-2270 Connecting Plug Kit
(8A) Receptacle wedge
(9) 8T-8732 Receptacle
(10) 174-0503 Connecting Plug Kit
(10A) Receptacle wedge
(11) 8T-8736 Connector Receptacle
(12) 8T-8731 Connector Plug
(13) 9W-1951 Receptacle
(14) 8T-9834 Connector Plug As
(15) 8T-8737 Seal Plug
(16) 9X-4391 Connector Plug As
(17) 186-3736 Connector Socket (16-18 AWG)
(18) 9W-0844 Connector Socket (14 AWG)
(19) 133-0969 Socket Connector
(20) 186-3735 Connector Pin (16-18 AWG)
(21) 9W-0852 Connector Pin (14 AWG)

Figure 1-1 Connectors

1.11 CHECKING PINS AND HARNESSES

PROPER PIN CONNECTIONS

The 8T-8729 Connector Pin (2) and the 8T-8730 Connector Socket (1) is designed to accept only one 16/18 AWG wire.

- **DO NOT** insert multiple wires of a smaller wire size. An incorrect method would be using two 24 AWG wires.

The 9W-0852 Connector Pin and the 9W-0844 Connector Socket is designed to accept only one 14 AWG wire.

- **DO NOT** insert multiple wires of a smaller wire size.

Figure 1-2 illustrates correct and incorrect examples of the use of two 20 AWG wires.

Figure 1-3 illustrates correct and incorrect examples of sealing plugs using Deutsch connectors.

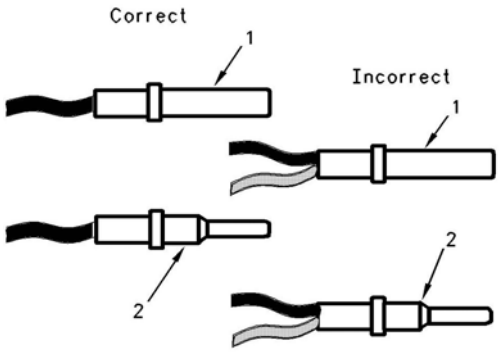


Figure 1-2 Proper Pin Connections

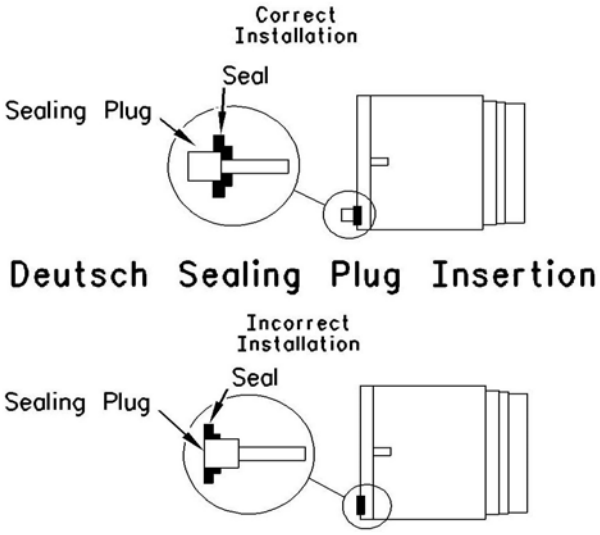


Figure 1-3 Deutsch Connector

PULL TEST

- Use the pull test is used to verify that the wire is properly crimped in the terminal and the terminal is properly inserted in the connector. Perform the pull test on each wire. Each terminal (socket or pin) and each connector should easily withstand 45N (10lb) of pull and each wire should remain in the connector body.

CHECK THE HARNESS

Once you have constructed and run the harness on the engine or locomotive, carefully inspect each wire for signs of:

- abrasion
- nicks
- cuts

The following areas are locations that should also be checked:

- Exposed insulation
- Points of rubbing wire
- Pass-through openings for proper clearance and harness support

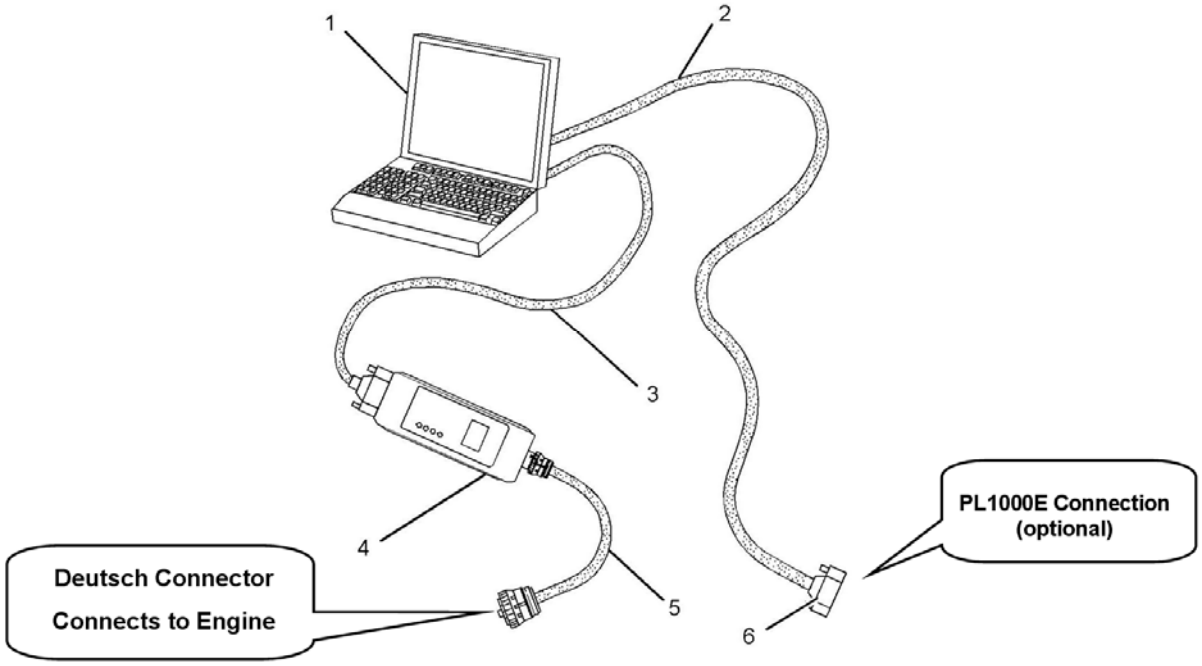
CHECK HOLD DOWN CLAMPS

- The hold down clamps for the harness in order to verify that the harness is properly clamped.
- All of the hold down clamps for the harness in order to verify that the harness is not compressed by the clamp.
- Pull back the harness sleeves in order to check for a flattened portion of wire. The flattened portion of wire is caused by the clamp that holds the harness

1.12 CAT SERVICE TOOL

This CAT Service Tool is used to diagnose system problems, upgrage LCM / ECM software, configure programable applications, and program setpoints. This tool is usually used by dealer service and manufacture's installation team and requires version 2004B or later of the Caterpillar ET and version 2005A or later of the Caterpillar Communications Tool Kit.

A complete understanding of engine software, sensors, and communications is vital for the accurate use of the Cat Service Tool. Contact your dealer for training on this tool.



1 PC / Laptop

2 PL1000 Communications adapter service cable (Connects PC RS-232 Port to RS-232 Port 3 on the PL1000E: **Optional**)

3 196-0055 Serial Cable

4 171-4401 Communication Adapter

5 207-6845 Adapter Cable As (Data Link)

6 RS-232 Serial Port Connector (PC RS-232 Port to RS-232 port 3 on the PL1000E)

Note: Items 3, 4, and 5 are part of the 171-4400 Communication Adapter Gp

Figure 1-4 Cat Service Tool

CONNECTING THE CAT SERVICE TOOL

The CAT Service tool connects to an RS232 port on a laptop or PC. The PC must have the CAT ET (Electronic Technician) software installed to communicate to the an LCM / ECM. The other connector on the CAT Service Tool is a round, 9-pin, Deutsch connector. It connects to its mating connector located on the locomotive and on an engine (Figure 1-4, on page 22).

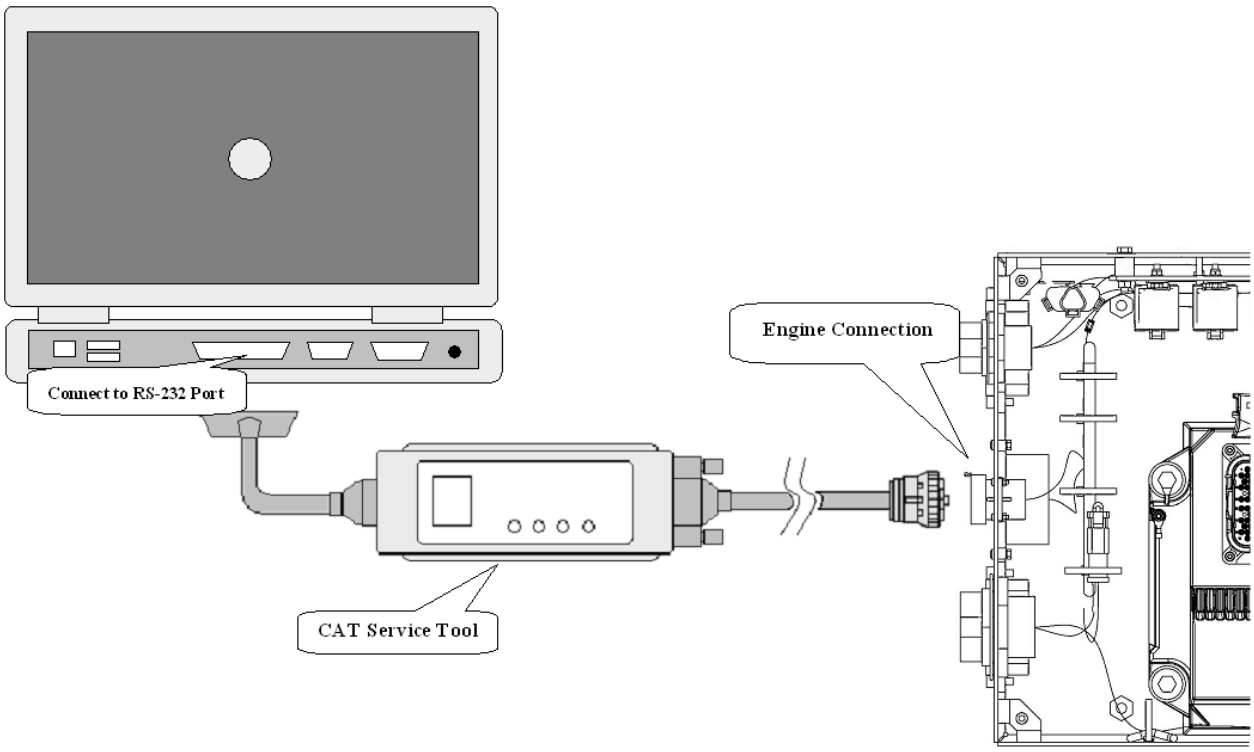


Figure 1-5 Connecting the CAT Service Tool

Once connected to a service tool connection, begin the diagnostics using CAT_ET software.

TYPICAL ENGINE AND NETWORK SCHEMATICS

NOTE: The schematics shown are for reference only and varies from locomotive to locomotive. Refer to your specific engine manual for the correct shematics.

Solid bold lines represent the connections provided by the 276-0785 Harness Assembly. Lighter lines and dashed lines represent the optional connections available for custom harnessing to meet the needs of your application (Figure 1-6 on page 24).

Study this example and locate these components on your engine. For more information consult the engine's A&I Guide or the locomotive Operators Manual (OM) and Trouble Shooting Guide (TSG).

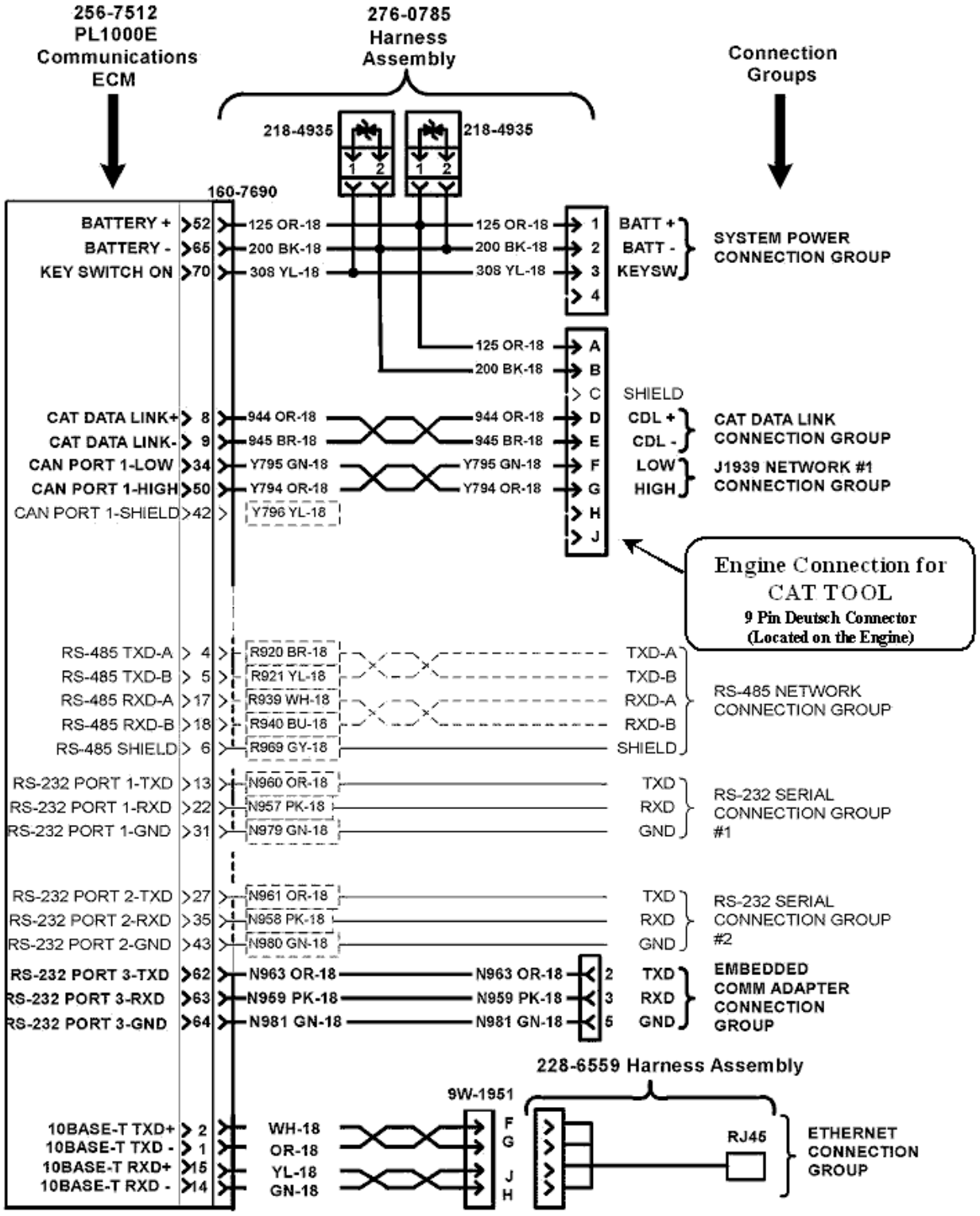


Figure 1-6 Typical Engine Schematic used with CAT TOOL

J1939 DATA LINK SPECIFICATIONS

The diagram below (Figure 1-7) shows typical CAT Datalink and J1939 and other network connections. For more information consult the locomotive Operators Manual (OM) and Trouble Shooting Guide (TSG) under service.

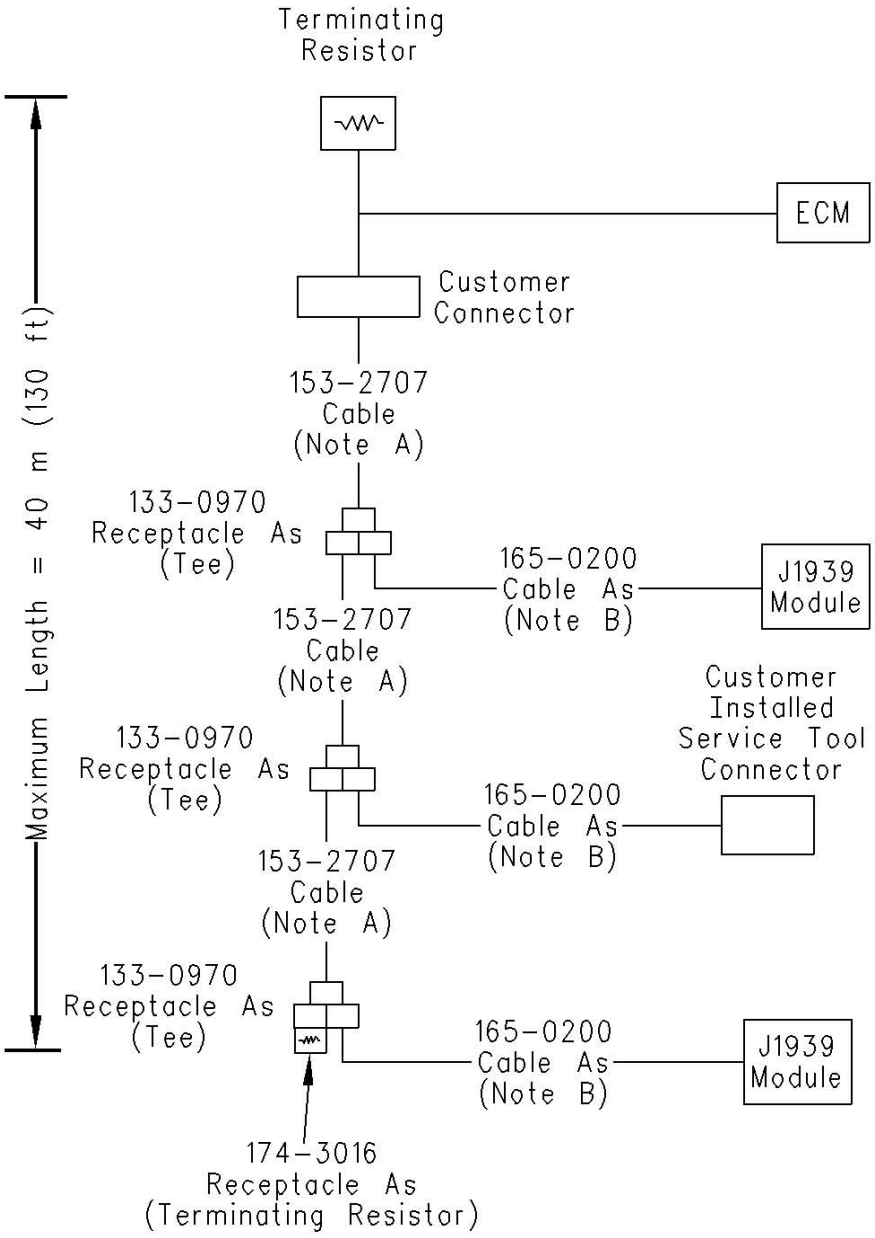


Figure 1-7 Typical Cabling for Data Link Connections

The specifications for J1939 Data Link is shown in Table 1-1 on page 26.

Table 1-1 J1939 Data Link Specifications

J1939 Data Link					
Parameter	**Minimum**	**Nominal**	**Maximum**	**Unit**	**Conditions**
Impedance	108	120	132	ohm	Three meter sample length measured at 1 Mhz between the two signal wires with shield grounded using open/short method
Specific Resistance	0	25	50	milliohm per meter	Measured at 20°C(1)
Specific Line Delay		5.0		ns/m	67% V_p(2)
Specific Capacitance	0	40	75	picofarads per meter	Between conductors
	0	70	110	picofarads per meter	Conductor to shield
Cable Size					See note (3)
0.5 mm² Conductor (20 AWG)	0.508			mm²	See note (4)
Wire Insulation Diameter	2.23		3.05	mm	
Cable Diameter	6.0		8.5	mm	
0.8 mm² Conductor (18 AWG)	0.760			mm²	See note (4)
Wire Insulation Diameter	2.5		3.5	mm	
Cable Diameter	8.5		11.0	mm	
Shield Effectiveness		200	225	milliohm per meter	Surface transfer impedance up to 1 Mhz Test method per MIL-C-85485
Temperature Range	-40		+125	°C	Heat aging: 3000 hours per ISO 6722, test with a mandrel 4-5X diameter of cable.(5)
Cable Bend Radius	4 x dia. of cable			mm	90° bend radius without cable performance or physical degradation.

(1) The differential voltage on the bus line seen by a receiving Electronic Control Unit (ECU) depends on the line resistance between it and the transmitting ECU. Therefore, the total resistance of the signal wires is limited by the bus level parameters of each ECU.

(2) The minimum delay time between two points of the bus line may be zero. The maximum value is determined by the bit time and the delay time of the transmitting and receiving circuitry.

(3) Other conductor sizes available. Component insulation dimensions may be larger than those specified in SAE J1128. Design engineers should ensure compatibility between cables, connectors, and contacts.

(4) Meet performance requirements of SAE J1128 for types GXL or SXL (includes drain wire where applicable).

(5) 125°C or per OEM specification.

BUS LINE – The J1939 bus line consists of a CAN_H, CAN_L and CAN_SHLD conductors. The CAN_H should be yellow in color while the CAN_L should be green. In addition, the cable must meet the following minimum requirements.

TOPOLOGY: The wiring topology of a J1939 network should be as close as possible to a linear structure in order to avoid cable reflections. In practice, it may be necessary to connect short cable stubs to a main backbone (or main trunk) cable, as shown in the figure on page 18. To minimize standing waves, nodes should not be all the same length.

1.13 CONNECTING DIRECTLY TO AN ENGINE

Figure 1-8 CAT Electronic Technician

This section covers how to locate the *Engine Service Connection* on the engines shown below.

- C18 Engines
- C175 Engines
- 3500 Engines

CAUTION

NOTE: On locomotives, the ENGINE CDL connector is located next to the LOCO CDL connector. No direct connection to the engine(s) should be required. The following is provided for reference only. Should a direct connection be required consult that engine's Trouble Shooting Guide before beginning.

To connect to the engine you must locate the Engine Service Connector located on the engine.

The engine diagrams below can aid you.

LOCATING THE ENGINE SERVICE TOOL CONNECTOR

On each Diagram is a list of components and guidelines to their location. Locate the *CIRCLE* and *number*. This is the location of the *Engine Service Connector*. It should guide you to the actual placement of the connector on the engine. See the sample engine diagram below (Figure 1-9 on page 28).

SAMPLE ENGINE

Locating the CDL connector in the diagrams below. A dark circle around a number indicates the CDL connector location as illustrated in Figure 1-9, see the red circled example.

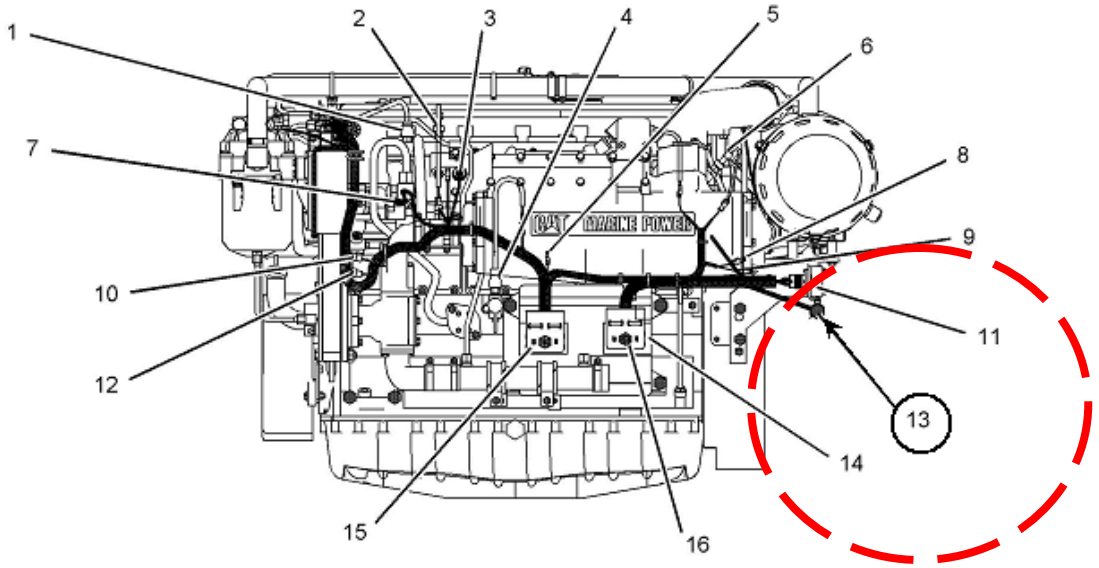
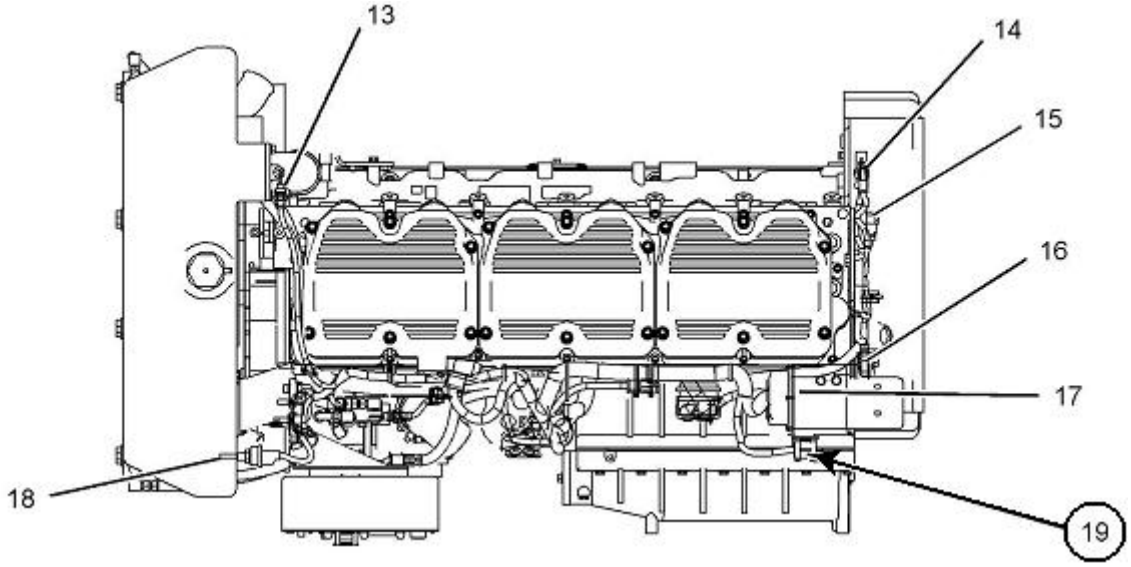


Figure 1-9 Engine Service Connector example

C18 ENGINE

On the C18 the service tool connector is identified as #19.



(13) Coolant temperature sensor

(14) Connector for the transmission oil

(15) Connector for the transmission oil sensor pressure sensor

(16) Timing calibration probe connector

(17) Customer Connector

(18) Coolant level sensor

(19) Service tool connector

Figure 1-10 Component Locations (typical example)

C175 ENGINE

The C175 locomotive engine has an electrical control box mounted in the front of the engine shown in Figure 1-11, circled in red.

The service tool connector is located on the left side of this electrical box Figure 1-12.

NOTE: Some locomotive models may not provide this connection at this location. This ENGINE CDL connector will be located near the LOCO CDL connector. For the correct placement of the LOCO connector see the trouble shooting guide for that locomotive.

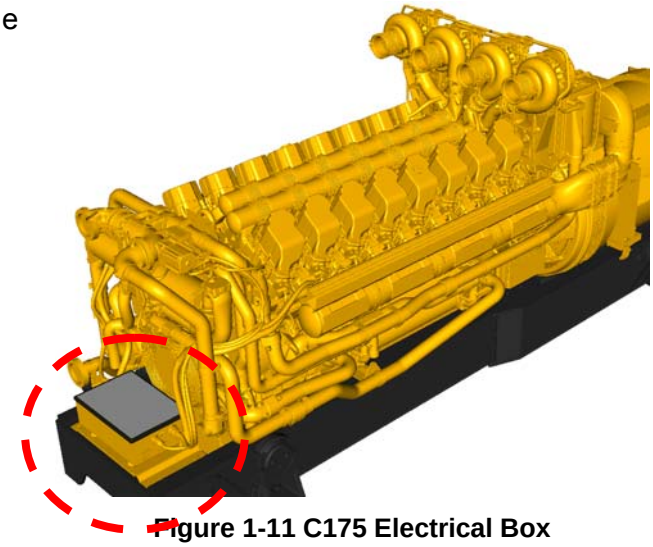


Figure 1-11 C175 Electrical Box

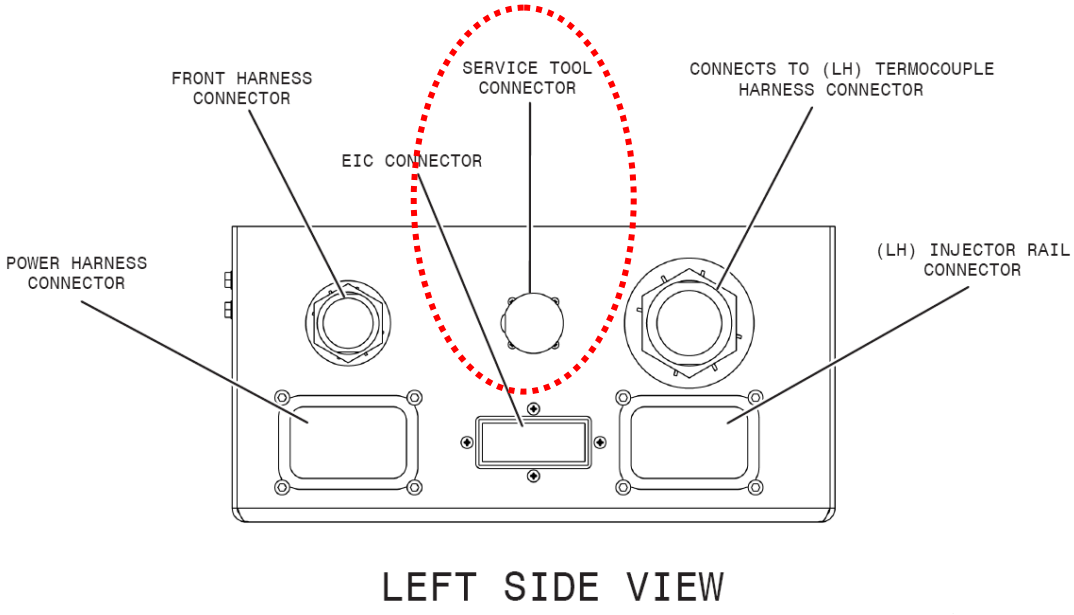


Figure 1-12 C175 Service tool Connection

3516 ENGINE – CDL CONNECTOR

The Engine connector for CDL is located in the front of the 3516 engine just right of the ECM, Figure 1-13.

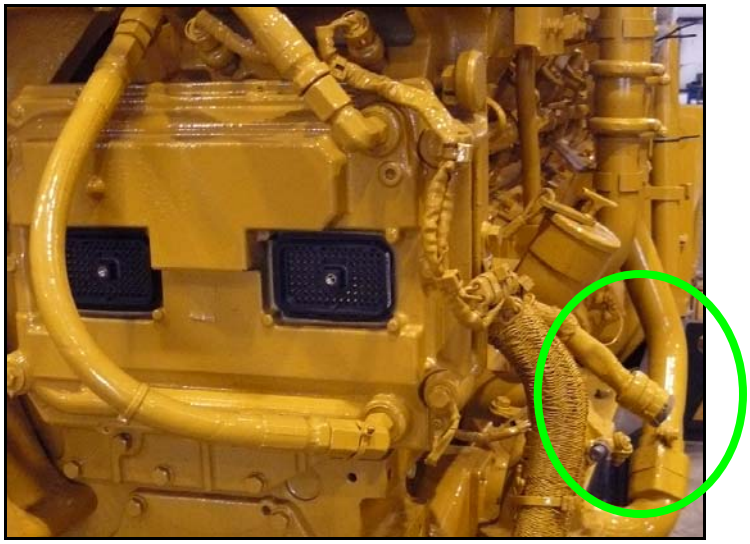


Figure 1-13 3516 CDL Connector

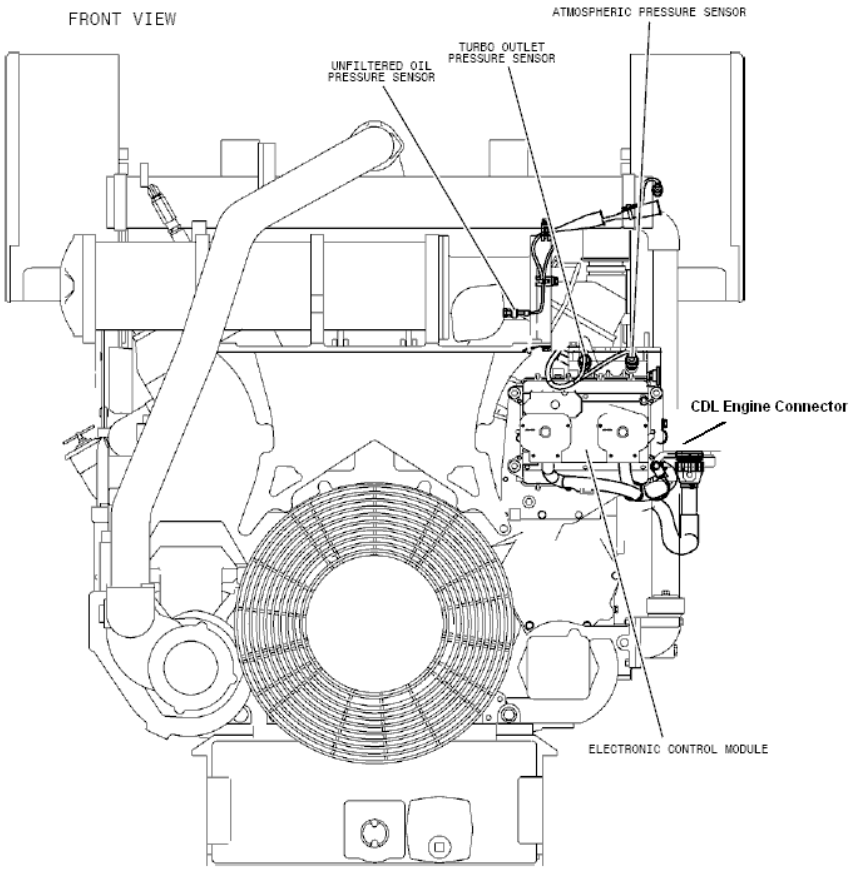


Figure 1-14 3516 Front View

ETHERNET AND LAN CONNECTION OPTIONS

The Ethernet and LAN connections show here are for reference only, however, these can be used for other situations (Figure 1-15 and Figure 1-16).

NOTE: For more information on the use of these connections, refer to the CAT ET user guide.

DIRECT CROSSOVER ETHERNET CONNECTION

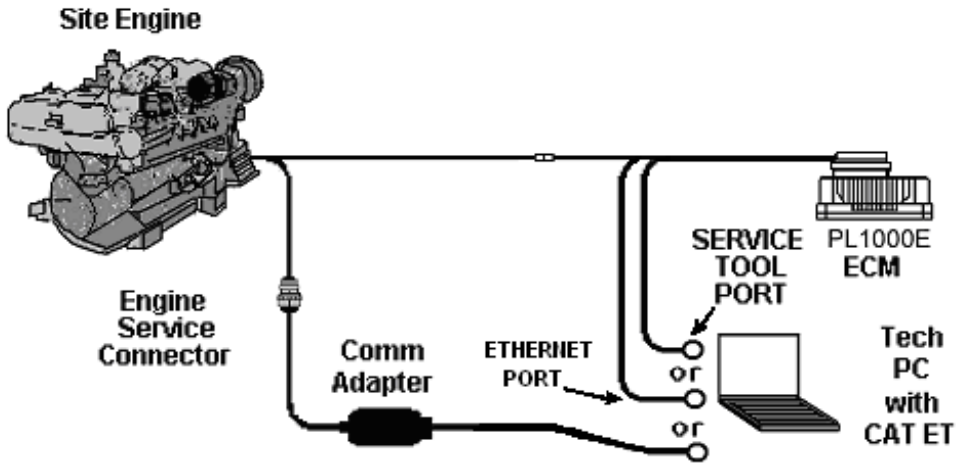


Figure 1-15 Direct Crossover Ethernet Connection

LAN NETWORK ETHERNET CONNECTION

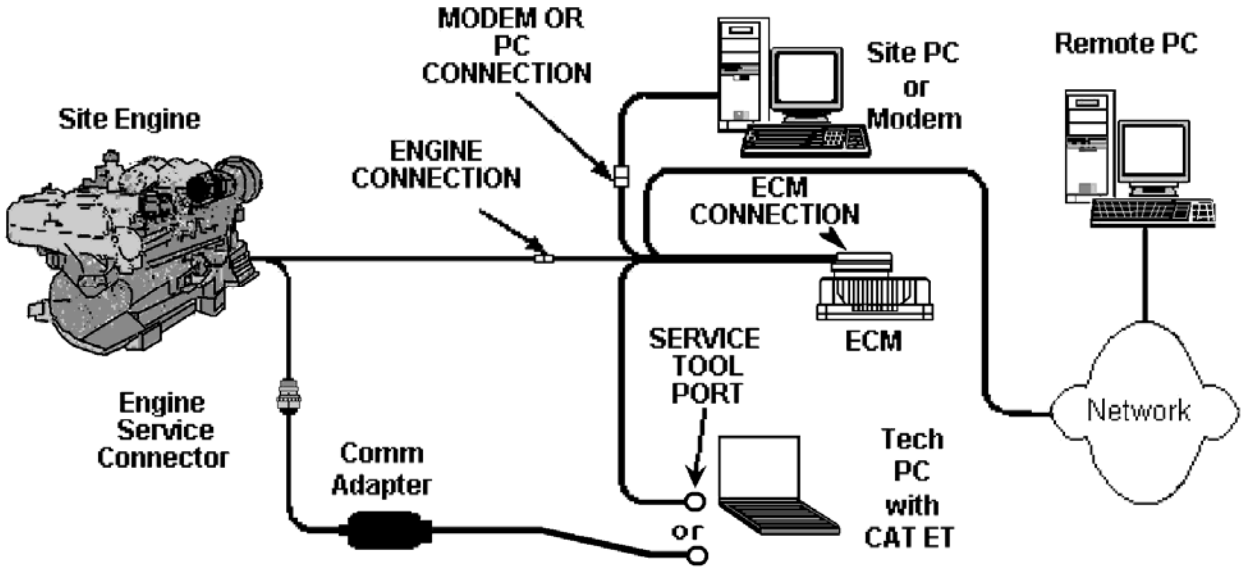


Figure 1-16 LAN Network Ethernet Connection

1.14 CONNECTING CAT ET TO A LOCOMOTIVE

NOTE: Locomotive diagnostics require version 2004B or later of the Caterpillar ET and version 2005A or later of the Caterpillar Communications Tool Kit.

CDL CONNECTIONS

Locomotives have several different location for the Cat Data Link (CDL) connectors.

In locomotives with a Low Voltage accessories console installed, they are usually located on the circuit breaker panel.

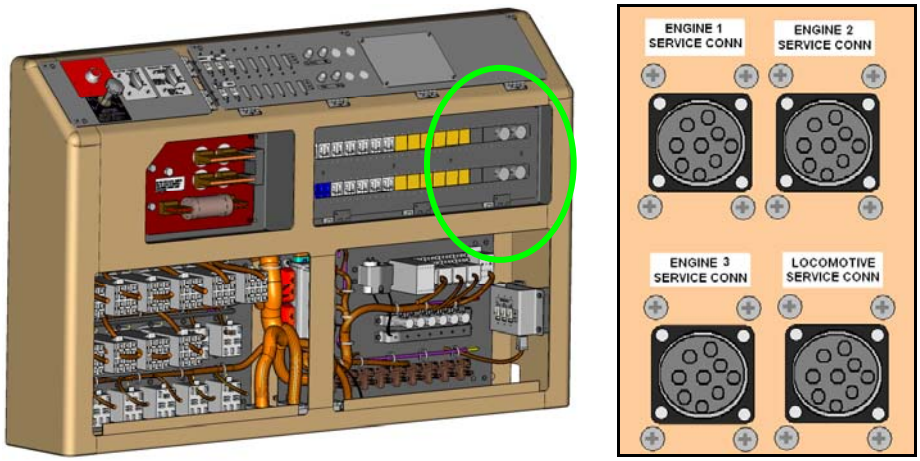


Figure 1-17 CDL LOCATIONS

Locomotive models with out a low voltage console will have the CDL connector mounted in the Electrical Locker to the rear of the locomotive cab Figure 1-18.

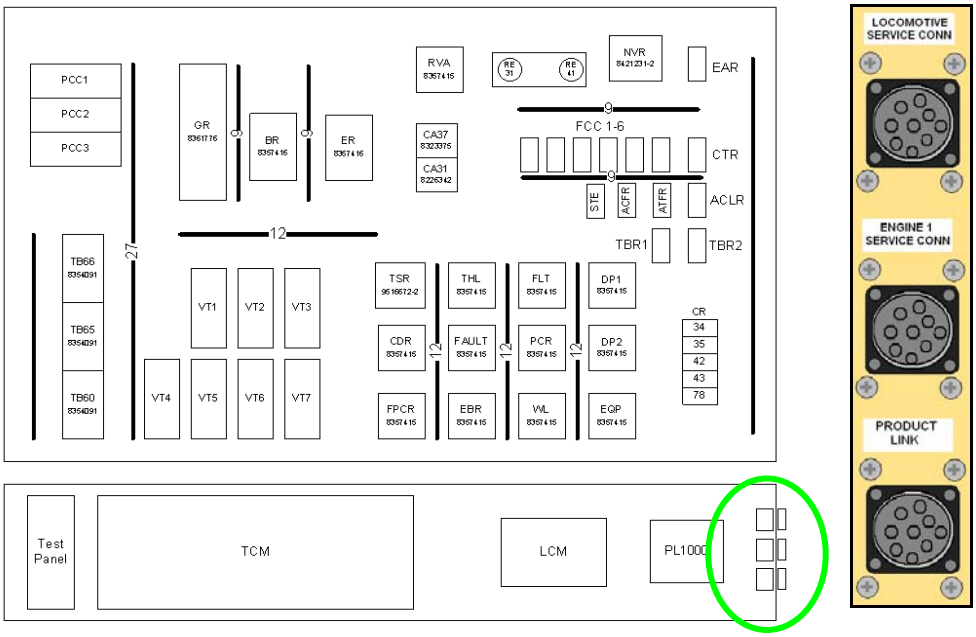


Figure 1-18 Electrical Locker CDL Connections

CDL WIRING

A schematic for the CDL wiring is provided below in Figure 1-19.

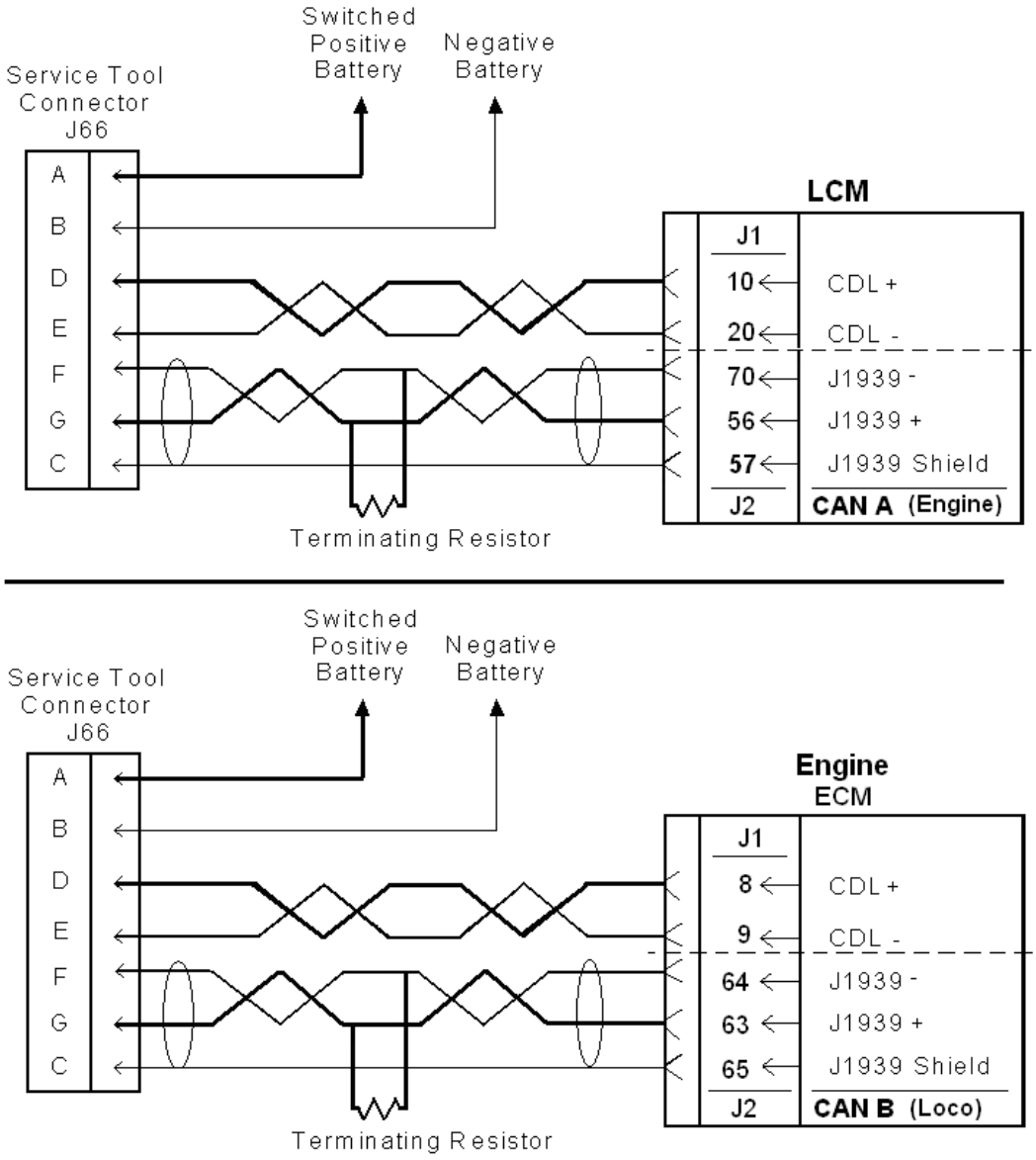


Figure 1-19 CDL Connector Schematic

NOTES:

2

2 BASIC PROBLEMS AND SOLUTIONS

This section provides some basic locomotive troubleshooting information. Many troubleshooting procedures can be performed through the Locomotive Control Module using CAT Service Tool (CAT ET). Major subsystems such as the TCM locomotive computer and electronic air brake are correlated through the Locomotive Control Module (LCM) and the CAT ET or displayed on the Color Machine Power Display (CMPD) screens (if equipped).

NOTE: CMPD equipped locomotives can access the diagnostic screens by pressing the Locomotive Data key on the CMPD Main Menu.

2.1 DIAGNOSTICS – TOOLS AND SOURCES

Locomotive faults and certain operating conditions detected by the Traction Control Module (TCM) and the Power Electronics module (PE or CPT) can be displayed automatically on CMPD (if equipped) and can be addressed through the TCM using the TCM analyzer tool, CANalyzer, Cat ET or CADet, Table 2-1.

