

Testing and Assessment of a Full Scale J1939 Network Model

Task Order 4 of the
Commercial Vehicle Safety Technology Diagnostics
and Performance Enhancement Program



U.S. Department of Transportation
Federal Motor Carrier Safety Administration

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Foreword

This project is one of several performed under the provisions of Section 5117 of the Transportation Equity Act of the 21st Century (TEA-21). The primary objective of this project was to explore the capacity of the Society of Automotive Engineers (SAE) J1939 network. The work performed under the project included:

- Collecting information from the commercial vehicle user, original equipment manufacturer (OEM), equipment supplier, and laboratory research.
- Profiling high-level functional requirements of component electronic control units (ECUs), which were sourced from industry, as well as surveying and interviewing key industry stakeholders.
- Developing the test matrix based on the input from industry and government.
- Developing a hardware-in-the-loop (HIL) heavy-duty vehicle J1939 network simulator.
- Identifying and estimating the issues related to the implementation of safety related technologies on the J1939 network on heavy-duty commercial vehicles.

The results of this project can be used by CMV OEMs, component suppliers, and motor carriers to help evaluate the ability of the J1939 Network to accommodate an increasing number of safety-related systems and accessory components. This document is the final report of the contract Task Order under which the study was performed.

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16. Abstract This project is one of several performed under the provisions of Section 5117 of the Transportation Equity Act of the 21st Century (TEA-21). The primary objective of this project was to explore the capacity of the Society of Automotive Engineers (SAE) J1939 network. The work performed under the project included: <ul style="list-style-type: none"> Collecting information from the commercial vehicle user, original equipment manufacturer (OEM), equipment supplier, and laboratory research. Profiling high-level functional requirements of component electronic control units (ECUs), which were sourced from industry, as well as surveying and interviewing key industry stakeholders. Developing the test matrix based on the input from industry and government. Developing a hardware-in-the-loop (HIL) heavy-duty vehicle J1939 network simulator. Identifying and estimating the issues related to the implementation of safety related technologies on the J1939 network on heavy-duty commercial vehicles. <p>The network testing conducted for this Task Order demonstrated that the commercial ECUs used in the network testing, that are representative of a generic and complex network on a commercial truck, implemented J1939 well within the standards. The results from the HIL simulator indicate the network appears to have 2.5 to 3 times the capacity currently used by the majority of commercial heavy vehicles in the U. S. today. This capacity should allow additional networked system controllers to be safely added to the J1939 network such as electronic stability control systems, roll stability control systems and wireless vehicle inspection systems.</p>					
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<u>LENGTH</u>					<u>LENGTH</u>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	Yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<u>AREA</u>					<u>AREA</u>				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	square kilometers	0.386	square miles	mi ²
<u>VOLUME</u>					<u>VOLUME</u>				
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gal	gallons	3.785	liters	l	l	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	cubic meters	1.307	cubic yards	yd ³
<u>MASS</u>					<u>MASS</u>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lbs)	0.907	megagrams	Mg	Mg	megagrams	1.103	short tons (2000 lbs)	T
<u>TEMPERATURE (exact)</u>					<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
<u>ILLUMINATION</u>					<u>ILLUMINATION</u>				
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m2	cd/m2	cd/m2	candela/m2	0.2919	foot-Lamberts	fl
<u>FORCE and PRESSURE or STRESS</u>					<u>FORCE and PRESSURE or STRESS</u>				
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

TABLE OF CONTENTS

List of Acronyms	viii
Definitions	ix
Executive Summary	ES-1
1. Introduction and Background.....	1
1.1. Reasons for Testing J1939	1
1.2. Concerns of J1939 Network Reliability.....	1
1.3. J1939 Communications Network	2
1.3.1. J1939 Documents	4
1.3.2. J1939 Connectors	5
1.4. Rationale for Hardware-In-the-Loop Simulator	6
2. Overview of Test Bed Setup	9
2.1. Simulator Design	9
2.1.1. Hardware.....	10
2.1.2. Software	11
2.1.3. Data Capture and Analysis	13
2.1.4. Driver Station.....	13
2.1.5. Graphical User Interface (GUI).....	14
2.2. Simulator Design and Fabrication Issues	15
2.2.1. Engine Simulator Reengineering.....	15
2.2.2. HIL Simulator Wiring Database.....	17
2.2.3. Limited Inter-Target Bandwidth	17
2.2.4. Generation of Crank and Cam Sensor Signals	18
2.2.5. Supplier Cooperation with Plant Modeling	19
2.2.6. ECU Connectors	19
2.3. Simulator Correlation and Validation	19
2.3.1. Network Data Collection from Tractor Test Bed	20
2.3.2. Correlation HIL Simulator Versus Actual Truck.....	23
3. Test Rationale and Series	27
3.1. Varied Test Parameters.....	28
3.1.1. Number of ECUs on Network – COTS and Virtual	28
3.1.2. Network Complexity	28
3.1.3. Simulated ECUs – Message Priority and Type	28
3.1.4. Cable Type – Shielded Versus Unshielded.....	29
3.1.5. Network Physical Integrity – Physical Faults	29
3.1.6. Driving Scenario – Safety-Critical Actions	29
3.2. Physical Fault Tests	29
3.2.1. Faults and Location.....	29
3.2.2. Physical Fault Tests – Data Collection.....	31
3.2.3. Physical Fault Tests – Data Presentation.....	31
3.2.4. Physical Fault Tests – Pass/Fail Criteria.....	32

3.3.	Network Loading Tests	32
3.3.1.	Traffic Levels and Priority.....	32
3.3.2.	Bus Arbitration	33
3.3.3.	Network Load Tests – Data Collection.....	34
3.3.4.	Network Load Tests – Data Presentation.....	34
3.3.5.	Network Load Tests – Pass/Fail Criteria.....	36
3.4.	Injected Noise Level.....	36
3.4.1.	Injected Noise Tests – Data Collection	37
3.4.2.	Injected Noise Tests – Data Presentation	38
3.4.3.	Injected Noise Tests – Pass/Fail Criteria	38
3.5.	Application Layer Issues	39
3.6.	Connector Diversity	40
4.	Testing Results	41
4.1.	Physical Fault Test Results.....	41
4.1.1.	Fault-Free Tests.....	41
4.1.2.	Signal-to-Noise Reducing Faults.....	42
4.1.3.	Segmenting Faults	43
4.1.4.	Network Failure Faults.....	45
4.1.5.	Fault location A: Between VECU and ABS.....	45
4.1.6.	Fault Location B: Between EECU and TECU.....	46
4.1.7.	Overall Physical Fault Testing Results	46
4.2.	Network Loading Test Results	46
4.2.1.	Network Response to Physical Faults While Under High Traffic Load.....	47
4.2.2.	Load Test LT31.....	47
4.2.3.	Load Test LT06.....	55
4.3.	Injected Noise Test Results.....	61
4.3.1.	Effect of Network Length on Noise Tolerance.....	62
4.3.2.	Comparison of J1939-11 (STP) vs. J1939-15 (UTP)	62
4.3.3.	Improper Termination Effects	62
4.3.4.	CAN_L Short to Vehicle/Battery Ground	63
5.	Conclusions	65
5.1.	Robustness of the J1939 Network.....	65
5.1.1.	Physical Fault Response	65
5.1.2.	High Bus Loading Response.....	65
5.1.3.	Injected Noise Response.....	65
5.2.	Summary of Key Results and Recommendations.....	66
	Appendix A: Simulator Validation – Additional Data.....	69
	Appendix B: Physical Fault Test Data.....	75
	Appendix C: Network Load Test Data.....	85
	Appendix D: Injected Noise Test Data	92
	Appendix E: Test Series Driving Scenarios and Test Procedures	126
	Appendix F: Test Matrix	132

LIST OF EXHIBITS

Exhibit 1.1 - J1939 3-Pin Connector Pin Assignments	5
Exhibit 1.2 - J1939 3-Pin Connector Schematic.....	6
Exhibit 1.3 - J1939 9-Pin Connector Assignments.....	6
Exhibit 1.4 - J1939 9-Pin Connector Schematic.....	6
Exhibit 2.1 - HIL Simulator Test Bed	9
Exhibit 2.2 - HIL Test Bed Simulator Block Diagram.....	11
Exhibit 2.3 - Engine Model	12
Exhibit 2.4 - Engine Model Torque Map.....	13
Exhibit 2.5 - Driver Station	14
Exhibit 2.6 - Graphical User Interface	15
Exhibit 2.7 - Tractor Test Bed	20
Exhibit 2.8 - Test Tractor Data Collection	21
Exhibit 2.9 - HIL Test Bed Wheel Speed During Acceleration.....	23
Exhibit 2.10 - Tractor Test Bed Wheel Speed During Acceleration	24
Exhibit 2.11 - HIL J1939 Network Load During Acceleration	25
Exhibit 2.12 - Tractor J1939 Network Load During Acceleration	25
Exhibit 2.13 - HIL Test Bed EEC1 Engine Speed During Acceleration	26
Exhibit 2.14 - Tractor EEC1 Engine Speed During Acceleration	26
Exhibit 3.1 - Physical Fault Case Schematic	30
Exhibit 3.2 - Physical Fault Case Description.....	30
Exhibit 3.3 - Example of Physical Fault Testing Results.....	31
Exhibit 3.4 - Failure Mode Classification.....	31
Exhibit 3.5 - Bus Arbitration Illustration	34
Exhibit 3.6 - Example of Load Test Results	35
Exhibit 3.7 - Noise Test Setup Block Diagram.....	36
Exhibit 3.8 - Test Harness Lengths (meters)	36
Exhibit 3.9 - Noise Test Termination	37
Exhibit 3.10 - Example of Injected Noise Test Results	38
Exhibit 3.11 - Connector Summary.....	40
Exhibit 4.1 - Physical Fault Tests: Network Configurations	42