Table 2-1 Diagnostic Conditions – Tools and Source

DESCRIPTION	TOOL	SOURCE
ENGINE REFUSES TO START		
1 Engine operation state is not "starting"	CADet	LCM
Engine Enable Switch Status In LCM	CADet	LCM
Estop Of Blue Box Status In LCM	CADet	LCM
Engine Remote Stop Is Closed	ET	ECM #_
Engine Fault Causing Shutdown	ET	ECM #_
Alt Fault	CADet	LCM
Companion Fault	CADet	LCM
Check Auxio 2 Message For Engine Start Message	CANalyzer	ECM #_
2 Engine Operation state is "starting"	CADet	LCM
Check For Engine Injection Disabled	ET	ECM #_
Check For Engine Faults	ET	ECM #_
3 Engine Cranking, But Not Starting	ET	ECM #_
Check Fuel Pressure	ET	ECM #_
Check Fuel Pump	CADet	LCM
4 Engine Not Cranking	ET	ECM #_
Check For Engine Faults	ET	ECM #_
Check For Starter Problem	ET	ECM #_
Check Starter Wiring	Meter	ECM #_
LOCOMOTIVE THROTTLE NOT RESPONSIVE	CANalyzer	Loco
Check Estop	CADet	LCM
Check Engine Run switch	CADet	LCM

Check TCM System For Communications Fault	Light	TCM
Check Blue Box Status For TCM	CADet	LCM
Check For Blue Box Notch Response On J1939 Data Link	CANalyzer	Loco
Check FPCR	Wiring	FPCR
Check For TCM Fault	CADet	LCM

NOT LOADING

Check EFS		
Check Engine Run Interlock		

ENGINE NOT CHANGING SPEED WITH THROTTLE

Check Throttle Message	CANalyzer	Loco
Check TSC1 Speed To Engine	CANalyzer	ECM #_
Engine Derated_	ET	ECM #_
Engine Faults_	ET	ECM #_
Check Priority	CADet	LCM
Check Engine Address	ET	ECM #_

AIR COMPRESSOR NOT COMING ON

	CADet	LCM
Check Air Pressure Status In LCM	CADet	LCM
Check Air Compressor Status In LCM	CADet	LCM
Check Inverter Status In LCM	CADet	LCM
Check Wiring Of Connected Inverter	Wiring	PEM
Check PEM Status	CADet	LCM
Override Air Compressor In LCM	CADet	LCM
Override Unloader Valve In LCM	CADet	LCM
Check Unloader Valve	Wiring	Compressor
Check Air Compressor Fan	Wiring	Compressor
Check Wiring Of Air Compressor Motor	Wiring	Compressor
Check Wiring Of Unloader Valve	Wiring	Compressor

TRACTION MOTOR BLOWERS NOT COMING ON

Check Traction Motor Blower Status	CADet	LCM
Check Traction Motor Currents	CADet	LCM
Check Throttle Message	CANalyzer	Loco
Check Traction Motor Blower Message	CANalyzer	Loco
Check Traction Motor Currents Message	CANalyzer	Loco
Check PEM Status	CADet	LCM
Check Inverter Status	CADet	LCM

Check J1939 Locomotive Network	CANalyzer	Loco

FUEL PUMP NOT WORKING

Check Fuel Pump Stat	CADet	LCM
Check Engine Stat	CADet	LCM
Check Wiring		

2.2 LOCOMOTIVE PROBLEMS

The following are basic problems that can occur with the electronic systems.

For more detailed diagnostics, see the Section 8: DIAGNOSTIC CODES on page 96.

PROBLEM: NO ELECTRICAL POWER

POSSIBLE CAUSE	SOLUTION
Battery knife switch open	Close battery knife switch.
No battery power.	Check batteries, cabling, and connections.
Open circuit breakers	Close circuit breakers.

PROBLEM: NO CMPD SCREENS

POSSIBLE CAUSE	SOLUTION
CAB DISP circuit breaker open.	Close circuit breaker.
Battery knife switch open.	Close battery knife switch.
No battery power.	Check batteries, cabling, and connections.

NOTE: No other locomotive crew-performed procedures are permitted for this system.

PROBLEM: ENGINE WON'T CRANK OR START

POSSIBLE CAUSE	SOLUTION
Starting fuse blown.	Replace fuse.
ENGINE CONTROL breaker is open.	Close breaker.
Low battery voltage.	Select the Air start mode only from the CMPD screen.
Absent or low air pressure.	Couple to other locomotive, hook up MR Equalizing line, then pump up main reservoirs.

PROBLEM: ENGINE CRANKS, BUT WON'T START

POSSIBLE CAUSE	SOLUTION
FUEL INJECTION switch is open.	Cycle the Engine Control circuit breaker.
Fuel system does not prime.	Close FUEL PUMP breaker.
Insufficient fuel.	Add fuel to tank.
Active EACH ECM fault.	Set FUEL INJECTION switch in STOP, then in RUN.

PROBLEM: LOCOMOTIVE WON'T LOAD

POSSIBLE CAUSE	SOLUTION
REVERSER HANDLE IS CENTERED message	Set reverser in Forward or Reverse.
NO LOADING message	If both TCCs (inverters) are cut out - try cutting one back in.
GEN. FIELD switch is Off (Down).	Set switch On (Up).
GROUND RELAY LOCKED OUT message	15 seconds after a ground occurs, TCM automatically resets the ground relay. TCM will reset GR twice more within a 5 minute period, then lock it out. Once GR locks out, it must be reset through the Locomotive Control Module - Locomotive Data function.
NO LOAD - PCS OPEN message, penalty or emergency brake application.	Set throttle in IDLE. Set independent brake in FULL and set automatic brake handle in EMER (emergency), wait 60 seconds, then set automatic brake handle in Release (REL). If air brakes do not recover, cycle AIR BRAKE breaker, then try to recover again.

PROBLEM: LOCOMOTIVE WON'T LOAD FULLY

POSSIBLE CAUSE	SOLUTION
REDUCED LOAD-TH6 LIMIT message: Clogged air filters or hot engine.	Try to reset.
REDUCED DYNAMIC BRAKE - GRID OVERCURRENT message.	Reduce dynamic brake handle setting immediately. Reset fault through Locomotive Control Module. If fault occurs again, cut out dynamic brake with the DYNAMIC BRAKE switch on the Engine Control Panel.

PROBLEM: ENGINE SHUT DOWN

POSSIBLE CAUSE	SOLUTION

NOTE: The EACH ECM system computer sends some of the following messages to the TCM locomotive computer. They will display on the Locomotive Control Module Locomotive Data function.

ENGINE SHUTDOWN - ENGINE OIL PRESSURE	Check engine oil level. **If oil level is too high, do not attempt to restart.** If oil level is OK, and strong smell of diesel fuel is not present, cycle FUEL INJECTION switch, then attempt to restart. If strong smell of diesel fuel is present, **do not attempt to restart.** If engine shuts down again for same problem, do not attempt another restart.
NO LOAD - ENGINE PROTECTION SHUTDOWN	Cycle ENGINE CONTROL breaker, then try

POSSIBLE CAUSE	SOLUTION
	restarting engine.
ENGINE SHUTDOWN - ENGINE OIL TEMPERATURE	Cycle ENGINE CONTROL breaker, then try restarting engine.
ENGINE SHUTDOWN - ENGINE CRANKCASE PRESSURE	Do NOT reset until qualified personnel have performed an engine inspection.
ENGINE SHUTDOWN - ENGINE COOLANT PRESSURE	Check coolant level. Cycle ENGINE CONTROL breaker, then try restarting engine.

PROBLEM: MISCELLANEOUS FAULT/ OPERATING CONDITIONS

POSSIBLE CAUSE	SOLUTION
Low ambient temperatures and **ENGINE SPEED INCREASE - TCC #n PREHEAT** message.	Normal operation: TCC computer requests TCM to increase diesel engine speed, which provides for greater companion alternator power for TCC heating.
ENGINE SPEED MINIMAL message	Locomotive may be isolated - set Isolation switch in RUN.
No Dynamic Brake	DYNAMIC BRAKE switch on Engine Control Panel may be in CUT OUT. Set it in CUT IN.
Speed Control fault	Reset COMPUTER CONTROL breaker, then run Speed Control Self-Test.

PROBLEM: NO CAB HEATING

POSSIBLE CAUSE	SOLUTION
Cab heater unit fan blows at all speeds and settings, but no heating	Change out unit. Unit has a two hour time-out. Turn it Off and back On to reset. Air filters are plugged Unit heats for a while, then trips breaker. Press reset button inside unit control panel (near power cables), then turn unit back on.

PROBLEM: SLIPPED PINION

POSSIBLE CAUSE	SOLUTION
Slipped Pinion Suspected	Apply independent air brakes fully. Go to throttle 1 or 2 Stall Test. Check TMRPMs on Creep Control screen. If all except one show zero, then that one pinion is slipping.

Take the following steps to avoid constant wheel slip caused by a slipped pinion: a. Disable the TCC with the defective pinion. b. Disable the Locked Wheel Detection on the locked wheel detection screen.

EMERGENCY OR PENALTY WARNING INDICATIONS/ RESET METHODS

INDICATION	RESET METHOD*
Automatic Brake Emergency	Method 1
Emer. Brake Valve Emergency	Method 1

INDICATION	RESET METHOD*
Remote Control Emergency	Method 1
Trainline Emergency	Method 2
EOT Emergency	Method 2
Overspeed Penalty	Method 3
OBC (on-board computer) Penalty (TCM/CMPD communications loss)	Method 3
Air Brake Power Up Penalty	Method 3

2.3 AIR BRAKE PROBLEMS

AIR BRAKE RESET METHODS

METHOD 1
Set automatic brake handle in EMERGENCY, then wait until the reset message appears or the fault disappears.

METHOD 2
Set automatic brake handle in EMERGENCY for 60 seconds, then move it to RELEASE.

METHOD 3
Set automatic brake handle in SUPPRESSION and hold for at least eight seconds, then return it to RELEASE.

AIR BRAKE RESET METHOD FAILURE

NOTE: If the above reset strategy is not successful, proceed as follows:

1: Cycle (Off, On) **AIR BRAKE BREAKER** on electrical control cabinet upper circuit breaker panel.

2: Set automatic brake handle in **SUP** (suppression) and hold there for **AT LEAST** eight seconds, then return it to **REL** (release).

NOTE: Once a penalty brake application is in progress, it cannot be suppressed.

If alarm bell cannot be reset or alarm recurs (possible brake system problem):

a) open AIR BRAKE breaker. Electronic air brake system back-up will provide normal trail unit brake operation.

READ THE FOLLOWING THREE WARNINGS.

⚠ WARNING

WARNING: STOPPING HAZARD
Do not, under any circumstances, permit a train to continue in operation if brake pipe air pressure falls below 45 psi. If that does happen, stop the train and recharge the brake pipe to the railroad-specified pressure. Failure to comply with this warning may result in the inability to control or stop the train.

WARNING: STOPPING HAZARD
If electronic air brake system suffers 24 Volt power loss and locomotive battery power loss while train is moving, a penalty brake application occurs at the SERVICE rate (BP pressure drops to zero). Crew may initiate an EMERGENCY brake application from the engineer's automatic brake handle, or from the EMERGENCY BRAKE VALVE on the conductor's console.

WARNING: STOPPING HAZARD
After an EMERGENCY BRAKE application, if the train is still moving, do not attempt to release brakes. Setting the automatic brake handle in REL while the train is moving may cause equipment damage and/or personnel damage.

AIR BRAKE SYSTEM OPERATING POWER IS LOST

NOTE: If electronic air brake system operating power is lost, the following occurs:

1: Alarm bell sounds. It can be silenced locally.

2: PCS opens, interrupting locomotive power. Dynamic brake operation is affected per Railroad Procedures.

3: A penalty brake application occurs and brake cylinder pressure rises to 78-80 psi, maximum.

4: Independent brake control does not operate, including the **BAIL- OFF** function.

5: The operator may reset the failure by cycling (Off, On) the **AIR BRAKE BREAKER** on the electrical control cabinet upper right circuit breaker panel.

NOTE: If locomotive is trailing in consist when electronic air brake system operating power is lost, **also note the following**:

BAIL-OFF

Bail-off is still permitted:

1: With reapplication limited due to further reductions in brake pipe pressure.

2: There is no change in air brake, power, or dynamic brake conditions.

3: Independent Brake will apply and release when commanded by the LEAD unit (limited to A&R pipe pressure.

2.4 PE BOX PROBLEMS

STEP		DESCRIPTION	SIGNAL SOURCE
A		**ENGINE ECM REFUSES TO START**	
	1	**Engine ECM oPower Electronics (PE)ration state is not "starting"**	LCM
	1.1	Engine ECM Enable Switch Status In the Locomotive Control Module	LCM
	1.2	Estop Of Locomotive Control Module Status In the Locomotive Control Module	LCM
	1.3	Engine ECM Remote Stop Is Closed	ENGINE ECM
	1.4	Engine ECM Fault Causing Shutdown	ENGINE ECM
	1.5	Alt Fault	LCM
	1. 6	Companion Fault	LCM
	1.7	Check Auxio 2 Message For Engine ECM Start Message	ENGINE ECM
	2	**Engine ECM oPower Electronics (PE)ration state is "starting"**	LCM
	2.1	Check For Engine ECM Injection Disabled	ENGINE ECM
	2.2	Check For Engine ECM Faults	ENGINE ECM
	3	**Engine ECM Cranking, But Not Starting**	ENGINE ECM
	3.1	Check Fuel Pressure	ENGINE ECM
	3.2	Check Fuel Pump	LCM
	4	**Engine ECM Not Cranking**	ENGINE ECM
	4.1	Check For Engine ECM Faults	ENGINE ECM
	4.2	Check For Starter Problem	ENGINE ECM
	4.3	Check Starter Wiring	ENGINE ECM
B		**LOCOMOTIVE THROTTLE NOT RESPONSIVE**	LOCO
		Check Estop	LCM
		Check Engine ECM Run switch	LCM
		Check TCM System For Communications Fault	TCM
		Check Locomotive Control Module Status For TCM	LCM
		Check For Locomotive Control Module Notch Response On J1939 Data Link	LOCO
		Check FPCR	FPCR
		Check For TCM Fault	LCM
C		**NOT LOADING**	
		Check EFS	
		Check Engine ECM Run Interlock	
D		**ENGINE ECM NOT CHANGING SPOWER ELECTRONICS (PE)ED WITH THROTTLE**	
		Check Throttle Message	LOCO
		Check TSC1 SPower Electronics (PE)ed To Engine ECM	ENGINE ECM
		Engine ECM Derated?	ENGINE ECM

	Engine ECM Faults?	ENGINE ECM
	Check Priority	LCM
	Check Engine ECM Address	ENGINE ECM
E	**AIR COMPRESSOR NOT COMING ON**	LCM
	Check Air Pressure Status In the Locomotive Control Module	LCM
	Check Air Compressor Status In the Locomotive Control Module	LCM
	Check Inverter Status In the Locomotive Control Module	LCM
	Check Wiring Of Connected Inverter of the POWER ELECTRONICS	PE Box
	Check POWER ELECTRONICS (PE) Status	LCM
	Override Air Compressor In the Locomotive Control Module	LCM
	Override Unloader Valve In the Locomotive Control Module	LCM
	Check Unloader Valve	COMPRESSOR
	Check Air Compressor Fan	COMPRESSOR
	Check Wiring Of Air Compressor Motor	COMPRESSOR
	Check Wiring Of Unloader Valve	COMPRESSOR
F	**TRACTION MOTOR BLOWERS NOT COMING ON**	
	Check Traction Motor Blower Status	LCM
	Check Traction Motor Currents	LCM
	Check Throttle Message	LOCO
	Check Traction Motor Blower Message	LOCO
	Check Traction Motor Currents Message	LOCO
	Check POWER ELECTRONICS (PE) Status	LCM
	Check Inverter Status	LCM
	Check J1939 Locomotive Network	LOCO
G	**FUEL PUMP NOT WORKING**	
	Check Fuel Pump Stat	LCM
	Check Engine ECM Stat	LCM
	Check Wiring	

3 CONNECTORS AND HARNESSES

This section covers component and wiring harness design requirements for the customer to design the required harnessing to interface to the engine. The pin-out information for the ECM and EIC are not included in this section, but, can be found in the Appendix B.

3.1 DT CONNECTOR

The DT connector is the preferred choice for in-line applications. The connector is available in 2,3,4,6,8 and 12 terminal configurations. It is also intended for SAE J1939 application use. The wire size range the connector will accept is 0.8 mm^2 (18 AWG), 1.0 mm^2 (16 AWG), and 2.0 mm^2 (14 AWG). The plug assembly with interface seal accepts socket terminals and the receptacle assembly accepts pin terminals. Sealing plugs are to be used in unused wire cavities.

A DT connector has a wedge that locks the pins and the sockets in place. The wedge can be removed and replaced without cutting the wires. The Wedge Removal Tool (p/n 147-6456) can be used to aid in the removal of the wedges. When the receptacle is inserted into the plug, a click should be heard as the two halves lock together. The connector should not be able to be pulled apart.

Following tables contain the Caterpillar part numbers for DT inline connector plug and receptacle kits for all available number of pin positions. The kit is comprised of the plug or receptacle and the respective locking wedge.

The connector is available with a wire seal end-cap. The end-cap is recommended for connector applications where constant exposure to fuel and engine oil is expected (i.e. fluid filter service areas, etc.). Occasional exposure to oil and fuel does not require a connector with an end-cap.

Table 3-1 Standard DT Connectors

STANDARD DT CONNECTORS		
Positions	**Cat Part Number**	
	Plug Kit	**Receptacle Kit**
2	155-2270	102-8802
3	155-2260	102-8803
4	155-2271	197-7565
6	155-2274	102-8805
8	155-2265	102-8806
12	155-2255	102-8801

Table 3-2 3 Position DT Connectors

DT CONNECTORS (All 3 Position)	
Component	Cat Part Number
Plug Kit	174-0503
Receptacle Kit	176-9299
Plug Resistor	174-3016
Receptacle Kit	134-2540
Receptacle Tee	133-0970

The connector has also been configured for bulkhead mountings and integral component applications (e.g. lamp housing, engine sensor, etc.). Terminal configurations and mounting configurations vary for these applications.

3.2 DEUTSCH HD CONNECTORS

This circular connector is used for inline and bulkhead applications, Figure 3-1. It is more expensive than other connector choices but easier to adapt to wire harness conduit applications (i.e. CSA, Marine, etc.). The connector is available in 3,6, and 9 terminal configurations.

The wire size range the connector will accept is 0.8 mm^2 (18 AWG), 1.0 mm^2 (16 AWG), and 2.0 mm^2 (14 AWG), and 3.0 mm^2 (12 AWG).

Table 3-3 HD Connectors

HD CONNECTORS		
Positions	**Plug Kit**	**Receptacle Kit**
3	8T-8731	8T-8732
6	8C-3654	7T-3272
9	8T-8735	8T-8736

NOTE: Interface sealing caps and wire strain relief(s) are available for the connectors. Contact the local Deutsch sales contact for more information on these components.

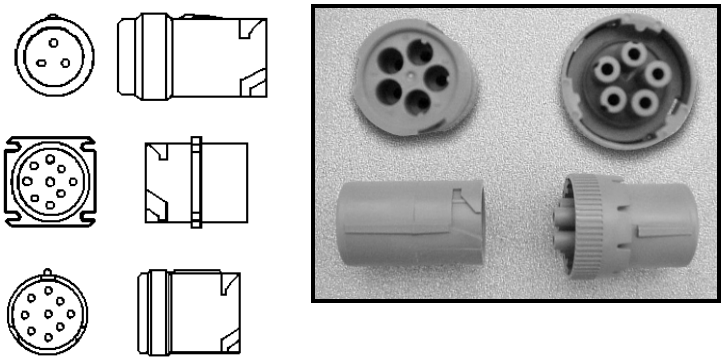


Figure 3-1 HD Connectors

The plug assembly with interface seal accepts socket terminals and the receptacle assembly accepts pin terminals. Sealing plugs are to be used in unused wire cavities.

Ensure that the wires in the plug align with the corresponding wires in the receptacle. Ensure that the index markings on the plug and the receptacle are aligned. Rotate the plug until the plug slips into the receptacle. Rotate the coupling by approximately 90 degrees until a click is heard. Ensure that the plug and the receptacle cannot be pulled apart.

Table 3-3 HD Connectors contains the Caterpillar part numbers for HD inline connector plug and receptacle for all available number of pin positions. Most common usage for the HD connector is the 9 position connector used for the Cat Service Tool interface.

3.3 AMPSEAL CONNECTORS

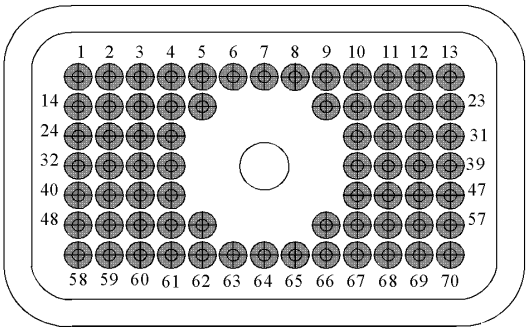


Figure 3-2 70 Pin Harness Connector (J1)

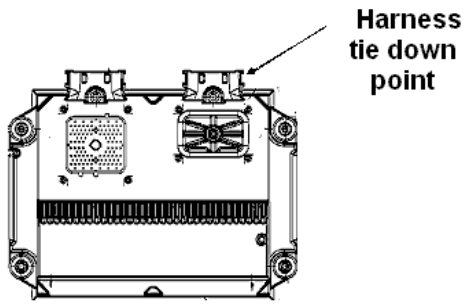


Figure 3-3 LCM Harness Tie Down Points

70 PIN CONNECTOR (J1)

The ECM uses an integral rectangular 70 pin Deutsch connector,

Figure 3-2 on page 45, to interface to the OEM vehicle wiring harness (Caterpillar part number 160-7689). ECM Connector Screw torque should be 6 N•m ±1 N•m (4.4 lb.- ft. ± 0.7 lb.- ft., 53 lb. - in. ± 8.9 lb. - in.).

HARNESS TIE DOWN POINT

The LCM has a harness tie-down point mounted to the outer LCM frame. A flexible strap may be employed to secures the OEM harness to this bracket, Figure 3-3. The use of this bracket requires a different harness dress cover called an End Bell.

CONNECTOR END-BELL

A Deutsch connector (Caterpillar part number 237-0336) Connector End-bell is available to provide additional protection and controlled wire routing for the harness at the LCM. This is a new part number for the A4 control.

70 PIN CONNECTOR SEALING (WEATHERPROOFING)

The LCM Connector Interface seal is serviceable using Caterpillar part number 159-9322, Figure 3-4.

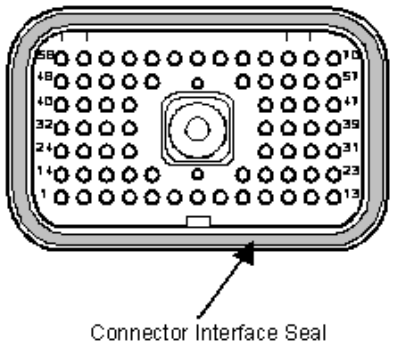


Figure 3-4 Connector Sealing

AMPSEAL CONNECTORS AND TOOLS

on page 47 provides the Standard Ampseal Connectors, Positions, Keys, and Part Numbers list.

Table 3-5 on page 47 provides the tools list needed to add wires to these connectors.

NOTE: Refer to Tool Operating Manuals SEHS9615-03, Servicing Deutsch HD and DT Style Connectors and NEHS0950, Using the 270-5051 Amp ATAC.

CONNECTOR TERMINALS

The terminals available for production use are stamped and formed, or machined. The lowest cost terminal option is stamped and formed. Machined terminals are also used for field repair. Terminals are available with nickel or gold plating.

Table 3-4 Ampseal Position, Key, Part #

STANDARD AMPSEAL CONNECTORS			
Positions	Key	Cat Part Number	
		Plug	Receptacle
2	1	230-4011	230-4012
2	2	238-8245	238-8246
2	3	238-8247	238-8248
2	4	281-8801	281-8802
3	1	230-4013	230-4014
3	2	237-0227	237-0228
3	3	281-8803	281-8805
3	4	281-8804	281-8806
4	1	230-5008	230-5009
4	2	239-7349	239-7350
4	3	281-8807	281-8809

Gold plating should be used for applications of 5 volts or less and/or less than 100 milliamps. Typically these low level circuits require low resistance at the pin/socket connection and gold plating is the best low cost choice. Nickel plated terminals can be used in power type circuits or circuits where low resistance at the pin/socket connection is not a concern,
Table 3-6.

CAUTION

Deutsch nickel-plated stamped and formed terminals are not recommended for use because of excessive voltage drop experience in laboratory tests.

4	4	281-8808	281-8810
6	1	230-5010	230-5011
6	2	239-7352	239-7353
6	3	281-8811	281-8812
8	1	231-2295	231-2300
8	2	231-2296	231-2301
8	3	231-2297	231-2302
8	4	231-2298	231-2303
12	1	230-4009	230-4010
12	2	239-7356	239-7357
12	3	241-8834	241-8835
12	4	281-8813	281-8812

3.4 WIRE TYPE AND GAUGE

Table 3-5 Ampseal Tools Needed

TOOLS NEEDED	
Wedge Removal Tool	147-6456
Crimp Tool	1U-5804
Ampseal Service Kit	270-5051

WIRE SELECTION

- Typical factors to be considered in the selection are voltage, current, ambient temperature, mechanical strength,
  connector sealing range, abrasion, flexure and extreme environments such as areas or locations susceptible to significant fluid concentrations.
- Wire must be of a type suitable for the application.

Wire must be selected so that the rated maximum conductor temperature is not exceeded for any combination of electrical loading, ambient temperature, and heating effects of bundles, protective braid, conduit and other enclosures.

Table 3-6 Connector Terminal Specifications

CONNECTOR TERMINAL SPECIFICATIONS				
AWG - Type	**Contact**	**Type**	**Plating**	**Cat P/N**
ECM Connector (J1)				
#16/ #18 - SXL and #14/#16/#18 - GXL	Socket	Stamped & Formed	Gold	126-1766
#14 - All	Socket	Machined	Gold	126-1768
#16/ #18	Socket	Machined	Gold	9X - 3402
HD/DT Connector (Standard)				
#14	Socket	Machined	Nickel	9W-0844
#14	Pin	Machined	Nickel	9W-0852
#16/ #18	Socket	Machined	Nickel	186-3736
#16/ #18	Pin	Machined	Nickel	186-3735

CONNECTOR TERMINAL SPECIFICATIONS				
AWG - Type	**Contact**	**Type**	**Plating**	**Cat P/N**
#14	Socket	Machined	Gold	126-1768
#14	Pin	Machined	Gold	126-1767
#16/ #18	Socket	Machined	Gold	9X-3402
#16/ #18	Pin	Machined	Gold	9X-3401
DT Connector (J1939 only)				
#16/#18 (J1939)	Socket (extended)	Machined	Gold	133-0969
#16/#18 (J1939)	Pin (extended)	Machined	Gold	133-0967

WIRE SIZE

The minimum conductor size used on caterpillar products is 0.8 mm2 (18 AWG). Smaller conductors are susceptible to breakage and fatigue failures.

SAE J1614, wiring distribution systems for construction, agricultural, and off-road work machines require wire sizes no smaller than 0.8 mm2 (18 AWG). ECM wire size requirements per connection are shown in Table 3-7.

Table 3-7 Wire Sizes

WIRE SIZES	
Circuit	**Size (AWG)**
Battery Negative	14
Positive Battery: Switched	14-18
Positive Battery: Un-switched	14
Digital Sensor Power	16-18
Digital Sensor Return	16-18
Analog Sensor Power	16-18
CAT Data Link (1)	18
J1939 (CAN) Data Link (2)	18
Switch to Ground	16-18
Low Side (300 mA) Driver	16-18
High Side (2 A) Driver	14-16
(1) 143-5018 Cable (Twisted Pair)	
(2) 153-2707 Cable (Shielded Twisted Pair)	

WIRE INSULATION

Thermoplastic polyvinyl chloride (PVC) insulation shall not be used in wire harness designs because of its low operating temperature range (-40 to 85°C), melt characteristics, and flammability characteristics.

Cross Linked Polyethylene (XLPE) is the primary wire insulation type used in chassis, cab, and engine compartment locations. It has a temperature rating of –50 to 120°C.

The voltage rating for Caterpillar 1E0815 wire and SAE J1128, Type SXL is 50 volts. The circuit voltage shall be considered when making wire selections. This wire insulation is also available with 50, 150, 300, or 600-volt ratings. The outside diameter range of the insulation is 0.089 to 0.131 in. (2.26 to 3.33 mm).

The Table 3-8 provides insulation diameter range for each gauge and wire type.

Table 3-8 ECM Wire Gauges

ECM CONNECTOR WIRE INSULATION AND GAUGE SIZE							
Wire Type	**Wire Gauge**			**Insulation Diameter**			
GXL	14			0.114 – 0.125			
	16			0.098 – 0.112			
	18			0.089 – 0.098			
SXL	16			0.116 – 0.131			
	18			0.103 – 0.118			
Metric Equivalents For AWG Wire Numbers							
AWG	20	19	18	16	14	12	4
Diameter (mm^2)	0.5	0.65	0.8	1	2	3	19

3.5 CONNECTOR SEAL PLUGS

All unused cavities for sockets and pins must be filled with Seal Plugs in order to ensure that the connector is sealed. Two options are available for plugging unused connector cavities. Either the Deutsch 114017 (Caterpillar part number 8T-8737) or PEI Genesis 225-0093-000 (Caterpillar part number 9G-3695) sealing plugs can be used.

The seal plugs are installed from the wire insertion side of the plug or receptacle. Correct installation of either of these cavity plugs is critical to maintain connector seal integrity. Figure 3-5 illustrates the correct insertion of the plug. The seal plug cap is designed to rest against the seal, not inserted in the hole in the seal.

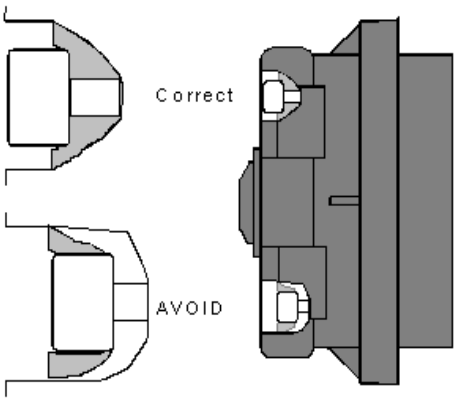


Figure 3-5 Plug Insertion

3.6 WIRING HARNESS DESIGN

HARNESS ROUTING

Wiring shall be routed to ensure reliability and to offer protection from the following:

Refer to Cat Publication - Guidelines For Routing And Installing Wire Harness Assemblies SEBD0402-00.

- Chafing/rubbing/vibrating against other parts
- Use as handholds or as support for personal equipment
- Damage by personnel moving within the vehicle
- Damage by impact, thrown or falling debris
- Damage by battery acid fumes, engine and hydraulic oil, fuel, and coolant
- Abrasion or damage when exposed to rocks, ice, mud, etc

- Vandalism damage (to the maximum extent practicable)
- Damage by moving parts
- Harsh environment such as nitrite mines, high temperatures, or areas susceptible to significant fluid or fume concentration

CAUTION

Wire harnesses shall not be located in close proximity to oil and fuel fluid fill areas or below fuel and oil filter locations. If these locations cannot be avoided then additional protective covers and shields must be provided to protect the harness.

Harnesses shall be located a minimum of 50 mm from high heat sources (e.g. exhaust manifolds, turbo chargers, hydraulic components, etc.) to avoid insulation and/or connector deterioration.

MAINTENANCE CONSIDERATIONS

The maintainability of the wiring system shall be an important consideration in the selection, design and installation of harnesses, cable assemblies and other wiring system components.

All wiring components shall be accessible, repairable, and replaceable (i.e. connector terminals).

High-pressure wash systems are now in frequent use by maintenance people.

When locating electrical connectors:

- Place them in accessible locations.
- Use other physical elements for protection and prevention of direct exposure to wash systems (e.g. Brackets, housings, sheet metal structure, etc.).
- Where direct exposure to high-pressure wash systems cannot be avoided, use protective shields. These shields will need to be designed and installed.

HARNESS BENDS

If the harness curvature is too close to the connector be sure the connector seals are not stressed. This applies to the routing of:

- Customer lines on or near the engine harness.
- ECM Customer Connector (J1/P1)

RADIUS BENDS

The minimum bend radius for a braided wire harness, as measured from the inside of the bend, shall be four times the outer diameter of the harness. Tighter bends are possible if the bend is preformed during harness manufacture. The bend radius size and location must be specified on the wire harness drawing.

JACKETED CABLE BENDS

Bends in jacketed cables shall be based on the manufacturer recommendations. A bend must not adversely affect the operating characteristics of the cable. For flexible coaxial

cables, the bend radius must not be less than six times the outside diameter. For semi-rigid coaxial cable, the bend radius must not be less than ten times the outside diameter of the cable.

FLEXIBLE CONDUIT BENDS

The minimum bend radius for flexible conduit must be six times the outer diameter of the conduit. Conduit bends shall not cause internal chafing of the wiring.

HARNESS BENDS (AT CONNECTORS)

Avoid wire harness bends within 25 mm (10 in) of the connector. When a harness bend is too close to the connector, the connector seal is stretched away from the wire, providing an opening for moisture entry. The wire should exit perpendicular to the connector before curving as necessary for routing, Figure 3-6.

BENDS NEAR A CONNECTOR

Wire harness bends near a connector must be no less than twice the wire harness diameter. Special consideration shall be given to connectors with large wire counts. Stresses placed upon the retention system of the connector can cause contact retention failures and wire pull out. In order to avoid this problem consider the following options:

- Pre-form the harness to the required bend.
- The harness assembly drawing shall detail the harness bend requirements (e.g. location and radius).

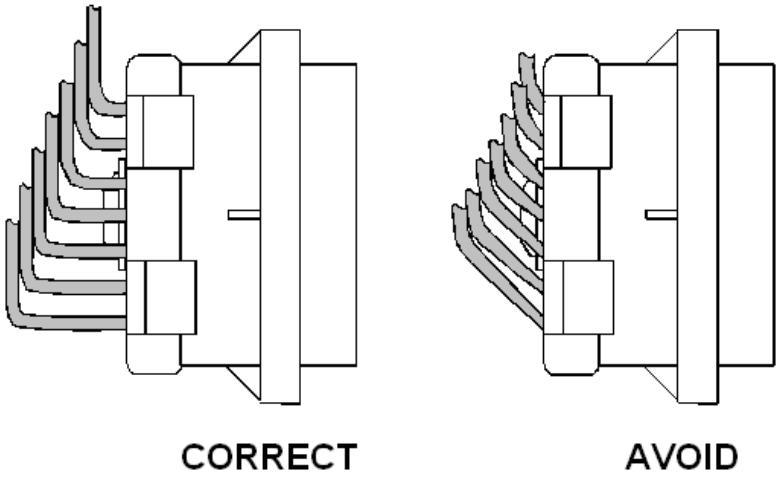


Figure 3-6 Example of Wire Harness Routing at the ECM Connector

- The harness braid protection should be applied up to the tangent point of the bend furthest from the connector.
- Connector orientation to the bend may be necessary and should be specified on the harness print.

- If harness braiding is used
- Increase the unbraided harness length to 150 mm. This will allow the wires to fan out when the harness is bent, greatly reducing the forces placed on the connector contact retention system.
- The connector should also be oriented properly with respect to the harness so that upon installation to the product the harness will not need to be twisted to align the connector.

DRIP LOOP

When a harness is routed downward to a connector, terminal block, panel, or junction box, a trap or drip loop shall be provided in the harness. This feature will prevent fluids or condensate from running into the above devices.

SEALING SPLICES AND RING TERMINALS

CATERPILLAR REQUIRES ALL RING TERMINALS AND SPLICES CONNECTED TO THE ENGINE ECM BE SEALED USING RAYCHEM ES2000 ADHESIVE LINED HEAT SHRINK TUBING OR EQUIVALENT.

Table 3-9 on page 52, below, shows heat shrink tubing sizing information.

Table 3-9 Heat Shrink Tubing Reference Table

HEAT SHRINK TUBING REFERENCE TABLE				
Cat Part Number	I.D. Before Shrink		I.D. After Shrink	
	(mm)	(inch)	(mm)	(inch)
8T-6342	3.20	0.126	1.58	0.062
3E-9553	4.70	0.185	1.78	0.070
125-7874	5.72	0.225	1.27	0.050
9X-2109	6.40	0.252	3.20	0.126
125-7875	7.44	0.293	1.65	0.065
119-3662		0.427	2.41	0.095
125-7876	17.78	0.700	4.45	0.175
8C-3423	68.00	2.678	22.00	0.866

3.7 WIRE CONNECTION CRIMP GUIDELINES AND TOOLING

WIRE CRIMP GUIDELINES

Use Table 3-10 and the following requirements to ensure the correct installation of terminals in the connectors:

- Do not solder the sockets and pins to the wires.
- Never crimp more than one wire into a socket or a pin. Connector pins and sockets are designed to accept only one wire of a specified gauge or gauge range.

- Do NOT insert multiple wires of a smaller gauge.
- All sockets and pins should be crimped on the wires. Use the Crimp Tool (Caterpillar part number)1U-5804 for 12 to 26 AWG wire.
- Perform the pull test on each wire. The pull test is used to verify that the wire is properly crimped in the terminal and the terminal is properly inserted in the connector. Each terminal (socket or pin) and each connector should easily withstand 45 N (10 lb) of pull and each wire should remain in the connector body.

WIRE CONNECTION CRIMP TOOLING

Insulation barrel crimp height for AMP 776093-1 stamped and formed sockets must be set according to the insulation diameter. Crimp width for all insulations is 0.145 inches maximum.

Table 3-10 Crimp Tool Specifications

CRIMP TOOL SPECIFICATIONS				
Crimp Tool Options	**DIE**	**Locator**	**Go (inches)**	**No-Go (inches)**
Deutsch Hand Tool HDT-48-00	N/A	N/A	0.045	0.50
Pico Model 400	414DA- 16N	4301-16	0.043	0.050

3.8 SERVICE TOOL CONNECTOR WIRING

SERVICE TOOL CONNECTOR PIN-OUTS

Figure 3-7 illustrates the pin-out location on the Deutsch HD 9 position connector for ease of reference. Wiring from the ECM to the Service Tool Connector is illustrated in Figure 3-8. The Cat Data Link wiring should be twisted two-conductor cable (18 AWG wire) with one twist per 25 mm (approx. 1 inch). Reference Caterpillar service tool cable (part number 143-5018). See Figure 3-8 for J1939 Data link wiring requirements.

- EPG Engine communication to Cat ET is via Cat Data Link (CDL) and the J1939 Data Link.

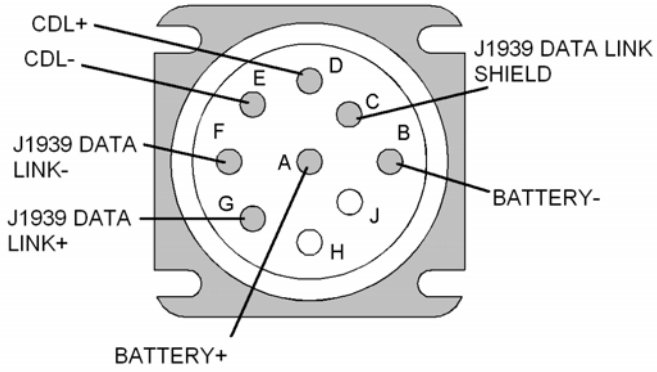


Figure 3-7 Service Tool Connector Pin Locations

SERVICE TOOL WIRING SCHEMATIC

The service tool wiring diagram is shown in Figure 3-8. Refer to the locomotive troubleshooting guide for the correct wiring of the specific locomotive.

TERMINATING RESISTOR

NOTE: A Terminating Resistor is required unless; the OEM is installing an OEM J1939-11 backbone, Figure 3-8 and Figure 3-10 on page 56.

3.9 CAN DATA LINK HARNESS DESIGN

The data link connector that Caterpillar uses is a modified DT connector, special wedge, cable, and extended socket. The harness assembly requirements are unique to typical Caterpillar wire harnesses, Figure 3-9. Caterpillar recommends 2 conductor shielded cable from Raychem Corp (Raychem part number 2019D0309-0 / Cat part number 153-2707) for all J1939 Data Link wiring. This is twisted pair wiring.

If the Caterpillar recommended cable is not used, the cable must meet J1939 specifications for conductors (refer to Table 3-11). For additional information regarding the electrical system design see the SAE publication J1939/11 Physical Layer. The minimum bend radius for the data link cable is 40 mm.

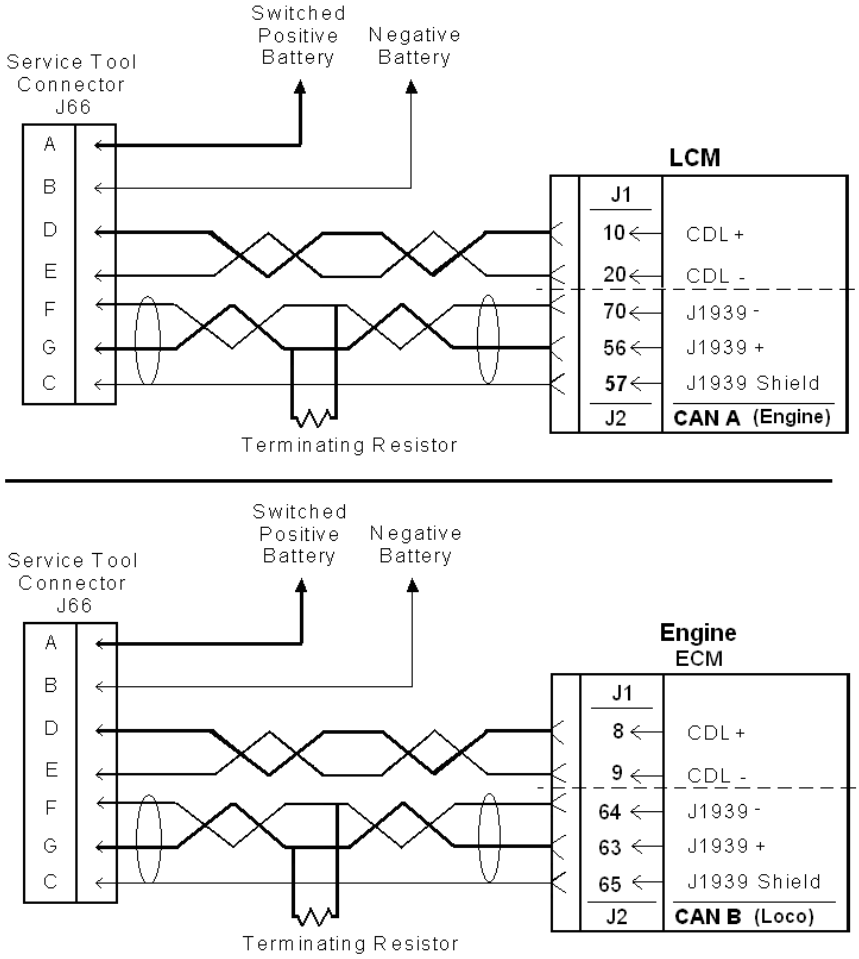


Figure 3-8 Service Tool Connector - Wiring Diagram

Table 3-11 J1939 Conductor Specifications

J1939 SPECIFICATIONS FOR CONDUCTORS			
Description	**Minimum**	**Nominal**	**Maximum**
Impedance (ohm)	108	120	132
Capacitance between conductors (pF/m)	0	40	75
Capacitance between conductors and shield (pF/m)	0	70	110

ASSEMBLING THE CONNECTOR

For proper data link function, identify the J1939 connector on the customer wire harness print, Figure 3-9.

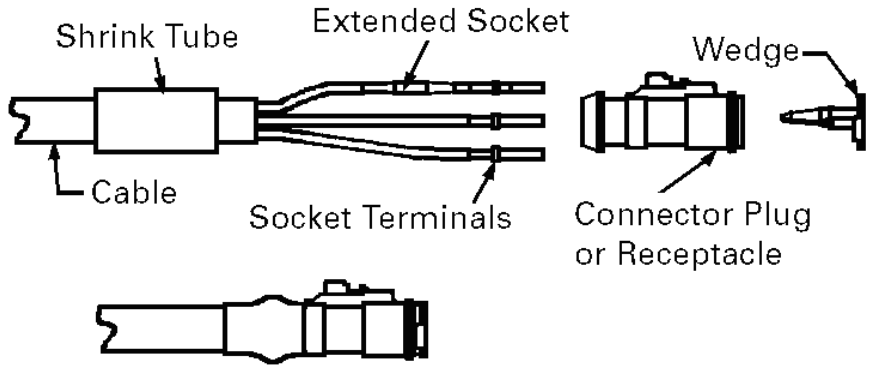


Figure 3-9 SAE J1939 Connector Assembly

THE FOLLOWING STEPS MUST BE USED:

1. Remove 75 mm of the outer jacket of Data Link shielded cable. (Reference Cat part number 153-2707)
2. Remove the foil shield from the exposed wires to within 3 mm of the cable jacket end.
3. Crimp gold plated socket terminals to the wires and the extended socket terminal to the drain wire.
4. Slide heat shrink tube over the cable end. (Reference Cat part number 125-7876)
5. Install the terminals into the appropriate connector cavity positions.
6. Install the wedge into the connector.
7. Apply the heat shrink tube over the back of the connector body and the jacket of the cable.

CAUTION: The above components and assembly procedures must be used to insure the cable to connector joint will be sealed. Failure to conform to these requirements will result in cable contamination and result in loss of shield performance. (See Figure 3-9).

3.10 CONNECTING MODULES TO THE CAN DATA LINK

The SAE J1939 Data Link is used to communicate engine information to an SAE J1939 compatible display or other desired SAE J1939 compatible modules.

Figure 3-10 on page 56 shows two J1939 modules properly connected to the J1939 data link

CAN DATA LINK KEY COMPONENTS

The Key components are as follows:

- The total length of the Data Link between terminal resistors must not exceed 40 m (130 ft).
- The length of each branch, or stub length, must not exceed 1 m (3.3 ft). Reference: Cable assembly that is 1m long with Deutsch DT 3 pin plug on one end (part number 165-0200) and, J1939 signal and shield wires with appropriate crimped socket on the other end for insertion into J1939 module connector.
- All splices and end nodes can be implemented using a connector tee. Reference: Deutsch DT receptacle assembly (part number 133-0970).
- Two terminal resistors must be installed. These two terminal resistors are critical for the proper operation of the network and one resistor is required at each end of the Data Link. Reference: Deutsch DT plug with termination resistor (part number 174-3016).
- One terminal resistor for the J1939 Data Link will be included in the frame harness. Any J1939 Data Link must have a terminal resistor at each end of the Data Link.
- A terminal resistor is required at the terminal ends of the Data Link cable. A terminal resistor is not required at each node on the Data Link.
- Any number of display modules or service tool connectors may be connected to the J1939 Data Link, providing the requirements for J1939 Data Link connections are met.

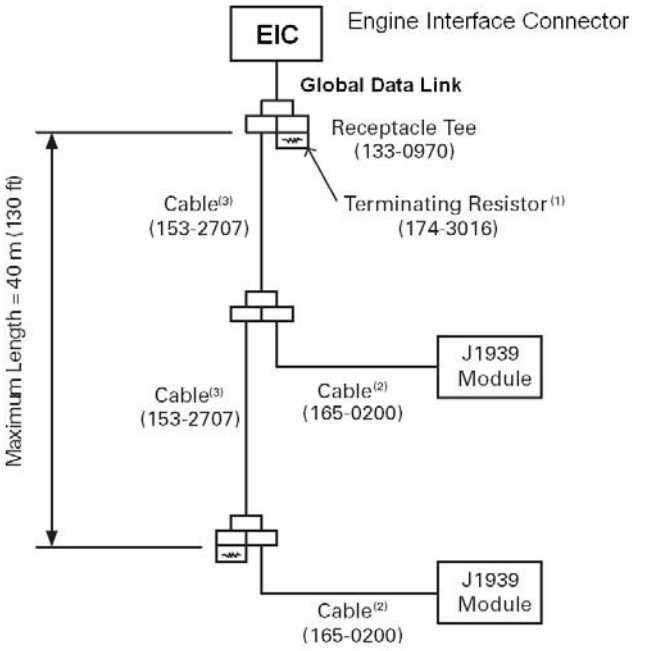


Figure 3-10 J1939 Multiple Module Installation

4 NETWORKS

The J1939 network provides internal information to devices attached to the engines, Locomotive Control Module (LCM), TCM control, the Power Electronics Module (PEM) and other devices using the serial data links of these components (Figure 4-1, page 57 and larger image on page 176).