Exhibit 4.2 - HIL Bus Loading During a Physical Fault Causing Reduced S/N (Headway Controller Engaged, CAN_L to Ground, Fault Location A).....	43
Exhibit 4.3 - Fault Location A: Between VECU and ABS.....	43
Exhibit 4.4 - HIL Bus Loading During a Segmenting Physical Fault Headway Controller Engaged, CAN_H Open, Fault at Location A.....	44
Exhibit 4.5 - Fault Location B - Between EECU and TECU at Location B	45
Exhibit 4.6 - HIL Bus Loading During a Physical Fault Causing Bus Failure Headway Controller Engaged, CAN_L to CAN_H, (Fault at Location A).....	46
Exhibit 4.7 - LT31 Network Loading.....	48
Exhibit 4.8 - LT31 Message Interval at 24.90% Load	48
Exhibit 4.9 - LT31 Message Interval at 99.30% Load	49
Exhibit 4.10 - LT31 Network Load - From 10 to 20 seconds	50
Exhibit 4.11 - LT31 Network Load - From 12.0 to 13.0 seconds.....	50
Exhibit 4.12 - LT31 Address 7 Message Intervals	51
Exhibit 4.13 - LT31 Address 19 Message Intervals	51
Exhibit 4.14 - LT31 Address 42 Message Intervals	52
Exhibit 4.15 - LT31 High Load Period.....	53
Exhibit 4.16 - Description of Parameter Group Numbers (PGNs) and Source (TX ECU)/Destination (RX ECU) ID numbers	54
Exhibit 4.17 - LT06 Network Loading.....	55
Exhibit 4.18 - LT06 Message Interval at 18.38% Load	56
Exhibit 4.19 - LT06 Message Interval - From 13.2 to 22.2 seconds.....	56
Exhibit 4.20 - LT06 Message Interval at 99.94% Load	57
Exhibit 4.21 - LT06 Network Load - From 13.2 to 22.2 seconds.....	57
Exhibit 4.22 - LT06 Network Load - From 21.8 to 22.0 seconds.....	58
Exhibit 4.23 - LT06 High Load Period.....	59
Exhibit 4.24 - LT06 High Load Period.....	60
Exhibit 4.25 - Noise Tolerance Summary	61
Exhibit A.1 - HIL TSC1 Messages During Acceleration	69
Exhibit A.2 - Tractor TSC1 Messages During Acceleration	69
Exhibit A.3 - HIL EEC2 Message Data While Under Headway Control.....	70
Exhibit A.4 - HIL EEC1 Data Under Headway Control.....	71
Exhibit A.5 - EEC1 Message SPNs in Exhibit A.4.....	71
Exhibit A.6 - EEC1 Torque Mode - SPN 899	72
Exhibit A.7 - HIL EEC1 Start Intervals and Engine RPM	72

Exhibit A.8 - HIL Adaptive Cruise Control Mode 73
Exhibit A.9 -ACC Modes..... 73
Exhibit A.10 - HIL CCVS Wheel Speed and Cruise Set Point 74

LIST OF ACRONYMS

ABS	Antilock Braking System
ACC	Adaptive Cruise Control
AMT	Automated Manual Transmission
ATC	Automatic Traction Control
CAN	Controller Area Network, specifically SAE J1939
CAN_H	CAN High voltage signal line
CAN_L	CAN Low voltage signal line
CAN_GND	CAN Ground line
CCVS	Cruise Control/Vehicle Speed
COTS	Commercial off-the-shelf
CWS	Collision Warning System
ECU	Electronic Control Unit
EECU	Engine ECU
HIL	Hardware-in-the-Loop
HWC	Headway Controller
OEM	Original Equipment Manufacturer
OS	Operating System
OSI	Open Systems Interconnection
MIL	Malfunction Indicator Lamp
MPH	Miles Per Hour
PC	Personal Computer
PCI	Peripheral Component Interconnect
PGN	Parameter group Number
RMS	Root Mean Square
RPM	Revolutions Per Minute
RX	Receiver
S/N	Signal-to-Noise Ratio
SAE	Society of Automotive Engineers
SPN	Suspect Parameter Number
STP	Shielded Twisted Pair (J1939-11)
TDC	Top Dead Center
TECU	Transmission ECU
TRMA	Terminator at the "A" end of the J1939 test bus
TRMB	Terminator at the "B" end of the J1939 test bus
TSC1	Torque/Speed Control #1