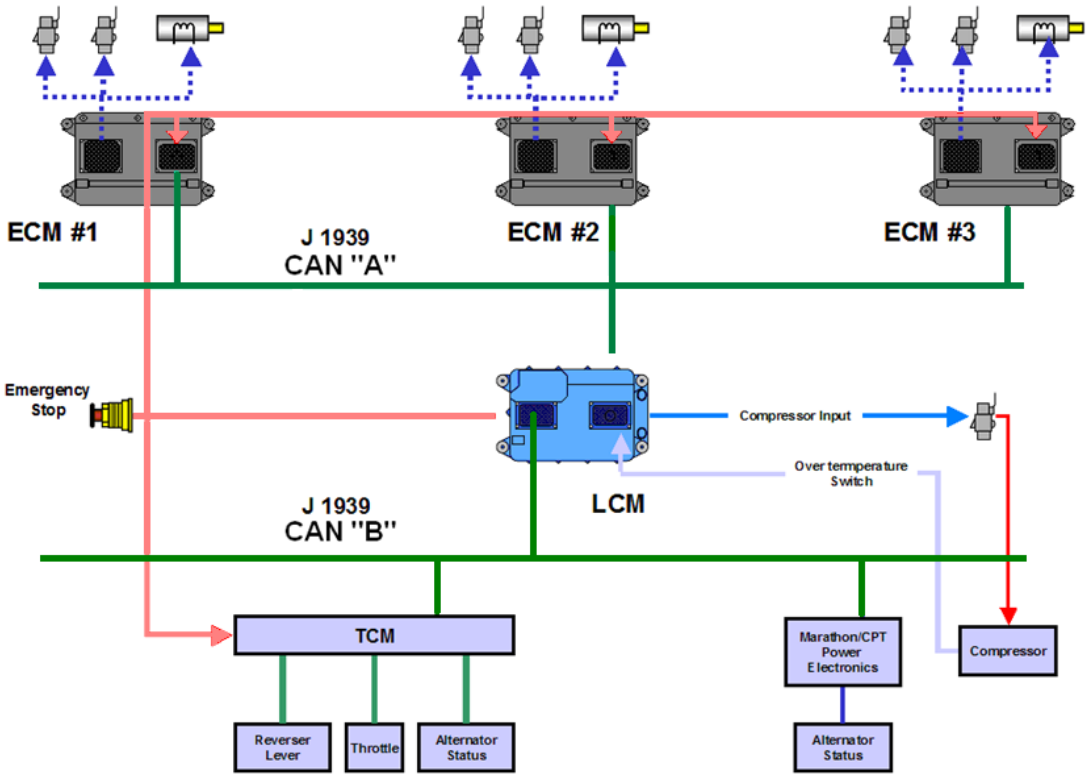


Figure 4-1 J1939 Multi-Engine Diagram

4.1 J1939 LOCOMOTIVE NETWORKS

The locomotive LCM uses two J1939 networks:

- **CAN A - ENGINE Network**
- **CAN B - LOCO Network**

CAN A ENGINE NETWORK

The CAN A ENGINE Network provides signals to and from the Locomotive Control Module (LCM) and the Engine Power Module(s) (EPM). Each EPM utilizes an onboard computer called the Engine Control Module (ECM) to monitor and adjust the EPM's engine.

CAN B LOCO NETWORK

The CAN B LOCO Network provides signals to and from the Locomotive Control Module (LCM) and the Traction Control Module (TCM), the Power Electronics Module (PEM), Color Machine Power Display (CMPD), Air Compressor, Power Modules, and other systems.

4.2 J1939 DATA LINK SPECIFICATIONS

The diagram below (Figure 1-7) shows typical CAT Datalink and J1939 and other network connections. For more information consult the locomotive Operators Manual (OM) and Trouble Shooting Guide (TSG) under service.

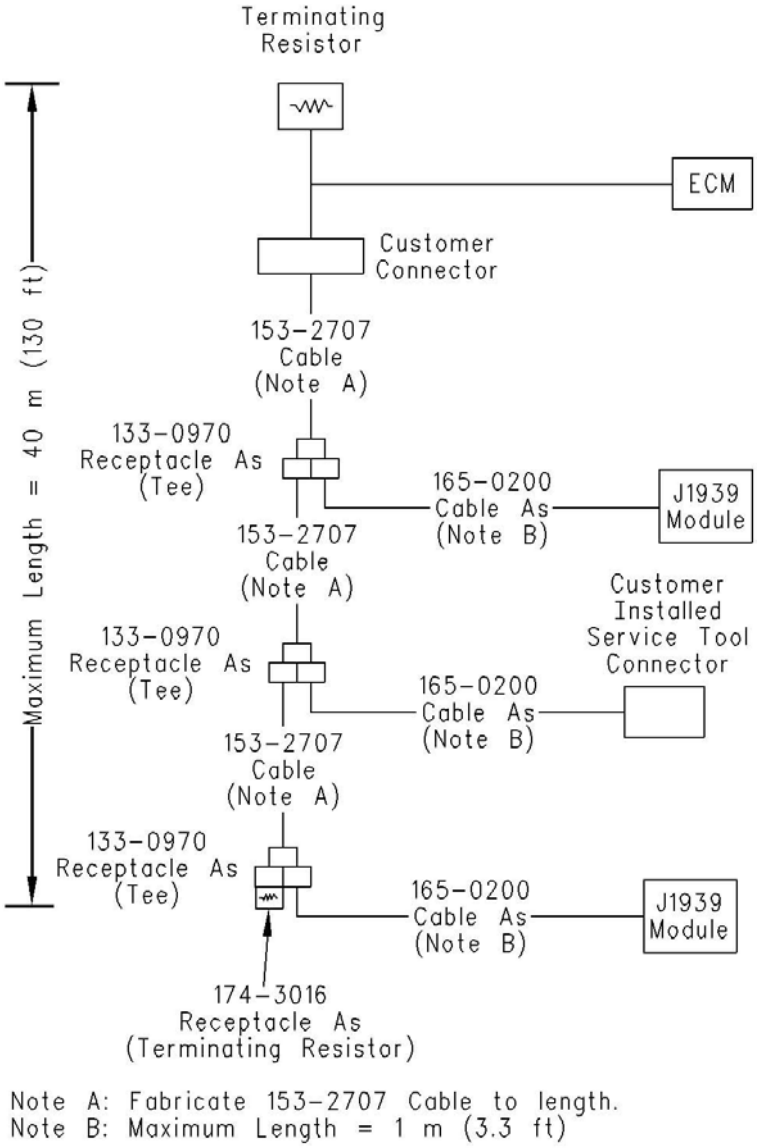


Figure 4-2 Typical Cabling for Data Link Connections

The specifications for J1939 Data Link is shown in Table 1-1 on page 26.

Table 4-1 J1939 Data Link Specifications

J1939 Data Link					
Parameter	**Minimum**	**Nominal**	**Maximum**	**Unit**	**Conditions**
Impedance	108	120	132	ohm	Three meter sample length measured at 1 Mhz between the two signal wires with shield grounded using open/short method
Specific Resistance	0	25	50	milliohm per meter	Measured at 20°C(1)
Specific Line Delay		5.0		ns/m	67% V_p(2)
Specific Capacitance	0	40	75	picofarads per meter	Between conductors
	0	70	110	picofarads per meter	Conductor to shield
Cable Size					See note (3)
0.5 mm² Conductor (20 AWG)	0.508			mm²	See note (4)
Wire Insulation Diameter	2.23		3.05	mm	
Cable Diameter	6.0		8.5	mm	
0.8 mm² Conductor (18 AWG)	0.760			mm²	See note (4)
Wire Insulation Diameter	2.5		3.5	mm	
Cable Diameter	8.5		11.0	mm	
Shield Effectiveness		200	225	milliohm per meter	Surface transfer impedance up to 1 Mhz Test method per MIL-C-85485
Temperature Range	-40		+125	°C	Heat aging: 3000 hours per ISO 6722, test with a mandrel 4-5X diameter of cable.(5)
Cable Bend Radius	4 x dia. of cable			mm	90° bend radius without cable performance or physical degradation.

(1) The differential voltage on the bus line seen by a receiving Electronic Control Unit (ECU) depends on the line resistance between it and the transmitting ECU. Therefore, the total resistance of the signal wires is limited by the bus level parameters of each ECU.

(2) The minimum delay time between two points of the bus line may be zero. The maximum value is determined by the bit time and the delay time of the transmitting and receiving circuitry.

(3) Other conductor sizes available. Component insulation dimensions may be larger than those specified in SAE J1128. Design engineers should ensure compatibility between cables, connectors, and contacts.

(4) Meet performance requirements of SAE J1128 for types GXL or SXL (includes drain wire where applicable).

(5) 125°C or per OEM specification.

BUS LINE – The J1939 bus line consists of a CAN_H, CAN_L and CAN_SHLD conductors. The CAN_H should be yellow in color while the CAN_L should be green. In addition, the cable must meet the following minimum requirements.

TOPOLOGY: The wiring topology of a J1939 network should be as close as possible to a linear structure in order to avoid cable reflections. In practice, it may be necessary to connect short cable stubs to a main backbone (or main trunk) cable, as shown in the figure on page 18. To minimize standing waves, nodes should not be all the same length.

4.3 NETWORK CONNECTIONS

The CAT DATA LINK is a proprietary link used to flash the LCM and other ECMs providing the latest upgrade in software.

The J1939 Locomotive Control Module is connected to the CAN “A” and CAN “B” networks a shown in Figure 4-3 on page 60.

The locomotive CAN “A” is referred to as the ENGINE Network and CAN “B” is referred to as the LOCO Network.

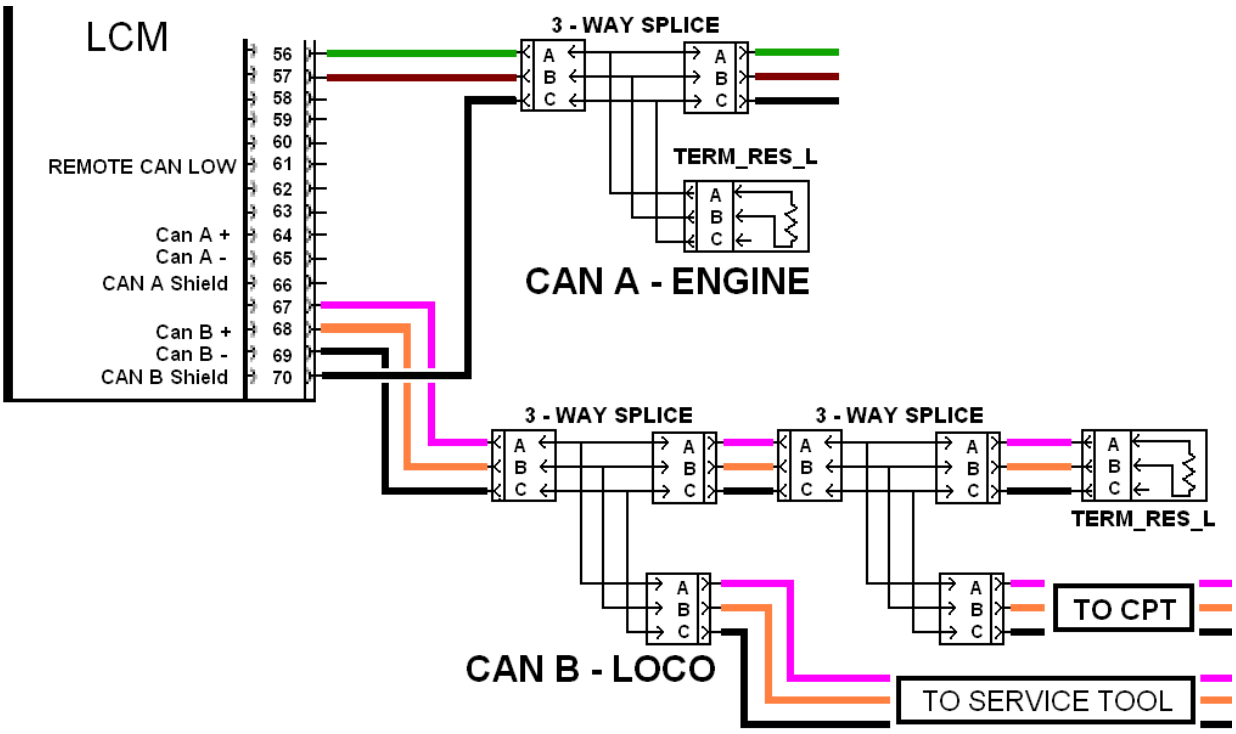


Figure 4-3 LCM Communication Schematic

5

5 LOCOMOTIVE CONTROL MODULE

The Locomotive Control Module (LCM) monitors and controls vital Engine Power Module (EPM) performance utilizing direct wired components and industry standard J1939 Data Buss and responds to signals from the Traction Control Module (TCM) and the Power Electronics Module PEM).

The following is a list of terms and definitions explaining the various features of the LCM. Some locomotives may not utilize all these features.

5.1 LCM LOCATION

The LCM is located in deferent locations depending upon the locomotive model. Below are several locations that the LCM may be located.

PR22B - LOW VOLTAGE CABINET – BELOW DECK

Below the Low Voltage (LV) cabinet on the upper deck of the locomotive is the below deck LV cabinet. This cabinet is accessible from the upper deck by removing the floor plates in front of the upper LV cabinet. The LV cabinet below deck, Figure 5-1, contains:

- Locomotive Control Module (LCM)
- Traction Control Modules
- Caterpillar Product Link
- GPS Unit
- Wireless Transceiver
- EFS Modules

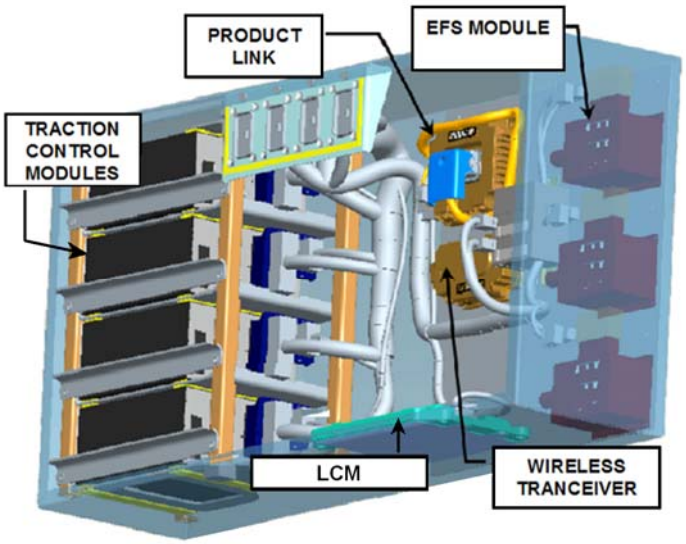


Figure 5-1 Low Voltage Cabinet - Lower Deck

PR30C AND PR40C – ELECTRICAL LOCKER

In Figure 5-2, the LCM can be located within the large electrical locker located in the rear of the cab on larger 6 axel locomotives. The LCM is usually in the middle compartment or in the upper right corner of the electrical locker. Refer to the specific troubleshooting guide for the locomotive model in question.

NOTE: Refer to the locomotive Owners manual (OMM) for current Information.

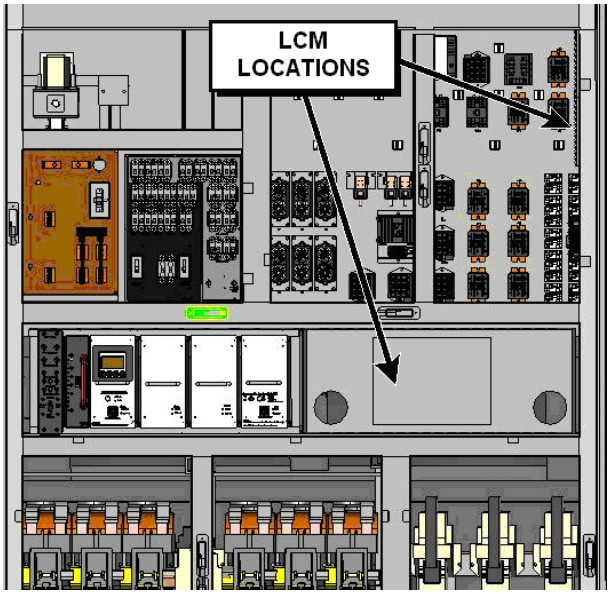


Figure 5-2 Electrical Locker

5.2 LCM FEATURES LIST

Table 5-1 lists the LCM features.

Table 5-1 LCM Features

LCM FEATURES LIST	
• Configured Number Of Engines Available • Cadetwin Support • A2l Support • Individual Engine Isolate Switches • Fuel Pump Control • Totals • Compressor Valve • Compressor Start • Compressor Percent • Notch Setting • Ave Number Of Engines Running • Engine Ordering • Priority Change • Available Engines/Alternators - Diagnostics • Lcm Events • Engine Diagnostics And Events • TCM Diagnostics	• Power-Up Sequence • No Simultaneous Cranking • Start From Cold Locomotive • Start From Parked Mode • Normal Engine Start • Target Load Calculation • J1939 Start Stop • J1939 Speed Control. • 3000hp - Fan Speed Output • Fan Speed Calculation For 3000 Hp • Emergency Stop Switch Input • Engine Or Alternator Fault Shutdown • Reverser Lever In Parked Mode Shutdown • Operation Trend Shutdown • Automatic Engine Shutdown • Service Tool Support • Wireless Communication (Future) • Cab Display, Engine Parameters & Status (Future)

5.3 MONITORED SYSTEMS

The LCM monitors and/or controls the following systems (Table 5-2):

Table 5-2 LCM Monitored Systems

LCM MONITORED SYSTEMS	
• Locomotive Control Module (LCM)	• Engine Operation Status
• Traction Control Module (TCM)	• Target Load
• Power Electronics Module (PE Module)	• Actual Load
• Air Compressor (AC)	• D8 Alternator
• Engine Control Module (ECM)	• J1939 Start
• Color Machine Power Display (CMPD)	• J1939 TSC1 Speed
• Product Link	• Air Pressure
• Electronic Air Brakes	• Inverter Controls
• Global Positioning Sensor (GPS)	• Battery Type
• Fuel System	• Inlet Manifold Temperature
• Cooling System	• Radiator Fans
• Emergency Fuel Cut Off (EFCO)	• Fuel Pump
• E-stop	• Inertial Blower

Each system has a number of subsystems, sensors, and controls, Figure 5-3. These systems communicate various status conditions of components that they monitor over the J1939 network along with hardwired communications connected directly to the LCM. The LCM then determines the correct coarse of action to take in response to these messages.

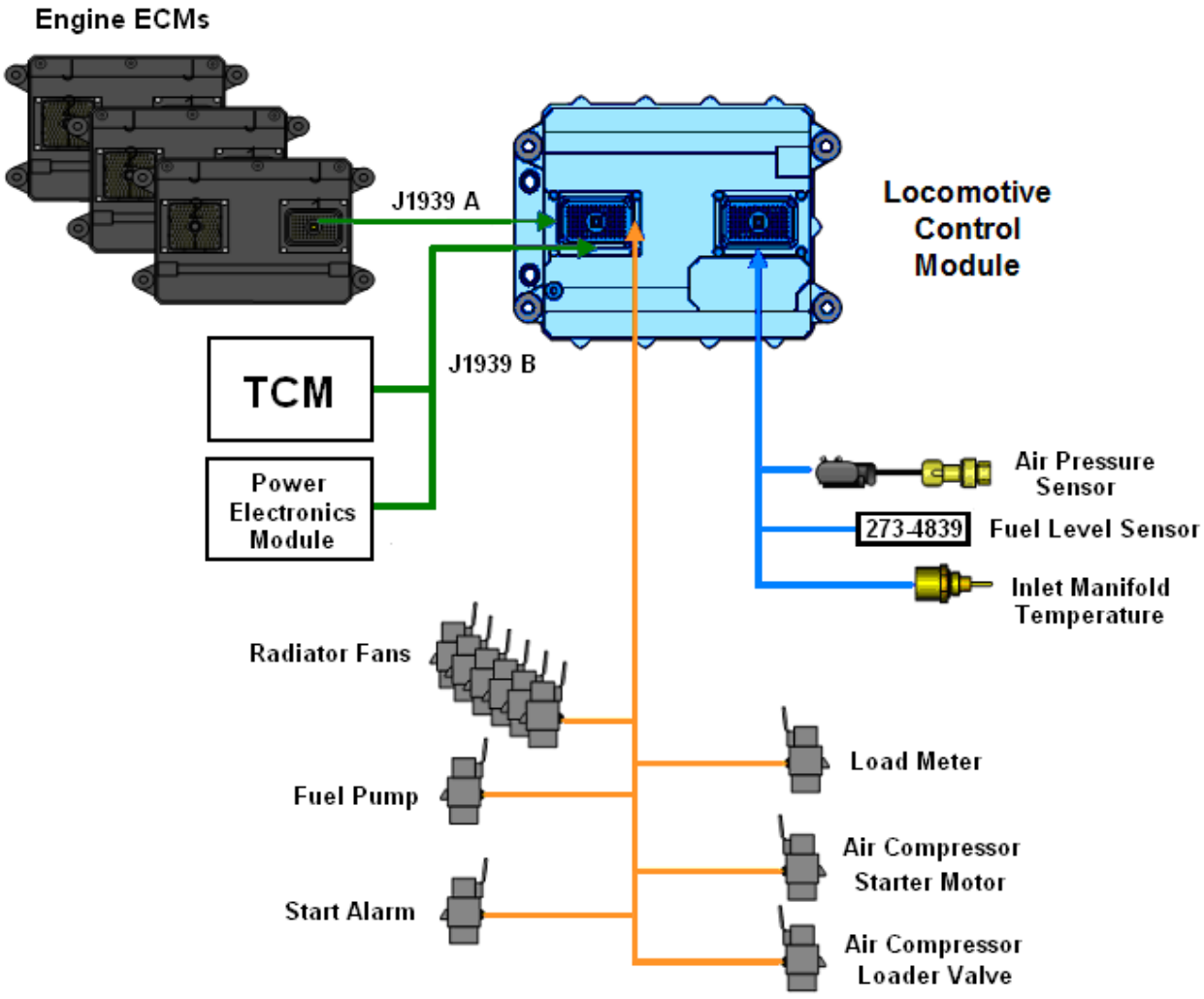


Figure 5-3 LCM Control Diagram

The LCM can provide a WARNING of an event, DERATE the locomotive there by reducing tractive effort, or SHUTDOWN the locomotive should a failure occur.

ELECTRONIC SYSTEMS CONTROL FLOW

The monitored and controlled functions of the electronic systems are shown in a simplified flow chart, Figure 5-4 on page 65, below.

Operator Inputs are monitored directly by the Traction Control Module (TCM). The TCM determines the tractive effort required and communicates that information to the Locomotive Control Module (LCM). The LCM then determines which engine to run and the desired rpm required for tractive effort. That information is communicated to the Engine Control Module (ECM) and the ECM starts and or modifies the RPM of that engine.

Accessory loads are monitored by the PE Box. The status of the PE Box is then communicated to the LCM.

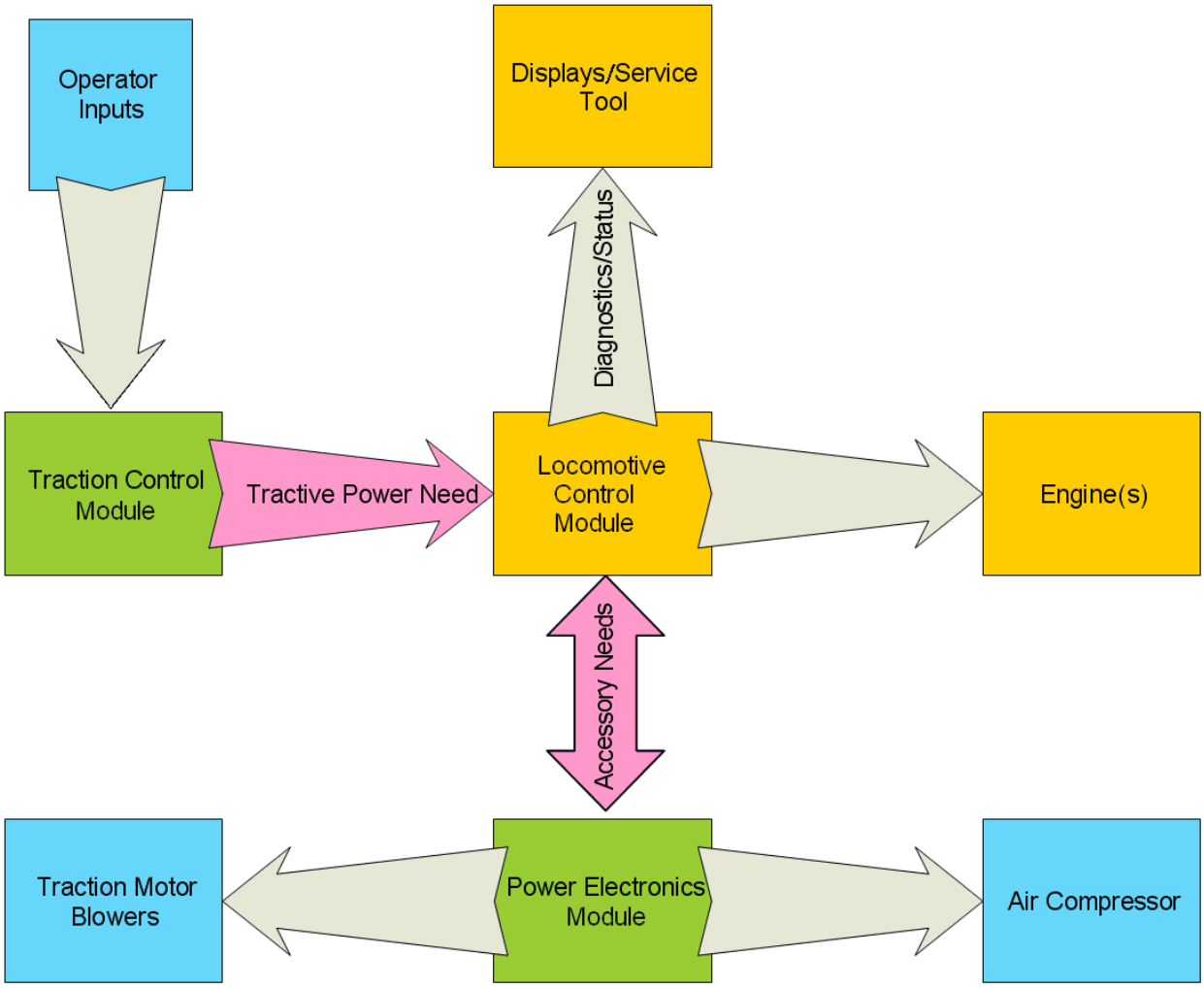


Figure 5-4 LCM Monitored Systems Flow Chart

5.4 ELECTRONIC SYSTEMS DETAILS

Each system has a number of functions that it monitors and controls. Below is a list of those details including some optional systems.

TCM (TRACTION CONTROL MODULE)

Notch	Dynamic Brake	Traction Motor Blower	User Controls
Reverser	Locomotive Mode	Traction Alternator 1	Wheel Slip
Motor Currents	Alt Faults	Traction Alternator 2	Switch Gear
Traction Buss Voltage	Dynamic Braking	Traction Alternator 3	

PEM (POWER ELECTRONICS MODULE)

- Power Supplies
- Inverter Controls
- Active Rectifiers
- Battery Charging
- Active Rectifier Temp. Faults
- Companion Temp. Faults
- Traction Alt Temp. Faults
- PEM Status
- Companion Power
- Gear Box Temps
- Companion Alternators 1, 2, 3

AIR COMPRESSOR

- Air Compressor Motor
- Air Pressure Sensor
- Air Compressor Start Motor
- Air Compressor Unloader valve
- Temperature Switch

ECM (ENGINE CONTROL MODULE)

- Engine Operation Status
- Percent Load
- Coolant Temperature
- Inlet Air Temperature
- Boost Pressure
- Engine Speed
- Desired Speed
- Key Switch
- E-Stop
- Fuel Pump

5.5 MONITORED SYSYTEMS - OTHER

PRODUCT LINK

Product Link is the on-board hardware consisting of an antenna, electronic radio and connecting wiring that gathers and wirelessly transmits important data such as locomotive location, hours and health information.

Using satellite technology, through *Dealer StoreFront* and *EquipmentManager*, Cat® Product Link provides two-way information flow between the locomotive on-board systems and your computer.

Benefits:

- Provides locomotive location
- Provides locomotive health information
- Eliminates trips for service
- Monitors fuel level and consumption meter hour readings
- Helps identify unscheduled machine operation
- Facilitates efficient maintenance scheduling
- Provide condition-based events and diagnostic reports and/or alerts
- Quickly identifies under-used machines or unscheduled use of machines

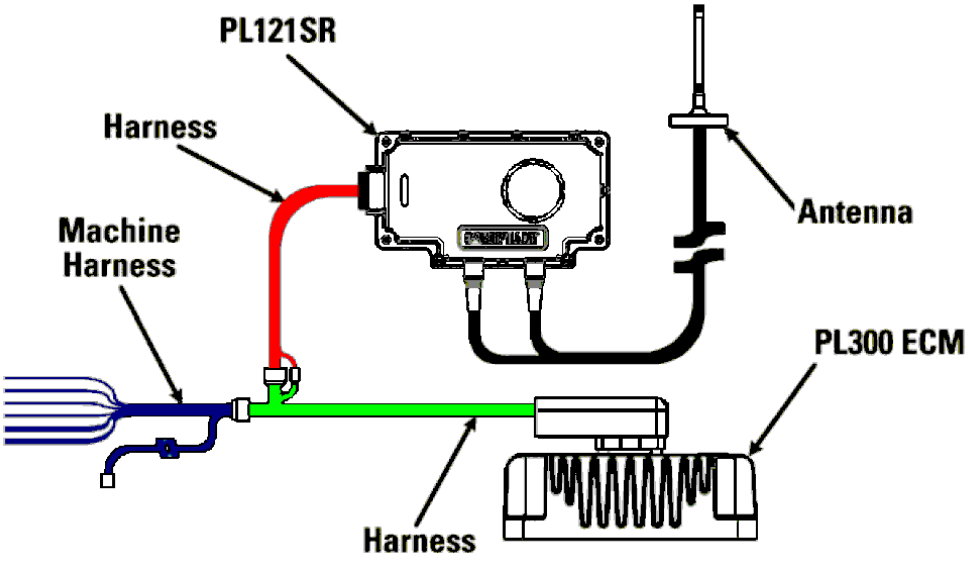


Figure 5-5 Product Link

ELECTRONIC AIR BRAKES

The CCB-26 is a microprocessor based electronic air brake system that can lead or trail a multiple unit system. Its general application is for non-integrated locomotives, switchers, cab cars and rebuilds of older locomotives.

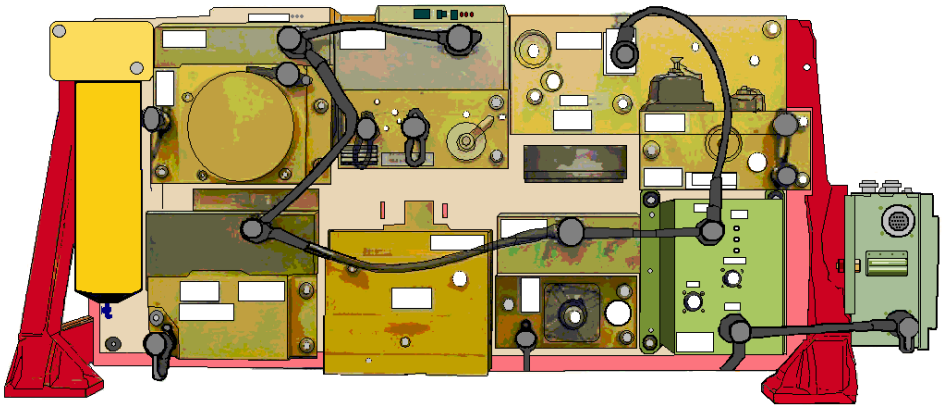


Figure 5-6 Electronic Air Brakes

The system contains 3 major components: the Electronic Brake Valve Controller (EBV), the Electro-Pneumatic Control Unit (EPCU) and the Relay Control Portion (RCP). The EBV allows the operator to command the computer using interfaces in the cab of the locomotive. The EPCU detects these signals and controls all pneumatic delegation to the rest of the system. The RCP supplies the discrete signal interface to the sanding systems and locomotive controls.

The CCB-36 is noted for its many economic and mechanical advantages. As compared to

previous models it requires less overhauls (once every 5 years as averse to 3), contains fewer parts and is cheaper to repair in the event of unforeseen damage.

5.6 OPTIONAL MONITORED ACCESSORIES

Additional accessories such as the Color Machine Power Display (CMPD) can also be monitored and utilized by the LCM.

CMPD

The Color Machine Power Display (CMPD) can be utilized to display diagnostic messages from the LCM and Engine ECM(s), then be able to enter data into the locomotive system to provide a variety of diagnostic capabilities. The CMPD will be available in the future.

Figure 5-7 CMPD

Figure 5-8 CMPD Rear View

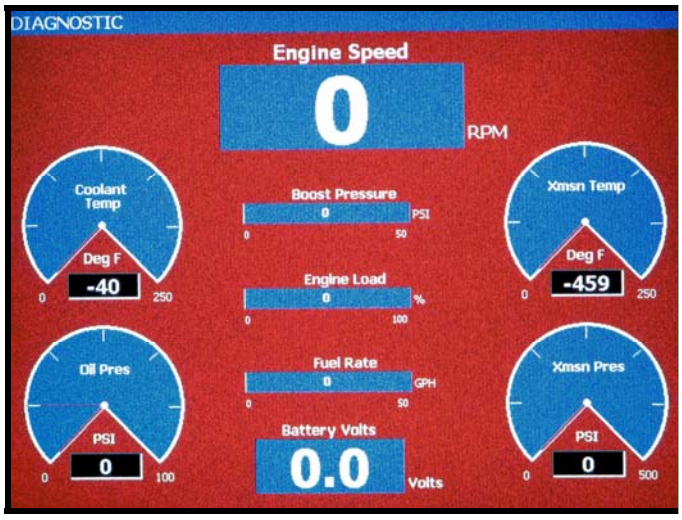


Figure 5-9 CMPD Screen

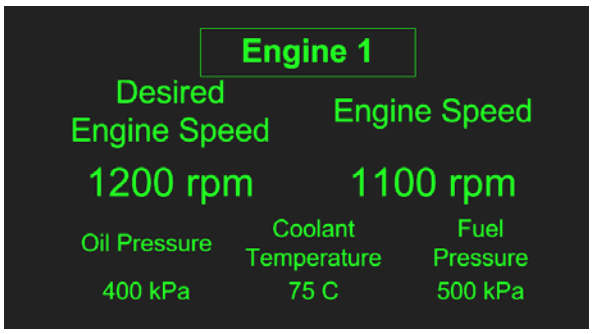


Figure 5-10 CMPD Engine #1 Screen

5.7 INPUTS

The Locomotive Control Module (LCM) has several Input and output channels (I/O) allowing the LCM to communicate directly to sensors and other devices.

Inputs covered in this section:

- Switch to +Battery (SWB)
- Active Analog Sensor Inputs @ 5 VDC
- Passive Analog Input (AIN_PAS)

SWITCH TO GROUND (SWG)

There are 35 **Switch to Ground (SWG)** inputs on the LCM. The switch to ground inputs are normally pulled high to +13VDC through a resistor.

- Minimum sourcing capability of 4mA
- Maximum sourcing capability of 10mA

Each input is protected from ESD, EMI, and short to +Battery faults.

SWITCH TO GROUND INPUT ELECTRICAL REQUIREMENTS

Switch inputs must activate with a resistive load of 50Ω or less to a potential of GND +0.75V

- Open circuit voltage 12.5VDC +/0.5VDC
- Short circuit current 10mA DC max
- Activation resistance 50Ω max to –BATT +0.75V GND diff.
- Deactivation resistance 4KΩ min to –BATT
- Survivable voltage range 0 VDC to +32 VDC continuous

SWITCH TO +BATTERY (SWB)

The three **Switch to +Battery (SWB)** inputs on the LCM have an internal pull down resistor. Each +Battery input is protected from ESD, EMI, and short to ground faults. Protection is provided against voltage transients of +150 to –600V.

SWITCH TO +BATTERY INPUT ELECTRICAL REQUIREMENTS

- Activation resistance 50Ω max to +BATT
- Deactivation resistance 4KΩ min to +BATT

ACTIVE ANALOG SENSOR INPUTS

There are two identical **Active Analog Sensor** Inputs on the LCM. Active Analog Sensor Inputs are interfaces between the LCM and active 5VDC analog sensors (such as pressure and temperature sensors). Internal protection is provided for short to +Battery and ground as well as ESD and EMI.

ACTIVE ANALOG INPUT ELECTRICAL CHARACTERISTICS

- Sense voltage range 0 – 5VDC
- Accuracy 2% of Full Scale
- Fault detection **Short to +Batt/open fault** – If sensor output is >4.8V for 1second the LCM will log a fault. *

  Short to ground fault – If sensor output is <0.2V for 1second the LCM will log a fault. *

  *(once the LCM is powered up)

PASSIVE ANALOG INPUT (AIN_PAS)

There are four **Passive Analog Sensor** inputs on the LCM. The Passive Analog Sensor Input is an interface between the LCM and passive 5VDC analog sensors (such as temperature sensors). Internal protection is provided for short to +BATT and ground as well as ESD and EMI. This input has an internal pull-up resistor to +5VDC.

PASSIVE ANALOG SENSOR INPUT ELECTRICAL REQUIREMENTS

- Sense voltage range 0 – 5VDC
- Accuracy +/50mV

INPUT SWITCH DESCRIPTIONS

KEY SWITCH

Switch input used to turn off functionality of the Locomotive Control Module.

EMERGENCY STOP

Switch input used to activate emergency stop messages to Engine Power Modules (EPM).

ENGINE 1 ENABLE

Switch input used to disable or enable Engine Power Module 1 (EPM1). The LCM will not allow engine 1 module to start If this switch is active.

ENGINE 2 ENABLE

Switch input used to disable or enable Engine Power Module 2 (EPM2). The LCM will not allow engine 2 module to start If this switch is active.

ENGINE 3 ENABLE

Switch input used to disable or enable Engine Power Module 3 (EPM3). The LCM will not allow engine 3 module to start If this switch is active.

5.8 OUTPUTS

The Locomotive Control Module (LCM) has a number of outputs capable of switching loads up to 2 amps.

Outputs included in this section are:

- 2Amp ON/OFF STANDARD DECAY Digital Driver

- 2Amp ON/OFF FAST DECAY Digital Driver
- 300mAmp Sinking Driver
- 2Amp PWM 1 Wire Driver
- 2Amp PWM 2 Wire Driver

OUTPUT SWITCH DESCRIPTIONS

COMPRESSOR VALVE OUTPUT
Digital Output to used to control the output valve relay of the air compressor.

COMPRESSOR STARTER OUTPUT (SD-40)
Digital Output to be used to control the starter relay for air compressor

FAN CONTROL
Digital outputs are used to control up to three, two-speed fan speed relays.

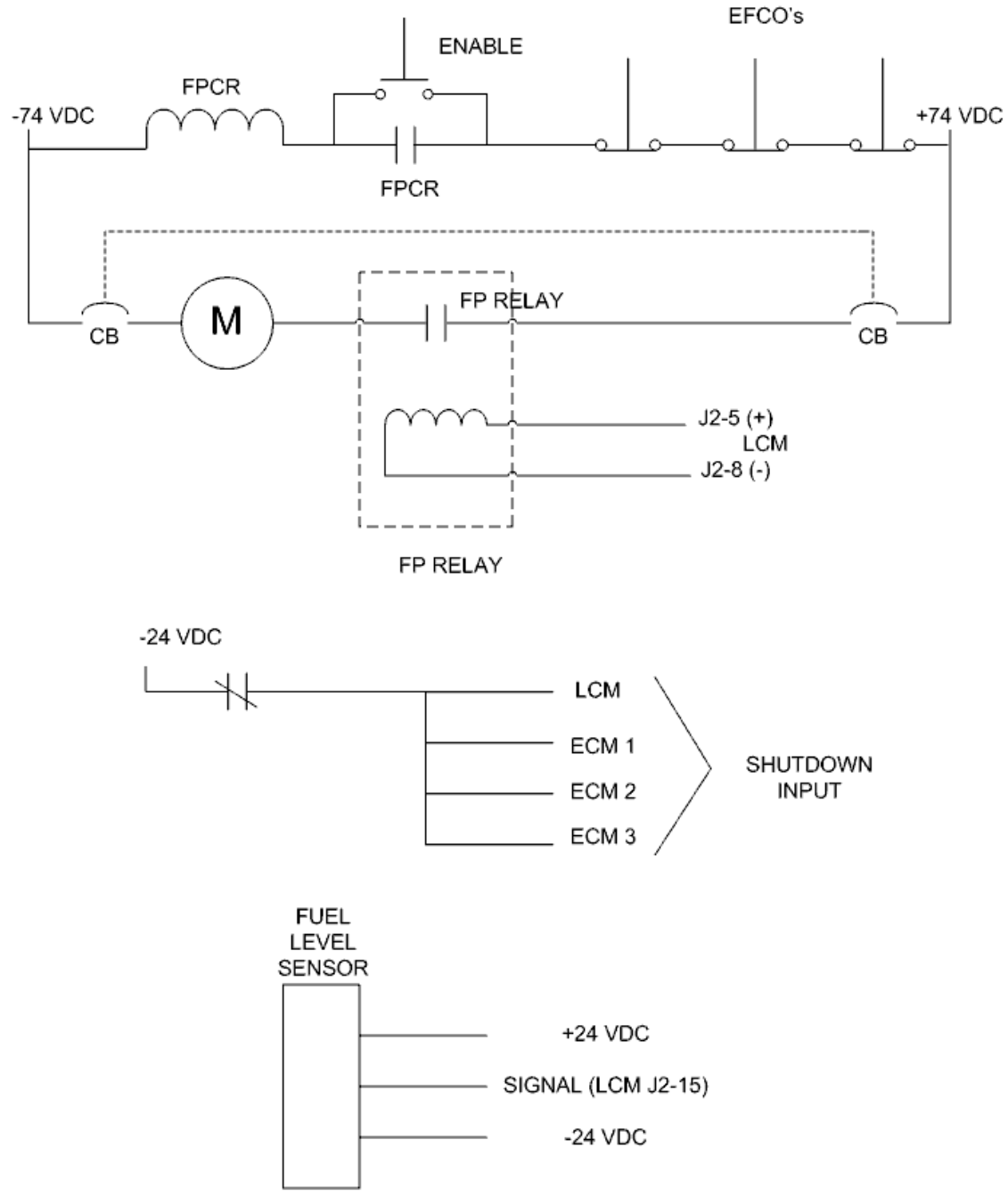
FUEL PUMP CONTROL
Digital output to be used to control the fuel pump relay of the locomotive.

In the case of an emergency shutdown (EFCO), the Locomotive Control Module will shutoff the fuel pump relay stopping the fuel pump (see
Figure 5-11, page 72).

SENSOR OUTPUTS

Sensor outputs are supply voltages used by the following sensors:

- Main Air Reservoir Pressure Sensor
- Air Brake Pressure Sensor
- AESS Start Alarm
- Fuel Level Sensor



FPCR = FUEL PUMP CONTROL RELAY
FP RELAY = FUEL PUMP
LCM = LOCOMOTIVE CONTROL MODULE
EFCO = EMERGENCY FUEL CUT OFF
ECM = ENGINE CONTROL MODULE
CB = CIRCUIT BREAKER
M = FUEL PUMP MOTOR

Figure 5-11 Typical Fuel Pump Circuit - PR22B

LCM PINOUTS

The Locomotive Control Module (LCM) pinouts are listed below. The CDL and CAN DATA LINK connections are color coded as shown in Table 5-3 and Figure 5-13 on page 75.

No customer connections to the LCM should be required.

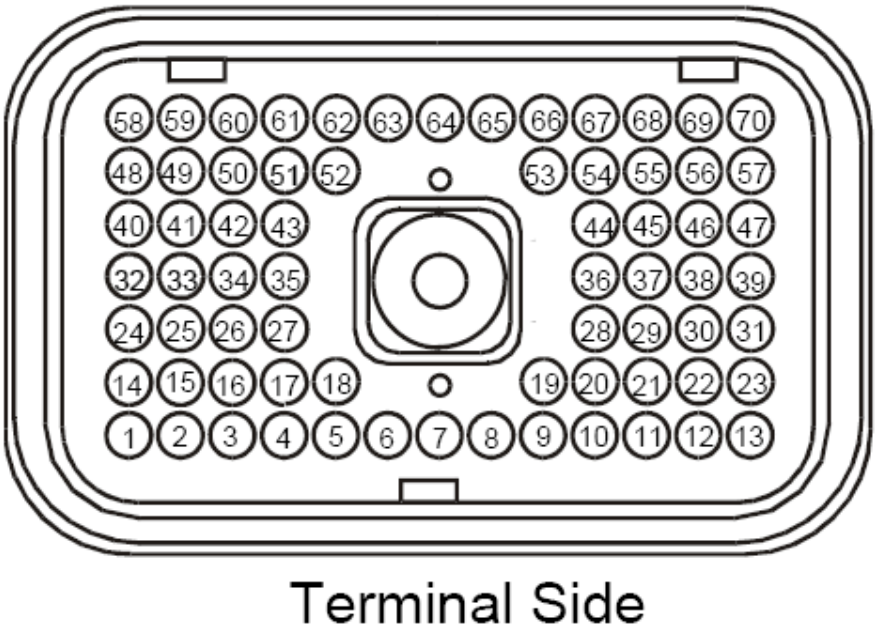
Communication connections are color coded in Table 5-3 and refer to corresponding pins in Figure 5-13 on page 75.

Table 5-3 LCM J1 & J2 Pinout

PIN	FUNCTION	NAME
J1-1	KEYSWITCH ON (SWK_O)	Keyswitch on
J1-10	**CDL+ (CDL)**	**CDL+**
J1-20	**CDL-**	**CDL-**
J1-21	5V SENSOR RET (A_RET)	
J1-23	-BATT (2)	Battery Negative
J1-26	SWG 1 (SWG)	Estop
J1-27	SWG 2 (SWG)	Engine 1 Enable SW
J1-28	SWG 3 (SWG)	Engine 2 Enable SW
J1-31	+BATT (1)	Unswitched Battery Positive
J1-32	SWG 4 (SWG)	Engine 3 Enable SW
J1-34	SWG 6 (SWG)	Differential Brake Pipe Pressure Switch (132-8759)
J1-36	ANALOG ACT 1 (AIN_ACT)	Main Air Reservoir Pressure (161-9932)
J1-37	ANALOG ACT 2 (AIN_ACT)	Not Used
J1-38	+BATT (4)	Unswitched Battery Positive
J1-39	+BATT (2)	Unswitched Battery Positive
J1-57	-BATT (3)	Battery Negative
J1-70	-BATT (4)	
J2-2	2A ON/OFF STD 1 (MS_DOUT_2A)	Compressor Unloader Valve
J2-5	2A ON/OFF STD 3 (MS_DOUT_2A)	Fuel Pump
J2-8	LOAD RET2 (L_RET)	Fuel Pump Return
J2-15	SWG/FREQ PHS 1	Fuel Level PWM (273-4839)
J2-20	DOUT_300mA – 7 (DOUT_0.3A)	Start Alarm
J2-56	**CAN A+ (CAN_J1939)**	**Engine CAN Datalink**
J2-57	**CAN A SHIELD**	**Engine CAN Datalink**
J2-64	**CAN B+ (CAN_PHS)**	**Locomotive CAN Datalink**
J2-65	**CAN B- (CAN_PHS)**	**Locomotive CAN Datalink**
J2-66	**CAN B SHIELD**	**Locomotive CAN Datalink**
J2-70	**CAN A- (CAN_J1939)**	**Engine CAN Datalink**

LCM J1 AND J2 CONNECTORS

Figure 5-12 shows the terminal connections on the LCM J1 and J2 connector. These connectors are keyed and can only fit on way. They can not be interchange with one another.



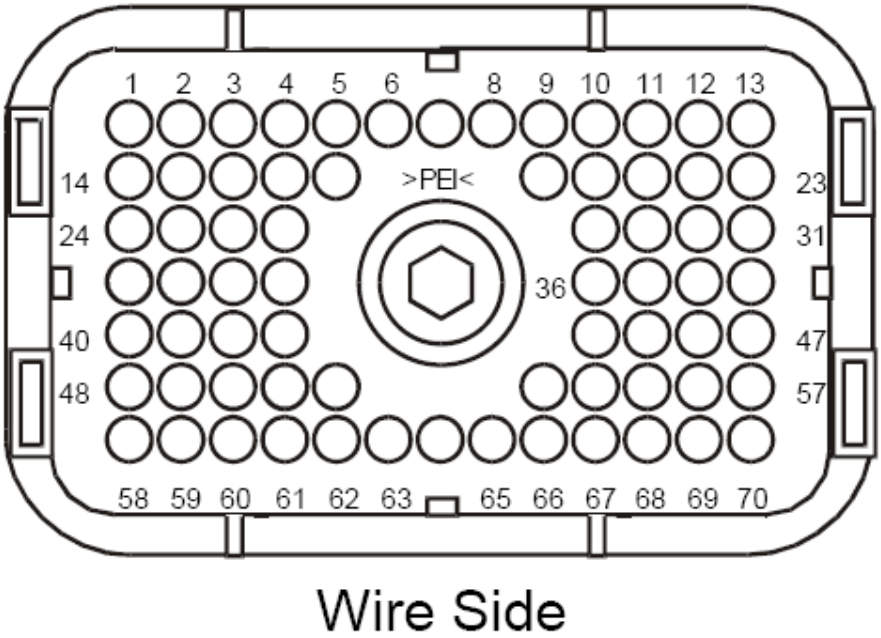
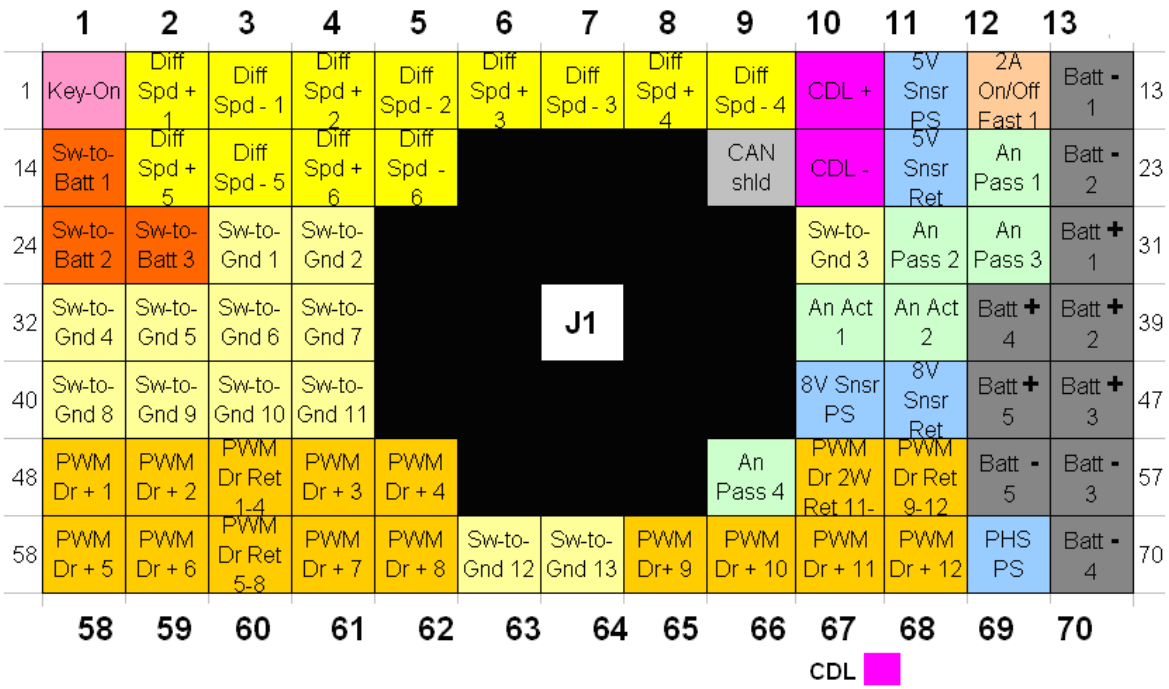


Figure 5-12 LCM 70 Pin Terminals

Pin functions are identified in Figure 5-13 (from wire side).



LCM Pinout

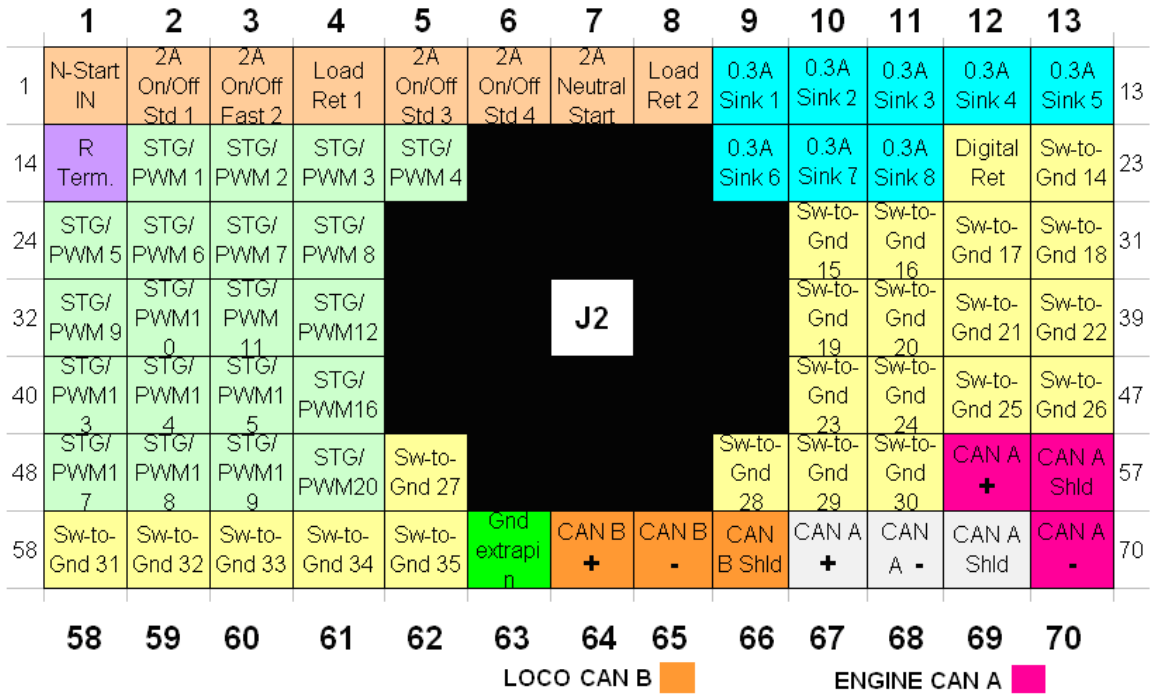


Figure 5-13 LCM J1 and J2 Pinouts

5.9 POWER REQUIREMENTS

CAUTION: This information is provided for reference only.

FUSING

The LCM requires five un-switched Battery (+) connections, five un-switched Battery (-) connections and an ignition key switch input. These connections carry nearly all power to the LCM during peak requirements and provide the LCM. The LCM fusing is done in the VEC module located in the low voltage control cabinet (PR22-series), Figure 5-1 on page 61 or in the electrical locker, Figure 5-2 page 62. The wiring is protected by a single 20 Amp fused circuit, fuse part # 113-8492.

LCM BATTERY (+)

PR22-SERIES

The LCM Battery (+) connections are made to the LCM, from the VEC Module located in the low voltage control cabinet.

PR30 AND PR40 SERIES

The LCM Battery (+) connections are made to the LCM in the electrical locker, Figure 5-2 page 62.

LCM BATTERY (-)

PR22-SERIES

The five Battery (-) connections are connected inside the low voltage control cabinet.

PR30 AND PR40 SERIES

The LCM Battery (-) connections are made to the LCM in the electrical locker, Figure 5-2 page 62.

CURRENT REQUIREMENTS

The LCM current requirements are shown in Table 5-4.

Table 5-4 LCM Current Requirements

MAXIMUM CURRENT CHARACTERISTICS	24V	UNITS
Sleep Mode Current Draw	14	mA
Steady-State Current Draw with Open I/O	850	mA
Inrush Current Duration at Power-Up with Open I/O, Key Switch tied to mains	3	ms
Inrush Current at Power-up with Open I/O, Key Switch activated with mains already powered	3.0	A
Inrush Current Duration at Power-Up with Open I/O, Key Switch activated with mains already powered	2	ms

FUSE AND CIRCUIT BREAKER LIST

Table 5-5 on page 77 is a list of blade fuses typically used in the LCPD Panel and other Caterpillar applications.

Table 5-5 Fuses and Circuit Breaker Sizes

CAT P/N	AMP	COLOR	VOLTS	TYPE
113-8490	10	Red	32	Blade
113-8491	15	Lt Blue	32	Blade
113-8492	20	Yellow	32	Blade
CIRCUIT BREAKER – VEC Module				
280-2709	15	- NA -	32	Blade

VEC MODULE

The VEC module is located in the low voltage control cabinet in the lower right compartment.

Use **15 amp circuit breakers**, part number 280-2709 for the VEC module.

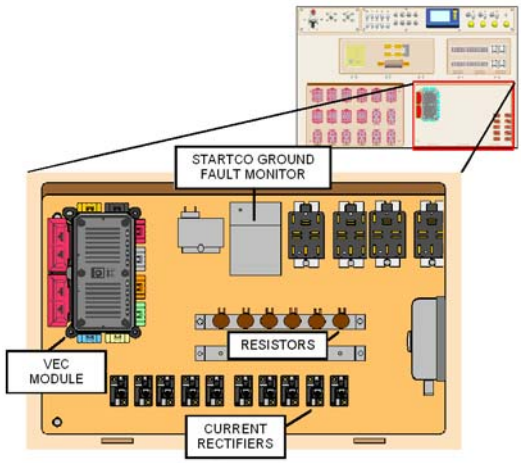


Figure 5-14 VEC Module Location

Figure 5-15 VEC Module

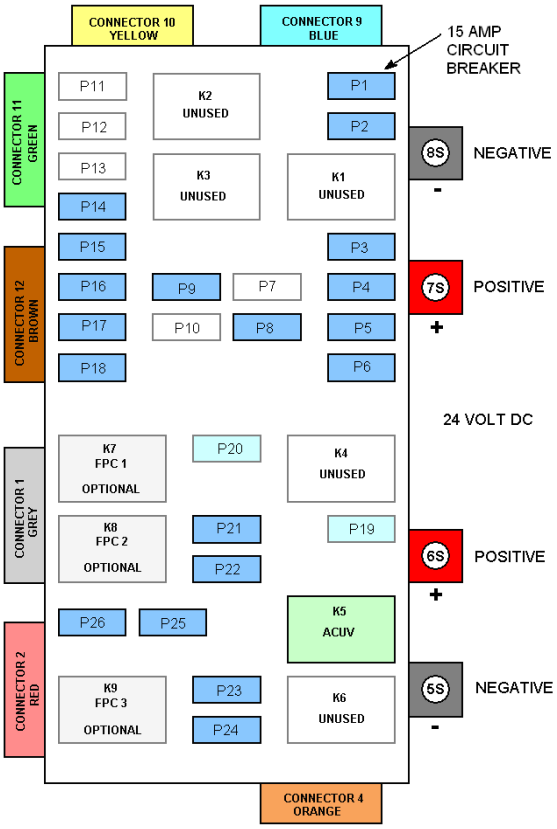


Figure 5-16 VEC Block LV Cabinet

Relays are K1 – K9.
Fuses are labeled as P1 – P26 and are rated @ 15 amps. Populated fuses are Blue.
Light Blue fuses are for optional circuits.
Populated relays are Light Green

See page 182 and page 184 for diagrams.

POWER SAVER MODES

ACTIVE MODE

When the knife switch is closed and the PE Module is powered ON, the LCM will become active, allowing the engine to start and run.

INTERNAL BATTERY

The LCM has an internal battery that powers critical circuits and battery backed memory when all power sources are disconnected from the LCM.

BATTERY LIFE

The internal battery is expected to meet a 15-year battery life if the LCM is stored, or switched off without any external battery connection, at a storage temperature at or below 30° C. The exact storage life is dependent on temperature. The storage life may fall to as low as 10 years if the storage temperature is elevated to 70° C.

5.10 ENGINE PRIORITY

The Locomotive Control Module (LCM) controls and maintains Engine Power Module (EPM) priority based on the quantity of fuel burned per engine. This strategy keeps overall engine wear and oil change intervals equal between the EPMs. Fuel consumption is the best indicator of both soot loading for the short term, and engine wear for the long term.

Should a new Engine Power Module be installed onto a locomotive with higher hour EPMs, This priority rotation strategy will account for the new EPM. A “fuel counter” resets after any one EPM passes a predetermined amount of fuel consumption.

ACTIVE

Priority change occurs when a critical engine diagnostic, generator diagnostic, requested re-prioritization, or the locomotive is in neutral for some configurable amount of time.

ENGINE ORDERING

The Locomotive Control Module will calculate the following for each EPM:

- **Primary EPM** = The lowest calculated value from all operable EPMs
- **Secondary EPM** = The second lowest value from the remaining operable EPMs
- **Tertiary EPM** = The last remaining operable EPM becomes the tertiary EPM.

This assignment changes when the primary EPM reaches a predetermined trip point:

1. **PRIMARY ENGINE** = Lowest fuel burned
2. **SECONDARY ENGINE** = Second lowest fuel burned
3. **THIRD ENGINE** = Most fuel burned

5.11 LOCOMOTIVE START UP

POWER-UP SEQUENCE

The EPMs are powered up in order of priority as stated in, Section 5.10 -- ENGINE PRIORITY. The Engine Power Modules computers (ECMs) are powered all the time.

NEUTRAL START

If the locomotive is in Neutral and the Throttle Lever is in notch 0 (Idle), the LCM will **NOT** request start up of the EPMs except when in AESS mode .

If the Reverser Lever is moved to Forward or Reverse, the Locomotive Control Module will wait for a defined period of time before starting the EPMs (Delayed Start).

DELAYED START

A predefined time is configurable for the EPMs to start (based on Reverser Lever moving from Neutral). This delay is only activated when the Notch Lever is set at idle.

NO SIMULTANEOUS CRANKING

One Engine Power Module (EPM) at a time is started to limit battery current draw during cranking. When the first engine is done cranking, the next engine is started and so on. The Locomotive Control Module reads the starting engine's operating status and activates the next engine to start **ONLY** when no EPM is in "**STARTING MODE**."

START FROM NEUTRAL SHUTDOWN MODE (AESS)

NOTE: See section 6, AESS - (Automatic Engine Start/Stop)

on page 84 for more information on AESS.

When the locomotive is in "**PARKED MODE**" (but **not** in a **COLD SHUTDOWN)** and all of the engines are **STOPPED --** an engine need to start (without any operator control inputs) for internal locomotive needs: to recharge locomotive batteries, maintain engine temperature, and run locomotive air compressor, etc.

MAINTAIN ENGINE TEMPERATURE

To maintain a certain engine temperature, Coolant Temperature air pressure is used to see if the engines need to be started or if the locomotive batteries are low.

ACCESSORY POWER

An accessory power request comes from the Locomotive Control Module to the Power Electronics Module (PEM) over the J1939 Data Link.

NORMAL ENGINE START

The Locomotive Control Module (LCM) can start specific engines based on a power request from the TCM control.

5.12 NUMBER OF ENGINES TO RUN

The Locomotive Control Module starts and stops the engines based on the accessory and tractive power request(s) from the TCM controller using J1939 messages.

REQUESTED POWER TO ENGINE RUN

The Locomotive Control Module receives Notch Power from the TCM controller over the J1939 data link.

NOTCH FEEDBACK
The Locomotive Control Module will resend the current notch received to the TCM control system.

TRACTIVE POWER
Tractive power is the power that the traction control needs for track adhesion. A notch request is sent by the TCM control system based on the tractive power need. A targeted load percentage is transmitted to the TCM control system to represent the tractive power remaining for use by the system.

The engine number is determined by the engine priority scheme described earlier in the ENGINE PRIORITY section on page 78.

ACCESSORY POWER
Accessory Power is the power needed for the air compressor, lights, etc. Since the companion alternators are attached to the shaft of each engine, changes to the traction control power will not affect the accessory power. In cases where more accessory power is needed then the current engine speed allows, the engine is commanded to a higher speed.

NOTE: Companion 1 is the companion alternator attached to the EPM with a priority of 1. Companion 2 is the companion alternator attached to the EPM with a priority of 2.

J1939 START STOP
The Locomotive Control Module utilizes the engine J1939 Start / Stop message.

TARGET LOAD CALCULATION
In Order for the Traction Control Module (TCM) to control excitation, a targeted load must be calculated. This load is the required load of the engine at current engine speed. This target load will determine how much load the generator must excite in reference to the full power of the module.

J1939 SPEED CONTROL
The Locomotive Control Module (LCM) sends the speed control signals to the Traction Control Module (TCM) which sends a torque speed control message to the LCM to control the desired speed of the engine.

Each engine has a different source address. The LCM knows the priority of each engine and the uses the corresponding address.

TSC RAMPED SPEED
Ramp rate of the engine(s) is determined by the J1939 Speed Control message.

CONFIGURATION
There should be a run time configurable parameter for the number of engines to run. Also specific trip points should also be configurable.

5.13 LOCOMOTIVE SHUTDOWN
All Engine Power Module (EPM) shutdowns are controlled by the Locomotive Control Module,

except for engine related protection strategies that have been preconfigured in each EPM's Engine Control Module (ECM, the computer that controls the C18 engine in each power module). Should a running Engine Power Module need to be shutdown, it is removed from the DC Buss and shutdown after a period of time

EMERGENCY STOP SWITCH INPUT

This is a hardwired input to Locomotive Control Module (LCM). When this input is activated the LCM sends a J1939 stop message to all active engines. This input is configurable to either normally open or normally closed. A locomotive EFCO reset is required for restart.

ENGINE OR ALTERNATOR FAULT SHUTDOWN

Engine diagnostics or alternator faults on a specific Engine Power Module (EPM) will force a shutdown of that EPM. Once the EPM is shutdown the Locomotive Control Module will reprioritize engines and start other EPMs appropriately.

REVERSER LEVER IN NEUTRAL SHUTDOWN

When the locomotive is in Neutral for the configured time, the Locomotive Control Module will shutdown EPMs until there is one active running EPM.

SHUTDOWN DELAY

There is a delay to the shutdown based on idle and neutral.

TRAIN LINE SHUTDOWN

Traction Control Module (TCM) will request a trainline shut down based on throttle input and will send that signal to the LCM which will begin shutdown procedures.

NORMAL SHUTDOWN

For fuel economy reasons, notch lever inputs, and shutdown timers on the Locomotive Control

Module (LCM) may need to shutdown the tertiary and/or the secondary Engine Power Module (EPM) should programmed requirements be met.

5.14 LOCOMOTIVE POWER LIMITED

Currently not available - Future Feature.

5.15 AIR COMPRESSOR CONTROL

The Air Compressor is powered by the Power Electronics Module (PEM).

The compressor speed is controlled by the Locomotive Control Module using a Percent Compressor message over the J1939 Data Link. This message is sent to the PEM (to control an inverter) and an unloader valve for the air compressor (an optional air sensor can also be used).

The Main Air Reservoir Sensor and Break Pipe Sensor define the operational states of the air compressor.

AIR COMPRESSOR VALVE

A digital output from the Locomotive Control Module activates the valve.

COMPRESSOR START
The LCM provides a digital output to Air Compressor Start Motor Relay to start compressor.

5.16 RADIATOR EPM FAN SPEED CONTROL
PR30 & 43 Three Each Engine will report the coolant temperature and inlet air temperature is sent to the Locomotive Control Module (LCM). Based on these temperatures and sensor fault conditions, the LCM will use auxiliary outputs to control the fan speed relays.

5.17 DIAGNOSTICS AND EVENTS

OPERABLE ENGINES
The Locomotive Control Module (LCM) identifies which Engine Power Module (EPM) are operable. This is based on engine status, alternator status, and/or diagnostics.

LOSS OF ENGINE J1939 NETWORK
Should a loss of communication occur with an Engine Power Module (EPM), the LCM will shutdown that EPM. The LCM will then reprioritize the remaining EPMs.

LOSS OF LOCOMOTIVE J1939 NETWORK
Should a loss of communications with the entire network occur, this will result in **complete shutdown** of the locomotive.

EVENTS
***Currently* EVENTS *is not available* - Future Feature**. The information provided below is for reference only.

EVENTS
The locomotive will shut down completely upon the following fault occurrences:

- **Unexpected Engine Shutdown (all Faults)**
- **Failure to Start Engine (all Faults)**

ENGINE DIAGNOSTICS AND EVENTS
ENGINE DIAGNOSTICS:
- Engine Diagnostics can result in the shutdown of specific Engine Power Module (EPM) and reprioritization of EPMs.

FAN SPEED DETERMINATION FAULTS (IF INSTALLED):
- Coolant Temperature Sensor Faults
- Oil Pressure Sensor Faults

TCM DIAGNOSTICS
The Traction Control Module can generate the following fault codes resulting in the shutdown of a specific Engine Power Module (EPM) and the reprioritization of EPMs.

- **REQUESTED SHUTDOWN**
- **ALTERNATOR FAULT**

The diagnostics (listed below) on the Traction Alternator are identified by the Traction Control Module (TCM) control. The Locomotive Control Module (LCM) receives a fault code from the TCM and will remove that Engine Power Module (EPM) from service.

- **OVER VOLTAGE**
- **UNDER VOLTAGE**

AIR COMPRESSOR DIAGNOSTICS

The failure of the Air Compressor Output Driver will result in a complete locomotive shutdown.

- **COMPRESSOR OUTPUT DRIVER**

6 AESS - (Automatic Engine Start/Stop)

Automatic Handling of engine starting and stopping based on specific criteria to maintain locomotive readiness.

6.1 AESS ENGINE STARTUP OPERATION

When the AESS system is **Enabled**, the system has the capability to control engine start up when the criteria outlined below are met.

AUTOMATIC START

The automatic engine start function will **not** operate unless the following conditions are met:

- The AESS enable switch is in the **ON** position.
- All AESS power circuit safety interlocks are **closed**.
- The engine was shut down previously as a result of an automatic stop. or if shutdown by EFCO, the EFCO has been reset by the operator

NOTE: The locomotive must be manually restarted after an EFCO

ENGINE RESTART

When the AESS system is **Enabled**, the engine will not restart unless one or more of the following conditions occur:

- The reverser handle is moved out of centered position.
- Engine Coolant Temperature is less than trip point
- Battery voltage is less than trip point
- Main reservoir pressure is less than trip point
- Brake pipe pressure is less than trip point1 if the parking brake is not set
- Brake pipe pressure is less than trip point2 if the parking brake is set (Future implementation)
- Parking Brake is set (Future implementation)
- The locomotive begins to move
- Auto stop time limit expires
- Fault conditions such as
    - J1939 Locomotive Datalink is ok
    - No Faults
    - EFCO inactive

OTHER OPTIONS

Additional features that may be require: (Future implementation)

- **Reverser Alarm –** IF all the locomotive criteria are met that would enable the locomotive to shut down, (including the timer but excluding the reverser position) an alarm will sound to remind the engineer to center the REVERSER.
- **Temporary AESS System Bypass –** This would be used if the locomotive was a lead unit in the consist and the crew wants the engine to stay powered to keep the accessory power operations on (heating and/or air conditioning).

6.2 AESS ENGINE SHUTDOWN OPERATION

When the AESS system is **enabled**, the system has the capability to control engine shutdown when the criteria outlined in this section are met.

AUTOMATIC ENGINE STOP

The Automatic Engine Stop function will **not** operate unless the following conditions are met:

- Reverser handle is in the centered position
- Throttle is in idle position.
- Locomotive speed is zero

ENGINE SHUT DOWN

The engine will **not** shut down unless the following conditions occur: All of the applicable engine and locomotive system parameters are within the range

required for reliable AESS operation.

- Engine Coolant Temperature is greater than the trip point
- Battery voltage low
- Battery charging amps are less than threshold (Future implementation)
- Air Compressor Status is Off
- Brake pipe pressure is greater than trip point1, if the parking brake is not set
- Brake pipe pressure is less than trip point2, if the parking brake is set (Future implementation)
- Parking Brake is set (configurable parameter, interlock from parking brake as switched input to LCM) (Future implementation)
- Fault conditions occur, such as:

  Bad datalink: Locomotive Faults
- Locomotive conditions occur, such as:

  EFCO Engine Enables Train Line Stop

6.3 ENGINE START ALARM

An alarm bell will ring for a period of at least 5 seconds prior to starting the locomotive engine and will ring periodically (for example, once every 5 to 15 minutes) whenever the engine has

been automatically shutdown by the AESS system and should be clearly audible outside and adjacent the locomotive.

6.4 FAILURE TO START/STOP ENGINE

In the case of an engine that will not shutdown based on a sent command from the blue box, a diagnostic will be logged for that engine stating failure to stop engine. That module will then be moved out of priority and tractive power to the engine will be turned off. The resulting diagnostic will also result from the loss of J1939 and would follow the procedures of the loss of j1939 for a power module. The engine can be shutdown through the fuel cut off if necessary.

6.5 AESS CONFIGURATIONS

The following feature for AESS can be configure in the LCM.

- Compile Feature should be configurable ON or OFF
- AESS Activation time
- Engine idle Speed
- Coolant Trip Point
- Inlet Air Trip Point
- Battery Voltage Trip Point
- Air Pressure Trip Point
- Brake Pressure Trip Point

Data shown in Table 6-1 is for the PR22 and PR 30 Series locomotives. Data for the PR43C in currently not available.

Table 6-1 Engine Auto Shutdown Trip Points

ENGINE AUTO SHUTDOWN		
Parameter	**Criteria**	**PR22/30 Trip Point**
Brake Cylinder	Greater than	30 psi (205 kPa)
Main Reservoir Pressure	Greater than	100psi (690 kPa)
Battery Voltage	Greater than	69 Volts
Battery Charging	Less than	25 Amps
Reservoir Centered & Throttle Idle	Greater than	15 Minutes
Ambient Temperature	Greater than	NA
IMT	Greater than	-10F (-23C)
Coolant Temperature	Greater than	105F (66C)
ENGINE AUTO START		
Parameter	**Criteria**	**PR22/30 Trip Point**
Brake Cylinder *	Less than	30 psi (205 kPa)
Main Reservoir Pressure	Less than	30 psi (205 kPa)
Battery Voltage	Less than	60 Volts
Reservoir NOT Centered & Throttle NOT Idle	Instantaneous	Initiate 5 sec alarm then start priority engine
Ambient Temperature	Less than	NA
IMT	Less than	-12F (-24C)
Coolant Temperature	Less than	41F (5C)

6.6 AESS INPUT SIGNALS

The following is a list of AESS inputs and descriptions.

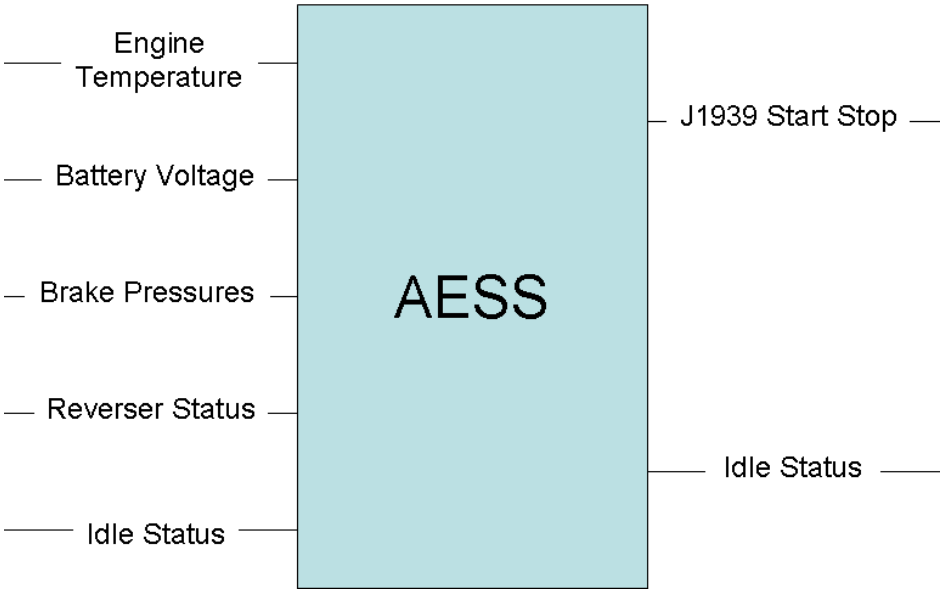


Figure 6-1 AESS Inputs

ENGINE TEMPERATURE 1 (ET1)

- **ENGINE COOLANT TEMPERATURE** - Temperature of liquid found in engine cooling system.
- **FUEL TEMPERATURE** - Temperature of fuel entering injectors.
- **ENGINE OIL TEMPERATURE 1** - Temperature of the engine lubricant.
- **TURBO OIL TEMPERATURE** - Temperature of the turbocharger lubricant.
- **ENGINE INTERCOOLER TEMPERATURE** - Temperature of liquid found in the intercooler located after the turbocharger.
- **ENGINE INTERCOOLER THERMOSTAT OPENING** - The current position of the thermostat used to regulate the temperature of the engine intercooler. The current position of the thermostat used to regulate the temperature of the engine intercooler. A value of 0% represents the thermostat being completely closed and 100% represents the thermostat being completely open.

MAIN AIR RESEVIOR AIR PREASURE VALUE

This is the air pressure reading for the main air reservoir. If the pressure doesn't meet a set point (low air pressure), the LCM will start an engine and will signal the PE Box to turn on the air compressor to increase air pressure.

COMPANION INPUT POWER – PE MODULE

The PE Box requires AC voltage(s) from the Companion Alternator(s) and locomotive battery voltage to operate. Below is a list of those inputs.

- Companion 1 alternator Input Power
- Companion 2 alternator Input Power
- Companion 3 alternator Input Power
- PE Battery Voltage
- Traction Alternator 1 Bus current
- Traction Alternator 2 Bus current
- Traction Alternator 3 Bus current

TRACTION CONTROL MODULE

The Traction Control Module (TCM) provides AESS with the following Inputs.

- Traction Alternator #1 Problem
- Traction Alternator #2 Problem
- Traction Alternator #3 Problem
- Selected Notch
- Reverser Handle Selection
- Dynamic Brake Setup
- Dynamic Brake Active
- Locomotive Service Mode
- Locomotive in Test Mode
- Locomotive in transition
- Unable to Load in Test
- Unable to Load in Power
- Unable to Load in DB
- TA1 Current Transducer Failure
- TA2 Current Transducer Failure
- TA3 Current Transducer Failure
- TM1 Current Transducer Failure
- TM2 Current Transducer Failure
- TM3 Current Transducer Failure
- TM4 Current Transducer Failure
- TM1 Voltage Transducer Failure
- TM2 Voltage Transducer Failure
- TM5 Current Transducer Failure
- TM6 Current Transducer Failure
- TM3 Voltage Transducer Failure
- TM4 Voltage Transducer Failure
- TM5 Voltage Transducer Failure
- TM6 Voltage Transducer Failure

6.7 AESS DIAGNOSTIC DESCRIPTIONS:

ALTERNATOR #1 PROBLEM

Communicates whether a problem (such as uncontrolled output) has been detected on Traction Alternator #1.

ALTERNATOR #2 PROBLEM

Communicates whether a problem (such as uncontrolled output) has been detected on Traction Alternator #2.

ALTERNATOR #3 PROBLEM

Communicates whether a problem (such as uncontrolled output) has been detected on Traction Alternator #3.

SELECTED NOTCH

This communicates the notch that has been selected on the locomotive's control stand.

REVERSER HANDLE SELECTION
This communicates the direction of the locomotive as selected by the locomotive's reverser handle.

DYNAMIC BRAKE SETUP
This communicates whether the locomotive controls have been set up for dynamic brake operation.

DYNAMIC BRAKE OPERATING
This communicates whether the dynamic brake on the locomotive is currently being applied.

LOCOMOTIVE SERVICE MODE
This communicates whether the locomotive is currently in switcher mode or road mode as selected by the operator.

LOCOMOTIVE IN TEST MODE
This communicates whether the locomotive is currently in Test Mode.

TRACTION ALTERNATOR #1 CURRENT TRANSDUCER FAILURE
This communicates whether or not the current sensor measuring the main current out of traction alternator #1 is functioning properly.

TRACTION ALTERNATOR #2 CURRENT TRANSDUCER FAILURE
This communicates whether or not the current sensor measuring the main current out of traction alternator #2 is functioning properly.

TRACTION ALTERNATOR #3 CURRENT TRANSDUCER FAILURE
This communicates whether or not the current sensor measuring the main current out of traction alternator #3 is functioning properly.

LOCOMOTIVE IN TRANSITION
This communicates when the locomotive is undergoing a transition. This transition could be either a field shunting transition or a major motor reconnection.

TRACTION MOTOR #1 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #1 voltage transducer.

TRACTION MOTOR #2 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #2 voltage transducer.

TRACTION MOTOR #3 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #3 voltage transducer.

TRACTION MOTOR #4 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #4 voltage transducer.

TRACTION MOTOR #5 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #5 voltage transducer.

TRACTION MOTOR #6 VOLTAGE TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #6 voltage transducer.

TRACTION MOTOR #1 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #1 Current transducer.

TRACTION MOTOR #2 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #2 Current transducer.

TRACTION MOTOR #3 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #3 Current transducer.

TRACTION MOTOR #4 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #4 Current transducer.

TRACTION MOTOR #5 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #5 Current transducer.

TRACTION MOTOR #6 CURRENT TRANSDUCER FAILURE
This communicates whether the TCM control system has detected a failure in the traction motor #6 Current transducer.

6.8 AESS OUTPUT SIGNALS

AUXILIARY INPUT OUTPUT STATUS 2

Start / stop message to the engine:

- Normal Engine Shutdown
- Normal Engine Start

START ALARM

An alarm bell will ring for a period of at least 5 seconds prior to starting the locomotive engine and will ring periodically (for example, once every 5 to 15 minutes) whenever the engine has been automatically shutdown by the AESS system and should be clearly audible outside and adjacent the locomotive.

NOTES:

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7 ENGINE MANAGEMENT SYSTEM

7.1 PRIMARY FUNCTIONS CONTROL STRATEGY

THE ENGINE GOVERNOR

The Engine Governor determines how much fuel to deliver to each cylinder to respond to changes in operator demand or engine load conditions.

AIR TO FUEL RATIO CONTROL

The control system has full authority over engine fuel delivery. The mechanical fuel/air ratio control is eliminated on an electronically controlled engine. Electronic control of the fuel/air ratio provides optimum performance while limiting emissions.

INJECTION TIMING CONTROL

Injection timing is varied as a function of engine operating conditions to optimize engine performance for emissions, noise, fuel consumption, and electrical power load.

TORQUE RISE SHAPING

Electronic controls provide increased flexibility to tailor the torque curve over a broad load range.

COLD STARTING STRATEGY

Before and during cranking, the engine monitors atmospheric pressure, air manifold intake temperature, and/or coolant temperature. Based on these inputs, the engine may execute a complex cold starting strategy that adjusts fuel volume, timing in order to start the engine.

Refer to the section titled: Cold Starting Aid (section 14) for more information. Refer to the Engine Operation and Maintenance Manual and the Troubleshooting Guide for more information.

COLD MODE OPERATION

Cold mode operation is activated based on the coolant temperature and/or IMAT. The low idle speed may be elevated when in cold mode. Refer to the Operation and Maintenance Manual and the Troubleshooting Guide for more information.

INTERLOCKS

Interlocks prevent unauthorized use of marketable engine control software and to prevent the accidental use of the wrong software. If either occurs, fuel injection is disabled so the engine won't start.

The software flash file contains an interlock code. The code has two parts, an engine code (known as the LCM interlock) and an application code (known as the rating interlock). For example, engine codes 7 and 8 are for 3408E and 3412E engines, respectively.

After software is flashed into a new LCM the interlock code in the flash file is automatically programmed into the LCM's permanent memory.

Factory passwords are **not** required for flashing a **new** LCM. A new LCM is an LCM that has never been flash programmed.

After software is flashed into an old LCM, the interlock code in the flash file is compared to the interlock code stored in the LCM's permanent memory. If the two do not match, then two things are done:

- Fuel injection is disabled, so the engine won't start, and
- A diagnostic is activated. On the Cat Data Link the diagnostic is 253-2 *Personality Module Mismatch*.

With a service tool the mechanic can read the information required to obtain a factory password. Once the password is entered the interlock code in the flash file is automatically programmed into the LCM's permanent memory.

7.2 CONFIGURATION PARAMETERS

When a new LCM is flashed the default values for all parameters are included in the flash files.

NOTE: Configuration Parameters are used to modify factory set parameters, to change or add engine performance and/or optional hardware, and to update software versions by *Flashing* the LCM via the Cat ET.

WHEN AND WHEN NOT TO REPROGRAM PARAMETERS

- Configuration Parameters do not need to be reprogrammed. The LCM parameters are re-flashed with an updated version of software flash file.

NOTES ON PROGRAMMING PARAMETERS

- **Changing parameters protected by factory passwords** may void Caterpillar warranty. Consult Industrial Application Support Center contacts before changing.
- **In order for the programmed values to change**, the key switch (switched power only) must be cycled off and on.
- **If there is an interlock error** (personality module mismatch), then the programmed parameters will not change. It may appear that the parameters are changed but, they will not change until the personality module mismatch code is cleared.

SOFTWARE FLASH FILE

If the LCM is connected to a computer, then the personality module (also known as flash file) is the software for the computer. The term flash file is derived by the method in which the software is programmed into the LCM — a technology known as flash programming.

The flash file contains the operating maps that define the performance and operating characteristics of the engine as will as the Industrial application feature support.

Once flashed, the LCM contains the following information to identify the flash file and supported ratings: (these can be viewed in the Configuration Parameter screen using the Cat® ET service tool).

Personality Module PN	Rated Peak Torque
Software Gp Release Date	Top Engine Speed Range
Rated Power	Test Spec

NOTE: The following information is provided as reference only.

EQUIPMENT ID
Equipment ID allows the customer to enter a description into the LCM in order to identify the installation. A maximum of 17 characters may be entered in the field. This parameter is only for reference by the customer. This parameter is not required.

ENGINE SERIAL NUMBER
Program the Engine Serial Number to match the engine serial number that is stamped on the engine information plate.

NOTE: When you are requesting factory passwords, always use the engine serial number that is resident in the LCM.

LCM SERIAL NUMBER
The LCM Serial Number is stored in the memory of the LCM. The LCMSERIALNUMBER can be accessed by the use of the service tool.

SOFTWARE GROUP PART NUMBER
This parameter identifies the part number of the flash file that is currently installed in the LCM.

SOFTWARE GROUP RELEASE DATE
This parameter identifies the release date of the flash file that is currently installed in the LCM.

SOFTWARE GROUP DESCRIPTION
This parameter identifies the description of the application for the flash file that is currently installed in the LCM.

7.3 SECURITY ACCESS PARAMETERS
Each programmable parameter has a tattletale. The tattletale allows Caterpillar or a dealer to determine if engine control software features have been adjusted or activated. This is indicates any unauthorized change(s) of the programmable parameters.

TATTLETALE
Each time a parameter is reprogrammed its individual tattletale is incremented and the total tattletale is incremented. All the individual tattletales are totaled for the factory password calculation so the factory password can only be used once.

TOTAL TATTLETALE
The total tattletale counts the number of changes that are made to the system parameters and is incremented when a logged event is cleared.

8 DIAGNOSTIC CODES

Diagnostic codes are provided by a number of electronic devices in the locomotive, among these are the LCM, TCM, PE Box, Electronic Air Brakes, Engine ECMs, etc. The following are representative of these codes and potential areas to diagnose should an error occur.

The LCM can display the following Diagnostic Codes over CAT ET or Color Machine Power Display (CMPD) if equipped.

NOTE: Should a locomotive be equipped with the CMPD, the CMPD can display following LCM diagnostic codes. This data is provided as reference only and is current at the time of this publication. New Display Codes may be added over time.