TX	Transmitter
UDP	User Diagram Protocol
UTP	Unshielded Twisted Pair (J1939-15)
Vbat	Battery high voltage
VECU	Vehicle (or Cab) ECU - Instrument Cluster
VPP	Voltage Peak-To-Peak

DEFINITIONS

Ground	Vehicle electrical ground
Terminator	The 120 Ohm terminating resistor at each end of the J1939 bus

EXECUTIVE SUMMARY

PROJECT FUNDING

Under the provisions of Section 5117 of the Transportation Equity Act for the 21st Century of 1998 (TEA-21), Congress authorized the U.S. Department of Transportation (USDOT) to:

“...conduct research on the deployment of a system of advanced sensors and signal processors in trucks and tractor trailers to determine axle and wheel alignment, monitor collision alarm, check tire pressure and tire balance conditions, measure and detect load distribution in the vehicle, and adjust automatic braking systems.”

As a result of a comprehensive technology scan, as well as numerous interviews with key industry stakeholders such as truck manufacturers, fleet operators, suppliers, and regulators, a variety of research areas were identified including the design, functionality, and performance of the Society of Automotive Engineers (SAE) J1939 network for commercial vehicle applications.

BACKGROUND

The SAE J1939 is a worldwide serial data bus communication standard for truck, bus, off-road, construction, and marine vehicle applications. The J1939 communication standard is a control and information data bus that supports critical safety-related systems and subsystems on heavy-duty tractors, trucks, converter dollies, and trailers. Safety-critical systems currently in production that utilize (or have the potential to utilize) the J1939 network include engines, transmissions, drive slip control (subset of antilock brake systems), collision avoidance, and lane guidance systems. Since the J1939 network represents an advanced high-speed network, the number of subsystems utilizing this network, both safety-critical (as related to fundamental vehicle systems and controls in the context of this study) and non-critical systems, will likely continue to increase on future commercial vehicles.

One of the most important potential applications of the J1939 data bus will be the next generation of brake systems, known generically as electronically controlled brake systems (ECBS). ECBS will employ the J1939 data bus to control the tractor and trailer brakes. The greatest safety improvements, gained through reductions in stopping distance and improved vehicle control, will be on combination vehicles that employ ECBS on both the tractor and the trailer. Currently, the tractor modulates the trailer's brake system through pneumatic control (compressed air). However, some U.S. fleets run double and triple trailers. These double and triple trailer applications are prone to greater problems (i.e., brake and vehicle control issues and/or brake wear problems) because of a brake imbalance between the tractor and the trailer(s). The brake control and wear problems can almost be eliminated by ECBS. In addition, roll stability control systems and electronic stability control systems (ESC) that are currently available can improve the stability of tractor-trailer combinations, using different levels of brake application at different wheels. These electronic ESC systems depend on reliable high-speed signal communication that the J1939 network provides.

Motor carrier industry stakeholders, such as the brake system suppliers, tractor and trailer original equipment manufacturers (OEMs), and the Federal government, have been working together to facilitate ECBS products for the heavy-duty trucking industry. The challenge the industry faces, however, is in minimizing the potential risks associated with the coexistence of both critical and non-critical systems on the same data bus. Therefore, the J1939 must be carefully tested to ensure that the “coexistence” does not undermine or compromise major vehicle systems such as brake controls. A second challenge is to ensure the long-term signal communications integrity of a system whose hardware components are subjected to the challenges of the physical environment (e.g., moisture, oil, dirt, road salt). The capacity of the network to accommodate additional devices that increase the network loading is also a concern.

For this study, a laboratory simulation of a commercial motor vehicle (CMV) J1939 network was tested and evaluated under a variety of conditions designed to “stress” the network. Testing and evaluation consisted of applying test loads designed to create high network load levels while simulating safety-critical actions, failed components in the network, and a weakened physical network. The performance of the data bus, defined by the integrity, accuracy, and speed of communications signals, was monitored during various physical fault conditions, network loadings, and injected noise levels. The tests also determined the effect of the physical condition of the network, such as cable type and length, on the performance of the network.

The results of this study can be used to contribute significantly to improving the safety- and performance-oriented state-of-the-practice for CMV signal communications. They provide quantitative information concerning the validity of the current design philosophy that combines safety-critical and non-safety-critical data communications devices and paths. They provide a quantitative measure of the network’s capacity to accommodate additional safety-critical networked devices. Additionally, they provide quantitative information to designers and manufacturers of the components, connectors, and systems to improve their physical and operational integrity for better safe performance and economy of operation.