8.1 FAULT CODE NOMENCLATURE

Below is a list of acronyms used in the CAT ET display codes. For example, the display code **AR1_Overload** means – **Active Rectifier #1 Overload.**

AC	Alternator Companion
Alt	Alternator
AR	Active Rectifier
Comms	Communications
Comp	Companion
CT	Current Transducer
Desat	Desaturation
Diff	Differential
DB	Dynamic Brake
GFC	Ground Fault Control
Loss of	Loss of Data Communications
MG	Main Generator
PE	Power Electronics Box
Press	Pressure
Reg	Regulation
TA	Traction Alternator
TCM	Traction Control Module
Temp	Temperature
TM	Traction Motor
TMB	Traction Motor Blower
VT	Voltage Transducer

8.2 FAULT CODES

The fault codes provide below are transmitted over the J1939 Data Link to the Locomotive Control Module (LCM). The LCM the responds to the fault code shown under the column **LCM RESPONSE.**

NOTE: Fault codes only apply to the locomotive models lists and designated by the letter “X”

Fault Codes for the following equipment are provided are:

- **POWER ELECTRONICS BOX**
- **THE TRACTION CONTROL MODULE**

8.3 POWER ELECTRONICS BOX TO LCM FAULT CODES

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
AR1_Overload	CID	x	x	x		3366
AR2_Overload	CID	x		x		3367
AR3_OverLoad	CID	x				3368
AC1_Overload	CID	x		x	Derate	3301
AC2_Overload	CID	x		x	Derate	3300
AC3_Overload	CID	x		x	Derate	4022
AR2_Comms	CID	x		x		3367
AR3_Comms	CID	x				3368
AC1_Comm_Fault	CID	x		x	Derate	3301
AC2_Comm_Fault	CID	x		x	Derate	3300
PE_Communications_Fault	CID	x	x	x	Warning Only	3466
AR1_Comms	CID	x	x	x		3366
Loss of PE J1939	CID	x			Warning Only	3466
AR1_OverVoltage	CID	x	x	x		3366
AR2_OverVoltage	CID	x		x		3367
AR3_OverVoltage	CID	x				3368
AC1_OverVoltage	CID	x		x	Derate	3301
AC2_OverVoltage	CID	x		x	Derate	3300
AC3_OverVoltage	CID	x		x	Derate	4023
PE_Bus_Overvoltage	CID	x	x	x	@ Speed Shutdown	3466
AR1_UnderVoltage	CID	x	x	x	@ Speed Shutdown	3366
AR2_UnderVoltage	CID	x		x	@ Speed Shutdown	3367
AR3_UnderVoltage	CID	x			@ Speed Shutdown	3368
AC1_UnderVoltage	CID	x		x	Derate	3301
AC2_UnderVoltage	CID	x		x	Derate	3300

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
AC3_UnderVoltage	CID	x		x	Derate	4025
PE_Bus_Undervoltage	CID	x	x	x	@ Speed Shutdown	
Ground_Fault_Comp_Alt_1	CID	x	x	x	Shutdown	3363
Ground_Fault_Comp_Alt_2	CID	x		x	Shutdown	3364
Ground_Fault_Comp_Alt_3	CID	x			Shutdown	3365
Ground_Fault_Traction_Alt_1	CID	x	x	x	Shutdown	4000
Ground_Fault_Traction_Alt_2	CID	x		x	Shutdown	4001
Ground_Fault_Traction_Alt_3	CID	x			Shutdown	4002
AC1_OverCurrent	CID	x		x	Derate	3301
AC2_OverCurrent	CID	x		x	Derate	3300
AC3_OverCurrent	CID	x		x	Derate	4021
PhaseOver_Comp_Alt_1	CID	x	x	x	Shutdown	3363
PhaseOver_Comp_Alt_2	CID	x		x	Shutdown	3364
PhaseOver_Comp_Alt_3	CID	x			Shutdown	3365
PhaseOver_Traction_Alt_1	CID	x	x	x	Shutdown	4012
PhaseOver_Traction_Alt_2	CID	x		x	Shutdown	4013
PhaseOver_Traction_Alt_3	CID	x			Shutdown	4014
AR1_Desat	CID	x	x	x	Warning Only	3366
AR2_Desat	CID	x		x	Warning Only	3367
AR3_Desat	CID	x			Warning Only	3368
AC1_Desat	CID	x		x	Derate	3301
AC2_Desat	CID	x		x	Derate	3300
AC3_Desat	CID	x		x	Derate	4019
PE_Any_Device_Desat	CID	x	x	x	Warning Only	3466
AR1_Synch	CID	x	x	x		3366
AR2_Synch	CID	x		x		3367
AR3_Synch	CID	x				3368
PhaseImbalance_Comp_Alt_1	CID	x	x	x	Shutdown	3363

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
PhaseImbalance_Comp_Alt_2	CID	x		x	Shutdown	3364
PhaseImbalance_Comp_Alt_3	CID	x			Shutdown	3365
PhaseImbalance_Traction_Alt_1	CID	x	x	x	Shutdown	4006
PhaseImbalance_Traction_Alt_2	CID	x		x	Shutdown	4007
PhaseImbalance_Traction_Alt_3	CID	x			Shutdown	4008
PE_No_Heartbeat	CID	x	x	x	Warning Only	3466
AR1_Internal_Fault	CID	x	x	x	Warning Only	3366
AR2_Internal_Fault	CID	x		x	Warning Only	3367
AR3_Internal_Fault	CID	x			Warning Only	3368
AC1_Internal_Fault	CID	x		x	Derate	3301
AC2_Internal_Fault	CID	x		x	Derate	3300
AC3_Internal_Fault	CID	x		x	Derate	4020
CompAltFieldReg_1	CID	x	x	x	Warning Only	3369
CompAltFieldReg_2	CID	x		x	Warning Only	3370
CompAltFieldReg_3	CID	x			Warning Only	3371
PE_Internal_Fault	CID	x	x	x	Warning Only	3466
CompAltTemp1	EID	x	x	x	Derate On Warning, Shutdown On Fault	3363
CompAltTemp2	EID	x		x	Derate On Warning, Shutdown On Fault	3364
CompAltTemp3	EID	x			Derate On Warning, Shutdown On Fault	3365
GearBoxTemp1	EID	x	x	x	Derate On Warning, Shutdown On Fault	4068
GearBoxTemp2	EID	x		x	Derate On Warning, Shutdown On Fault	4069
GearBoxTemp3	EID	x			Derate On Warning, Shutdown On Fault	4070
RectifierTemp1	EID	x	x	x	Derate On Warning, Shutdown On Fault	3366
RectifierTemp2	EID	x		x	Derate On Warning, Shutdown On Fault	3367
RectifierTemp3	EID	x			Derate On Warning, Shutdown On Fault	3368
TractionAltTemp1	EID	x	x	x	Derate On Warning, Shutdown On Fault	4065
TractionAltTemp2	EID	x		x	Derate On Warning, Shutdown On Fault	4066
TractionAltTemp3	EID	x			Derate On Warning, Shutdown On Fault	4067
AirFilterDiffPress_1	EID	x	x	x	Warning Only	4071
AirFilterDiffPress_2	EID	x		x	Warning Only	4072

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
AirFilterDiffPress_3	EID	x			Warning Only	4073
AR1_Overtemp	EID	x	x	x		3366
AR2_Overtemp	EID	x		x		3367
AR3_Overtemp	EID	x				3368
PEAmbientTemp	EID	x	x	x		916
PEHeatSinkTemp	EID	x	x	x		917
AC1_Temp_Fault	CID	x		x	Derate	3301
AC2_Temp_Fault	CID	x		x	Derate	3300
AC3_Temp_Fault	CID	x		x	Derate	4024

8.4 TRACTION CONTROL MODULE TO LCM FAULT CODES

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
TA1_Engine_Limit	CID	x			Warning Only	4099
TA1_Exciter_Disabled	CID	x			Warning Only	4104
TA1_Excitation_Limit	CID	x			Warning Only	4100
TA1_GFC_Down	CID	x			Warning Only	4102
TA2_Engine_Limit	CID	x			Warning Only	4103
TA2_Exciter_Disabled	CID	x			Warning Only	4105
TA2_Excitation_Limit	CID	x			Warning Only	4104
TA2_GFC_Down	CID	x			Warning Only	4106
TA3_Engine_Limit	CID	x			Warning Only	4107
TA3_Exciter_Disabled	CID	x			Warning Only	4109
TA3_Excitation_Limit	CID	x			Warning Only	4108
TA3_GFC_Down	CID	x			Warning Only	4110
Unable_Load_DB	CID	x			Warning Only	4080
Unable_Load_Power	CID	x			Warning Only	4081
Unable_Load_Test	CID	x			Warning Only	4082
Loss of TCM j1939	CID	x			Warning Only	3337
TA1_Current_Transducer_Failure	CID	x	x	x	Warning Only	4074
TA2_Current_Transducer_Failure	CID	x		x	Warning Only	4075
TA3_Current_Transducer_Failure	CID	x			Warning Only	4076
TM1_Current_Transducer_Failure	CID	x	x	x	Warning Only	3350
TM1_Voltage_Transducer_Failure	CID	x	x	x	Warning Only	3356
TM2_Current_Transducer_Failure	CID	x	x	x	Warning Only	3351
TM2_Voltage_Transducer_Failure	CID	x	x	x	Warning Only	3357
TM3_Current_Transducer_Failure	CID	x	x	x	Warning Only	3352
TM3_Voltage_Transducer_Failure	CID	x	x	x	Warning Only	3358
TM4_Current_Transducer_Failure	CID	x	x	x	Warning Only	3353

FAULT CODE	TYPE	PR22B	PR30C	PR43C	LCM RESPONSE	CID/EID
TM4_Voltage_Transducer_Failure	CID	x	x	x	Warning Only	3359
TM5_Current_Transducer_Failure	CID				Warning Only	3354
TM5_Voltage_Transducer_Failure	CID				Warning Only	3360
TM6_Current_Transducer_Failure	CID				Warning Only	3355
TM6_Voltage_Transducer_Failure	CID				Warning Only	3361
Traction_Alt_1_Fault	CID	x				4077
Traction_Alt_2_Fault	CID	x				4078
Traction_Alt_3_Fault	CID	x				4079
Contactor_Fault_B	CID	x			Warning Only	3293
Contactor_Fault_P1	CID	x			Warning Only	3294
Contactor_Fault_P2	CID	x			Warning Only	3295
Contactor_Fault_P3	CID	x			Warning Only	3296
Contactor_Fault_P4	CID	x			Warning Only	3297
Contactor_Fault_P5	CID	x			Warning Only	3298
Contactor_Fault_P6	CID	x			Warning Only	3299
Contactor_Fault_S14	CID	x			Warning Only	3344
Contactor_Fault_S25	CID	x			Warning Only	3345
Contactor_Fault_S36	CID	x			Warning Only	3346
Grid_Blower_A_Fault	CID	x			Warning Only	3308
Grid_Blower_A_Transducer_Fault	CID	x			Warning Only	3045
Grid_Blower_B_Fault	CID	x			Warning Only	3309
Grid_Blower_B_Transducer_Fault	CID	x			Warning Only	3045
Ground_Relay_Trip	CID	x			Warning Only	3347
MG_Voltage_Transducer_Fault	CID	x			Warning Only	4098
need excessive wheel slip					Derate	

8.5 LCM FAULT CODES

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
AC1_Comm_Fault	X		X	Derate Locomotive		
AC1_Desat	X		X	Derate Locomotive	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
AC1_Internal_Fault	X		X	Derate Locomotive		
AC1_OverCurrent	X		X	Derate Locomotive	The PE shall monitor the currents for each inverter In the event that the current of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	
AC1_Overload	X		X	Derate Locomotive		
AC1_OverVoltage	X		X	Derate Locomotive	The PE shall monitor the voltage for each inverter In the event that the voltage of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	
AC1_Temp_Fault	X		X	Derate Locomotive		
AC1_UnderVoltage	X		X	Derate Locomotive		
AC2_Comm_Fault	X		X	Derate Locomotive		
AC2_Desat	X		X	Derate Locomotive	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
AC2_Internal_Fault	X		X	Derate Locomotive		
AC2_OverCurrent	X		X	Derate Locomotive	The PE shall monitor the currents for each inverter In the event that the current of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
AC2_Overload	X		X	Derate Locomotive		
AC2_OverVoltage	X		X	Derate Locomotive	The PE shall monitor the voltage for each inverter In the event that the voltage of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	
AC2_Temp_Fault	X		X	Derate Locomotive		
AC2_UnderVoltage	X		X	Derate Locomotive		
AC3_Desat	X		X	?	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
AC3_Internal_Fault	X		X	?		
AC3_OverCurrent	X		X	?	The PE shall monitor the currents for each inverter In the event that the current of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	
AC3_Overload	X		X	?		
AC3_OverVoltage	X		X	?	The PE shall monitor the voltage for each inverter In the event that the voltage of any inverter exceeds a peak value, the PE shall broadcast the inverter status via the datalink.	
AC3_Temp_Fault	X		X	?		
AC3_UnderVoltage	X		X	?		
Air System Rate of Change					Main Air pressure rate of change is outside of predetermined limits	
AirFilterDiffPress_1	X	X	X	Warning Only		
AirFilterDiffPress_2	X		X	Warning Only		
AirFilterDiffPress_3	X			Warning Only		
AR1_Comms	X	X	X			
AR1_Desat	X	X	X	Warning Only	Desaturation is when an IGBT running saturated	

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
					(meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
AR1_Internal_Fault	**X**	**X**	**X**	Warning Only		
AR1_Overload	**X**	**X**	**X**			
AR1_Overtemp	**X**	**X**	**X**			
AR1_OverVoltage	**X**	**X**	**X**			
AR1_Synch	**X**	**X**	**X**			
AR1_UnderVoltage	**X**	**X**	**X**	@ Speed Shutdown Module		
AR2_Comms	**X**		**X**			
AR2_Desat	**X**		**X**	Warning Only	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
AR2_Internal_Fault	**X**		**X**	Warning Only		
AR2_Overload	**X**		**X**			
AR2_Overtemp	**X**		**X**			
AR2_OverVoltage	**X**		**X**			
AR2_Synch	**X**		**X**			
AR2_UnderVoltage	**X**		**X**	@ Speed Shutdown Module		
AR3_Comms	**X**					
AR3_Desat	**X**			Warning Only	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
AR3_Internal_Fault	X			Warning Only		
AR3_OverLoad	X					
AR3_Overtemp	X					
AR3_OverVoltage	X					
AR3_Synch	X					
AR3_UnderVoltage	X			@ Speed Shutdown Module		
CompAltFieldReg_1	X	X	X	Warning Only	The PE shall monitor the open/closed state of three (3) N. O. alarm contacts. Each contact, when closed, indicates a fault condition in the corresponding CA voltage regulator. Upon detection of contact closure, PE shall send an appropriate status message update via datalink	
CompAltFieldReg_2	X		X	Warning Only	The PE shall monitor the open/closed state of three (3) N. O. alarm contacts. Each contact, when closed, indicates a fault condition in the corresponding CA voltage regulator. Upon detection of contact closure, PE shall send an appropriate status message update via datalink	
CompAltFieldReg_3	X			Warning Only	The PE shall monitor the open/closed state of three (3) N. O. alarm contacts. Each contact, when closed, indicates a fault condition in the corresponding CA voltage regulator. Upon detection of contact closure, PE shall send an appropriate status message update via datalink	
CompAltTemp1	X	X	X	Derate On Warning, Shutdown On Fault		
CompAltTemp2	X		X	Derate On Warning, Shutdown On Fault		
CompAltTemp3	X			Derate On Warning, Shutdown On Fault		
Contactor_Fault_B	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_P1	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
Contactor_Fault_P2	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_P3	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_P4	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_P5	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_P6	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_S14	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_S25	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Contactor_Fault_S36	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Fuel System Restriction					Fuel pressure from engines at speed are too low	
GearBoxTemp1	X	X	X	Derate On Warning, Shutdown On Fault		
GearBoxTemp2	X		X	Derate On Warning, Shutdown On Fault		
GearBoxTemp3	X			Derate On Warning, Shutdown On Fault		
Grid_Blower_A_Fault	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Grid_Blower_A_Transducer_Fault	X			Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
Grid_Blower_B_Fault	X			Warning Only	ZTR Determines Faulty Contactor	CDL diagnostic will be logged for this fault.
Grid_Blower_B_Transducer_Fault	X			Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
Ground_Fault_Comp_Alt_1	X	X	X	Shutdown Module	MPT shall monitor the vector sum of the phase currents for each active rectifier. The vector sum shall represent the zero-sequence fault current	Shutdown the engine Module of the corresponding companion
Ground_Fault_Comp_Alt_2	X		X	Shutdown Module	MPT shall monitor the vector sum of the phase currents for each active rectifier. The vector sum shall represent the zero-sequence fault current	Shutdown the engine Module of the corresponding companion
Ground_Fault_Comp_Alt_3	X			Shutdown Module	MPT shall monitor the vector sum of the phase currents for each active rectifier. The vector sum shall represent the zero-sequence fault current	Shutdown the engine Module of the corresponding companion
Ground_Fault_Traction_Alt_1	X	X	X	Shutdown Module	The PE shall monitor the vector sum of the phase	

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
					currents for each traction alternator. The vector sum shall represent the zero-sequence fault current. In the event that the zero-sequence fault threshold current of any traction alternator is exceeded, the PE shall broadcast the traction alternator status via the datalink.	
Ground_Fault_Traction_Alt_2	X		X	Shutdown Module	The PE shall monitor the vector sum of the phase currents for each traction alternator. The vector sum shall represent the zero-sequence fault current. In the event that the zero-sequence fault threshold current of any traction alternator is exceeded, the PE shall broadcast the traction alternator status via the datalink.	
Ground_Fault_Traction_Alt_3	X			Shutdown Module	The PE shall monitor the vector sum of the phase currents for each traction alternator. The vector sum shall represent the zero-sequence fault current. In the event that the zero-sequence fault threshold current of any traction alternator is exceeded, the PE shall broadcast the traction alternator status via the datalink.	
Ground_Relay_Trip	X			Warning Only		CDL diagnostic will be logged for this fault.
Locomotive Derate					When the locomotive is derated by the LCM	
Locomotive Shutdown				Shutdown Locomotive		
Loss of PE J1939	X			Warning Only	Loss of Prop_PE_Status message for 10 sec	
Loss of TCM j1939	X			Warning Only	Loss of Prop_ZTR message for 10 sec	CDL diagnostic will be logged for this fault.
MG_Voltage_Transducer_Fault	X			Warning Only		
need excessive wheel slip				Derate		
PE_Any_Device_Desat	X	X	X	Warning Only	Desaturation is when an IGBT running saturated (meaning that the (effective) collector - emitter voltage is near 0, has an increase in current sufficient to exceed the base/gate voltage capability to keep the c-e voltage near 0 (very high current or gate drive failure).	
PE_Bus_Overvoltage	X	X	X	@ Speed Shutdown Module		

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
PE_Bus_Undervoltage	X	X	X	@ Speed Shutdown Module		
PE_Communications_Fault	X	X	X	Warning Only		
PE_Internal_Fault	X	X	X	Warning Only		
PE_No_Heartbeat	X	X	X	Warning Only		
PEAmbientTemp	X	X	X			
PEHeatSinkTemp	X	X	X			
PhaseImbalance_Comp_Alt_1	X	X	X	Shutdown Module	The PE shall monitor the imbalance of the phase currents for each alternator. In the event that the phase imbalance threshold of any alternator is exceeded, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseImbalance_Comp_Alt_2	X		X	Shutdown Module	The PE shall monitor the imbalance of the phase currents for each alternator. In the event that the phase imbalance threshold of any alternator is exceeded, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseImbalance_Comp_Alt_3	X			Shutdown Module	The PE shall monitor the imbalance of the phase currents for each alternator. In the event that the phase imbalance threshold of any alternator is exceeded, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseImbalance_Traction_Alt_1	X	X	X	Shutdown Module	The PE shall monitor the imbalance of the phase currents for each traction alternator. In the event that the phase imbalance threshold of any traction alternator is exceeded, the PE shall broadcast the traction alternator status via the datalink	
PhaseImbalance_Traction_Alt_2	X		X	Shutdown Module	The PE shall monitor the imbalance of the phase currents for each traction alternator. In the event that the phase imbalance threshold of any traction alternator is exceeded, the PE shall broadcast the traction alternator status via the datalink	
PhaseImbalance_Traction_Alt_3	X			Shutdown Module	The PE shall monitor the imbalance of the phase currents for each traction alternator. In the event that the phase imbalance threshold of any traction alternator is exceeded, the PE shall broadcast the	

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
					traction alternator status via the datalink	
PhaseOver_Comp_Alt_1	X	X	X	Shutdown Module	The PE shall monitor the phase currents for each alternator. In the event that the phase current of any alternator exceeds a peak value, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseOver_Comp_Alt_2	X		X	Shutdown Module	The PE shall monitor the phase currents for each alternator. In the event that the phase current of any alternator exceeds a peak value, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseOver_Comp_Alt_3	X			Shutdown Module	The PE shall monitor the phase currents for each alternator. In the event that the phase current of any alternator exceeds a peak value, the PE shall broadcast the alternator status via the datalink.	Shutdown the engine Module of the corresponding companion
PhaseOver_Traction_Alt_1	X	X	X	Shutdown Module	The PE shall monitor the phase currents for each traction alternator. In the event that the phase current of any traction alternator exceeds a peak value, the PE shall broadcast the traction alternator status via the datalink.	
PhaseOver_Traction_Alt_2	X		X	Shutdown Module	The PE shall monitor the phase currents for each traction alternator. In the event that the phase current of any traction alternator exceeds a peak value, the PE shall broadcast the traction alternator status via the datalink.	
PhaseOver_Traction_Alt_3	X			Shutdown Module	The PE shall monitor the phase currents for each traction alternator. In the event that the phase current of any traction alternator exceeds a peak value, the PE shall broadcast the traction alternator status via the datalink.	
RectifierTemp1	X	X	X	Derate On Warning, Shutdown On Fault		
RectifierTemp2	X		X	Derate On Warning, Shutdown On Fault		
RectifierTemp3	X			Derate On Warning, Shutdown On Fault		
TA1_Current_Transducer_Failure	X	X	X	Warning Only		CDL diagnostic will be logged for this fault.
TA1_Engine_Limit						

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
TA1_Excitation_Limit						
TA1_Exciter_Disabled						
TA1_GFC_Down						
TA2_Current_Transducer_Failure	x		x	Warning Only		CDL diagnostic will be logged for this fault.
TA2_Engine_Limit						
TA2_Excitation_Limit						
TA2_Exciter_Disabled						
TA2_GFC_Down						
TA3_Current_Transducer_Failure	x			Warning Only		CDL diagnostic will be logged for this fault.
TA3_Engine_Limit						
TA3_Excitation_Limit						
TA3_Exciter_Disabled						
TA3_GFC_Down						
TM1_Current_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM1_Voltage_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM2_Current_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM2_Voltage_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM3_Current_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM3_Voltage_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM4_Current_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM4_Voltage_Transducer_Failure	x	x	x	Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM5_Current_Transducer_Failure				Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM5_Voltage_Transducer_Failure				Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.

FAULT CODE	PR22B	PR30C	PR43C	LCM RESPONSE	DEFINITION OF FAULT	DETAILS
TM6_Current_Transducer_Failure				Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
TM6_Voltage_Transducer_Failure				Warning Only	ZTR determines Faulty Transducer	CDL diagnostic will be logged for this fault.
Traction_Alt_1_Fault	X					
Traction_Alt_2_Fault	X					
Traction_Alt_3_Fault	X					
TractionAltTemp1	X	X	X	Derate On Warning, Shutdown On Fault		
TractionAltTemp2	X		X	Derate On Warning, Shutdown On Fault		
TractionAltTemp3	X			Derate On Warning, Shutdown On Fault		
Unable_Load_DB	X			Warning Only		
Unable_Load_Power	X			Warning Only		
Unable_Load_Test	X			Warning Only		

9

FAILURE MODES

The **SEVERITY** of the failure is base upon a value of 1 – 10, where 1 is the lowest and 10 is the highest level of severity.

Know **Causes And Mechanisms Of Failure** are listed here and should not be considered as all inclusive.

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
INCORRECT START ORDER	LCM CONTROLS ENGINE ORDER - BASED ON FUEL USAGE	Frequency Of Engine Service Not Consistent	Problem With Priority Strategy Data Link Failure From Engine Performance Map
		Engine Wear Not Consistent	Problem With Priority Strategy Data Link Failure From Engine Performance Map
FAIL TO START	AUTO START / STOP	Not Operable	Data Link Failure From Engine Data Link Failure From Master Control Starter Failure Starter Power Supply Fuel Supply Engine Temp Too Cold Incorrect Engine Selection
FAIL TO STOP		Excessive Fuel Consumption	Data Link Failure From Engine Data Link Failure From Master Control Improper Start /Stop Strategy Incorrect J1939 Addressing
FAILS TO RECOGNIZE INOPERABLE ENGINE	LCM IDENTIFIES OPERABLE ENGINES	Degraded Train Performance	Wrong Engine Status Engine Diagnostics Data Link Failure From Engine Wrong Alternator Diagnostics Wrong PE Diagnostics Data Link Failure From Locomotive Controller
INCORRECT ENGINE CONFIGURATION IN BLUE BOX		Degraded Train Performance	Wrong Software Loaded Incorrect User Configuration

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
INCORRECTLY IDENTIFIED ENGINE AS BAD		Degraded Train Performance Improper Service Interval	From Fails To Recognize Wrong PE Diagnostics
LOSS OF J1939 ENGINE 1/2/3	DIAGNOSTICS	In Correct Number Of Engines Operating	Data Link Failure Software In Compatibility From Engine In Correct Bus Termination
LOSS OF J1939 ZTR/CPT		Loss Of Air Compressor(Brakes)	Data Link Failure Software Incompatibility In Correct Bust Termination
		Loss Of Traction Motor Blower	Data Link Failure Software Incompatibility In Correct Bust Termination
		Loss Of Traction Motor	Data Link Failure Software Incompatibility In Correct Bust Termination
		Loss Of Companion (No Accessory Power)	Data Link Failure Software Incompatibility In Correct Bust Termination
		Loss Of Battery Charger	Data Link Failure Software Incompatibility In Correct Bust Termination Open/Short
COMPRESSOR OUT PUT DRIVER FAILURE		Loss Of Brakes	In Correct Strategy Open/Short
STOP FAILURE	D INPUTS	Failure To Send Out Shut Down Messages	In Correct Strategy
FAILURE TO START ENGINE 1/2/3		In Correct Number Of Engines Operating	Data Link Failure

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
			Software In Compatibility From Engine Engine Too Cold To Start Mechanical Problem
UNEXPECTED SHUTDOWN		In Correct Number Of Engines Operating	Data Link Failure Software In Compatibility From Engine Alternator Faults Mechanical Problem
E STOP NOT OPERABLE	EMERGENCY STOP OF LOCOMOTIVE ESTOP	Engine Would Not Stop	Loss Of Data Link Message Incorrect Data Link Message Interpretation
		Excessive Wear On Generators	Loss Of Data Link Message Incorrect Data Link Message Interpretation
UNEXPECTED SHUT DOWN OF THE ENGINE		In Correct Number Of Engines Operating	Broken Wire To Blue Box Incorrect Data Link Message Interpretation
FAILS TO SEND SHUT DOWN MESSAGE ON J1939 TO ENGINE ECM		Engines Would Not Shut Down	Loss Of Data Link Message Incorrect Data Link Message Interpretation
ERROR IN LOCOMOTIVE MODE	LOCOMOTIVE MODE	Wrong Number Of Engines And Use	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
		Long Haul Mode Failure	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
		Switcher Mode Failure	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
		Loss Of Productivity	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
		Excessive Start Stop Of Engines	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
INCORRECT NEUTRAL LEVER SIGNAL	NEUTRAL MODE	Incorrect Start/Stop Strategy	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
		Degraded Performance	Incorrect Operator Use
ERROR IN START FROM COLD LOCOMOTIVE	START FROM COLD LOCOMOTIVE	Engines Running At Non Preferable Temps??	Incorrect Operator Use
INCORRECT NOTCH SELECTION		Incorrect Power	Incorrect Map Data
		Excessive Load On The Excitation Loader /Alternator/Generator	Incorrect No Of Engines Available Incorrect Prioritization Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation
		Incorrect Start/Stop Strategy	Incorrect Accessory Map Data
INCORRECT ACCESSORY POWER SELECTION		Incorrect Power	Incorrect Map Data
		Excessive Load On The Excitation Loader /Alternator/Generator	Incorrect No Of Engines Available Incorrect Prioritization
		Incorrect Start/Stop Strategy	Loss Of Data Link Incorrect Data Link Message Incorrect Data Link Message Interpretation Loss Of Data Link

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
			Incorrect Data Link Message
INCORRECT ENGINE SPEED	MASTER LCM J1939 ENGINE SPEED CONTROL	Excessive Wear On T He Engines/Generators	Incorrect Data Link Message Interpretation Incorrect Engine Selection Map Data
		Incorrect Fuel Economy	Incorrect Bus Timing
		Incorrect Power Out Put	Incorrect J1939 Addressing Incorrect Terminization Od The Bus
MORE ENGINES RUNNING THEN NECESSARY		Loss Of Fuel Economy	Loss Of Data Link Incorrect Data Link Message
	OPERATIONAL TRENDING (OUT PUTS)		Incorrect Data Link Message Interpretation Trending Strategy
SIMULTANEOUS CRANKING	ENGINE POWER UP SEQUENCE	Draws More Current Then Desired	Software Strategy
		Drained Batteries/Damaged	Software Strategy
UNABLE TO SERVICE BLUE BOX	CDL SERVICE TOOL	Unable To Identify Number Of Operable Engines	Loss Of Data Link User Configuration
UNABLE TO SERVICE J1939	ISOLATION OF J1939	Loss Of Data Link	Open/Short Voltage Spikes Current Spikes Improper Installation Of Wiring Harness RF /EMI Interference
FAILURE OF THE BLUE BOX		Loss Of Data Link	Open/Short Voltage Spikes

PROBLEM	FEATURE	FAILURE EFFECTS	CAUSES / MECHANISMS OF FAILURE
			Current Spikes
ECM FAILURE/BLUE BOX	POWER SUPPLY ISOLATION FOR LCM	Loss Of Data Link	Open/Short Voltage Spikes Current Spikes
	LO	Loss Of Air Compressor /Imminent Brake Failure	Open/Short Voltage Spikes Current Spikes
		Loss Of Engine Function	Open/Short Voltage Spikes Current Spikes

9 POWER ELECTRONICS MODULE

PE modules vary from one locomotive to another. This module represents a typical multi-engine locomotive system and is shown for reference only. Refer to the specific locomotive's manuals for current schematics and operational characteristics.

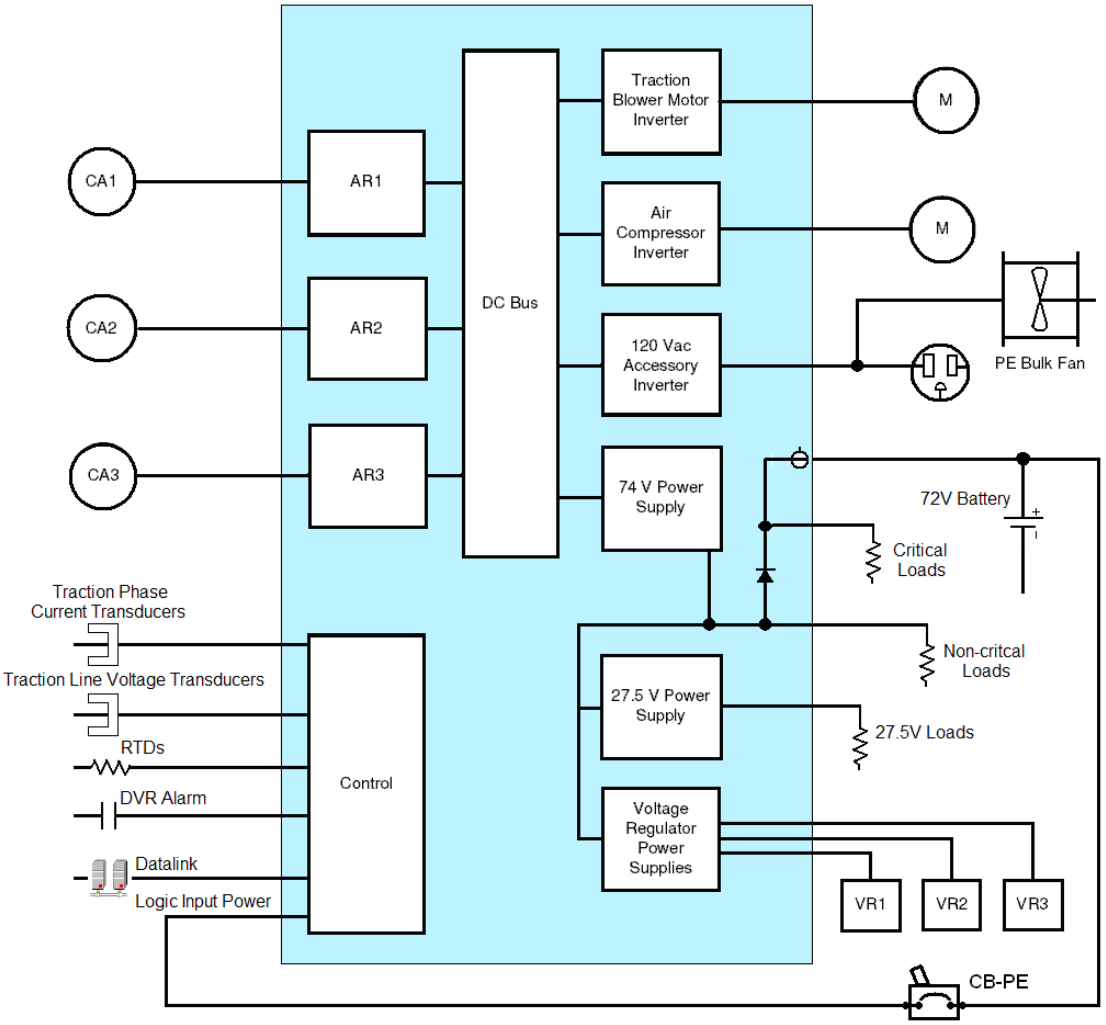


Figure 9-1 PE Module Block Diagram

The Power Electronics module utilizes inverters to convert the variable voltage from the Engine Power Module's (EPM's) companion alternators into 24 VDC computer power circuit, 440 VAC 3Ø air compressor voltage, variable traction motor blower power at 480 VAC 1 Ø, and two 74 VDC locomotive circuits and one 74 VDC battery supply and charging circuit.

The PEM communicates to the Traction Control Module (TCM) and the Locomotive Control Module (LCM) that logs faults and commands engine shutdowns should the Power Electronics Module fail. Communication is over the J1939 CAN-B (LOCO) network.

9.1 DEFINITIONS

ACCESSORY POWER – Power source for all locomotive electrical loads except traction motors and engine electrical systems.

ACTIVE RECTIFIER (AR) – Power rectifier utilizing power transistors that converts variable voltage, variable frequency power from Companion Alternator to a regulated DC bus voltage. The active rectifier has the ability to control power factor of the Companion Alternator load.

BULK CAPACITOR DISCHARGE – The reduction of stored energy within a DC capacitor from 90% of initial voltage to 10% of initial voltage.

COMPANION ALTERNATOR (CA) – Any of the three independently driven three phase, variable voltage / variable frequency synchronous alternators that provide input power to the Power Electronics converter.

DATALINK – The serial communication infrastructure of the locomotive for CAN-enabled devices.

POWER ELECTRONICS (PE) – The multi-input / multi-output power converter that converts Companion Alternator power to various AC and DC outputs to power locomotive Accessory Power loads.

9.2 LOCOMOTIVE AND PE BOX CONTROL FLOW

A PE module CONTROL flow diagram (PR22 series multi-engine) is provided in Figure 9-2. This control diagram shows the control flow for the Multi-Engine platform locomotives. Up to three locomotive Electrical Power Modules (EPM) can be controlled with this PE Box. The control flow for locomotives with fewer engines can be seen by eliminating the unused number of power modules.

NOTE: PR30 and PR43 series locomotives do not utilize the GEAR BOX features.

Refer to the specific locomotive's reference manuals for current schematics and operational characteristics.

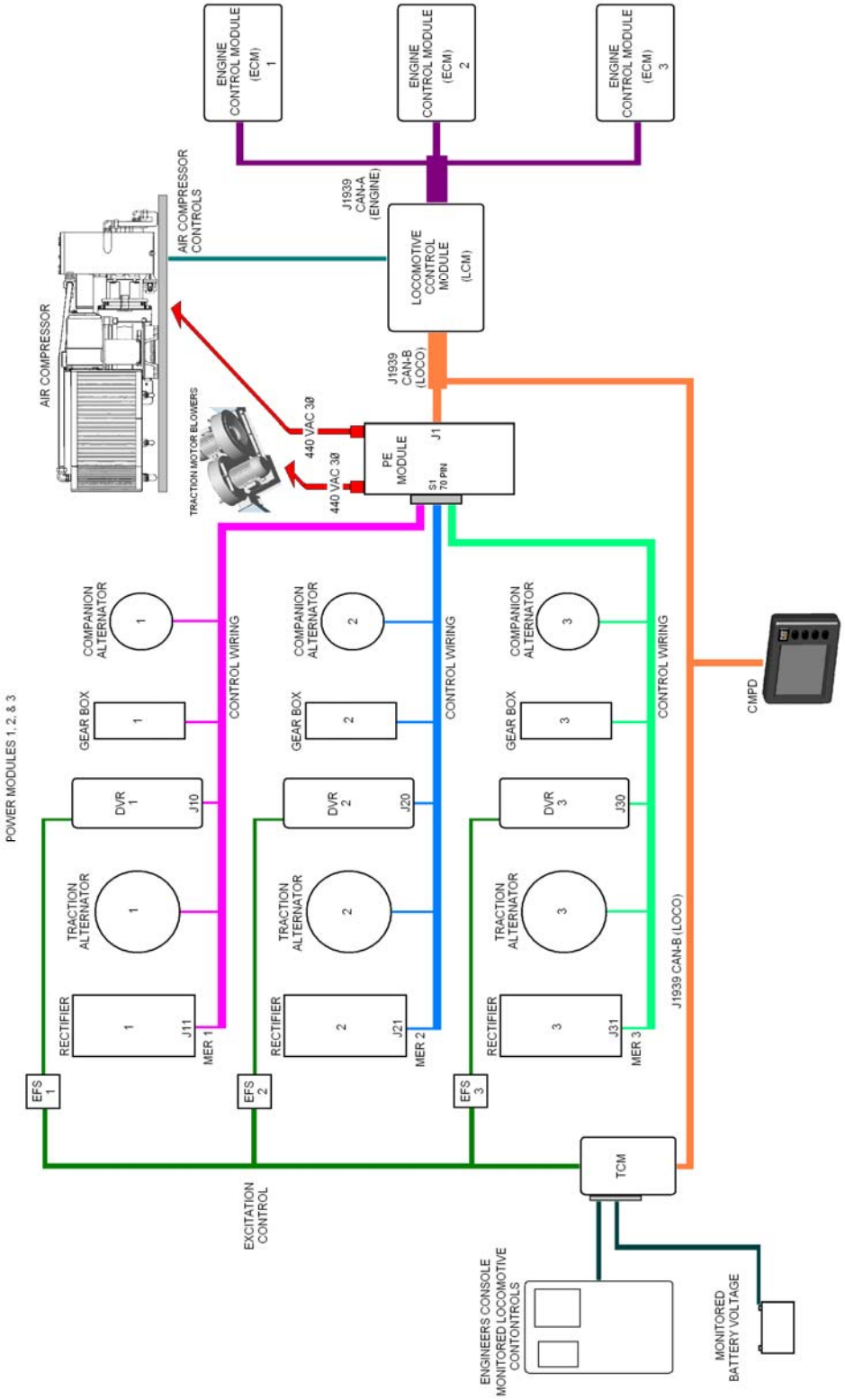


Figure 9-2 PE Module Control Diagram

9.3 OPERATION

COMPANION SELECT

The PE Box accepts input power from one, two, or three companion alternators. These alternators can operate asynchronously and at different voltage levels. Once a data link is established a datalink command is used to select the input power from each alternator independently.

ACTIVE RECTIFIERS

The active rectifiers of the PE Box can be independently disabled (Active Rectifier 1, 2, or 3) in the event that:

- the datalink Companion Selection message bits are not set
- if the Compressor Motor Speed Request message heartbeat is not detected
- if applicable faults exist

NOTE: The nominal input voltage/frequency characteristic: 179 – 460 V(rms), 23.3 – 60 Hz (linear relationship). The active rectifier power inputs present a nominal unity power factor to each companion alternator at rated load.

The active rectifiers provide smooth transitioning and load sharing of the input power sources without disruption of PE output power supplies.

POWER

The power to each active rectifier is monitored for broadcasting Measured Power via the datalink.

The active rectifiers, also, can limit power drawn from each companion alternator based on the speed of the alternator:

Companion Alternator Speed (RPM) / (Hz)	Companion Alternator Line Voltage (Vrms)	Maximum Real Power @ 0.9 PF (kW)	Maximum Apparent Power (KVA)	Maximum Continuous Current (Arms)
700 / 23.3	186.4	13	14.5	45
900 / 30	240	20	22	53
1800 / 60	460	50	55.6	70

Each alternator input to the PE Box has a frequency-dependent current limit based upon a curve derived from the table above. This current limit is linearly interpolated between 23.3 and 60 Hz.

ZERO SEQUENCE FAULT

The vector sum of the phase currents for each active rectifier is monitored and is the Zero

Sequence Fault current. The PE will broadcast a message over the datalink when that the Zero Sequence Fault threshold current of the corresponding companion alternator (CA) is exceeded (see Table 9-1).

Table 9-1 Electrical Characteristics

PARAMETER	TEST CONDITIONS	MIN	TYPICAL	MAX	UNITS
Input Voltage		179		460	V(rms)
Input frequency		23.3 (700)		60 (1800)	Hz (RPM)
Input power factor	Vin = 460 V; Iph = 56 A; f = 60 Hz	0.9		1.0	P.U.
Input current total harmonic distortion	Vin = 460 V; Iph = 56 A; f = 60 Hz		5		% of total
Input power measurement accuracy			+/-5		kW
Input voltage without damage	No load; f = 60 Hz; 10 sec max			566	V(rms)
Zero-sequence fault threshold current		18		22	A(rms)

74 V DC SUPPLY

The PE Box provides 3 74Volt DC outputs:

- 74 V Battery Charging
- 74 V Critical Accessory Loads
- 74 V Non-critical Accessory Loads

The DC output for battery charging and the 74 V DC accessory loads are separate outputs with separate terminals for charging and separate terminals for the accessory loads.

There is an isolation diode separating the non-critical 74 V accessory loads from critical 74 V accessory loads and 74 V battery charging circuits (Figure 9-3).

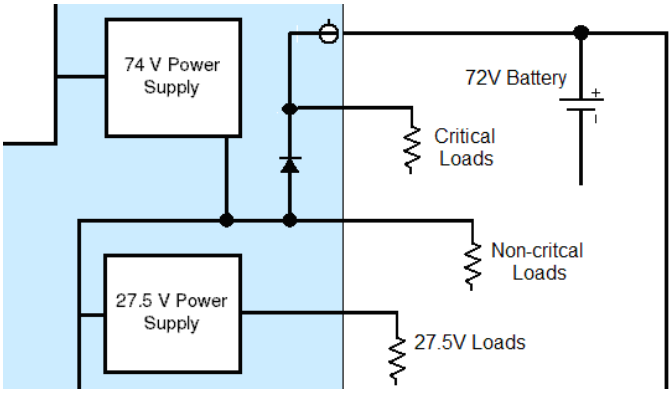


Figure 9-3 74V DC Circuits

Battery fusing is part of the Low Voltage Cabinet and is not part of the PE.

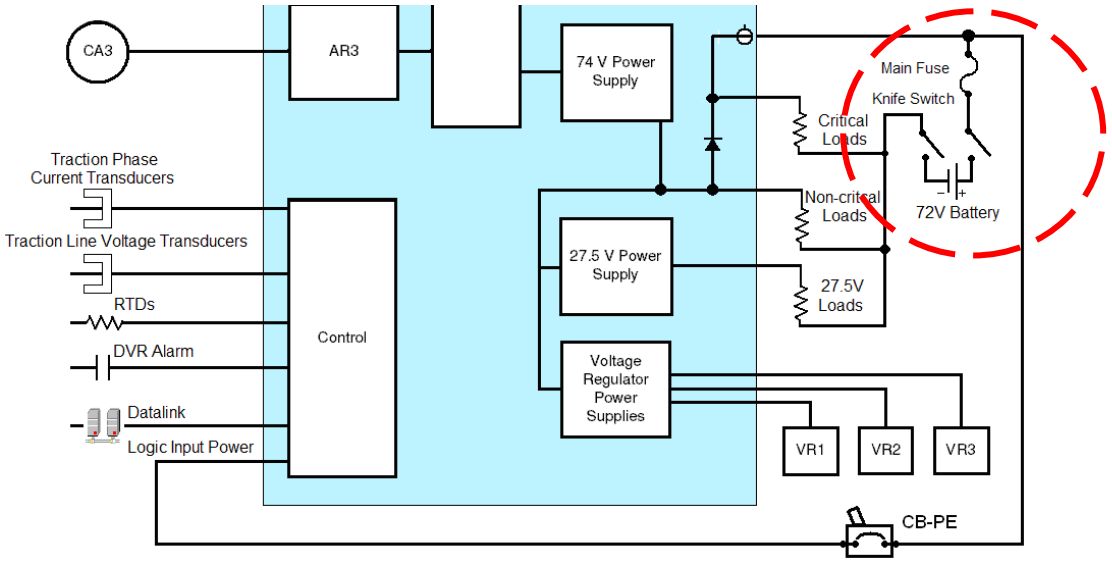


Figure 9-4 PE Box Fusing

AUTOSTART

The Outputs will auto-start when 74V DC power is applied and at least one companion is active when no PE-specific faults are pending.

TOTAL CONTINUOUS OUTPUT CURRENT

The total continuous output current rating (battery charging plus accessory loads plus scaled 27.5V output loads) = 270 A DC

9.4 27.5 VOLT SUPPLY

The 27.5 V DC supply is used to power the locomotive computer sysytems, Figure 9-5.

Continuous output current rating of 27.5 V output: 100 A DC

Table 9-2 27.5 V DC Specifications

PARAMETER	TEST CONDITIONS	MIN	TYPICAL	MAX	UNITS
Output voltage	Vin = 460 V, 60 Hz; Iout = 100 A	26.1	27.5	28.9	V(dc)
Output current limit	Vin = 460 V, 60 Hz	100			A(dc)
Bulk capacitor discharge time	Vout = 27.5 V prior to discharge			300	Seconds
Dielectric isolation from input source	1 minute application; leakage < 5 mA	2500			V(rms) sinusoidal

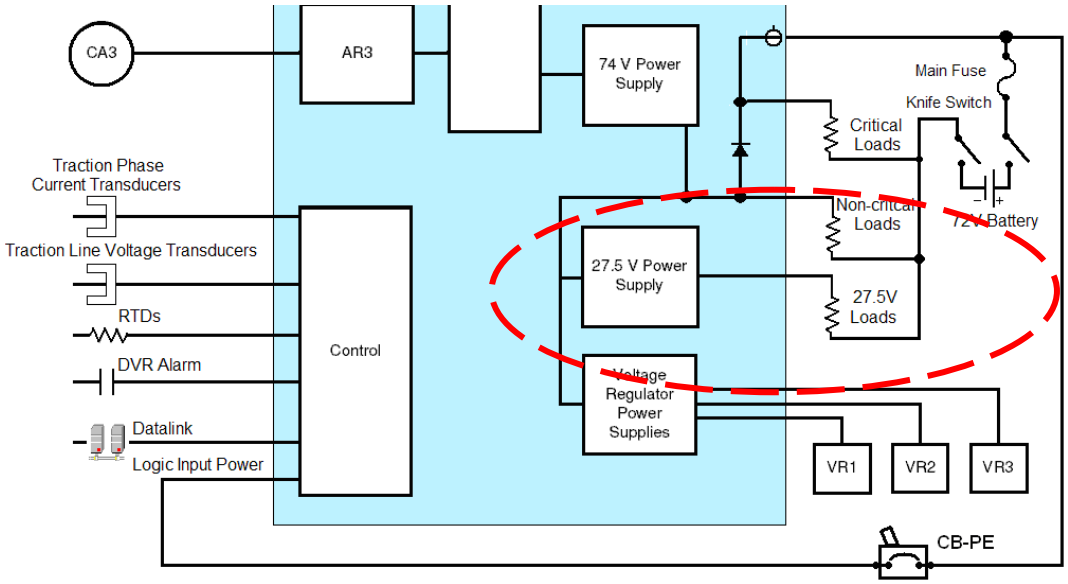


Figure 9-5 27.5 V DC Diagram

9.5 DC AND AC OUTPUTS

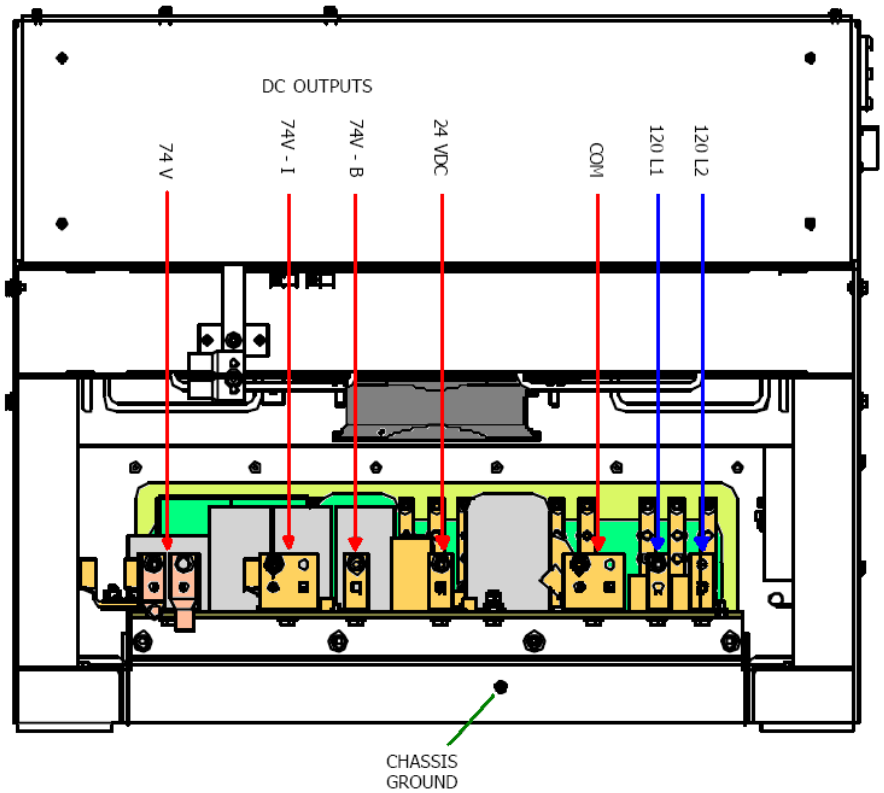


Figure 9-6 PE Module DC and AC Outputs

Figure 9-7 DC And AC Accessory Power Output Terminal Assignments

DC AND AC ACCESSORY POWER OUTPUT TERMINAL ASSIGNMENTS	
Name	**Description**
+27.5 V	+27.5 V output
COM	Common
+74 – V	+74 V critical load output
+74 – I	+74 V total non-critical load output
+74 – B	+74 V battery charger output
120 L1	120 Vac accessory load hot output
120 L2	120 Vac accessory load neutral output

PE MODULE AC INPUTS AND OUTPUTS

Refer to the specific locomotive's Trouble Shooting Guide for current schematics and operational characteristics.

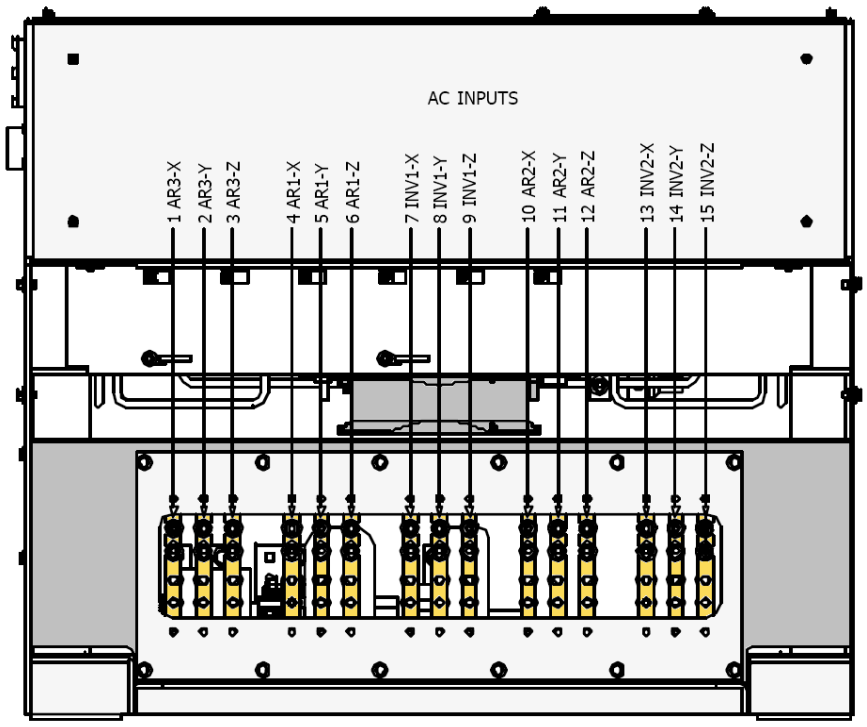


Figure 9-8 PE Module AC Inputs and Outputs

The three companion alternators connect to the PE module as shown in Figure 9-8.

AC INPUTS:

CA-3	CA-1	CA-2
1 APR3-X	4 APR1-X	10 APR2-X
2 APR3-Y	5 APR1-Y	11 APR2-Y
3 APR3-Z	6 APR1-Z	12 APR2-Z

CA = COMPANION ALTERNATOR

AC INVERTER OUTPUTS:

7 INV1-X	13 INV2-X
8 INV1-Y	14 INV2-Y
9 INV1-Z	15 INV2-Z

TRACTION BLOWER MOTOR INVERTER OUTPUT

The PE module provides a three phase variable voltage / variable frequency AC output with a constant volts per hertz characteristic for powering traction blower motor(s). In the event of a phase over-current fault, the output will automatically soft re-start. The output frequency is controlled via J1939 datalink command.

The PE provides soft start for the Traction Blower Motor inverter output.

- **OUTPUT FREQUENCY RANGE**: 20 Hz – 60 Hz
- **CONTINUOUS OUTPUT CURRENT RATING**: 90 A(rms)
- **CONTINUOUS OUTPUT POWER RATING**: 75 KVA at 0.9 PF lagging

Figure 9-9 Traction Blower Motor Inverter Electrical characteristics

Parameter	Test Condition	Min	Typical	Max	Units
Output voltage	Vin = 460 V, 60 Hz; fout = 20 Hz	152	160	168	V(rms)
	Vin = 460 V, 60 Hz; fout = 60 Hz	456	480	504	V(rms)
Overload current	Vin = 460 V, 60 Hz; fout = 60 Hz; 10 sec duration	180			A(rms)
Soft-start ramp time	Vin = 460 V, 60 Hz; fout = 60 Hz		32		seconds
Instantaneous over-current trip			240		A(rms)

COMPRESSOR MOTOR INVERTER OUTPUT

The PE provides a three phase variable voltage / variable frequency AC output with a volts per hertz for powering the air compressor.

The output frequency is controlled via J1939 datalink command.

In the event of a phase over-current fault trip, the output shall automatically soft re-start.

The PE provides soft start capability for the Compressor Motor Inverter Output.

- **OUTPUT FREQUENCY RANGE**: 3.75 – 60 Hz
- **CONTINUOUS OUTPUT CURRENT RATING**: 90 A(rms)
- **CONTINUOUS OUTPUT POWER RATING**: 75 KVA at 0.9 PF lagging

Table 9-3 Compressor Motor Inverter Electrical characteristics

Parameter	Test Condition	Min	Typical	Max	Units
Output voltage	Vin = 460 V, 60 Hz; fout = 20 Hz	152	169	168	V(rms)
	Vin = 460 V, 60 Hz; fout = 60 Hz	456	480	504	V(rms)
Overload current	Vin = 460 V, 60 Hz; fout = 60 Hz; 10 sec duration	180			A(rms)
Soft-start ramp time	Vin = 460 V, 60 Hz; fout = 60 Hz		5		seconds
Instantaneous over-current trip			240		A(rms)

AC ACCESSORY INVERTER OUTPUT

The PE provides a single phase fixed voltage / fixed frequency AC output for powering electronic and non-electronic loads requiring a filtered sine wave output.

The output is isolated from PE internal high voltage DC bus.

The output will auto-start if at least one companion is active when no PE-specific faults are pending.

In the event of a phase over-current fault trip, the output will automatically soft re-start.

The neutral output is electrically connected to locomotive chassis ground.

- **CONTINUOUS OUTPUT CURRENT RATING**: 60 A(rms)
- **CONTINUOUS OUTPUT POWER RATING**: 7.2 KVA at 1.0 PF

Table 9-4 Accessory Inverter Electrical characteristics

Parameter	Test Condition	Min	Typical	Max	Units
Output voltage	Vin = 460 V, 60 Hz;	114	120	126	V(rms)
Output frequency	Vin = 460 V, 60 Hz;	58.8	60	61.2	Hz
Overload current	Vin = 460 V, 60 Hz; 10 sec duration	120			A(rms)
Instantaneous over-current trip	Vin = 460 V, 60 Hz;		160		A(rms)
Dielectric isolation from input source	1 minute application; leakage < 5 mA	2500			V(rms) sinusoidal

PE MODULE POWER INPUT AND CONTROL CONNECTORS

The Control connections are shown in Figure 9-10 below.

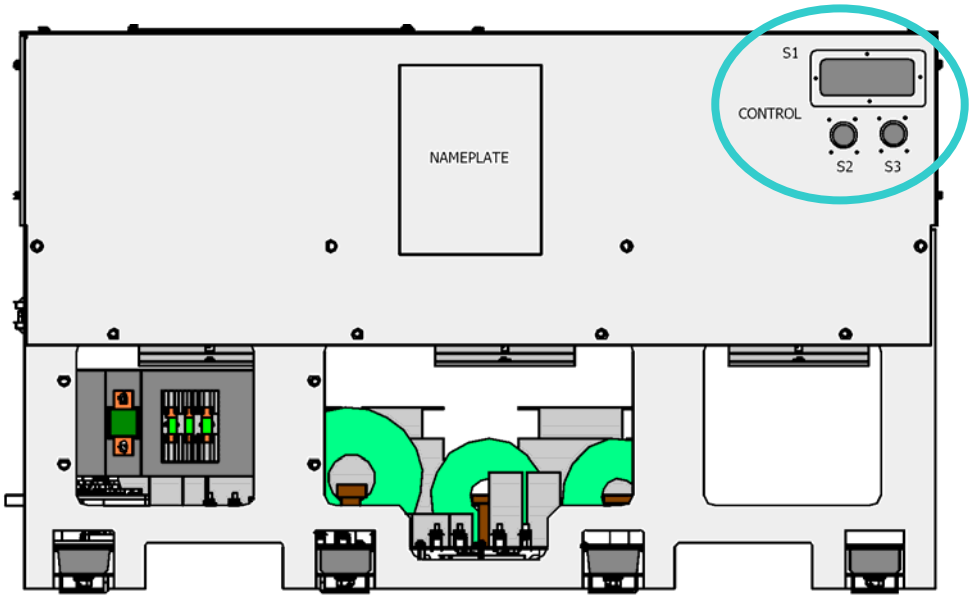


Figure 9-10 PE Module Power Input And Control Connectors

120V POWER INPUT CONNECTOR (S2)

- Connector Physical Description: 9-position connector with flange mounting provisions, pin contacts; Deutsch Part No. HD10-9-12-P.
- Pin Assignments:

Table 9-5 PE Signal Connector #2 (S2)

PE SIGNAL CONNECTOR #2 (S2)		
Pin No.	**Name**	**Destination**
A	+120V1	Field #1 power (J10-5)
B	COMV1	Field #1 power (J10-6)
C	+120V2	Field #2 power (J20-5)
D	COMV2	Field #2 power (J20-6)
E	+120V3	Field #3 power (J30-5)
F	COMV3	Field #3 power (J30-6)
G	N/C	
H	N/C	
J	N/C	

74V POWER INPUT CONNECTOR (S3)

- Connector Physical Description: 6-position connector with flange mounting provisions, pin contacts; Deutsch Part No. HD10-6-12-P.

- Pin Assignments:

Table 9-6 PE Signal Connector #3 (S3)

PE SIGNAL CONNECTOR #3 (S3)		
Pin No.	**Name**	**Description**
A	+74V	PE logic power
B	+74V	PE logic power
C	COM	PE logic power
D	COM	PE logic power
E	N/C	
F	N/C	

CONTROL

- Connector Physical Description: 70-position connector with flange mounting provisions, 70 pin contacts.
- Pin Assignments:

Table 9-7 PE Signal Connector #1 (Control – PRODUCTION VERSIONS)

PIN NO.	NAME	DESCRIPTION
1	RTD_TRACT_ALT_1+	Traction Alternator 1 RTD
2	GNDISO4	Traction Alternator 1 RTD
3	RTD_TRACT_ALT_2+	Traction Alternator 2 RTD
4	GNDISO5	Traction Alternator 2 RTD
5	RTD_TRACT_ALT_3+	Traction Alternator 3 RTD
6	GNDISO6	Traction Alternator 3 RTD
7	TR3_TEMP_1	Traction Rectifier 3 Heatsink Temp
8	IPHY_TRAC_ALT3	Traction Alternator 3 Phase Y Current
9	TR2_TEMP_1	Traction Rectifier 2 Heatsink Temp
10	IPHY_TRAC_ALT2	Traction Alternator 2 Phase Y Current
11	TR1_TEMP_1	Traction Rectifier 1 Heatsink Temp
12	IPHY_TRAC_ALT1	Traction Alternator 1 Phase Y Current
13	TR1_TEMP_2	Traction Rectifier 1 Internal Ambient Temp
14	TR2_TEMP_2	Traction Rectifier 2 Internal Ambient Temp
15	TR3_TEMP_2	Traction Rectifier 3 Internal Ambient Temp
16	N/C	
17	IPHX_TRAC_ALT1	Traction Alternator 1 Phase X Current
18	IPHX_TRAC_ALT2	Traction Alternator 2 Phase X Current
19	IPHX_TRAC_ALT3	Traction Alternator 3 Phase X Current
20	VDC_TRAC_ALT1	Traction Rectifier 1 Equivalent DC Voltage
21	CAN_H	Can High Signal
22	CAN_L	Can Low Signal

PIN NO.	NAME	DESCRIPTION
23	VDC_TRAC_ALT2	Traction Rectifier 2 Equivalent DC Voltage
24	VDC_TRAC_ALT3	Traction Rectifier 3 Equivalent DC Voltage
25	IPHZ_TRAC_ALT1	Traction Alternator 1 Phase Z Current
26	IPHZ_TRAC_ALT2	Traction Alternator 2 Phase Z Current
27	IPHZ_TRAC_ALT3	Traction Alternator 3 Phase Z Current
28	GNDISO	Companion Field Regulator 1 Fault Input
29	/CFR1_IN	Companion Field Regulator 1 Fault Input
30	GNDISO1	Companion Alternator 1 RTD
31	RTD_COMP_ALT_1+	Companion Alternator 1 RTD
32	GNDISO	Companion Field Regulator 2 Fault Input
33	/CFR2_IN	Companion Field Regulator 2 Fault Input
34	GNDISO2	Companion Alternator 2 RTD
35	RTD_COMP_ALT_2+	Companion Alternator 2 RTD
36	GNDISO	Companion Field Regulator 3 Fault Input
37	/CFR3_IN	Companion Field Regulator 3 Fault Input
38	GNDISO3	Companion Alternator 3 RTD
39	RTD_COMP_ALT_3+	Companion Alternator 3 RTD
40	GNDISO7	Gearbox 1 RTD
41	RTD_GEARBOX_1+	Gearbox 1 RTD
42	GNDISO8	Gearbox 2 RTD
43	RTD_GEARBOX_2+	Gearbox 2 RTD
44	GNDISO9	Gearbox 3 RTD
45	RTD_GEARBOX_3+	Gearbox 3 RTD
46	GNDISO	Air Filter Maintenance 1 Fault Input
47	/AFM1_IN	Air Filter Maintenance 1 Fault Input
48	GNDISO	Air Filter Maintenance 2 Fault Input
49	/AFM2_IN	Air Filter Maintenance 2 Fault Input
50	GNDISO	Air Filter Maintenance 3 Fault Input
51	/AFM3_IN	Air Filter Maintenance 3 Fault Input
52	-15V	Supply to Traction Alternator 1 Current Sensors
53	-15V	Supply to Traction Alternator 1 Current Sensors
54	COM	Supply to Traction Alternator 1 Current Sensors
55	COM	Supply to Traction Alternator 1 Current Sensors
56	+15V	Supply to Traction Alternator 1 Current Sensors
57	+15V	Supply to Traction Alternator 1 Current Sensors
58	-15V	Supply to Traction Alternator 2 Current Sensors
59	-15V	Supply to Traction Alternator 2 Current Sensors
60	COM	Supply to Traction Alternator 2 Current Sensors
61	COM	Supply to Traction Alternator 2 Current Sensors
62	+15V	Supply to Traction Alternator 2 Current Sensors
63	+15V	Supply to Traction Alternator 2 Current Sensors
64	-15V	Supply to Traction Alternator 3 Current Sensors

PIN NO.	NAME	DESCRIPTION
65	-15V	Supply to Traction Alternator 3 Current Sensors
66	COM	Supply to Traction Alternator 3 Current Sensors
67	COM	Supply to Traction Alternator 3 Current Sensors
68	+15V	Supply to Traction Alternator 3 Current Sensors
69	+15V	Supply to Traction Alternator 3 Current Sensors
70	N/C	

Table 9-8 PE Signal Connector #1 (Control – EARLY VERSIONS)

PE SIGNAL CONNECTOR #1		
Pin No.	**Name**	**Destination**
1	RTD_TRACT_ALT_1+	Traction Alternator 1 RTD
2	GNDISO4	Traction Alternator 1 RTD
3	RTD_TRACT_ALT_2+	Traction Alternator 2 RTD
4	GNDISO5	Traction Alternator 2 RTD
5	RTD_TRACT_ALT_3+	Traction Alternator 3 RTD
6	GNDISO6	Traction Alternator 3 RTD
7	TR3_TEMP	Traction Rectifier 3 Temp
8	IPHY_TRAC_ALT3	Traction Alternator 3 Phase Y Current
9	TR2_TEMP	Traction Rectifier 2 Temp
10	IPHY_TRAC_ALT2	Traction Alternator 2 Phase Y Current
11	TR1_TEMP	Traction Rectifier 1 Temp
12	IPHY_TRAC_ALT1	Traction Alternator 1 Phase Y Current
13	N/C	
14	N/C	
15	N/C	
16	N/C	
17	IPHX_TRAC_ALT1	Traction Alternator 1 Phase X Current
18	IPHX_TRAC_ALT2	Traction Alternator 2 Phase X Current
19	IPHX_TRAC_ALT3	Traction Alternator 3 Phase X Current
20	N/C	
21	CAN_H	Can High Signal
22	CAN_L	Can Low Signal
23	N/C	
24	N/C	
25	IPHZ_TRAC_ALT1	Traction Alternator 1 Phase Z Current
26	IPHZ_TRAC_ALT2	Traction Alternator 2 Phase Z Current
27	IPHZ_TRAC_ALT3	Traction Alternator 3 Phase Z Current
28	GNDISO	Companion Field Regulator 1 Fault Input

PE SIGNAL CONNECTOR #1		
Pin No.	**Name**	**Destination**
29	/CFR1_IN	Companion Field Regulator 1 Fault Input
30	GNDISO1	Companion Alternator 1 RTD
31	RTD_COMP_ALT_1+	Companion Alternator 1 RTD
32	GNDISO	Companion Field Regulator 2 Fault Input
33	/CFR2_IN	Companion Field Regulator 2 Fault Input
34	GNDISO2	Companion Alternator 2 RTD
35	RTD_COMP_ALT_2+	Companion Alternator 2 RTD
36	GNDISO	Companion Field Regulator 3 Fault Input
37	/CFR3_IN	Companion Field Regulator 3 Fault Input
38	GNDISO3	Companion Alternator 3 RTD
39	RTD_COMP_ALT_3+	Companion Alternator 3 RTD
40	N/C	
41	N/C	
42	N/C	
43	N/C	
44	N/C	
45	N/C	
46	GNDISO	Air Filter Maintenance 1 Fault Input
47	/AFM1_IN	Air Filter Maintenance 1 Fault Input
48	GNDISO	Air Filter Maintenance 2 Fault Input
49	/AFM2_IN	Air Filter Maintenance 2 Fault Input
50	GNDISO	Air Filter Maintenance 3 Fault Input
51	/AFM3_IN	Air Filter Maintenance 3 Fault Input
52	-15V	Supply to Traction Alternator 1 Current Sensors
53	-15V	Supply to Traction Alternator 1 Current Sensors
54	COM	Supply to Traction Alternator 1 Current Sensors
55	COM	Supply to Traction Alternator 1 Current Sensors
56	+15V	Supply to Traction Alternator 1 Current Sensors
57	+15V	Supply to Traction Alternator 1 Current Sensors
58	-15V	Supply to Traction Alternator 2 Current Sensors
59	-15V	Supply to Traction Alternator 2 Current Sensors
60	COM	Supply to Traction Alternator 2 Current Sensors
61	COM	Supply to Traction Alternator 2 Current Sensors
62	+15V	Supply to Traction Alternator 2 Current Sensors
63	+15V	Supply to Traction Alternator 2 Current Sensors
64	-15V	Supply to Traction Alternator 3 Current Sensors
65	-15V	Supply to Traction Alternator 3 Current Sensors
66	COM	Supply to Traction Alternator 3 Current Sensors
67	COM	Supply to Traction Alternator 3 Current Sensors
68	+15V	Supply to Traction Alternator 3 Current Sensors

PE SIGNAL CONNECTOR #1		
Pin No.	**Name**	**Destination**
69	+15V	Supply to Traction Alternator 3 Current Sensors
70	N/C	

9.6 PROTECTION

The PE Box communicates the status, fault word, and diagnostic data via datalink message(s).

FAULT TYPES

TYPE 1 faults indicate detection of abnormal operating conditions whereby normal operation is assumed to be recoverable.

RESPONSE TO TYPE 1 FAULTS:

The PE Box will take remedial action:

- Communicate fault data via the datalink
- Auto-reset the affected function upon return to reset-ready conditions. There is no limit to the number of such auto-resets.

TYPE 2 faults indicate detection of abnormal operating conditions whereby normal operation may not be recoverable.

RESPONSE TO TYPE 2 FAULTS:

The PE Box will take remedial action:

- Communicate fault data via datalink
- Auto-reset the affected function upon return to reset-ready conditions. The PE Box will allow no more than ten (10) auto-resets of type 2 faults during a single power cycle of the PE Box. Upon exceeding the maximum number of auto-resets, the PE Box will latch off faulty hardware or the entire system if necessary.
- The PE Box will clear a Type 2 latch-off condition upon power cycling.

TYPE 3 faults indicate detection of abnormal operating conditions whereby normal operation is not expected to be recovered and further operation of the PE may result in damage to equipment.

RESPONSE TO TYPE 3 FAULTS:

In response to one (1) of these faults, the PE Box will:

- Latch off all outputs and communicate fault data via datalink.
- The PE will clear a Type 3 latch-off condition upon power cycling.

PROTECTION CHARACTERISTICS

Table 9-9 provides a list of Protection Characteristics for the PE Box.

Table 9-9 PE Box Protection Characteristics

PROTECTED DEVICE	PROTECTION	ACTION	RESET CONDITIONS
Companion Alternator	Phase over-current	• Disable AR input • Broadcast status message	• No pending CA OT fault on same CA • CA enabled
	Phase current imbalance	Broadcast status message	N/A – monitor only
	Zero-sequence fault current	Broadcast status message	N/A – monitor only
	Stator winding over-temperature	Broadcast status message	N/A – monitor only
Traction Alternator	Phase over-current	Broadcast status message	N/A – monitor only
	Phase current imbalance	Broadcast status message	N/A – monitor only
	Zero-sequence fault current	Broadcast status message	N/A – monitor only
	Stator winding over-temperature	Broadcast status message	N/A – monitor only
Gearbox	Over-temperature	Broadcast status message	N/A – monitor only
PE	DC bus overvoltage	• Shut down all PE functions • Broadcast PE status	Bus voltage falls within operating range

9.7 ELECTRICAL AND MECHANICAL SPECIFICATIONS

A) ELECTRICAL

1. **Input Power**
    a. One or two out of three Companion alternators. Internally selected by the PE via integral contactors.
    b. 3-phase, 230VAC/30Hz to 460VAC/60Hz. 2:1 speed range
        i. Accessory power used per alternator will be mapped to the alternator speed.
            1. 40KW, 50KVA @ 0.8PF maximum at 900RPM
            2. 100KW, 125KVA @ 0.8PF maximum at 1800RPM
    c. Input voltage regulator
        i. Maximum continuous current: 160ARMS per channel
            1. PE input shape factor, 0.8 minimum
        ii. Peak alternator output voltage, operational load dump: 566VAC
2. **DC Output1**
    a. Isolation from input source: 2500VAC for 1-minute
    b. Regulated 74VDC, 5%
    c. 270ADC maximum continuous, current limited
    d. Battery maintenance

i. Charge current limit, adjustable: 40A to 80A
ii. Separate battery and load terminals.
    1. Engine starting motor will not be part of the 270A loads and will connect directly to the starting battery.
    2. Internal precharge circuitry for battery connection
    3. Integral battery fusing
iii. Battery discharge current, unit switched off: 20mA maximum

e. Output will auto-start without an external enable signal, pending normal operating conditions.

3. DC Output2, 3, 4

a. Isolation from input source: 2500VAC for 1-minute
b. Common to Output1
c. Regulated 120VDC, -0%, +10%
    i. Diode coupled to Output1 for alternator startup.
    ii. Outputs individually switched on/off, pending normal operating conditions.
        1. Load capacitance: 50uF
        2. Load resistance: 20 ohms
        3. Output off for alternator speed less than 800RPM
        4. Output on for alternator speed greater than 850RPM
d. Current limit per output: 8.0ADC max continuous
    i. Outputs fused by customer

4. AC Output1

a. Fixed 480VAC, 60Hz, 3-phase
    i. Output will auto-start without an external enable signal and ramp up to rated output, pending normal operating conditions.
b. Loads are exclusively motors, which will not require filtering of the inverter's output PWM voltage.
    i. Loads include radiator fan, air conditioner, other fans.
        1. This output is normally enabled while loads are electrically connected or disconnected from the inverter output.
c. 90ARMS max continuous output current.
    i. Overload 135ARMS for 60-seconds
    ii. Instantaneous over current trip 180ARMS
        1. Auto soft restart following a phase over current condition.
d. Maximum continuous output
    i. 60KW
    ii. 75KVA @ 0.8PF

5. AC Output2

a. Variable output parameters
    i. Voltage range 160-480VAC, 3-phase
    ii. Frequency range 20Hz to 60Hz.
        1. Constant VF relationship.
    iii. Output will start pending an external enable signal and ramp up to rated output, pending normal operating conditions.
b. Load is exclusively the Traction Motor blower, which will not require filtering of the inverter's output PWM voltage.
    i. This output is normally enabled while the output voltage/frequency is varied.

c. 105ARMS max continuous output current.
    i. Overload 158ARMS for 60-seconds
    ii. Instantaneous over current trip 210ARMS
        1. Auto soft restart following a phase over current condition.
d. Maximum continuous output
    i. 70KW
    ii. 87.5KVA @ 0.8PF

6. AC Output3

a. Fixed 480VAC, 60Hz, 3-phase
    i. Output will start pending an external enable signal and ramp up to rated output, pending normal operating conditions.
b. Load is exclusively the Compressor Motor, which will not require filtering of the inverter's output PWM voltage.
    i. This output is enabled or disabled to operate a normally connected load.
        1. Compressor system contains an over pressure switch which will cause the Compressor Motor to electrically disconnect from this inverter.
c. 60ARMS maximum continuous output current.
    i. Overload 90ARMS for 60-seconds
    ii. Instantaneous over current trip 120ARMS
        1. Auto soft restart following a phase over current condition.
    iii. Maximum continuous output
        1. 40KW
        2. 50KVA @ 0.8PF
d. Hardware over pressure limit shutdown.

7. External logic power required

a. 74VDC @ 2.0A (from battery pack)
b. Internally fused.
c. Operating range 40VDC to 100VDC
    i. Transient over voltage ride through 150VDC max for 100mS without damage
    ii. Possible load dump clamped by customer
d. (2) external terminal block connections: +74V and GND
    i. Remote +74V shutoff supplied by customer.

8. Protections

a. Companion Alternators
    i. input fusing
    ii. Phase imbalance fault
    iii. Ground fault
        1. TBD amps, not for protection of personnel.
    iv. Over temperature warning/fault
b. Traction Alternators
    i. Phase over current
    ii. Phase imbalance
    iii. Ground fault
        1. TBD amps, not for protection of personnel.
    iv. Over temperature warning/fault
c. Gearbox

i. Over temperature warning/fault
d. Air filter maintenance
i. Restricted air filter warning/fault
e. Type1 Faults, unlimited auto-reset; TBD outputs.
i. Ambient under/over temperature
ii. Heat sink under/over temperature
iii. DC bus over/under voltage
iv. Output overload(s)
f. Type2 Faults, limited number of auto-resets then latched; TBD outputs.
i. Communication error
ii. Output phase over current
iii. Reset through power cycling or J1939 port.
g. Type3 Faults, latched. All outputs.
i. Internal hardware.
ii. Transistor desaturation.
iii. Reset through power cycling or J1939 port.

9. Display

a. Green “POWER” LED
b. Red “PE FAULT” LED
c. Red “RECTIFIER OT FAULT” LED
d. Red “ALTERNATOR OT FAULT” LED
e. Red “COMPANION REGULATOR FAULT” LED
i. Any regulator fault contact
f. Red “AIR FILTER MAINTENANCE” LED

10. Electrical Interface Connections

a. Companion phase connection: Ring lug to feed through terminal block
b. Outputs: Ring lug to feed through terminal.
c. Deutsch style J1939 CAN bus, receptacle
d. terminal block connection for Companion alternator RTD inputs
i. (3) total, isolated 2500VAC for 1-minute
e. terminal block connection for Traction alternator RTD inputs
i. (3) total, isolated 2500VAC for 1-minute
f. terminal block connection for gearbox RTD inputs
i. (3) total, isolated 2500VAC for 1-minute
g. terminal block connection for (3) air filter maintenance contacts
1. 2-connections per contact (6) total): CONTx and Common
2. NC switch position for normal operation, 50mA nominal
3. +24VDC operating voltage
h. terminal block connection for (3) Isolated NO regulator fault contacts
1. 2-connections per contact (6) total): CONTx and Common
2. Switch closure indicates fault condition, 50mA nominal
3. +24VDC operating voltage
i. terminal block connection for (3) traction rectifier over temperature contacts
1. 2-connections per contact (6) total): TSTATx and Common
2. Switch closure for normal operation, 50mA nominal
3. +24VDC operating voltage
j. DB9 connector for (6) traction rectifier phase current sensors
1. (1) output per sensor plus (3) power supply connections, (9) total

11. Standards, design to:

a. UL-508 where applicable, no approval
b. IEEE 519 where applicable, no approval
c. J1939-11, J1939-71

B) MECHANICAL

12. Packaging

a. Electronics NEMA4, magnetics ventilated NEMA 4
b. Estimated size 56" x 30" x 17"
c. Material cold rolled steel sheet
d. External finish CAT yellow.
e. Mounting feet on bottom of 30”x17” side
    i. Integral vibration isolating mounting feet

13. Shock/vibration

a. 10G/2G any axis.

C) ENVIRONMENTAL

14. Temperature range

a. Operating ambient: -20C to +50C
b. Storage ambient: -40C to +85C

15. Cooling

a. Integral cooling fans
    i. Ambient air 50 degC or less.
    ii. Customer supplied air filtration

16. Altitude

a. 0-1000M with no derate
b. Relative Humidity – 5 to 100% non condensing
c. Pollution grade – 2

D) COMMUNICATIONS

17. J1939 parameters

a. AC Output1, Radiator Fan, air conditioner, fans.
    i. Inverter status, output
    ii. Fault word, output
b. AC Output2, Traction Motor Blower
    i. Output voltage/frequency command, input
        1. 1-second ping rate or “heart beat”
        2. TBD format
        3. Inverter will be disabled if the “heart beat” is not present for TBD seconds.
    ii. Inverter status, output
    iii. Fault word, output
c. AC Output3, Compressor Motor inverter
    i. Run/stop request, input
        1. 1-second ping rate or “heart beat”
        2. TBD format

3. Inverter will be disabled if the “heart beat” is not present for TBD seconds.

ii. Inverter status, output
iii. Fault word, output

d. 74V Output, Battery Charger
   i. Converter status, output
   ii. Fault word, output

e. 120V Outputs
   i. Alternator1-3 engine speed, input
      1. 1-second ping rate or “heart beat”
      2. TBD format
      3. Output(s) will be disabled if the “heart beat” is not present for TBD seconds.
   ii. Module Fault word, output
   iii. Output1-3 status, output

f. PE
   i. Alternator selection, input
   ii. Output(s) will be disabled if the “heart beat” is not present for TBD seconds.
   iii. Total input power, output
   iv. Companion alternator status, output
   v. Traction alternator
      1. status, output
      2. calculated DC bus current, output
   vi. Unit fault word, output
   vii. (3) Isolated regulator fault contact status, output
   viii. (3) Isolated traction rectifier over temperature contact status, output
   ix. Periodic handshaking signal (heart beat) with system controller for all outputs
      1. TBD message every TBD seconds.
      2. PE will be disabled if the “heart beat” is not present for TBD seconds.
         a. disabled state will reset non fatal faults.

10 WIRE HARNESS DESIGN GUIDE

Wire Harness Design Guide

Caterpillar Inc.
Component Products & Software Technologies
Wiring Harness Center of Excellence

Version 0.0
February 14, 2007

Author: Wire Harness Design Guide Rewrite 6-Sigma Team

This document supersedes all previous versions of the Wire Harness Design Guide

10.1 PURPOSE:

This document is intended to serve as a designer's guide to wire harness design. It will define wiring harness design methods for meeting the physical, electrical, and environmental requirements for various product applications while capitalizing on operating integrity, quality, efficiency, economy, uniformity, manufacturing practices and service. Included are methods for routing and supporting a wire harness and cable assembly, protective coverings, identification, and connector and terminal application. This document will provide alternative components and methods to meet most Caterpillar Design Control requirements.

Given the great diversity of components for harness design and construction, it can be difficult for the less experienced designer to determine the best construction for a new harness design. The starting point should always be the use of...

- 1E0815 wire,
- yellow braided covering,
- a sealed connector with
- protection of the wire seals and
- rubber insulated p-clips for mounting.

Rules for routing straight through mounting clips, and meeting minimum bend radii must also be followed. When this well established approach does not meet product requirements, reviewing the alternatives contained herein will be of great value. Since each alternative has pros and cons, design alternatives should be reviewed with someone expert on the topic prior to freezing the design.

10.2 SCOPE:

This procedure applies to Caterpillar Inc. products with a nominal operating voltage of 12 or 24 volts DC. Exceptions to this document may exist in regulations such as Marine Society, military application requirements, generator sets (UL, CSA, VDE), high voltage applications, and any other special application products.

10.3 REFERENCES:

APPLICABLE REFERENCES

Engineering Standard B6.10

Engineering Standard B6.11

Engineering Standard J9.11

1E0815 Electrical Wire

1E2358 Wire Harness Processing Specification

1E2364 Material and Dimensions- Insulated Electrical Terminal

1E2365 Processing – Electrical Cable Assemblies

1E2277 Material and Dimensions- Insulated Electrical Terminal

1E2286 Strap - Cable

SAE J821 Electrical Wiring Systems

SAE J1127 Battery Cable

SAE J1128 Low Tension Primary Cable (50 volt)

SAE J1283 Electrical Connector for Auxiliary Starting

SAE J1614 Wiring Distribution Systems

SAE J1811 Power Cable Terminals

SAE J1908 Electrical Grounding Practice

SAE J1939/11 Physical Layer

SAE J2030 Heavy Duty Electrical Connector

Safety Design Guide, Product Safety - Machines -

http://www.tc.cat.com/pcat/psec/web/Design-Guide/SDG_2006.pdf ISO 9247 Electrical Wires and Cables – Principles of Identification

RELATED REFERENCES

1E0279 Tightening - Fasteners and Other Threaded Parts

1E0515 Hose

1E0716 Hose

1E1028 Hose

CCTV Design Guide -

http://www.tc.cat.com/pcat/psec/web/Design-Guide/Design-Guide-CCTV.pdf

CLMS Training 08C0036

SAE J1939/15 Reduced Physical Layer, 250K bits/sec, Un-Shielded Twisted Pair

SEBD0402-00 - Guidelines for Routing and Installing Wire Harness Assemblies

Special Instructions – Servicing DT Connector SEHS9615

Special Instructions – Use of CE Connector Tools SEHS9065

10.4 DEFINITIONS

BACKSHELL - a part that attaches to the wire entry side of a connector which may attach to the harness covering, provide wash protection and provide some strain relief benefit.

BOOT - an elastomeric part that protects the otherwise exposed wires between a connector or terminal and the harness covering, wire or cable. Boots often completely cover terminals and typically are color coded red or black.

BRANCH – A section of harness that divides off of the main trunk of the harness and extends to a point of termination.

BREAKOUT – The point at which a branch separates from the main trunk of the harness.

BUSS BAR (BUS BAR) – In areas such as a fuse box or an electrical panel requiring tools to enter, rectangular copper bars can be utilized to connect high current items together instead of large gage wires or cables.

CABLE - A single metallic stranded insulated conductor, designed to carry current in an electric circuit and is 4 AWG (19 mm2) to 4/0 (103 mm2).

CONDUCTOR – The current carrying element(s) in a wire or cable comprised of a series of uninsulated strands twisted together. Conductor size is specified using the American Wire Gage (AWG) or mm2.

CONNECTOR – A coupling device that provides an electrical and mechanical junction between two wires or between a wire(s) and an electrical component, which also provides electrical insulation between circuits.

CONNECTOR PLUG – The connector containing the coupling ring or active retention device of the mating pair. The connector plug usually contains socket terminals.

CONNECTOR RECEPTACLE – The connector containing the static retention device of the mating pair. The connector receptacle usually contains pin terminals.

FLEX JOINT – Two components between which there is wiring with relative motion between the two components. An example of a low amplitude high frequency flex joint would be a rubber mounted engine on a frame or a rubber mounted cab on a frame. There will be relative motion between the rubber mounted item and the frame. The displacement between the two items is small and the angular motion of the harness/cable is small. An example of a low frequency high amplitude flex joint would be typically found between two frames on a machine such as the front and rear frame of a wheel loader, between a tractor and scraper, off highway truck frame and the wishbone, boom and stick of an excavator or forest product, or backhoe loader, etc. Wiring in these articulation joints must tolerate large angular movements.

HARNESS – An assembly of any number of wires and their terminations, which is designed and fabricated so as to allow for installation and removal as a unit. A harness may or may not have a protective outer covering.

HARNESS SUPPORT – Support provided for wiring that carries the weight of the wiring and secures it in the intended position.

MULTI-CONDUCTOR CABLE OR JACKETED CABLE – Two or more insulated, stranded conductors contained in a common covering or jacket. The multiconductor cable may incorporate one or more insulating or metallic layers in its construction. Jacketed cables may also include an uninsulated stranded conductor (drain) for EMI/ RFI protection.

SPLICE - the permanent metallurgical joining of two or more wires.

Strain relief - any method or part that provides a gradual wire transition from a rigid member (connector or support) to unsupported wire so that the wire will not kink or have a high stress at the exit from the connector or support.

STRAND – The solid component members of a conductor.

TERMINAL / CONTACT – An electrically conductive device attached to a wire to facilitate connection to an electrical component or wire.

WIRE – A single metallic stranded insulated conductor, designed to carry current in an electric circuit and is 6 AWG or smaller. For the purpose of this document, “wire” refers to an “insulated

electric wire."

WIRE ROUTER - a backshell that directs the wire but typically would not attach to the harness covering.

WIRE SEGMENT – A length of wire that is continuous and unbroken between its two intended points of termination.

WIRING – Wires, cables, harness bundles, and their terminations, associated hardware, and support, installed in the vehicle.

WIRING COMPONENTS – An item or part used in the design and assembly of a wiring system such as terminals, connectors, junction boxes, conduit, clamps, insulation and supports.

10.5 COMPONENTS

COMMONALITY

The selection of components for use in wire harnesses is driven by many factors with one being commonality. Common use of "preferred" high quality, good-performing components allows us to leverage volumes and maintain or lower component cost.

An objective in the selection of parts should be to maximize commonality and minimize the variety of wiring components and related servicing tools required in the construction, installation and maintenance of the electrical wiring system. See the P463 Electrical Components website for preferred wiring system component recommendations.

COMPONENT SELECTION AND INSTALLATION

The wiring and associated components shall be suitable for their application and selected and installed in accordance with the recommendation of this document and the component prints. Many component references are located at http://catelectronics.corp.cat.com/organization/1024/ and Similar Parts Index in WECAP. The wiring Harness Components team in Cat Electronics should be contacted to advise on design options, part performance or address any other concerns.

METALS

Metals used in the installation of wiring shall be corrosion resistant or shall be suitably protected to resist corrosion and electrolytic action during normal service life.

NONMETALLIC

Nonmetallic materials used, including plastics, fabrics and rubber, shall be moisture and flame resistant, shall not support fungus growth, shall not support combustion, and shall not be adversely affected by weathering, UV, applicable fluids and propellants, temperature and ambient conditions encountered during operation of the product.

10.6 WIRE

WIRE SELECTION

Wire must be of a type suitable for the application. Wire must be selected so that the rated maximum conductor temperature is not exceeded for any combination of electrical loading, ambient temperature, and heating effects of bundles, protective braid, conduit and other

enclosures. Typical factors to be considered in the selection are voltage, current, ambient temperature, mechanical strength, connector sealing range, abrasion, flexure and extreme environments such as areas or locations susceptible to significant fluid concentrations.

Although providing a sealed connection system is the primary design direction, in some situations, it may be possible for fluids to wick through the wire stranding. In this case, non-wicking wire may be available. A less expensive and more easily acquired solution would be to make a one-to-one wire splice that is sealed with dual wall heat shrink tubing. Water will not wick beyond the splice.

Fusible wire links shall not be used on Caterpillar products because of potential fire hazards and troubleshooting difficulties.

MINIMUM WIRE SIZE

The minimum conductor size used on Caterpillar products is 18 AWG (SAE 0.8 mm2 or ISO 0.75 mm2). Smaller conductors are susceptible to breakage and fatigue failures, and are difficult to insert into some connector systems due to reduced column strength. SAE J1614, Wiring Distribution Systems for Construction, Agricultural, and Off-Road Work Machines and SAE J2202, Heavy Duty Wiring System for Trucks require wire sizes no smaller than 0.8 mm2 (18 AWG).

WIRE INSULATION MATERIAL

SAE J1128 or J1127 Thermoplastic Polyvinyl Chloride (PVC) insulation shall not be used in wire harness designs because of its low operating temperature range (-40 to 85°C), and melt and flammability characteristics.

125C rated PVC and other thermoplastic wire insulations may be used in fused circuits but not in circuits without circuit protection. PVC and other thermoplastic wire insulations shall not be used in the engine compartment or similar environments where there is a potential high heat exposure. Because PVC's abrasion performance is one third of XLPE's or PP (polypropylene), PVC shall not be used in areas where abrasion is possible or in areas where dust and grit may accumulate.

Cross Linked Polyethylene (XLPE or Cross-linked Polyolefin, XLPO) is the primary wire insulation type used in chassis, cab, and engine compartment locations. It has a temperature rating of –50 to 120°C.The voltage rating for Caterpillar 1E0815 wire, SAE J1128 and ISO 6722 is 60 VDC. The circuit voltage shall be considered when making wire selections. This wire insulation is also available with higher voltage ratings.

Polyvinylidene Fluoride (Kynar® PVDF) insulation is used in hostile environments such as within an engine valve cover, transmission, etc. This insulation is resistant to fluids used in Caterpillar products, has high temperature capability (-65 to 150°C), and is more expensive than XLPE insulation. Teflon® (ETFE, TFE) wire has a very thin wall thickness. It is resistant to fluids used in Caterpillar products and has temperature capability to 260°C.

WIRE INSULATION THICKNESS

1E0815, commonly known as SAE J1128 Type SXL, wire has traditionally been used at Caterpillar in all areas of the machine. With the thick wall and XLPO insulation, abrasion performance is maximized. However, this wall thickness is not necessary in all areas of a machine. 1E0815 may not be the optimal choice in some situations such as in flex harnesses, or when bundle diameters are excessive, or where the environment is (rarely) benign.

Moving one step down in wall thickness, the SAE J1128 type GXL wire is equivalent to JASO 608-92 Type AEX. Also GXL wire has approximately the same wall thickness as ISO 6722 heavy wall. In comparison, GXL, AEX and ISO polypropylene insulated wires have approximately 2/3 of the abrasion performance of 1E0815 (SXL) wire. ISO PVC heavy wall wire has approximately 20% of the abrasion performance of 1E0815.

SAE J1128 type TXL has a slightly greater wall thickness than ISO 6722 thin wall. In comparison, TXL wire has approximately 1/3 of the abrasion performance of 1E0815 (SXL) wire. The thin wall ISO 6722 PVC insulated wire has approximately 10% the abrasion performance of SXL and should only be used in the most benign environments.

CONDUCTOR SIZE

All conductor sizing has been done using SAE J1128 and J1127. Most conductor sizes in JASO 608-92 are similar to the SAE sizes. ISO 6722 conductor sizes often fall between SAE sizes. If conductors are converted from SAE to ISO, use the next larger conductor size. If a small conductor size is desired, circuit analysis needs to be performed to assure adequate current carrying capability and voltage drop requirements are maintained.

SAE J1128 SIZE MM2 (AWG)	SAE J1128 MIN MM2	ISO 6722 MM2	JASO D608 MM2
0.5 (20)	0.508	0.5	0.5
0.8 (18)	0.76	0.75	0.85
1 (16)	1.12	1	1.25
		1.5	
2 (14)	1.85	2	2
		2.5	
3 (12)	2.92	3	3
		4	
5 (10)	4.65	5	5
8 (8)	7.23	6	8
13 (6)	12.1	10	
19 (4)	18.3	16	
32 (2)	31.1	25 or 35	
40 (1)	38.1	35	
50 (1/0)	48.3	50	
62 (2/0)	59.8	50 or 70	
81 (3/0)	77.6	70	
103 (4/0)	98.5	95 or 120	

Table 1: Conductor Size Comparison

BATTERY CABLE INSULATION

The preferred minimum cable size for the starting system is 2/0. The start motor to frame

ground cable shall be no smaller than the battery cables but may need to be larger for dual starting motor systems. This is to ensure that starting currents will be adequately handled in jump-start conditions.

B+ battery cables shall be red. The battery interconnect cable shall be red. The B- battery cables shall be black. Reference ISO 9247. The B+ cable protection boot shall be red and the B- cable protection boot shall be black.

The operating temperature range of 1E0140, 1E0141, 1E0142 and 1E0144 cable is -40°C TO 80°C and should not be used for new designs. Thermoplastic insulation shall not be used for battery cables. XLPE insulated cable will not melt if overheated, has excellent abrasion performance and shall be used for all battery cables.

The Caterpillar Inc. Safety Design Guide states that electrical connections, except for those to chassis ground that are unfused or fused above 20 amps shall not be exposed. Protection is recommended to prevent inadvertent contact by personnel or possible electrical shorts due to contact with conductive items. Protection may be provided by various means such as non-conductive boots or shields, protective enclosures or removable access panels.

Refer to SAE J1908 for acceptable practices to ground to the frame.

WIRE COLOR

Each wire shall be identified with an identification code per ISO9247 and the Cat Electronics Electrical Systems Standard Circuit Numbers spreadsheet:

(http://catelectronics.corp.cat.com/organization/1024/secure/circuits.htm).

The code shall use color and alphanumeric characters marked on the wire insulation according to requirements in 1E2358. Eleven wire colors shall be used for circuit identification and are identified in Table 2. Other color choices and striped wire shall not be used because of color recognition difficulties in low light conditions (e.g. tractor manhole, instrument panel, engine compartment, etc.). Single color wiring systems are not permitted.

COLOR	ABBREVIATIONS
Blue (Light)	BU
Brown	BR
Gray	GY
Green (Light)	GN
Orange	OR
Pink	PK
Purple	PU
Red	RD
White	WH
Yellow	YL
Black	BK

Table 2: Wire Insulation Color

WIRE SPLICING

Splices may be either supported by a metal band or joined ultrasonically per 1E2358.

A large number of insulated wires spliced together will cause the conductors on the outer wires to bend excessively at the exit from their respective wire insulation. This stress may cause

failure at a later date. Therefore, splicing best practice is:

- The total number of wires entering the splice joint (both sides combined) should not exceed 7.
- The maximum number of wires in any one side of the splice joint should not exceed 4.
- The total Cross Sectional Area (CCSA (CCSA) of wires per splice side (including insulation) shall not exceed 103 mm².
- The Wire Cross Sectional Area (WCSA) on both sides of the splice must be balanced so both sides fall within the WCSA range of the heat shrink sleeve insulator.

All splices shall be insulated with adhesive lined heat shrink sleeve. Preferred heat shrink part numbers for splice insulation are 125-7874, 125-7875, 119-3662 and 125-7876.

10.7 CONNECTORS

Preferred connector part numbers are listed on the Cat Electronics' Electrical Harness & Components website http://catelectronics.corp.cat.com/organization/1024/. Connectors shall be selected on the basis of the installation location's environment (interior or exterior, fluid exposure, temperature, vibration, etc.) and durability expectations for the end product.

When possible connectors shall be selected so that terminals on the "live" or "hot" side of the connection are socket type rather than pin type to minimize personnel hazard at voltages >36 volts and to prevent accidental shorting of live circuits when the connector is unmated.

WATER SEALED

Connectors, whenever possible, shall be sealed against the ingress of water and water vapor under all service conditions including changes in humidity and temperature. Exceptions may exist in some areas where the exposure to water is remote. Note that cabs are often sprayed down and should not be considered a dry environment. Connectors shall have an interfacial seal as well as sealing at wire ends. Environmental resistant connectors with wire sealing grommets are preferred; however, potting may be used where a grommet seal connector would not be suitable (i.e. Military Specification (MS) connector.)

A sealed electrical connector must have a wire insulation diameter compatible with the sealing range of the wire grommet. Elastomeric grommets are generally qualified to seal on wires having smooth extruded insulation. Only one wire per grommet hole is permitted. Sealing on tape, braid, or un-smooth non-circular insulation is not permitted. The wiring shall be installed so transverse loads will not compromise the integrity of the sealing feature of the device. In other words, the wiring shall be designed to exit the seal straight before bending. The harness design therefore must consider the need for adequate wire length, support location near the connector and adequate bend radii.

Various connector families have differing sealing capabilities, 1.4 psi and 5 psi commonly. The 1.4 psi level of sealing is adequate for splash. 5 psi capability will address rapid temperatures change causing internal pressure or vacuum in the connector that can possibly draw in standing

water on the seal.

CONNECTOR WIRE ENTRY PROTECTION

Most wire seals are inadequate in high pressure water wash. In those cases, adapters or wash deflectors are required to prevent water entry into the connector. Some applications such as Commercial Marine, require the wires between the connector and wiring bundle covering to be protected and/or sealed. Backshells or boots are highly recommended to protect the wire seals when the connector is located in an area where it may be subjected to water wash.

VIBRATION

The vibration capability of each connector family varies substantially. This is a function of terminal choice & plating, connector pair latching tightness, terminal security within the connector, the axis of vibration relative to the connector orientation, wire strain relief and clamping location, etc. Vibration levels vary with position on cab, chassis and engine. Always test the connector for suitability of use in a new vibration environment.

TEMPERATURE

Most of the connectors used at Caterpillar are rated for use from -40ºC to 125ºC. See the individual connector specifications for detailed information. Avoid locations where the connector is used outside the appropriate temperature range. Plastics often become brittle, impact strength reduced and rubbers less elastic at low temperatures. At high temperatures the life of the product will be adversely affected due to accelerated plastic deformation and the elongation of many elastomers will be reduced.

TERMINAL (CONNECTOR)

Caterpillar has standardized on removable crimp terminals in electrical connectors. The terminal interface shall comply with the dimensional and performance requirements of MIL-C-39029. The round cross section terminal reduces wire harness induced torsion loads and resulting wire and terminal fatigue problems. This standardization effort provides terminals that can be repaired or replaced with existing field service tools. The terminals can be sourced from multiple suppliers since they are interchangeable and intermateable. These terminals are produced as machined (from solid stock) or stamped and formed (from sheet metal stock). The vibration performance of the stamped and formed sockets is superior to the machined and should be used on all engine and any other high vibration application. Because size 20 terminals bend easily, size 16 is the generally recommended minimum terminal size.

Box and blade contacts are commonly used in automotive style connector systems and are being picked up for use in Caterpillar applications with B10 life in the 2000 - 6000 hour range. Longer life may be expected when used in interior applications or other areas with low vibration and low peak temperatures. This terminal system frequently uses tin plated terminals. (Note that the automotive style connectors are a light duty design and should not be used in areas where mechanical durability (impact, crush...) is required.)

TERMINAL PLATING

Gold plated terminals must be used in all high vibration applications and in all dry circuit applications (<5 volts or <0.200 amp) - this is the preferred terminal plating. These terminals may also be used with voltages over 5 volts and in low vibration applications. Nickel contacts should not be used in high vibration applications and should only be applied in circuits where the voltage is >5 and current >0.200 amp. The stamped & formed alternative (not preferred)

does not meet Caterpillar's minimum performance requirements, so should not be used in product requiring long life.