OVERVIEW OF APPROACH

Work on this project consisted of the following subtasks:

- Collect information on the hardware and software requirements to support J1939 related system functionality from the commercial vehicle user, CMV OEM, equipment suppliers, and component manufacturer communities engaged in equipment and component design and integration
- Conduct a comprehensive literature search and review of documents published by public, quasi-public (e.g., associations, committees, coalitions, institutes, etc.), and private companies that have conducted J1939-related research and development
- Compile a comprehensive test matrix and test plan based on industry, public, and Federal agency input
- Identify specific features and capabilities available and incorporated in commercially available electronic control units (ECUs)
- Construct a hardware-in-the-loop (HIL) J1939 simulator

- Validate the simulator
- Perform, record, and report on physical fault testing
- Perform, record, and report on network load testing
- Perform, record, and report on noise tolerance testing

SUMMARY OF RESULTS

The following are key observations and results from the testing of the J1939 network using the HIL simulator.

Physical Fault Testing

The network response to physical faults was as specified in J1939. Faults that resulted in a reduced network signal-to-noise (S/N) ratio allowed the network to function nominally with no operator observable loss of function. When the network was subjected to physical faults where the SAE J1939 Recommended Practice states that network communication should not be possible, the network failed.

Network Load Testing

The network handled bus loads up to 100 percent of its rated capacity without error, and the performance of the network remained nominal. The process of producing bus loadings of up to 100 percent, required the use of six virtual ECUs with each transmitting two high-rate, high-priority messages. This additional emulated traffic represented a 150-percent increase over the maximum observed network load of the nominally operating HIL simulator test bed during complex operating conditions. Physical faults induced during high bus loading produced qualitatively similar results to those observed in the physical fault test series.

Noise Tolerance Testing

The SAE J1939 Recommended Practice does not specify a tolerance to injected Gaussian white noise. However, the J1939 network exhibits a tolerance that appears consistent with other similar communications networks, which have specifications for injected noise tolerance, such as MIL-SPEC-1553. Both the J1939-11 with shielded twisted pair (STP) test harness and the J1939-15 unshielded twisted pair (UTP) test harnesses performed equally well for injected noise. The noise tolerance for a harness of the maximum specified length of 40 meters was within 0.3 dB of the noise tolerance demonstrated by harnesses with lengths of 14.8 meters (37 percent of maximum specified length) and 25.2 meters (63 percent of maximum specified length).

Summary of Testing

Based on the network testing conducted, the commercial-off-the-shelf (COTS) ECUs used in the network testing that are representative of a typical complex network on a commercial truck implemented J1939 well within the standards. The results from the HIL simulator indicate the network appears to have 2.5 to 3 times the capacity (30 to 40%) currently used by the majority of

commercial heavy vehicles in the United States. However, this testing did not include an extensive survey of COTS ECUs, and an ECU that does not comply with J1939 specifications could have a major impact on the performance and reliability of the network. The ECUs that were used in this test were from large, established manufacturers that have a proven capability to provide ECUs that meet network specifications. Industry members have reported problems with specific ECUs creating bus loadings on the network that greatly exceed those that were observed during this testing.

The COTS ECUs used in this network-testing program demonstrated excellent adherence to J1939 network specifications. They performed very well even when network loading reached 100 percent. Even a relatively well-equipped heavy truck, as represented by the HIL simulator, uses only up to 42 percent of the J1939 network. Thus, there is significant room for additional networked devices.

While not specifically a planned part of the testing, an issue regarding improper shifting of the transmission, which occurred during a physical failure of the network, was identified and confirmed within the industry. This issue highlighted the CMV OEMs' or ECU vendors' lack of ownership of the network and the corresponding responsibility for integration, condition monitoring, and performance of the network and associated harnessing. The original work accomplished in developing the HIL simulator has attracted industry attention, and may be incorporated into commercial products as a tool for engine and vehicle simulation.

1. INTRODUCTION AND BACKGROUND

In this section, we discuss the reasons for testing the J1939 communication network, network reliability concerns, related standards documentation, physical connectors, and test simulator rationale.

1.1. REASONS FOR TESTING J1939

The Society of Automotive Engineers (SAE) J1939 network, on-board the vehicle, provides a high-speed communications network that a number of subsystems both safety-critical and non-critical currently utilize. It is probable that the number of subsystems that require this network will increase on future commercial vehicles.

There is currently a high degree of integration between engines and automated transmissions on heavy-duty tractors. This level of integration is required for the transmission to shift properly and reliably. Similarly, for safety technologies to operate and perform predictably and reliably, ECUs from a wide variety of suppliers must utilize the J1939 network. The network must be able to support the wide variety of systems that will utilize the network without compromising the performance of the safety-related systems. Safety related systems currently in production that utilize (or have the potential to utilize the J1939 network) include systems such as:

- Engines
- Transmissions
- Engine retarders
- Automatic traction control
- Collision warning and avoidance systems
- Lane guidance systems

Two important near term safety related applications of the J1939 data bus are electronically controlled brake systems (ECBS) and stability control systems. ECBS communicate over the J1939 data bus to more effectively control the tractor and trailer brakes to provide improved braking performance. Stability control systems for tractor-trailer combinations require a reliable, high-speed signal communication such as J1939 network to command different levels of brake application at different wheels to prevent or correct vehicle instability.