Tin plated contacts commonly used in box and blade systems, like nickel are susceptible to fretting corrosion. Fretting corrosion is the phenomena where the plating material wears and oxidizes. The build up of oxide creates an insulating layer with consequent circuit intermittencies. Since gold will not oxidize, gold plated terminals will not fret until the gold plating is completely worn through. Tin plated contact systems have reduced mating cycle capability

(~10). As it is very difficult to get a good crimp from the hand crimp (service) tool, servicing of the contacts requires a spot solder. Typically, short lengths of wire attached to the terminal are released with a butt splice for servicing.

Silver plated contacts commonly used in MS connectors are similar to gold in performance but are susceptible to tarnish in certain industrial atmospheres.

The temperature rating of the gold, nickel or silver plated terminals used at Caterpillar allow their usage at ambient temperatures of 125ºC at full rated current. However, tin plated terminals are typically derated to zero current at 125ºC. It is imperative when using tin plated box and blade terminals to review the derating curves to compare ambient temperature to the allowed current of the contact. Caterpillar testing has demonstrated that tin plated ring and lug terminals can be used at full rated current at ambient temperatures up to 125ºC. Note that the wire insulation temperature rating, which is typically 125ºC, is the sum of ambient temperature and temperature rise due to resistive heating of the conductor.

CONNECTOR INSTALLATION

Connectors shall be used to join wires to wires or to components when a connection is required to aid product assembly or field service of components, or wiring. Adequate space shall be provided for mating and unmating connectors without the use of tools. At least 18mm for small connectors 6 pins or less, or at least 25 mm for larger connectors shall be provided around the connectors to facilitate mating and unmating. Connectors shall be located and installed so that they will not provide handholds or foot rests to operating and maintenance personnel. The plug and receptacle shall be visible for engagement and orientation of polarizing key(s). Wiring support should be provided within 125 - 175 mm of the connector. Mated connectors shall not be strained by attached wiring.

Electrical connectors may have unique mounting or fastening requirements. For this reason, individual component drawings should be reviewed and any special application requirements noted on the harness assembly drawing.

LOCATION OF MULTIPLE CONNECTORS

Connectors used in multiple electric circuits in the same location shall be installed so that it will be impossible to mate the wrong connector in another mating unit. (Ref.: Caterpillar Inc. Safety Design Guide) It is preferred that wiring be routed and supported such that an improper connection cannot be made.

The order of precedence for making a connector selection for a multiple connector location shall be as follows:

1. The connectors shall be different sizes or have different insert arrangements.
2. Alternate between plug and receptacle connectors.

3. The connectors with the same insert arrangements shall have alternate insert positions or keying positions.
4. If none of the above requirements can be met, identical connectors shall have color coded sleeves attached to the wiring near the connector that identifies the associated connector mating half. In cases where one of the connectors is bulkhead mounted, a color identifier on the adjacent structure shall code the connector.

CONNECTOR DRAINAGE

Connectors shall be located in a horizontal position to avoid trapping water. Connectors

installed external to the machine, such as in engine compartments, wheel wells, etc., shall be given special attention to protect against entry of oil and moisture into the connector. Connectors shall not be located beneath fluid lines, fluid fittings, fill tubes or filters. Protective covers must be provided for receptacles and plugs, which may be left unmated.

When a harness is routed downward to a connector, terminal block, panel, or junction box, a trap or drip loop should be provided in the harness. This preferred practice will prevent fluids or condensate from running into the above devices.

SECURITY WIRE

Non-self-locking connectors with threaded coupling rings (Mil-C-5015 type) located in areas of high vibration, and in areas which are normally inaccessible for periodic maintenance inspection, shall have the coupling ring security-wired or otherwise mechanically locked to prevent opening of the connector due to vibration. A corrosion resistant steel wire shall be used for the security wire. Use lock wire part number 5P0562.

POTTING

Military connectors with a backshell shall be potted with a semi rigid potting material according to the requirements in 1E2358 Wire Harness Processing Specification. Caterpillar uses wire with a larger diameter than military wire. We also mix wire sizes within the same connector, therefore requiring potting for connector wire sealing purposes. Wire harness protection braid, heat shrink sleeves or tape shall not extend into the potted material.

UNUSED TERMINAL CAVITIES

Sealing plugs shall be inserted in unused grommet holes of environmentally sealed connectors. Applicable sealing plug part numbers shall be called for in the bill of material of the wire harness print.

UNUSED CONNECTORS

Unused connectors must be sealed to prevent water entry into the electrical system, and to prevent contamination of the connector if required for future use. Use a mating connector with sealing plugs in all cavity positions or a sealing cap made specifically for the unused connector.

CONNECTOR ACCESSORIES (METALLIC)

Strain relief accessories shall not be used to terminate ground wires or shields unless the accessory was specifically designed to terminate ground wires or shields. Ground wires shall not be terminated to saddle clamp or end bell screws.

10.8 TERMINALS (NON CONNECTOR)

RING TERMINALS

Ring terminals are used in locations where permanence of connection is required (e.g. circuit breaker, alternator, start motor, power relay, etc.).

SPLIT RING (SNAP RING) TERMINALS

These terminals are used for ease of assembly. Multiple split ring terminals shall not be stacked on the same screw or stud because of their tendency to spread open during fastener tightening. They shall only be used for circuits of 15 amps or less.

SEALED HEAT SHRINK TUBING

Sealed heat shrink tubing shall be used whenever possible with ring and spring spade terminals for terminal insulation and prevent fluid wicking inside wires. Heat shrinkable sleeves consume less space than molded insulators. Molded terminal insulators or heat shrink without adhesive do not provide a sealed joint. Care must be taken to assure that the wire strands are sealed at the end, and that the heat shrink tubing and adhesive is not in the area where the terminal will seat electrically.

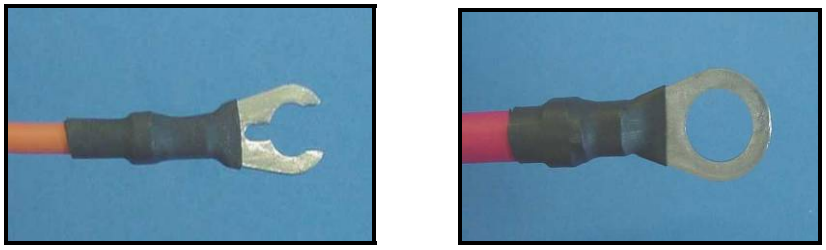


Fig. 1: Examples of Sealing of Terminals

PRE-INSULATED CRIMP TERMINALS

They are recommended for field service needs only. These terminal assemblies are not sealed and are less robust than production terminals. The terminal material is a plated soft copper.

Fig. 2: Pre-insulated Terminal

BLADE TERMINALS

Blade Terminals provide a simple and quick means for making a connection to an electrical device. Single blade terminal use shall be avoided because the terminal design lacks positive locking to its mating terminal. Historical performance of this terminal design on Caterpillar products has been poor. If a blade terminal use cannot be avoided, then select a high mating

force terminal. (Note: High mating force complaints can be expected from assembly people.)

BATTERY CABLE TERMINALS

Battery cable terminals must conform to the requirements outlined in 1E2364 and 1E2365. Caterpillar requires the use of lead die cast terminals for tapered post battery applications. This terminal provides a corrosion protection barrier over the stripped conductor. Caterpillar die cast terminals are manufactured to special requirements that assure good electrical performance and retention to battery post terminals.

FIG 3: Production Die Cast Terminal

Fig 4: Field Service Crimp Terminal

MISCELLANEOUS

It may be advantageous to terminate two wires in a single terminal to avoid stacking terminals under a screw or nut. However, this approach is not consistent with the preferred production processes at our harness suppliers. A splicing alternative should be considered.

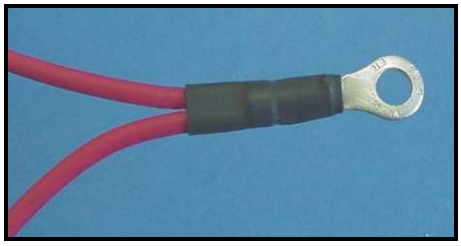


FIG 5: Two Wire Termination (Daisy Chain) - Not Preferred

When short jumper wires (daisy chaining) are used to connect such things as light switch terminals, the minimum wire length between terminals shall be 100 mm. This allows wire harness manufacturers to crimp terminals with semi-automated machines. Again, this approach is not consistent with preferred production processes at our harness suppliers. This operator dependent process relies on the crimp operator to fully insert all conductors into the terminal to achieve a reliable crimp.

If the wires are the same size, a terminal that is two wire sizes larger than the wire being terminated should be used. (Example: two 14 gage wires would require a 10-gage terminal). The termination of two different wire sizes or more than two wires within a single terminal is possible if the total conductor area of the wires and the terminal crimp capacity area are

compatible. This is not a preferred practice but is occasionally done when there is no other component opportunity immediately available.

All barrels of terminals must be insulated. If a barrel is not insulated, add heat shrink tubing to cover it.

Wire terminals for fastener sizes of 4 mm / No. 6 or smaller shall not be used on Caterpillar products. This terminal size cannot be kept tight because of low fastener torque capability.

Electrical components generally require terminal nut or screw torque other than those listed in 1E0279. For this reason, individual component drawings should be reviewed for any special application requirements.

No terminal, such as a ring terminal, shall be left hanging “hot”. The terminal shall be covered with a polyolefin heat shrink tube and crimp sealed at the open end. Vinyl tape can then be used to secure the end of the unused wire back onto the harness with a minimum of three wraps.

Wire terminal fastener torque retention tests indicate an internal tooth star washer located between the wire terminal and the electrical component (e.g. lamp, switch, etc.) provides the maximum torque retention capability for the connection. The internal tooth lock washer also assures the terminal will not move or loosen relative to the component if the terminal or wire is bumped. A split lock washer may be used to maximize surface contact area and current carrying capability but will not lock the terminal to the device as securely. A flat washer under the head of the screw head or nut will eliminate terminal “walk around.”

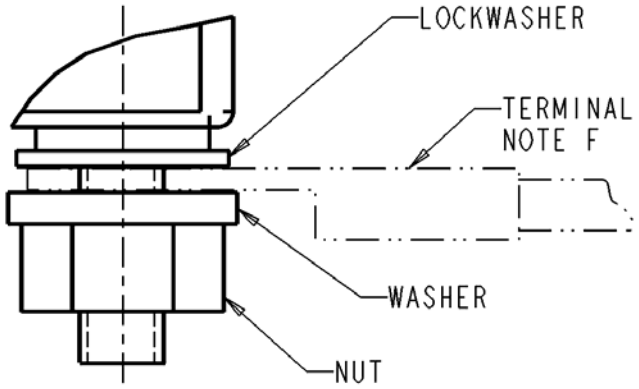


Fig 6: Preferred Ring Terminal Attachment Method

JUNCTION BOX

A junction box can be used to provide special protection for wiring and components. Wires within a junction box must have a controlled routing path avoiding contact between the wire insulation and the walls of the box or components within the box. Wires shall be tie wrapped and/ or clip supported to maintain an orderly routing.

The boxes are made from metal or nonmetallic material. Sealed junction boxes are preferred but complete sealing is often difficult to achieve and maintain. In splash resistant junction boxes, drainage holes must be provided at opposite corners, allowing moisture and dirt drainage from

the box. Assure drainage holes are not located to be a source of water or dirt entry. A metal junction box must be fabricated from a gage size sufficient to provide stiffness and rigidity. The box must be capable of supporting multiple attachments without flexing or deforming under service conditions and provide support and alignment for hinged or removable covers.

10.9 WIRE HARNESS PROTECTION

There are numerous alternatives for covering and protecting bundles of wires. Choices such as injection molded carriers and over molded wiring, although excellent, are not discussed in this document since they are specific to an application, require tooling and often may be expensive. Additionally, paint protection as discussed in B6.10 and 1E2358 should not be considered a covering system. Although paint protection sleeving has benefit in protecting the printing on wires going through product painting, it offers very little protection thereafter. Harnesses with a rubber hose covering are often found in flexing application and will be discussed in the "Flex Harness Construction" section.

COVERING	BREAKOUT & DIAMETER TOLERANCE	COST	FLEXI-BILITY	TEMPER-ATURE	ABRA-SION	COMMENTS
Vinyl tubing	NA	4	5	60ºC	3-4	Difficult to assemble into harness
Slit plastic conduit	4	3-5	4	80ºC, 105ºC, 125ºC, 200ºC	2-4	Easy for harness assembly, slit should be oriented down or water will collect, abrasive particles can collect
Unslit plastic conduit	4	3-5	4	80ºC, 105ºC, 125ºC, 200ºC	2-4	Water or abrasive particles can collect, difficult to assemble
Pre-Woven Sleeve - expandable	NA	3	5	110ºC, 125ºC	3	May be difficult to assemble harness.
Pre-Woven Sleeve - fiberglass	NA	3	5	250ºC	3	May be difficult to assemble harness.
Braided harness	2	4	2	107ºC, 138ºC, 150ºC, 250ºC	3-4	
Vinyl covered Metal Conduit	4	1	1	107ºC	5	Excellent impact strength. Wire insulation may wear on inside metal surface. Difficult to assemble into harness
Reinforced Tapes (cloth, fiberglass)	4	2-4	3	105ºC, 125ºC, 180ºC	2-4	Electrical tape is not an external protective covering
Custom molded trays	5	1-4	NA	As required	4-5	
Elastomeric Overmolding	5 molding breakouts 1 jacketing	2	4	105ºC, 125ºC	5	Commonly polyurethane as in cable jackets or foam mold

Table 3: Wiring Harness Covering Comparison (1=Worst, 5=Best)

10.10 BRAID

Vinyl covered nylon braid is Caterpillar's standard wire protective method. Braid provides a moderate degree of mechanical protection and is suitable for most Caterpillar product applications. It is a heat stabilized, fire retardant material that can be applied over any wire bundle size and conforms well to changes in bundle size. If the harness is exposed to severe abrasion conditions, additional protection must be provided. A double or triple covering of braid may be applied to the entire harness or to specific areas if noted on the harness assembly drawing.

If the harness is continuously exposed to hydraulic, transmission or engine fluids, then special fluid resistant braid materials must be used.

Braid may be applied to any bundle diameter and any lengths greater than 150 mm. Braid lengths shorter than 150 mm will significantly add to harness cost. Breakouts should be combined when possible and short breakouts left unbraided. In many applications, braid is not applied to lengths less than 250 mm.

It is not advised to braid onto the back of a connector. If a harness with braid onto the back is bent near the connector during installation, the wires on the outside of the bend radius are under high tension. Often the wires will break or terminals will pull out due to the lack of strain relief.

Braiding does have some disadvantages. Braiding bundles with many wires produces a very stiff harness that may not be able to be installed without significant stresses in the wires, splices and/or connectors & terminals. Part to part reproducibility and length tolerance control are more difficult with braided harnesses. Likewise, diameters can vary and are often not a standard clip size.

NYLON BRAID

Nylon braid is used for applications with operating temperatures up to 107°C. For higher temperature applications a 138°C material is available. Nylon braid is available in Yellow, Black, and Gray colors.

POLYESTER BRAID

Polyester braid is used in fluid compartments (e.g. under engine valve cover, inside transmission, etc.). This material adds stiffness to the wire harness. Braid color is black.

KYNAR® BRAID

Kynar® braid is used in high temperature, fluid compartment applications (e.g. under engine valve cover, inside transmission, etc.). Braid color is light blue.

EXPANDABLE BRAIDED NYLON SLEEVING

Expandable braided nylon sleeving may be used to provide a moderate degree of mechanical protection with good flexibility. It may be incorporated into the harness assembly or applied retrospectively. As it can be awkward to apply, it is best used in short lengths. Cut ends should be cauterized to prevent fraying and the sleeving will generally need to be anchored at each end by, for example, a cable tie or heat shrink tube to prevent movement. Because of its ability to be removed and re-used it is ideal for covering wires right up to the back of a connector, while still allowing access for service.

FIBERGLASS SLEEVE

Woven fiberglass sleeve (reference 6V5652) is mainly used to protect short length wires (e.g. sensor lead wires). A gap of 10±2 mm is required between the sleeve and connector or terminal to avoid connector seal stress. Because the woven sleeving fits loosely, the wire bundle will be much more flexible than braided wiring while providing similar protection.

Sleeve use should be limited to short lengths that would be impractical to braid or for areas where it is desirable to apply wire protection during vehicle assembly. Care must be used in selecting the diameter of tubing in order to facilitate assembly. In general, the tubing should be limited to a 50% wire fill factor calculated by comparing the total cross sectional area of the wire with the tube internal cross sectional area. Higher fill factors are possible, but are progressively more difficult to assemble.

10.11 CONDUIT

CONDUIT (CONVOLUTED, FLEXIBLE NON METALLIC)

Plastic flexible conduits are often used in low to moderate durability applications or in applications with little abrasion potential. Conduit may capture dust and grit so that the wires may abrade against the inside of the conduit. If the application may collect abrasive dusts, one solution is to use end caps with un-slit conduit to prevent dust entry. Alternatively, packing the conduit to ~80% fill will eliminate most of the motion of the wires within the conduit.

Slit conduit may trap fluids and cause wire insulation damage if frequently or continuously exposed to fluids such as engine oil. The designer needs to assure that the slit is oriented downwards in the application by appropriate notes on the harness assembly drawing.

Un-slit conduit may also trap fluids but does not have the issues with slit orientation and the slit opening up during use. However, it is difficult to achieve greater than 50% fill factor except in short lengths.

Conduit fittings, tees, and endpoints must be used to protect wires from damage. Fittings are required to avoid wire chaffing by the exposed edges of the conduit. Electrical tape shall not be used for breakout control or to control conduit splitting excepting perhaps in protected cab environments. Electrical tape is not ultraviolet light, high temperature, or fluid resistant capable.

The conduit size of slit conduit or short runs of un-slit conduit shall be determined by using a 65% to 80% wire fill factor. This is required to facilitate wire installation in the conduit and help prevent the conduit slit from opening at bends.

CONDUIT (RIGID METALLIC)

Rigid conduit provides maximum protection for the wire harness. Preformed bends provide a controlled routing path for the harness. The conduit material shall be a corrosion resistant alloy such as stainless steel or some aluminum alloys. The ends of the conduit shall be flared with

sharp edges removed. Machined breakout slots can be provided in the conduit but require wire protective grommets.

Conduit size shall be determined by using a 50% wire fill factor. This is required to facilitate wire installation in the conduit by the wire harness supplier.

CONDUIT (FLEXIBLE STEEL)

Flexible steel conduit (1E0657) provides maximum protection for wire harnesses and battery cable while adding routing flexibility. Protective plastic ferrules must be used with steel conduit to prevent wire damage at the conduit ends. Special plastic tees, ferrules, and end fittings are available for use.

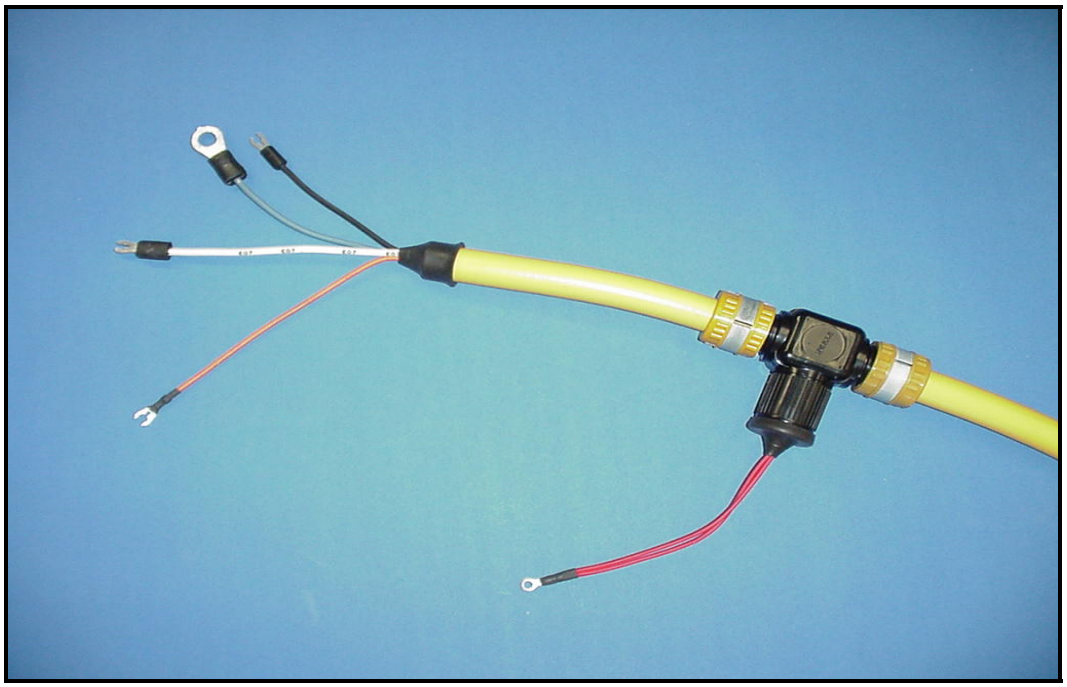


Fig 7: Steel Conduit Wiring Harness

Moisture will collect in low areas of the conduit routing path and will cause the conduit to rust internally. This problem can be avoided by careful harness routing that will avoid moisture traps.

Fig 8: Conduit Tee

Additionally, there is the potential of wire or cable insulation wear inside the steel conduit. This is a particular concern if there is a loose fit of the contained wiring or cable and high vibration. Electrical shorts may result.

FLEXIBLE PLASTIC TUBE

Flexible vinyl tubing (IE0689) is suitable for use in protected areas where there is UV light exposure. The cost is comparable to nylon braid, and the abrasion resistance is only slightly better than vinyl tape. The maximum operating range is 60°C. Use should be limited to short lengths that would be impractical to braid or for areas where it is desirable to apply wire protection during vehicle assembly. Care must be used in selecting the diameter of tubing in order to facilitate assembly. In general, the tubing should be limited to a 50% wire fill factor calculated by comparing the total of the wire cross sectional area with the tube internal cross sectional area. Higher fill factors are possible, but are progressively more difficult to assemble.

10.12 TAPE

VINYL ADHESIVE ELECTRICAL TAPE

Vinyl adhesive electrical tape is used for wire bundling, or light duty insulating. The material has a maximum temperature rating of 105°C. Tape ages quickly (6 months) when exposed to heat and ultraviolet light (UV) losing its plasticizers. The tape will then dry out and become brittle. Exposure to fluids (e.g. oil, diesel fuel, etc.) causes the adhesive qualities to deteriorate causing the tape to unravel. Vinyl tape has no harness protection value.

Vinyl tape shall not be used as a primary protective cover or wire harness support. Tape may be used for wire harness bundling purposes in locations where exposure to heat above 105°C, UV light, and fluid exposure will not exist. Wire harness flexibility is significantly reduced with full tape coverage.

REINFORCED TAPES

Glass or cloth reinforced tapes are used for localized abrasion protection. It is also used for bundling wires in place of cable ties or vinyl tape.

TERMINAL (AND CONNECTOR) BOOTS

Boots are elastomeric coverings for terminals, connectors, etc. Although high temperature elastomers are available, typical boots are made from materials rated to 105°C so the part number drawing should be consulted for specific material and properties. If used for long periods above their rated temperature, they may discolor and lose their elasticity. More so than plastic, elastomers often swell or become sticky when exposed to various fuels, coolant, oils or lubricants. While their function is to provide electrical insulation to terminals, they also provide strain relief and physical protection to the back of the terminal (or connector). To minimize the collection of debris, dirt or water in the boot, one of the openings in the boot should always be at the lowest point.

Protection (i.e. insulating boots, shields, covers, etc.) of exposed terminals that always have voltages present is recommended to prevent accidental short circuits. Protection is required when a 12 mm round rigid metal bar, 250 mm long, can short from a terminal to ground or to another terminal thus causing a condition that is unacceptable. The terminals of the starter relay are to be shielded to meet the requirements of SAE J1493. If two or more terminals are

stacked, the top terminal should have the boot, and the terminals beneath only need to be insulated with heat shrink tubing.

10.13 WIRE HARNESS SUPPORT

Wire harnesses shall be secured to the machine, engine, etc. to provide support and routing control. Routing control prevents rubbing against other components and limits motion in high vibration areas. Support points shall be located at approximate intervals of 200 to 450 mm on horizontal harness runs. Smaller harnesses need more support at shorter intervals than do larger harnesses.

Wire harnesses should be supported with a clip approximately 150 mm from a connector so that the wire exits the connector straight. This will prevent side loading and distortion of connector seals, and reduce tension on the terminals.

It is highly recommended that green tape be used as an aid to proper clip location and harness routing. A double wrap of green tape approximately 25 mm wide should be placed on the harness covering to locate critical support locations such as the first clip point on either side of a flex harness.

The preferred method for wire harness support in high vibration applications is by use of rubber insulated sandwich clamps, rubber insulated p-clips or saddle clips.

P-clips provide a more permanent means than tie wrap-based systems because during field service they are less likely to be discarded. Upon reassembly of the harness, the clamps or clips serve as a reminder to the repair person to replace them in their original location.

To ensure that the harness will not rub, harnesses require additional support points when routed through or around bulkheads, gussets and structural members. Wiring within junction boxes and panels shall be well secured and routed to eliminate any contact with grounded metal surfaces.

When wiring is routed through cutouts in a machine structure, supports must be installed on each side of the cutout to locate the harness in the middle of the opening. This will prevent contact with the edges of the cut out. A grommet around the edge of a hole will give additional protection but should not be used as the primary bundle support.

Methods used to support a flexing wire harness shall not restrict harness motion in the flex joint as this could cause mechanical strain and work hardening of the conductors leading to breakage.

Support for wiring is required at both sides of a flex joint. For example, the battery cable routed from the starter motor to the machine frame must be supported on the engine before routing to the frame. This prevents both failure of the ring terminal and the low torque threaded starter motor connection from loosening.

The harness bundle should run straight through the axis of the clamp or clip without a tight bend at either end. This will minimize wear at the edges and minimize stresses within the harness that may lead to wire breakage.

Clamps and clips should not pinch the harness but also should not be loose on the harness. Those with rubber liners are much more tolerant of variations in bundle diameter.

A number of systems employing tie wraps are available as an alternative to clamps.

Note that wider tie wraps offer better support than narrow ones.

Tie wraps must be adequately and correctly tensioned.

By their nature, tie wraps are tolerant of variations in bundle diameter and eliminate the need to carry multiple sizes of fixed bundle diameter clamps, which reduces inventory and purchasing costs while simplifying the assembly process.

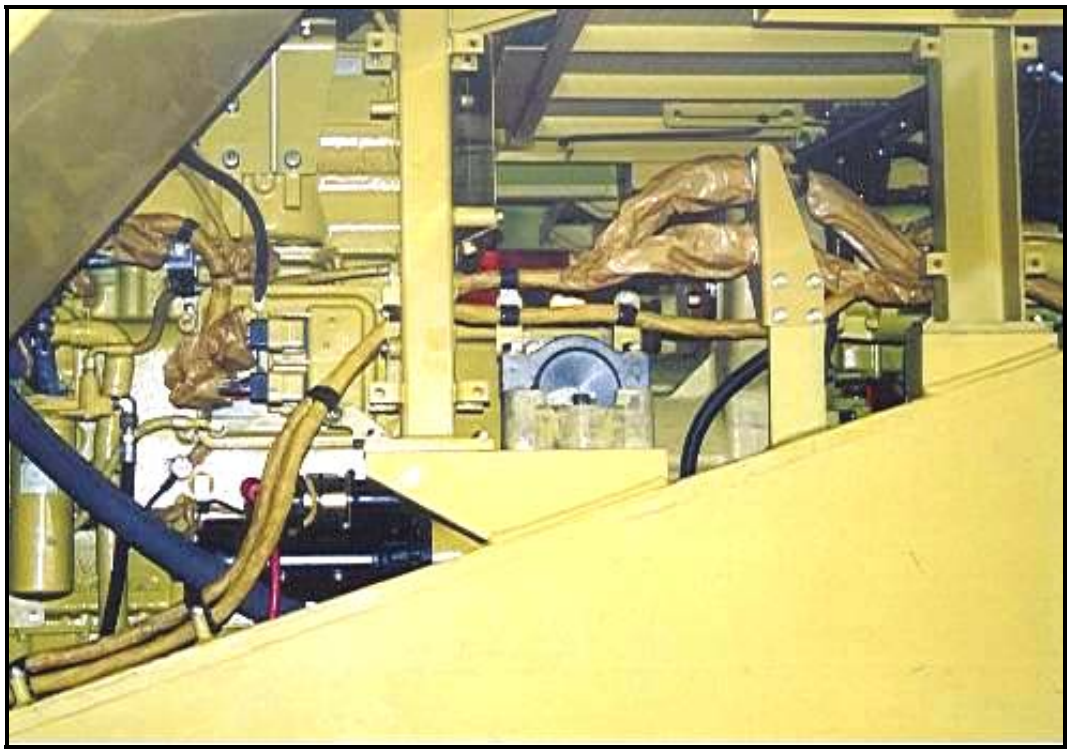


Fig. 9: Example of Good Harness Clipping and Routing

ITEM	EASY INSTALLATION	HEAVY SUPPORT	ABRASION RESISTANCE	TEMP. CAPABILITY	CHEMICAL RESISTANCE	SERVICING
P-clip (Vinyl)	3	3	3	4	3	4
P-clip (Rubber)	3	4	4	4	3	4
Rubber Sandwich	2	5	5	4	3	3
Ladder Clips	3	3	3	4	3	3
Chain Link	2	3	2	4	4	3
Worm Link	2	2	1	4	4	3
Saddle Clip	3	4	4	4	4	4
Fir Tree, Tie Strap	4	2	4	3	4	2
Stud Clip, Tie Strap	4	2	4	3	4	2
Self Adhesive, Tie Strap	3	1	4	2	1	2

Table 4: Cable and Harness Support Comparison Chart (1=worst, 5=best)

P-CLIP (VINYL INSULATED)

The vinyl insulated P-clip shall be sized to hold the wire harness securely to the machine or engine without damaging the insulation. If the correct size P-clip is not available, the harness can be double or triple braided in the P-clip area to help provide a snug fit. A P-clip shall hold only one harness. The vinyl coating may wear through in certain applications at the edge of the clips and continue to abrade the harness covering and wiring. For this reason vinyl coated P-clips must not be placed directly onto battery cables or bare wire bundles. Vinyl insulated p-clips may be used when the cable or wiring has an additional covering and can be routed straight through the axis of the clip opening.

Fig. 10: Vinyl Dip P-Clip

RUBBER INSULATED P-CLIP

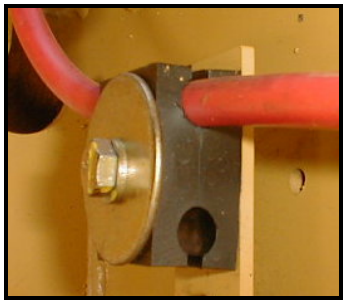
(ref. Cat engineering standard J9.11)

These are the preferred type of P-clip. They are similar to the vinyl coated p-clips but have the advantage of improved edge wear resistance, and better tolerance to varying bundle diameters. These clips are excellent in high vibration applications.

Fig. 11: Rubber Insulated P-Clip

RUBBER SANDWICH CLAMP

Cables and wiring harnesses may be supported using rubber sandwich clamps. Examples include Stauff® clamps or an assembly of 2G8767 washer, 6G2256, and 6G2263 spacer. These are the most robust harness and cable mounting methods. However, care must still be taken to assure the cable or harness is routed in the axis of the support since there is limited strain relief using hard rubber as a support.



Rubber Clamp

Stauff® Clamp

Fig. 12: Rubber Sandwich Clamps

LADDER CLIP

Ladder clips are used in conjunction with tie wraps for supporting/securing wiring. The ladder clip may be attached to existing bolts on the machine as long as the integrity of that bolted joint is not compromised. A ladder clip shall not be used to secure a flexing harness. A ladder clip must not be used to support an unprotected (without fuse or circuit breaker protection) battery cable, alternator B+ lead or air inlet heater wires. Machine vibration and wire/ cable flexing may cause the ladder clip to wear and to wear through the cable/ wire insulation. These circuits are usually not protected by fuse or circuit breaker. A high energy, catastrophic short circuit may result. A ladder clip can support a battery cable if the battery cable is in 1E657 conduit.

The harness must be tie wrapped perpendicular to the ladder clip. The harness cannot be tie wrapped at an angle or in line with the ladder clip. Harnesses must not be tie wrapped to the end (across or between the tips) of the ladder clip. The tie wrap must be placed around the rungs of the ladder clip and not on the sides of the ladder clip. These clips offer a variety of locating positions.

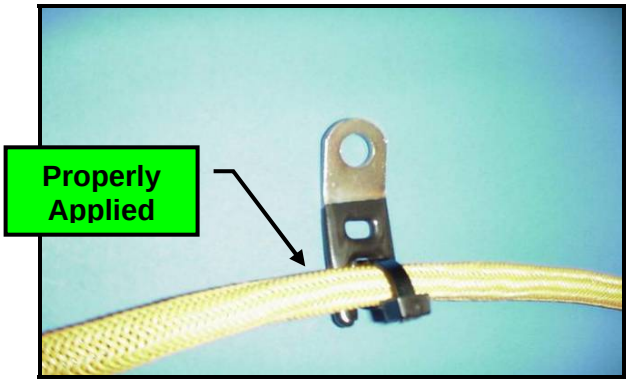


Fig. 13: Ladder Clip Properly Applied

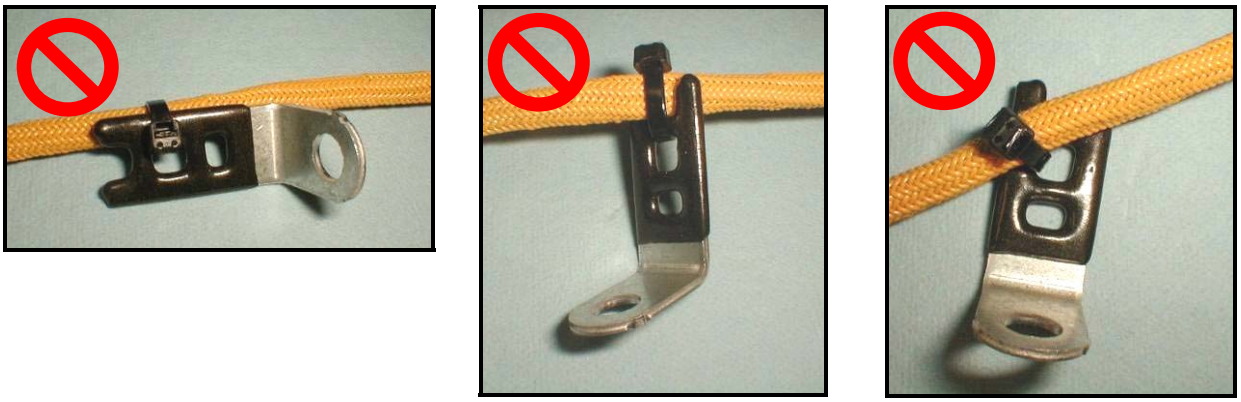


Fig. 14: Three Ladder Clips Improperly Applied

SADDLE CLIP

Saddle clips are plastic harness bundle supports that are bolted onto the frame, and provide.

wire tie slots for the addition of tie wraps. Preferred saddle clips have a metal insert in the

mounting hole to support proper bolt tension. Saddle clips provide better support and location than ladder clips. Saddle mount clips provide better abrasion performance than ladder clips but not as good as the rubber insulated p-clips.

Fig. 15: Saddle Clip after Vibration Testing

Other types of saddle clip are available. For example, 206-2423 and 200-6345 comprise two saddles which are joined back-to-back but which are free to rotate relative to each other. This allows the fixing together of two harnesses that are not parallel, while providing separation between the two.

“FIR TREE” CLIP & STUD-MOUNTED "PUSH-ON" CLIP

A fir tree clip is inserted into a hole and provides a slot for the addition of a tie wrap. Some clips are supplied with a tie wrap pre-loaded. Avoid clips with integral tie wraps molded into the clip since the tie wrap may be cut during service and not easily replaced. The best grip is achieved when the fir tree is pressed into a threaded hole. For through holes, at least one barb should extend through the back surface. Similar to the fir tree clips, the push-on clips are pushed onto a threaded stud.

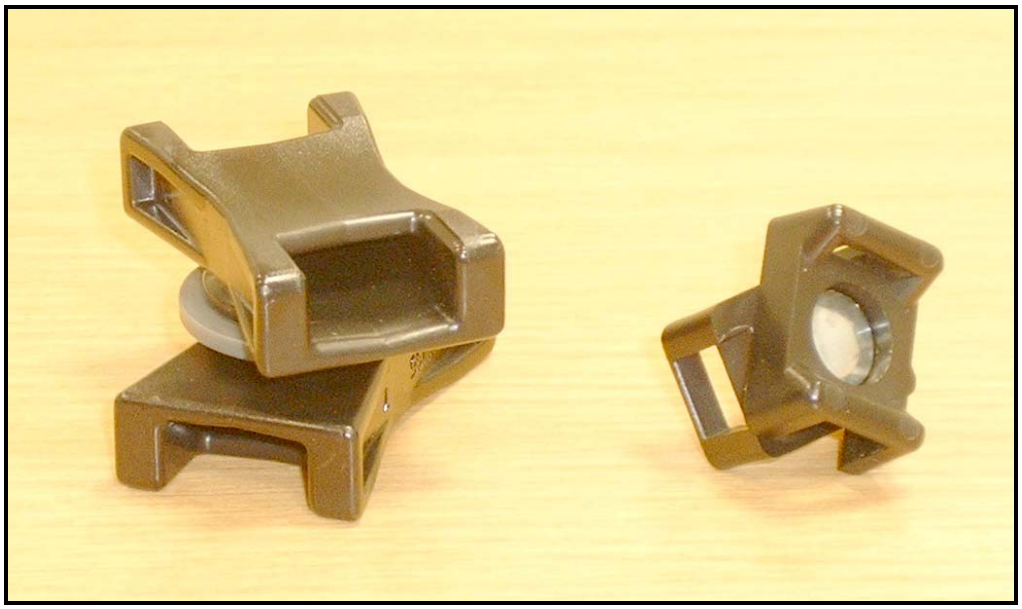


Fig. 16: Saddle Clips with Swivel Feature

The fir tree clips should be heat stabilized, UV stabilized 6,6 polyamide. When exposed to high temperatures, the polyamide may become brittle. Fir tree clips should not be located in areas where they may be impacted, crushed or pulled on since they are susceptible to potential breakage or pull out. The push-on clips are more robust in this regard.

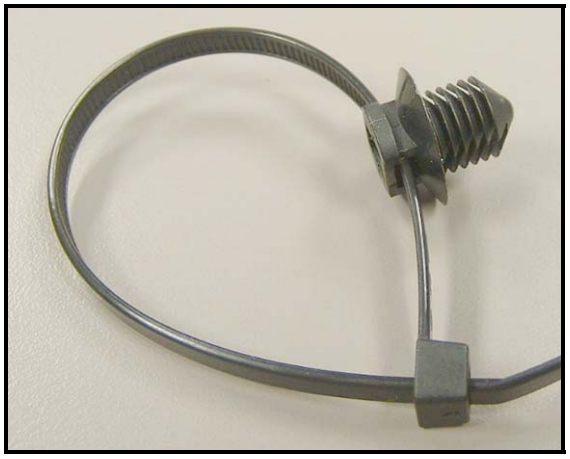


Fig. 17: Fir Tree Clip with Tie Wrap (206-1345)

Fig. 18: Push On Clip with Tie Wrap (270-5143)

CHAIN LINKS & WORM LINKS

Chain or worm links shall not be used for supporting unprotected (without fuse or circuit breaker protection) battery cables or the alternator B+ lead or air inlet heater wires. Machine vibration and wire/ cable flexing will cause the link to wear through the cable/wire insulation. These circuits are usually not protected by a fuse or circuit breaker. A high energy, catastrophic short circuit may result. Chain or worm links must not be used as the support for a flex joint.

Chain links are used to locate points where wire harness tie wrap support is to be placed. A single link is welded to each securing point. Weld beads, “berries” or “spatter”, must be avoided in the clamping area to avoid damage to the wire harness.

The 7TI099 chain link is welded to the machine at each of the small ends such that the centers of the long ends are raised above the mating surface, allowing clearance for the plastic tie under the link. The link shall not be inverted. The welding specification for the 7T1099 link must comply with Figure 19.

The 5D9629 link (sometimes referred to as a “worm link”) must be welded to the machine along one side of the link such that the center is raised above the machine surface, allowing clearance for the tie wrap under the link. The welding specification for the 5D9629 link must comply with Figure 18. This link does not provide adequate wiring harness support in many applications since the bundle will move against the link and mounting surface. Additionally, the ends of the link may be sharp enough to abrade the harness. The 5D9629 link is not recommended.

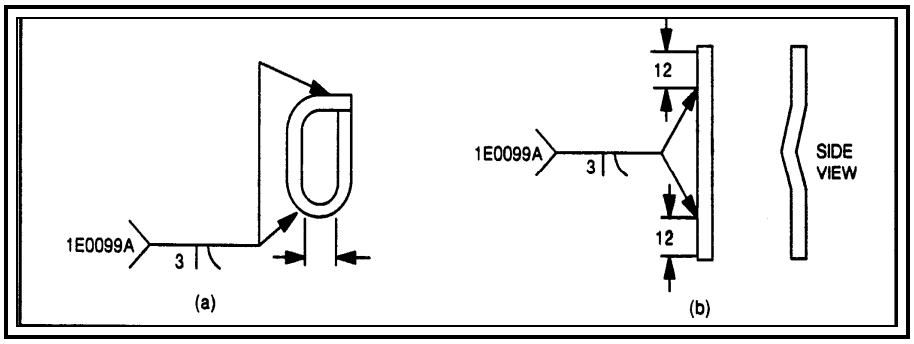


FIG. 19: Chain Link (A), Worm Link (B)

A wire harness shall be routed parallel to the long sides of the 7T1099 link or the length of a 5D9629 link. The 7T1099 link should be used for wire harnesses with an outside diameter greater than 12 mm. The tie wrap shall encircle both legs of the link with the harness retained between the link and tie. See Figure 20.

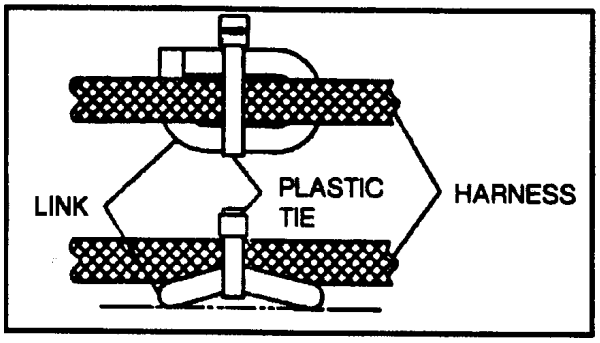


Fig. 20: Chain Link with Proper Harness Attachment

Small diameter harnesses of approximately 12 mm or less, should be retained by placing the tie wrap around the harness, and only one leg of the 7T1099 link or the 5D9629 link as shown in Figure 21. To prevent abrasion against the end of the form, the chain link should be attached to

the leg opposite the ends of the link as shown in Figure 21 (a). To assure the bundle does not rotate around the chain link, a second wire tie can be added.

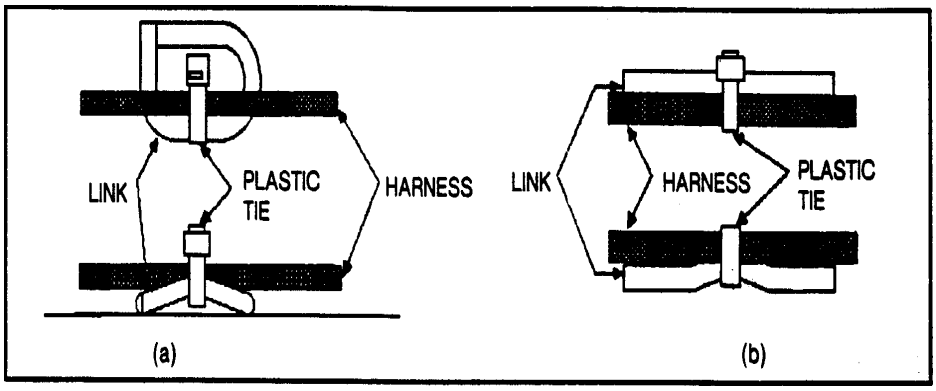


Fig. 21: Chain Link with Proper Small Harness Attachment

TIE WRAP

Tie wraps (aka cable ties, wire ties, tie straps) provide a means for supporting harnesses in product applications and are used to bundle wires in a wire harness. Tie wraps are convenient to use and misuse. Tie wraps are often located indiscriminately without an understanding of potential negative consequences. During field service tie wraps may not be replaced, or replaced in their original location. Service personnel also may use low-grade aftermarket tie wraps that will not survive the environment causing new problems with unsupported harnesses.

Care must be taken when applying tie wraps within fluid compartments where there are moving mechanical components such as within engines, transmissions, final drives, etc. Failed tie wraps or tie wrap cut-off ends can interfere with moving mechanical components and plug oil passage holes.

Tie wraps are also used in conjunction with ladder clips, chain links, etc. as described above. Use only tie wraps that comply with the requirements specified in 1E2286. This engineering standard also provides guidance for bundle diameter range, tensile strength and dimensional information. Wide ties are recommended because they provide better harness support with less motion-induced abrasion than narrow ties. Tie wraps must be installed with a tie wrap tool. Knife blades, pliers, side cutters, etc. shall not be used to trim tie wraps due to the danger of inadvertently cutting wire insulation or of leaving sharp protrusions that may create a personal hazard.

Tie wraps are also used to bundle wires together in a wire harness and control breakout points. This approach is typically applied on wiring behind the dash. Tie wrap bundling will provide a more flexible harness than braiding and make assembly to the product easier. (This assumes no adhesive tape is used on the harness.)

Tie wraps shall not be used in any location where failure of the tie wrap will result in damage to the wire harness and cause a catastrophic product failure.

10.14 WIRE HARNESS DESIGN

Harness design begins with a well thought out routing plan early in the machine or engine design. A dedicated routing path should ensure harness producibility, simplify installation &

service, minimize interferences and rub points, provide adequate support locations, and simplify the harness design process. Also see mounting supports section for mounting considerations.

SERVICE LIFE

The wiring and associated components used for the wiring installation shall be selected and installed to assure high reliability over the service life of the product.

Wiring shall be routed to ensure reliability and to offer protection from the following:

- Rubbing or vibrating against other parts.
- Use as handholds or as support for personal equipment.
- Damage by stepping on or by personnel moving within the vehicle.
- Damage by impact, thrown or falling debris.
- Damage by battery acid fumes, engine and hydraulic oil, fuel, and coolant.
- Abrasion or damage when exposed to rocks, ice, mud, etc.
- Vandalism damage (to the maximum extent practicable).
- Damage by moving parts.
- Additional protection may be required for harsh environment such as nitrite mines, high temperatures, or areas susceptible to significant fluid or fume concentration.

Wire harnesses shall not be located in close proximity to oil and fuel fluid fill areas or below fuel and oil filter locations. If these locations cannot be avoided then additional protective covers and shields must be provided to protect the harness. Additionally, alternative materials must be considered where significant or continuous oil, fuel or hydraulic fluid exposure is inevitable.

Harnesses shall not be located within 250 mm of or above high heat sources (e.g. exhaust manifolds, turbo chargers, hydraulic components, etc.). When this recommendation cannot be followed, high temperature materials, heat shields and protective or reflective insulation are often used to avoid wire insulation and/or connector deterioration. Reflective insulation is not recommended since the reflectivity can change over time due to corrosion, painting and/or dirt accumulation.

MAINTENANCE CONSIDERATIONS

Reliability and durability are our primary concerns in harness design. Understanding the pitfalls of the various components, extreme exposures in various applications, and the maintainability requirements of the wiring system are important considerations in the selection, design and installation of harnesses, cable assemblies and other wiring system components. Wiring components, particularly connectors and terminals, shall be accessible, repairable and replaceable using standard repair techniques, tools and components.