1.2. CONCERNS OF J1939 NETWORK RELIABILITY

The challenge the industry faces is in minimizing the potential risks associated with the coexistence of both critical and non-critical systems on the same data bus. Critical safety systems would include braking-related systems, collision warning systems (CWS), roll stability systems, adaptive cruise control, and engine and transmission systems. These systems must communicate in real time or near real time to operate properly. This is due to the extremely short time intervals on which the operations of these systems occur. Systems such as light controls, data loggers, vehicle tracking systems, sleeper compartment controls, entertainment

systems, engine and emissions control diagnostics, HVAC controls, and power accessories that utilize the J1939 network do not need to be controlled in real time to provide acceptable functionality, and delays of up to one second do not affect their operation. As each of these types of systems operates on the network, it increases the bus loading and stress on the network. Therefore, J1939 must be carefully tested to ensure that the coexistence does not undermine or compromise major vehicle systems such as brake controls.

J1939 is critical to the proper operation of several components on the vehicle. These components include the engine, transmission (automated), antilock braking system (ABS), and CWS. Engines can experience a reduction in power if data is not received from the J1939 network. An automated transmission would be inoperative without the J1939 data link, and an ABS would not be able to provide automatic traction control functionality. In addition, a CWS would not have adaptive cruise control functionality without a functional J1939 data link. An example of an operational condition in which the J1939 network would be stressed includes an adaptive cruise control collision warning that requires an emergency stop with electronically controlled ABS activation, which requires engine braking and automated transmission downshifting.

1.3. J1939 COMMUNICATIONS NETWORK

In the early 1990s, the SAE started developing a Controller Area Network (CAN)-based application standard for in-vehicle communication in heavy-duty commercial vehicles. In 1998, the SAE published the first edition of J1939 Communications Network Standards Manual and it is continuously updated to reflect changes in technical advances and user experience. J1939 is a high-speed communications network designed to support real-time control between ECUs that may be physically distributed throughout a vehicle. The J1939 network connects ECUs within a commercial vehicle, such as those for the engine, transmission, and brake systems. J1939 was intended to replace both the legacy diagnostic J1587 and J1708 networks and provide for real-time, high-speed control of both safety and non-safety related systems.

The SAE has defined three distinct communication protocol classifications for North America – Class A, Class B, and Class C. Class A is an SAE classification for low data rate networks that peak as high as 10 Kb (Kilobits) per second. Class A devices typically support convenience operations such as actuators and “smart” sensors. The implementation of Class A has helped to reduce the bulk of automotive wiring harnesses. The second SAE classification is the Class B protocol. Class B networks support data rates as high as 100Kb per second, and typically are designed to support between module, non-real time control, and communications. The use of Class B networks can help eliminate redundant sensors and other system elements by providing a means to transfer data between modules. For example, the SAE J1850 standard for onboard diagnostics (OBDII) is a Class B protocol. Class C is the last of these three classifications, and is designed for performance as high as 1 Mb per second. Because of this level of performance, Class C is typically used for critical, real-time control. Class C facilitates distributed control via high data rate signals typically associated with real-time control systems. The most predominant in-vehicle networking standard for Class C is a CAN.

The CAN protocol is a communications method developed for real-time control applications. As a Class C network, CAN operates at data rates of up to 1 Mb per second. CAN was

originally developed in the mid 1980s by Robert Bosch GmbH of Germany for use in the light-duty automotive industry as a cost-effective communications bus for in-car electronics. The light-duty automotive industry continues to use CAN for an increasing number of applications, and CAN is now also being used in many other industrial control applications as well as by the heavy-duty automotive sector.

The use of J1939's CAN protocol permits any ECU to transmit a message on the network when the bus is idle. Every message includes an identifier that defines the message priority, its sender, its receiver, and the data that is contained within it. Collisions are avoided due to the arbitration process that occurs while the identifier is transmitted. This permits high-priority messages to get through with low latency times because there is equal access on the network for any ECU, but when multiple ECUs are simultaneously attempting to transmit, the highest priority message prevails.

CAN applications in transportation include:

- Passenger vehicles
- Heavy duty trucks and buses
- Off-highway and off-road vehicles
- Passenger and cargo trains
- Maritime electronics
- Aircraft and aerospace electronics

In transportation applications, the suppliers of component ECUs are responsible for the proper functionality and conformity of their devices to the particular CAN specification and communication protocol. The vehicle OEM provides the actual physical portion of the network consisting of the wiring harness on which the various component ECUs communicate.