HIGH PRESSURE WASH

High-pressure wash systems, including high pressure spray washers and water cannons, are now in frequent use by maintenance people. Connector seals will fail when hit directly with high pressure spray. Many connection systems have adapters available that can be attached to the back of the connector to protect the wire seals from direct high pressure wash. Where direct exposure to high pressure wash systems cannot be avoided then protective shields will need to

be designed and installed. For the benefit of service, connectors should be placed in accessible locations.

APPEARANCE

The primary purpose for the wiring system is to provide safe, reliable, durable electrical and electronic component function. There is, however, another important and intangible value to consider when designing the wiring system. The appearance of the wire harness and its routing path should reflect an orderly, well thought out design plan. A poorly executed plan can have a negative impact on customer perceptions of the entire product. Use the product's horizontal and vertical lines for routing paths. Design preformed bends into large harnesses to facilitate product assembly and improve appearance. Use other product elements to shield or hide the harness from view. Benchmark new machine, truck and automotive product applications for ideas.

HARNESS BENDS

The minimum harness bend radius best practice is 8-10 times the bundle diameter for a tightly bundled covering system. When a braided harness is bent, there is tension in the wires on the outside radius that may lead to broken wires or splices. With a loose covering, the minimum harness bend radius best practice is 8-10 times the largest wire or cable diameter.

The minimum bend radius for a braided wire harness as measured from the inside of the bend shall be four times the outer diameter of the harness. Tighter bends are possible if the bend is preformed during harness manufacture. The bend radius size and location must be specified on the wire harness drawing

Bends in jacketed cables shall be based on manufacturer recommendations. A bend must not adversely affect the operating characteristics of the cable. For flexible coaxial cables, the bend radius must not be less than six times the outside diameter. For semi-rigid coaxial cable, the bend radius must not be less than ten times the outside diameter of the cable.

The minimum bend radius for flexible conduit must be six times the outer diameter of the conduit. Conduit bends shall not cause internal rubbing of the wiring.

HARNESS BENDS NEAR CONNECTORS

Wires should exit the rear of connector straight for 25 mm minimum before the harness is bent so that the wires do not side load and distort the wire seals. The harness bend rules in the previous section apply from there on out.

Special consideration shall be given to connectors with large wires (4, 6, 8, 10, and 12 AWG) particularly when small wires are also present and other connectors with large wire counts. Stresses placed upon the retention system of the connector can cause contact retention failures and wire pull out. In order to avoid this problem consider the following options:

Pre-form the harness to the required bend. The harness assembly drawing shall detail the harness bend requirements (e.g. location and radius). The harness braid protection should be applied up to the tangent point of the bend furthest from the connector. Connector orientation to the bend may be necessary and should be specified on the harness print.

Increase the unbraided harness length to 150 mm. This will allow the wires to fan out when the harness is bent, greatly reducing the forces placed on the connector contact retention system. The connector should also be oriented properly with respect to the harness so that upon installation to the product the harness will not need to be twisted to align the connector.

FLEXING HARNESS

Applications that require flexing during their normal operation require special attention. Typical applications, including articulation joints, scraper hitches, lift arms, etc., have comparably large movements at low frequencies. In contrast, the relative motion between the isolation mounted

engine or between cab and frame is low amplitude but at much higher frequencies. In either case, provisions in the design must accommodate these movements or conductor failure will result.

Failures in flexing applications may be due to conductor breakage due to flexing fatigue or tensile stress, as well as wire wear. Flex life is affected by total bend angle, frequency, mechanical load, wire insulation type and thickness, conductor size, harness protection material & tightness of the covering as these all influence the amount of stress in the conductors. If a flex joint is allowed to rub on anything, the result will be accelerated wear and possible shorts to ground or other circuits. Furthermore, there must be special design consideration for proper routing, support, and strain relief.

Flexing harnesses may require extensive testing to verify performance.

HARNESS FLEXIBILITY

Many harnesses are difficult to route due to their being too stiff. This is a rather typical situation for a braided harness with many wires. Flexibility can be managed in a number of ways.

Although a number of techniques will be discussed, the primary methods related to wiring harness construction include high flex wire stranding, wire count reduction (more wiring assemblies), thinner wire insulation, and loose wire covering.

WIRING COUNT

As wire count in a tightly bundled harness increases, the flexibility of the harness decreases. As a wiring bundle with a large diameter is flexed, there is greater tension on the wires on the outside of the bend radius. The larger the bundle, the larger the stress, the larger the required bend radius. If a large number of wires must be flexed, the designer should consider options to reduce the bundle size and/or increase bundle flexibility.

WIRE INSULATION TYPE AND THICKNESS

1E0815 (XLPE, SAE J1128 Type SXL) is the primary wire insulation type used in most harness applications. SXL wire insulation is rather thick and works well for static applications. Thinner wire insulation (e.g. SAE J1128 Types GXL or TXL) provides a wire that is slightly more flexible but has a more dramatic effect on harness flexibility as the bundle size increases. If thinner insulation is used, additional protection at any potential wear areas should be considered.

Alternative insulation materials may also need consideration. XLPE is less flexible than PVC or Polypropylene but changing to a more flexible insulation will also reduce the abrasion resistance (PVC only) and/or temperature performance of the harness. PVC and polypropylene insulation types will accept a post extrusion heat set which is required for coiled cable harness manufacturing or when a preformed shape is required.

CONDUCTOR GAUGE AND STRANDING

Conductor gauge and stranding play an important role in flex applications. Wire with a high strand count is more flexible than the same gauge wire having fewer strands. For heavy gauge cables, specifying a high strand count is the easiest way to increase flexibility. In general, larger

gauge conductors and conductors with low strand counts are not recommended for flex applications. Flexible ground straps, which are usually made of woven high strand count conductors, are often used in flex applications.

LAY

Lay is a measurement of the twist of the individual conductor strands in a wire or the twist of the wires in a wiring assembly or multiconductor cable. The lay is the distance through which the

twisting completes 360 degrees. A small value is more flexible than a large value. Twisting eliminates any single conductor from being on the outside of the bend and taking all the tensile stress. Cat does not typically specify the lay of the strands within the wire and should therefore be assumed to be of long lay construction.

Wires can be twisted within an assembly. However, most harness suppliers are not well equipped to twist more than 2 or 3 wires together. Additionally, twisted wires tend to untwist over time unless held in the twisted orientation in some manner until addition of the final covering.

Although lay may be specified for a harness, it is most often applied to jacketed multiconductor cables to increase their flexibility and reduce conductor stresses. The twisting of wires in a bundle is also important in providing the necessary circular cross-section of a coiled cable harness. Special separating liners and nylon fillers are sometimes required to provide a circular cross-section. Wire orientation within the twisted bundle is important. If the cable contains large

and small wires, the large wire(s) should be located in the core and the smaller wires symmetrically around the core to better distribute tensile and compressive forces. (reference 2G6710 and 2G6720).

HARNESS COVERING

Harness covering can have a profound affect on harness flexibility. A tightly braided harness is stiff and does not allow the wires to easily slip by one another during flexing. This may cause

significant wire tensile forces that may result in wire failure. The tension on the outer wires increases as the braided bundle diameter increases.

An unbraided harness is nearly as flexible as the individual conductors. Localized abrasion protection must be provided in any areas where the harness may contact another surface and at mounting support locations. This approach cannot apply to large spans or areas with large motion since the wires need to be better managed.

Recommended coverings for flexing applications with a large range of motion include jacketed multiconductor cables, flexible hose, or jacketed cable. Rubber tubing, plastic conduits and loose fitting sleeving may be applicable in some less severe situations.

In areas where there will be high cycle high amplitude flexing, special constructions should be considered. Polyurethane jacketed multiconductor cables can be constructed with high abrasion performance, the desired degree of flexibility, and due to the memory of the thermoformed cable, a certain amount of spring back. Cable coils (e.g. telephone receiver cord) can also be constructed with polyurethane jacketed custom cables.

10.15 FLEXING HARNESS ROUTING AND SUPPORT

STRAIN RELIEF

Strain relief is important at the transition of the harness from a flexing member to a static member. The wiring going through the mounting clamp should have some kind of strain relief present to assure that the bundle does not flex sharply against the edge of the support. When a hose is used as a covering and is clamped to the stationary locations, strain relief comes naturally.

ROUTING

In flexing applications it is important to assure the harness can flex through the whole range of

motion without stretching or being pinched. The excess wiring during the compression or shortening cycle needs to be managed so it does not catch, snag, slap or rub.

A flexing harness should be located so that it will pass through the centerline of the pivot point. This will eliminate stretching of the assembly and provide uniform bending. The ends of the hose should be clamped equidistant from the center of the flex point to insure a smooth and controlled bend.

When the harness cannot be routed through the pivot point centerline, a reverse bend or loop should be used to provide a uniform bend form and avoid stretching.

The harness should also be routed to prevent the entrance and accumulation of water and dirt within the harness covering. Water lying in low spots can freeze and damage the wire or hose.

In harnesses or cables with small flex amplitude, the designer must assure the flex joint contains a “U”, "S" or “L” shaped bend so the harness/cable can flex. Ground straps are often used across small amplitude flex joints.

A harness or battery cable flex joint must be kept isolated from other harnesses, cables and objects.

If a battery cable or an unfused cable such as a secondary steering motor cable is routed through an articulation joint, each cable must be routed in its own covering.

SUPPORT

The preferred clip to secure each end of a battery cable flex joint is the rubber insulated p-clip or

rubber sandwich clamp.

The preferred clip to secure each end of a harness flex joint is the P clip, rubber insulated p-clip or rubber sandwich clamp.

Flex joints must not be supported by tie wraps except in lower durability applications with cradle supports. Tie wraps cannot hold the harness/cable secure enough to prevent motion. Relative motion results in harness/cable wear and shorts.

10.16 FLEX HARNESS CONSTRUCTION

Since the wiring will be in motion, use conservative wire bend radii or fatigue failures will result.

Flex joints must not use a breakout for support. Flex joints must not contain a breakout. The relative motion can fatigue the breakout resulting in early harness failure.

- There should not be any connectors in the flex joint.

To ensure the flex joint is assembled as designed, consider adding green tape markers to locate flex joint clipping.

Braided construction is often used for low amplitude flex joints. Braided construction may also be used in high amplitude flexing applications when the bend radius is not severe and the routing well controlled. As bundle diameters increase, the braided harness becomes less flexible and may not be well suited for these flexing applications.

CONSTRUCTION WITH HOSE

Hose is the most common harness covering used for high amplitude flex applications (e.g. articulation joint, hitch) and provides good flexibility while providing protection for the harness. The most common types of hoses used are radiator and heater hose as those provide more flexibility than hydraulic hoses. Care must be taken in the selection of hose due to variations in

hose material. It is recommended that the designer perform testing and validation to insure the hose and harness design is correct for their application. A strain relief clip, grommet, heat shrink tubing or rubber sleeve should be provided for wires exiting or entering the hose to provide abrasion protection of the wires at the entrance to the hose, and to keep dirt and water from entering the hose.

Within the flexing portion of the harness, do not braid, tape, clip, or splice, wires. This will allow sliding motion between the wires. Clipping or taping wires can cause concentrated bend points and localized stress points. Taping wires during harness construction can also result in crossed over, kinked, or twisted wires that cause concentrated bend points.

MULTICONDUCTOR JACKETED CABLES

If a jacketed multiconductor cable (e.g.129-2068) will be used, for example across scraper hitches, limit the bundle diameter to reduce wire stress at the outside of the bend radius. If the cable contains large and small wires, place the large wire in the core and the smaller wires

symmetrically around the core (reference 2G6710 and 2G6720). Contrahelically wound conductors are recommended. The design should allow for a small amount of sliding motion between the wires. Special separating liners and nylon fillers are sometimes required to provide a cylindrical shape. Many of these cable types are custom to an application and are not recommended for general use. Heat shrink or similar transition at the entrance and exit point of the cable jacket should be in place to keep dirt and water from entering the jacket.

CONSTRUCTION WITH PLASTIC CONDUIT

Plastic convoluted tubing may be used in lower durability applications since this covering cannot provide the same support or impact protection as a hose. The design and construction techniques are the same as those used for wiring in hose. The material selected must not age in the application. PVC tubing is not recommended. Slit conduits must not be used in flexing applications because wires can get pinched in the slit and either wear through wire insulation or pinch the wires until fatigue and breakage occurs.

10.17 SAE J1939/ 11 - DATA BUS WIRING

The harness assembly requirements for J1939/11 cable and connectors are unique. The data bus connector is a modified DT connector with a special wedge, special cable, and incorporates one extended socket. See Figure 22 for typical cable to connector construction. The minimum

bend radius for the data bus cable is 40 mm. In order that the data bus will function as intended, the harness assembly must meet the requirements as specified in SAE J1939/11 (e.g. harness part number 286-0833 or 280-2476). Failure to conform to these requirements will result in moisture entry and result in loss of shield performance.

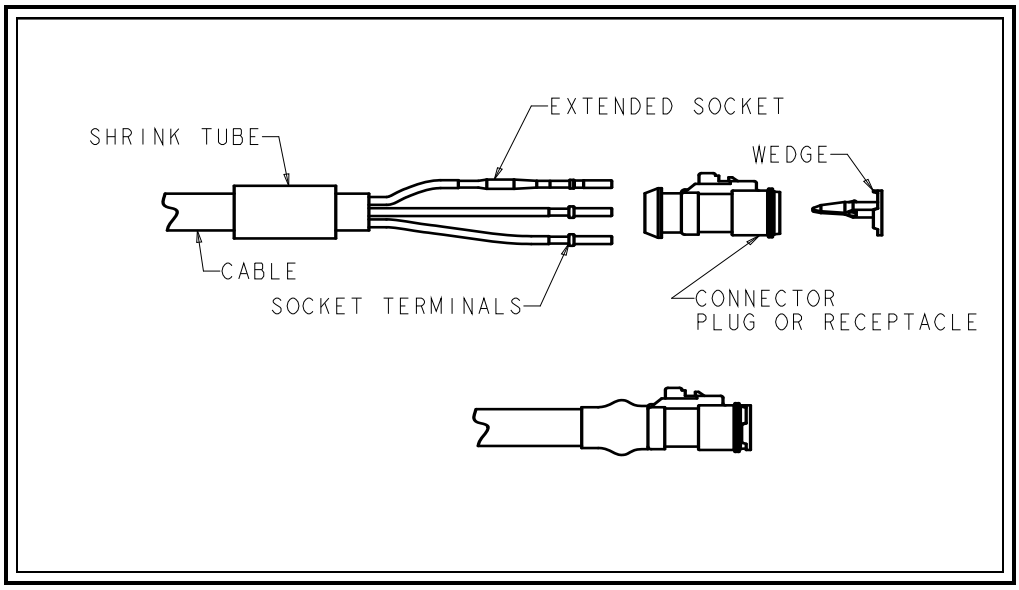


Fig. 22: SAE J1939/11 Connector Assembly

APP

INDEX

1 *APPENDIX* ELECTRICAL NOMENCLATURE

These acronyms are used through out the electrical systems and diagrams for this locomotive.

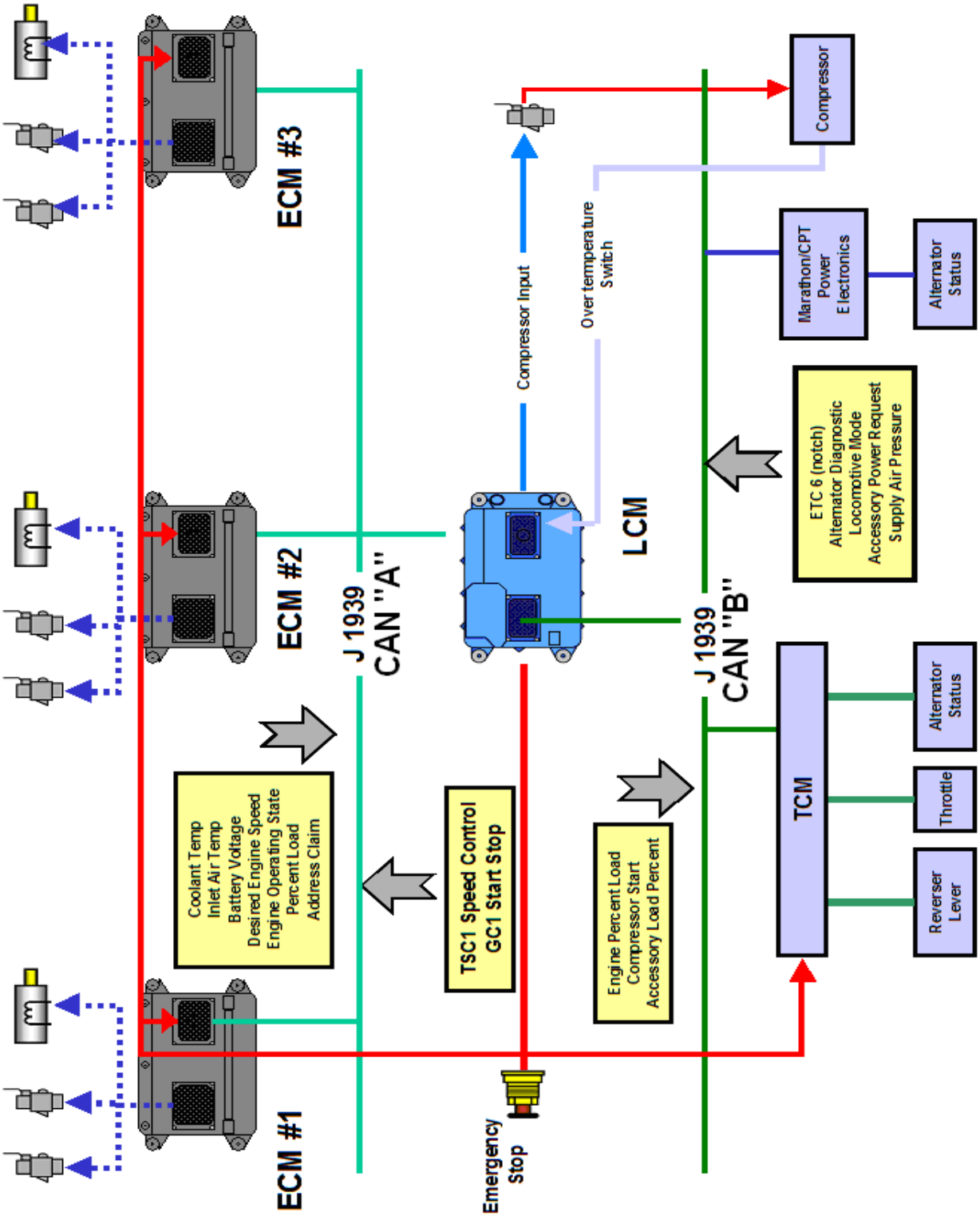
Table 10-1 Electrical Acronyms

ACRONYM	DESCRIPTION
AC-AGR	Cooling Fan Contactor Automatic Ground Reset
AV, BV, CV, DV	Governor Speed Setting Solenoids
AVR, BVR, CVR	Throttle Response Contactors
AWS	Auxiliary Wheel Slide Relay
B	Brake Power Contactor
BCT	Brake Current Transductor
BF	Battery Field Contactor Relay
BFA	Battery Field Auxiliary
BKBL	Relay Dynamic Brake Grid Blower Motor
BPR	Brake Positioner Relay
BPS	Brake Program Switch
BR	Relay Backward
BTR	Brake Transition Relay
BWA	Brake Warning Auxiliary
BWR	Brake Warning Relay
BX	Brake Power Auxiliary
B-	Brake Transfer Switches Relay
CCR	Compressor Control
COLR	Cutout Limit Relay (Generator Current Limit)
COR	Motor Cutout Relay
CORX	Motor Cutout Auxiliary Relay
CRL	Relay Compressor
CRBC	Battery Charging Rectifier
CRFPC	Fuel Pump Contactor Delay Rectifier
CRGR	Relay Ground Relay Rectifier
DBR	Dynamic Brake Regulator
DRR	Decrease Resistance Relay
D-	Dynamic Grid Shorting Contactor
EBT	Electro Thermal Blowdown Timer
EFCO	Emergency Fuel Cutoff Switch
EFL	Engine Filter Light Relay
EL	Excitation Limit Light Relay
ELD	Excitation Limit Delay Relay
ELR	Excitation Limit Relay
ER	Engine Run Relay
ESS	Emergency Sanding Switch
ETS	Engine Temperature Switch
FCT	Field Current Transductor
FL	Field Loop Contactor
FLC	Field Loop Control Relay
FLT	Field Loop Transductor
FLX	Field Loop Auxiliary Relay
FLY	Field Loop Auxiliary Relay
FOR	Forward Relay
FPC	Fuel Pump Contactor
FPCR	Fuel Pump Contactor Relay
FPR	Fuel Pump Relay
FSA	Field Shunt Auxiliary Relay
FSC	Field Shunt Control Relay
FSD	Field Shunt Delay Relay
FS-	Field Shunt Contactor
FTR	Forward Transition Relay
FTRA	Forward Transition Auxiliary Relay
FTX	Forward Transition Auxiliary Relay
FVS	Filter Vacuum Switch
GCR	Generator Current Relay
GCT	Generator Current Transductor
GDL	Ground Detection Light Relay
GF	Generator Field Contactor
GFA	Generator Field Auxiliary Contactor
GFD	Generator Field Decay Contactor
GFR	Generator Field Relay
GPT	Generator Potential Transformer
GR	Ground Relay
GS	Generator (Engine) Start Contactor
GSA	Generator (Engine) Start Auxiliary Relay
GVT	Generator Voltage Transductor
GV-	Main Generator Voltage Regulator Module
GX-	Main Generator Field Current Regulator Module
IPS	Independent Brake Pressure Switch
I RR	Increase Resistance Relay
IS	Isolation Switch
ISA	Isolation Switch Auxiliary Relay
LOR	Lockout Relay
LOS	Low Oil Switch
LOTR	Lube Oil Transfer Contactor
LR	Load Regulator
LRP	Load Regulator Positioner
MCO-	Motor Cutout Relay

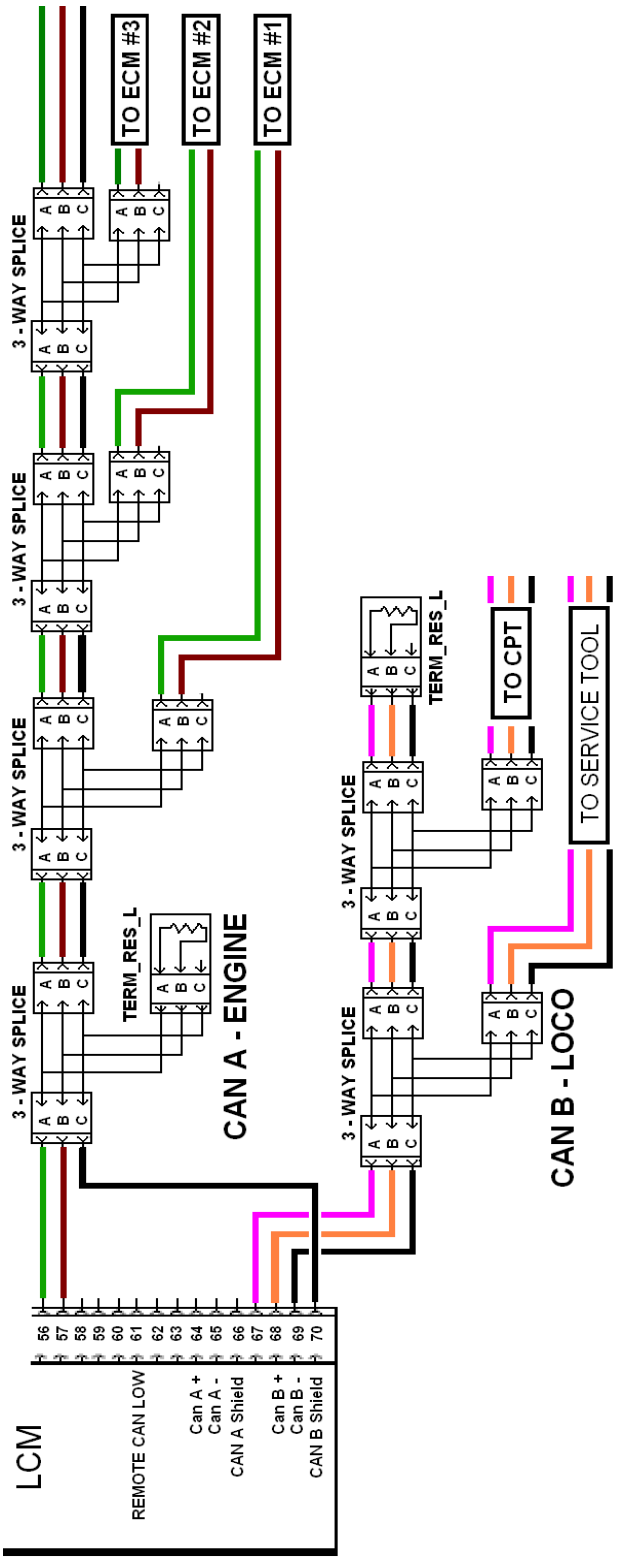
ACRONYM	DESCRIPTION
MFP	Motor Field Protection Relay
MFT	Motor Field Current Transductor
MSSF, MSSR	Manual Sanding Switch - Forward - Reverse (Pressure Switch Actuated By Remote Valve)
MVCC	Magnet Valve - Compressor Control
MV-	Magnet Valve - Reservoir Or Filter Blowdown
MVDBI	Magnet Valve - Dynamic Brake Interlock
MVOS	Magnet Valve - Train Overspeed
MVSF	Magnet Valve - Sanding Forward
MVSH	Magnet Valve - Shutter Control
MVSR	Magnet Valve - Sanding Reverse
MVWC	Magnet Valve -Water Cooler
M-	Motor Power Switchgear
NVR	No (AC) Voltage Relay
OCL	Overcurrent Lockout Relay (Dynamic Brakes)
OCP	Open Grid Circuit Protection Relay
ORS	Overriding Solenoid
OSR	Overspeed Relay
OVR	Overvoltage Relay
PCP	Performance Control Panel
PCR	Pneumatic Control Relay
PCs	Pneumatic Control Switch
PFS	Parallel Field Shunt Relay Brake
POT	Potential Relay
PR	Parallel Relay
PRA P-	Parallel Relay Auxiliary Power Contactor - Parallel
QS	Transistorized Switch
RCP	Rate Control Panel
REBC	Battery Charging Resistor
REDB	Dynamic Brake Rheostat/ Resistor
REFS	Resistor - Motor Field Shunt
REGID	Dynamic Brake Resistor
REMFS	Resistor - Motor Field Shunt
RER	Reverse Relay
RVF	Direction Transfer Switch -Forward
RVR	Direction Transfer Switch - Reverse
RVRA	Reverser Switch Auxiliary Relay
SBP	Sensor Bypass Panel
SCC	Starting Current Contactor
SCC	Series Connecting Contactor (Battery Field)
SCR	Controlled Rectifier - Generator Excitation
SEN	Sensor -SCR Trigger

ACRONYM	DESCRIPTION
SF	Shunt Field Contactor
SFT	Shunt Field Transfer Relay
SHS-	Selector Handle Cam Operated Switches
SP-	Series-Parallel Power Contactor
ST-	Starter Solenoid Contacts
SSS	Service Selector Switch
SS-	Sequence Stepping Relay Transition
STS	Shutter Temperature Switch
SWO	Simultaneous Wheel Overspeed Relay
S-	Series Power Contactor
S-	Sequence Relay-Transition
S-A	Series Power Contactor Auxiliary Relay
T	Transformer
TA, TB, TC	Fan Control Temperature Switches
TCR	Train Control Relay
TCR	Temperature Compensating Relay
TDF	Slip Control Timing Relay (Time Delay Generator Field)
TDLO	Time Delay -Lube Oil Transfer
TDO	Slip Control Timing Relay (Time Delay Overriding Solenoid)
TDP	Time Delay Positioner Relay
TDR	Transition Delay Relay
TDS	Time Delay Sanding Relay
THS-	Throttle Controlled Cam Switches
TLPC	Turbo Lube Pump Contactor
TLTD	Turbo Lube Time Delay Relay
TRP	Throttle Response Panel
TST	Transition Sequence Test
T-	Switch Transformer
VR	Voltage Regulator
WCR	Wheel Creep Relay
WL	Wheel Slip Light Relay
WS	Wheel Slip Relay
WSC	IDAC Wheel Slip Control Panel
WSR	Wheel Slip Relay/Wheel Speed Relay
WST-	Wheel Slip Transductor
WS-	Wheel Slip Relay
Z-	Zener Diode

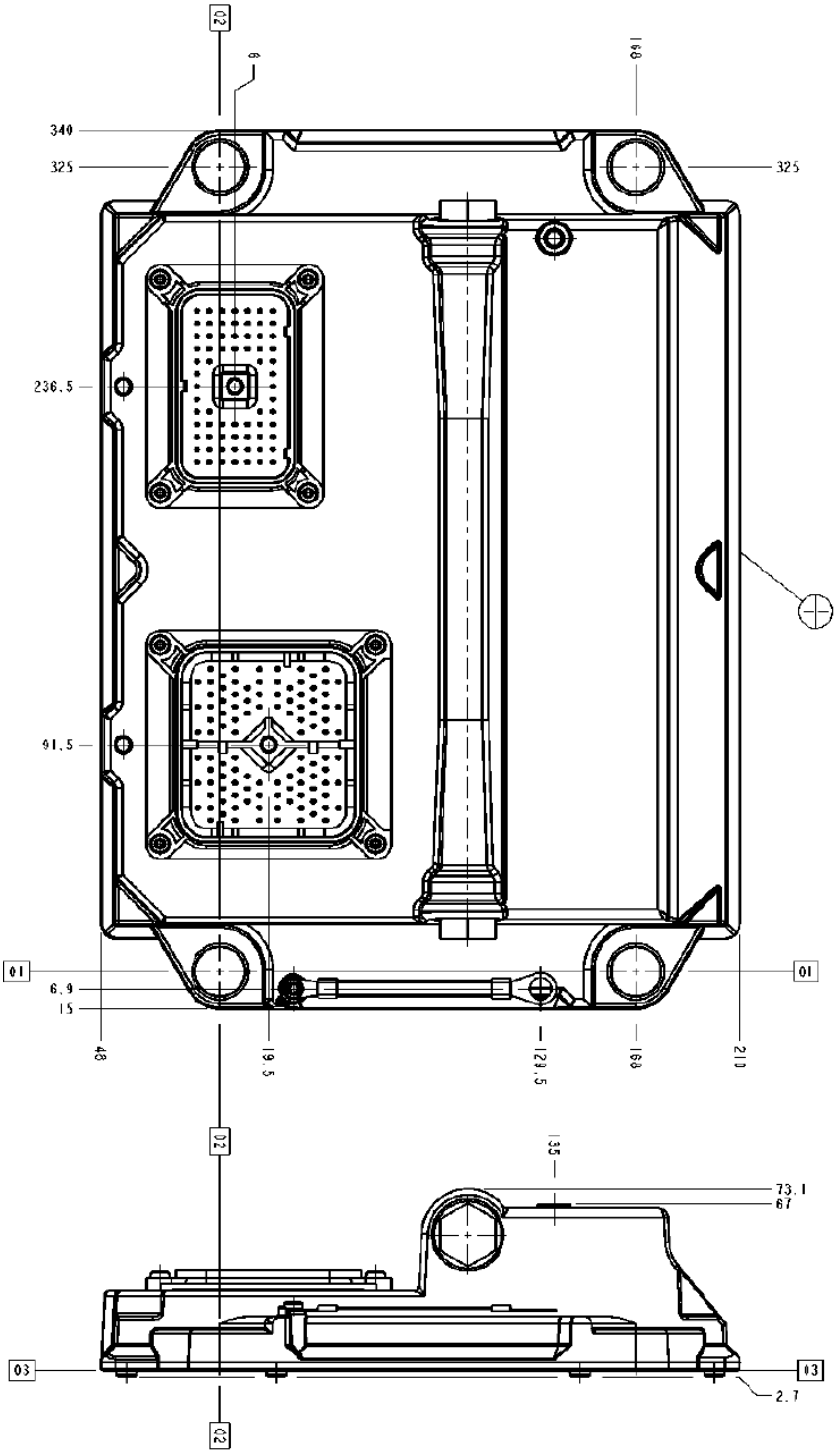
2 *APPENDIX* J1939 MULTI-ENGINE NETWORK DIAGRAM



3 *APPENDIX* J1939 LCM SCHEMATIC



4 APPENDIX LCM MOUNTING DIAGRAM



5 APPENDIX VEC MODULE

VEC MODULE

The VEC module is located in the low voltage control cabinet in the lower right compartment. It provides most of the 24 VDC fusing and some 24 VDC relay control for the locomotive.

NOTE: Use **15 amp circuit breakers**, part number 280-2709 for the VEC module (Figure 10-1, page 182) when replacing any defective circuit breaker.

FUSE AND CIRCUIT BREAKER LIST

Below is a list of blade fuses and circuit breakers typically used in the VEC module. **Error! Reference source not found.** shows the standard VEC module populated with relays and circuit breakers.

Figure 10-1 Fuses and Circuit Breaker Sizes

CAT P/N	AMP	COLOR	VOLTS	TYPE
113-8490	10	Red	32	Blade
113-8491	15	Lt Blue	32	Blade
113-8492	20	Yellow	32	Blade
CIRCUIT BREAKER – VEC Module				
280-2709	15	Lt Blue	32	Blade

POPULATED VEC MODULE

15 AMP CIRCUIT BREAKERS	RELAYS	OPTIONAL RELAYS	OPTIONAL CIRCUIT BREAKERS
P1 P2 P3 P4 P5 P6 P8 P9 P14 P15 P16 P17 P18 P21 P22 P23 P24 P25 P26	K5	K7 K8 K9	P19 P20

- Fuses are labeled as P1 – P26 and are rated @ 15 amps. Relays are K1 – K9
- Populated fuses are Blue.
- Light Blue fuses are for optional circuits.
- Populated relays are Light Green

See Figure 10-2 on page 183.

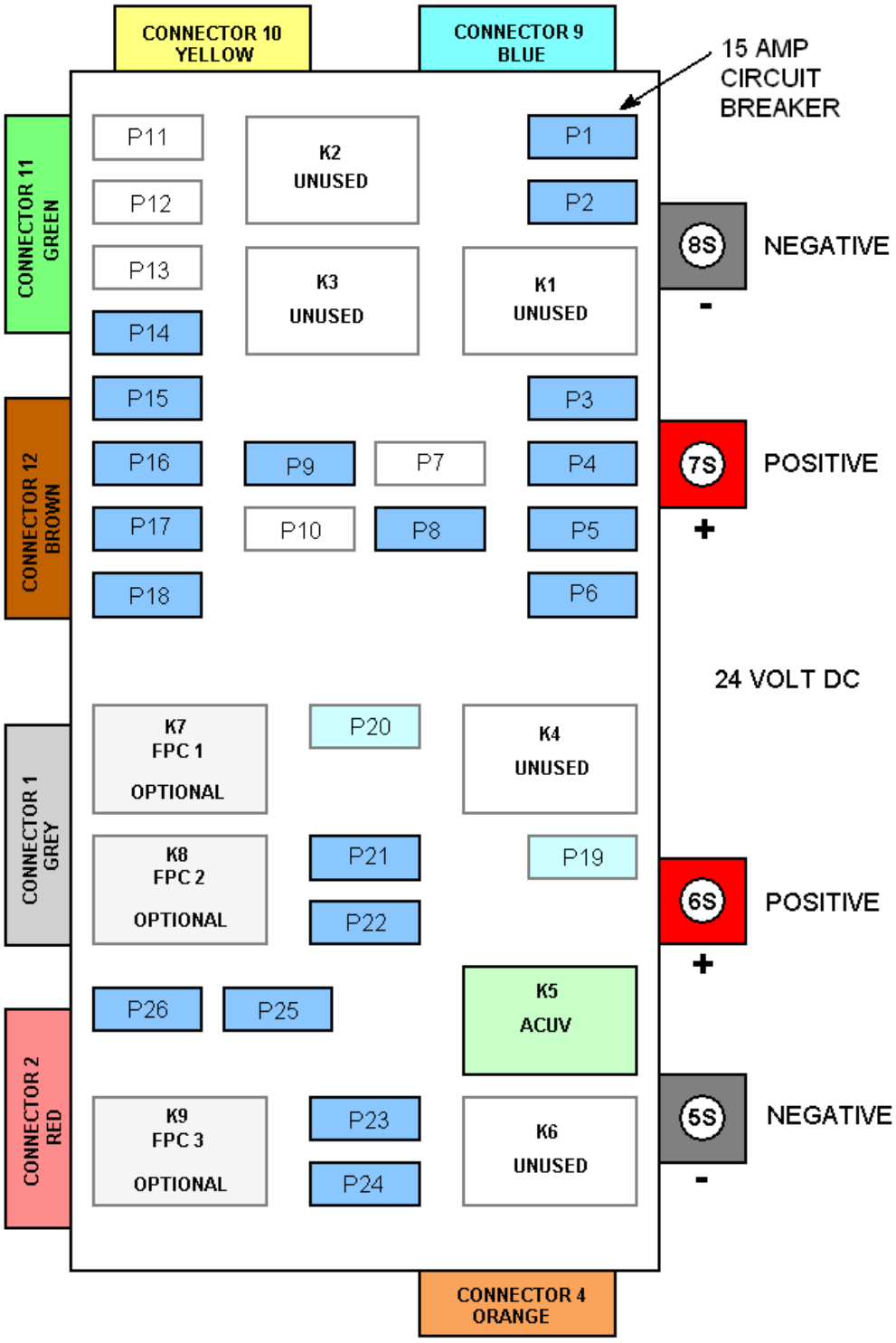
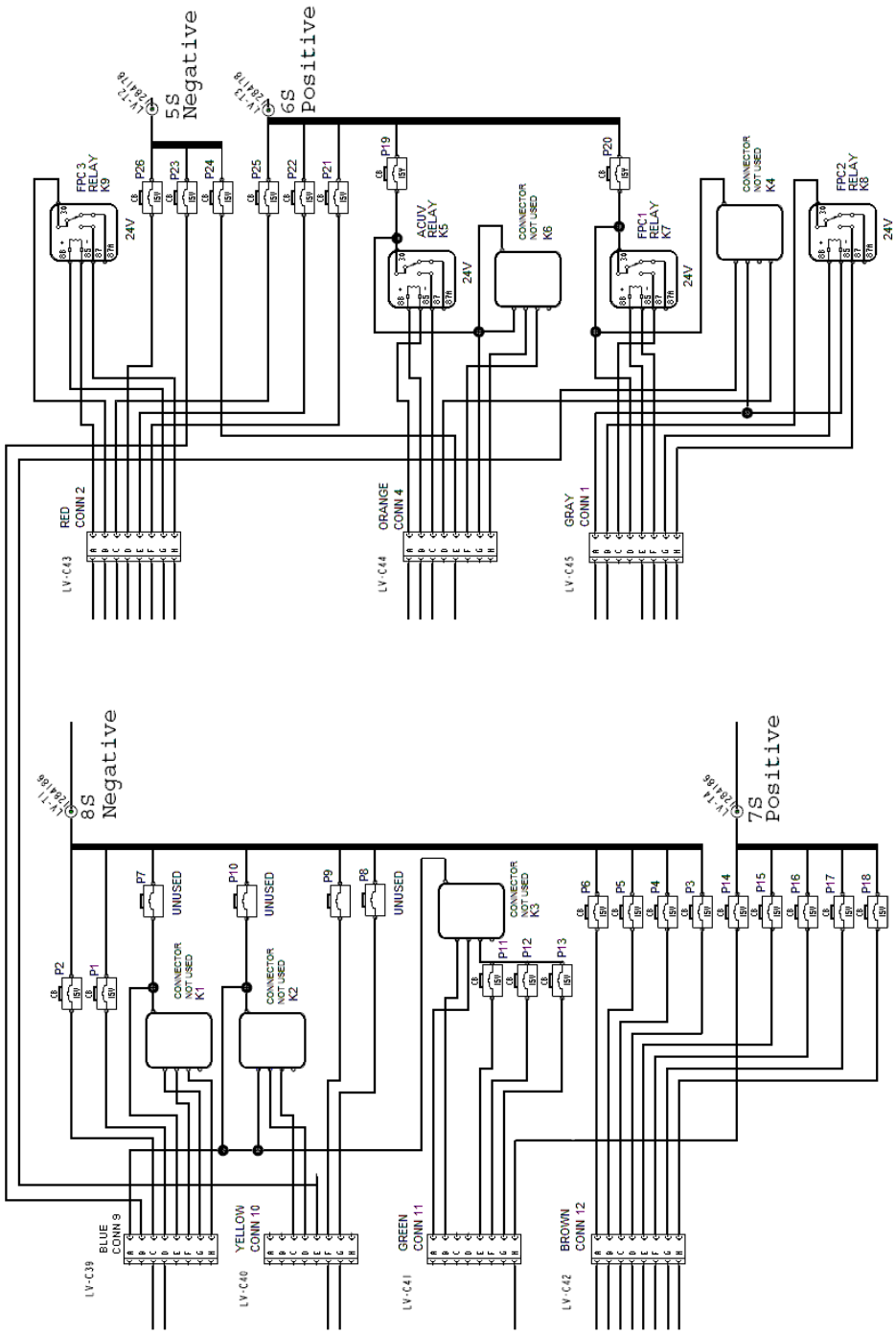


Figure 10-2 VEC Module – Populated

VEC MODULE SCHEMATIC

The VEC Module may vary from locomotive to locomotive. Refer to the specific locomotive's Trouble Shooting Guide for current schematics and operational characteristics.



6 *APPENDIX* PRODUCT LINK SCHEMATIC

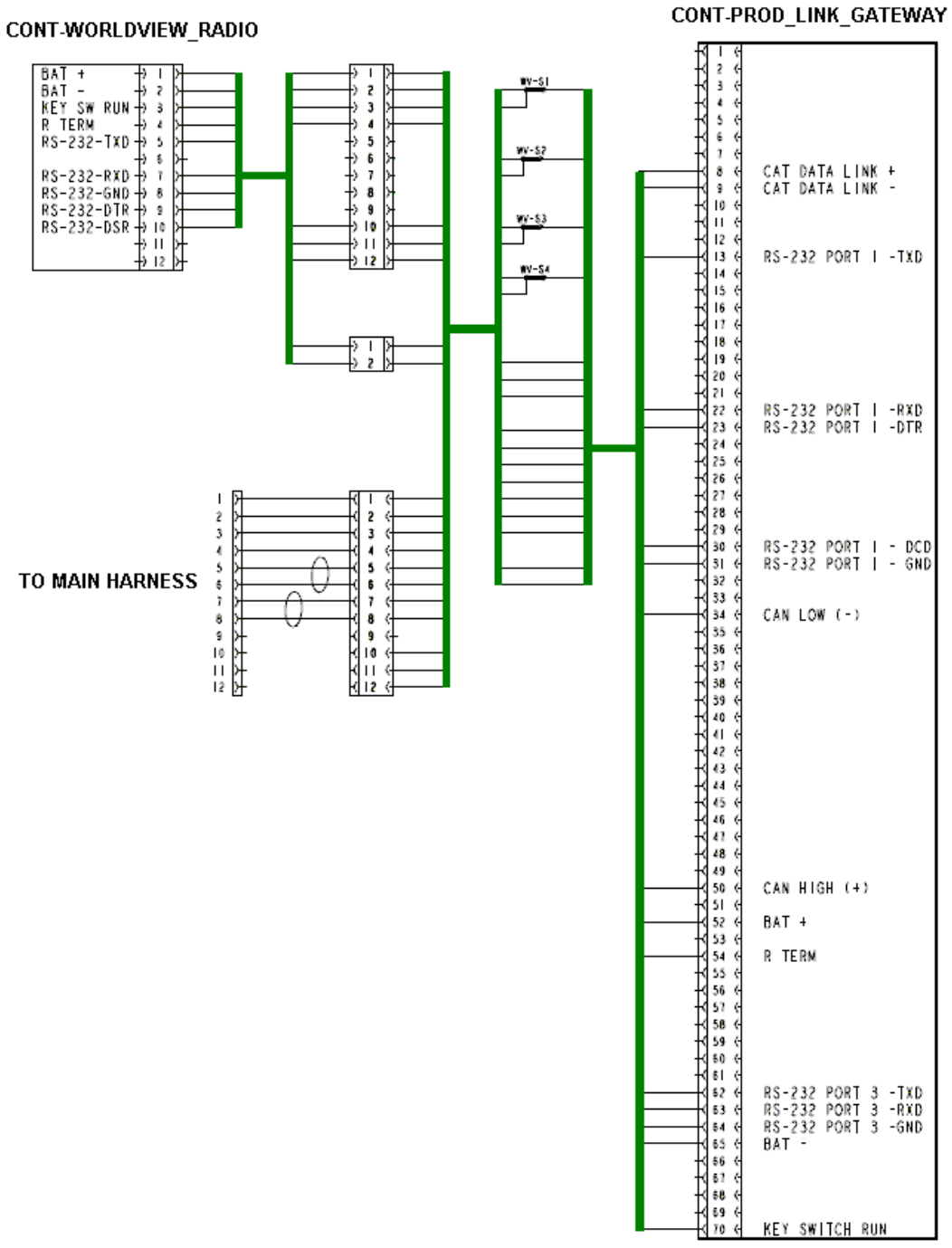


Figure 10-3 Product Link Schematic

Glossary Of Terms

Bit	One unit of information. A bit can have a value of 0 or 1.
CAN	**Controller Area Network:** A serial communications protocol which supports distributed real-time control with a high level of security. The message format supports 0 to 8 bytes of information from 1 to 1000k baud. J1939 is a layer of specification placed on the CAN network by SAE. Caterpillar controls follow this specification which identifies an update rate of only 250k baud.
CAT	**Data Link Caterpillar Proprietary Data Link:** High-speed (62.5 Kbaud) serial communications system used on vehicle systems for module to module data transfers.
Cat ET	**Caterpillar Electronic Technician:** Proprietary service tool for use on Caterpillar's electronic engines.
CDL	**CAT Data Link**
CID	**Component Identifier** (when referring to the data link)
CPU	**Central Processing Unit:** For Cat electronics, this typically refers to the microprocessor integrated circuit in a control module
EC-1	Caterpillar's proprietary set of electrical and environmental test criteria which are applicable to Caterpillar electronic modules.
LCM	**Electronic Control Module:** General term used to refer to the electronic module in a system. The original meaning was "Engine Electronic Control Module".
EEPROM	**Electrically Erasable Programmable Read Only Memory:** Electronic memory in the LCM for customer parameters, fault log, and trip recorder data
EPROM	**UV Electrically Erasable Programmable Read Only Memory:** Electronic memory in the personality module for software control algorithms. Must be removed from the LCM to reprogram
ET	**Electronic Technician:** Caterpillar PC software which serves as an electronic service tool for service technicians.
FLASH	**Bulk electrically erasable programmable read-only memory:** Electronic memory in the personality module for software control algorithms. Replaces EPROM memory. Can be reprogrammed without removal from the LCM via the data link. Also used to describe the act of programming the memory via a data link and service tool i.e. "flash program the LCM"
FMI	**Failure Mode Identifier:** Code used by electronic controls to tell what type of failure has occurred
J1939	Protocol for messages used on the CAN data link.
Kbaud	1000 bits of information per second
MID	**Message Identifier:** Code used by electronic controls to identify the data link message type

PID	**Parameter Identifier:** Code used by electronic controls to identify a particular piece of data (parameter)
PWM	**Pulse Width Modulated:** Electrical signal consisting of a series of pulses at a specific frequency. The width of the pulses determines the information being transferred.
RAM	**Random Access Memory:** Electronic memory in the LCM for software variables
Resolution	In this document, resolution refers to the number of pixels contained within a display. Typically, resolution is expressed in terms of height and length of the display in terms of pixels. For example, a display's resolution may be referred to as being 240 pixels tall and be 320 pixels long.
SAE	**Society of Automotive Engineers**
SPI	**Serial Peripheral Interface:** Acronym for Serial Peripheral Interface. SPI is a method of communication most often used to communicate between microcontrollers.

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