The complexity of modern heavy-duty vehicles has increased considerably with the growing number of microprocessor-controlled devices developed for transportation applications. This increased complexity has required an alternative method for replacing dedicated wires in a harness that run to each individual device. In addition, the introduction of electronic engine and transmission controls and the increasing number of accessories and communication devices require an on-board communications network that can be shared by these systems. This network must be durable, reliable, and resistant to external and environmental effects that would degrade its performance. Additionally, this network must have the capacity to allow growth to accommodate future safety-critical and non-safety-related components.

The SAE defines and publishes recommended practices for vehicles developed through a series of committee meetings, followed by a balloting and review process. The SAE Truck and Bus Control and Communications Sub-Committee published the first edition of the J1939 set of Recommended Practices supporting SAE Class A, B, and C communication functions in 1998. These specify a CAN-based application profile for in-vehicle communication in heavy-duty vehicles. The J1939 network connects ECUs within a truck and trailer system, with the trailer connection requiring a "bridge" device to allow connection of the trailer J1939 network to the truck J1939 network. J1939 is intended to supersede the J1587/J1708 networks that are

currently implemented on heavy-duty vehicles. The J1939 specification contains message definitions for components such as engine, transmission, and brake systems dedicated to diesel engine applications.

1.3.1. J1939 Documents

The purpose of the SAE's set of J1939 documents is to provide a set of Recommended Practices to support an open interconnect system for various electronic systems that allows devices to communicate with each other over a standard electronic network architecture. The J1939 specification is an implementation of a CAN bus, which permits any device to transmit a message when the bus is idle. Every message includes an identifier defining the message priority, what ECU sent it, and what data is contained within it. Data packet collisions are avoided due to the arbitration process that occurs while the identifier is transmitted. This arbitration process also permits high-priority messages to be transmitted with low latency (delay) times because there is equal access on the network for any device. In particular, the J1939 specification includes a high-level protocol, network speed, types of connector, etc. The J1939 set of specifications is available from SAE (www.sae.org). These documents list a layered abstract description for the J1939 communications and computer network protocol corresponding to the Open Systems Interconnection (OSI) seven layer model. This model divides the functions of a protocol into seven layers followed by the computing and networking industry. The seven layers of the OSI model include the physical, data link, network, transport, session, presentation and application layers. The interface between layers dictates the specifications on how one layer interacts with another so that a layer written by one manufacturer can operate with a layer from another.

The J1939 specification documentation includes:

- J1939 Recommended Practice for a Serial Control and Communications Vehicle Network
- J1939-01 Recommended Practice for Control and Communications for On-Highway Equipment
- J1939-11 Physical Layer (250 Kbps, shielded twisted pair)
- J1939-12 Physical Layer (twisted quad of wires and active bus termination)
- J1939-13 Off-Board Diagnostic Connector
- J1939-15 Reduced Physical Layer (250 Kbps, unshielded twisted pair)
- J1939-21 Data Link Layer
- J1939-31 Network Layer
- J1939-71 Vehicle Application Layer
- J1939-73 Application Layer Diagnostics
- J1939-74 Application - Configurable Messaging
- J1939-81 Network Management

The physical portion of the J1939 network consists of the wiring harness and connectors. The bus length can be up to 40 meters (unless repeated) with one meter stubs to component ECUs.

The bus runs at 250 Kb per second, with up to 30 nodes connected. The network harness can consist of shielded twisted pair cable (J1939-11) or unshielded twisted pair cable (J1939-15) and specified connectors as discussed in Section 1.1.2.

1.3.2. J1939 Connectors

In order for systems and components to be properly attached to the J1939 network harness on a vehicle, a connector is required. The J1939 documentation specifies two types of connectors – a 3-pin connector and a 9-pin connector.

The Deutsch 3-pin connector (part number DT06-3S-E008), shown in Exhibits 1.1 and 1.2, is used for interconnection within the vehicle. This 3-pin connector, described in the J1939-11 specification, is used to link an ECU or a terminating resistor to the backbone of the network. The 3-pin male key is commonly referred to as the “stub” connector, and the female key is known as the “through” connector. If the 3-pin connector is used to connect a J1939-11 compliant ECU to a J1939-15 network, the drain wire (CAN_GND) will not be connected, and a sealing plug will be installed in its place. Because it is the only specified J1939 3-pin connector, this Deutsch 3-pin connector is used in the HIL simulator as it is in commercial vehicle J1939 networks.

The other standard type of J1939 connector is the 9-pin connector, shown in Exhibits 1.3 and 1.4, which is used for vehicle diagnostic purposes. The J1939-13 specification describes the 9-pin connector as an off-board diagnostic connector that is typically mounted in an easily accessible location inside the driver’s cab area. The Deutsch 9-pin connector (part number HD10-9-1939P) is a connector commonly used in vehicle diagnostics applications.

Exhibit 1.1 - J1939 3-Pin Connector Pin Assignments

3-pin Deutsch DT06-3S-E008	Signal	Description
A	CAN_L	CAN bus line, dominant low
B	CAN_GND	CAN ground
C	CAN_H	CAN bus line, dominant high

Exhibit 1.2 - J1939 3-Pin Connector Schematic

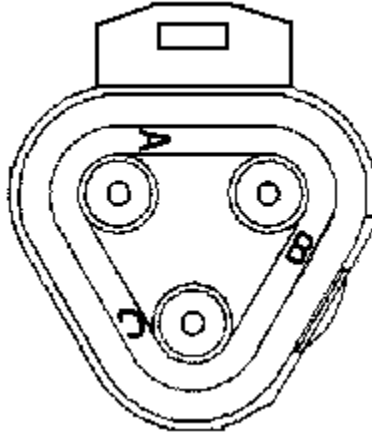
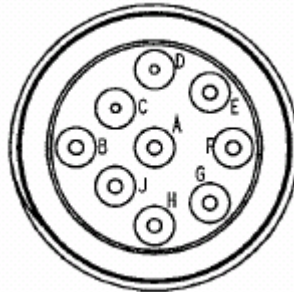


Exhibit 1.3 - J1939 9-Pin Connector Assignments

9-pin Deutsch HD10-9-1939P	Signal	Description
A	BATTERY -	Battery return
B	BATTERY +	Positive battery supply
C	CAN_H	CAN bus line, dominant high
D	CAN_L	CAN bus line, dominant low
E	CAN_GND	CAN ground

Exhibit 1.4 - J1939 9-Pin Connector Schematic



1.4. RATIONALE FOR HARDWARE-IN-THE-LOOP SIMULATOR

The test program involved the procurement of equipment, the development of the test bed, and the performance of network utilization and environmental testing.

As the OEMs and component developers have insight into the number and types of devices that will be utilizing the J1939 network, the research team requested comments and solicited advice

from design engineers of several heavy-duty vehicle OEMs and major system suppliers, including members of the SAE J1939 Committee, on the compilation of the test plan and test program. Specifically, these groups assisted in identifying and acquiring the actual ECUs or simulated devices that were incorporated into the test bed network and also concurred with the particular scenarios chosen for the testing. These test scenarios included:

- Emergency maneuvers
- Alternate physical layer (J1939-15, unshielded twisted pair)
- Injected noise
- Physical layer faults
- Additional simulated systems

From the initial industry contacts, the J1939 component suppliers expressed a common concern that the network be an accurate model of an actual truck-borne system. Many had hoped that an actual truck would be utilized for the setup, but if not, at a minimum, the setup would incorporate as many actual COTS ECUs as possible instead of emulated ECUs. Due to this shared industry position, it was apparent that to provide the most credible and useful test of the J1939 network, actual ECU hardware must be integrated into the test bed setup.

The research team recommended using a full-scale HIL laboratory network for the test activity, rather than a production Class 8 truck tractor for several reasons. The goal of the program was to test the performance of a nominal J1939 network in a laboratory setting as opposed to that of a particular production vehicle. Also, there was a need for accessibility to system components, specific locations on the network cabling and harnesses, and fabrication complexity beyond normal manufacturing processes. In addition, it is impractical (and presents potential safety implications) to implement the network traffic loading, physical failures, driving scenarios, and test monitoring equipment while actually operating a vehicle.

To increase the fidelity of the test, actual commercially available J1939 compatible systems and production hardware were used whenever possible to more accurately simulate a typical truck network. This included using an actual engine ECU, instrument panel and vehicle ECU, a collision warning and adaptive cruise control system, an ABS system, and potentially an ECBS system and an event data recorder (EDR). While these systems originally were proposed to be a mixture of simulated ECUs and as much actual hardware as practical, discussions with industry contacts revealed a preference for utilization of the actual physical hardware for these components, which would help to build credibility for the study results in the industry. This type of test bed setup using actual production hardware from various suppliers had not previously been attempted (or, if it had, the results had not been placed in the public domain), and industry contacts expressed an interest in seeing such testing performed.

Using several commercially available systems, as opposed to emulating their operation using a generic personal computer, presented new challenges in determining the exact equipment (e.g., system ECUs, sensors, mechanical actuators/valves) required to operate the system on the network. These components, while commercially available and widely used in the commercial vehicle market, were often difficult to obtain in the limited quantities required for this test (often requiring purchase directly from truck repair and parts facilities).

In the commercial vehicle industry, it is generally the responsibility of the truck OEM to integrate the various subsystems into the truck OEM wiring harness. Because the development of this HIL simulation was completed independent of OEM sponsorship, additional challenges arose in the acquisition and fabrication of the appropriate wiring and harnessing necessary to set up the test bed. OEM wiring harnesses were neither available nor desirable because they are fabricated for a specific CMV and the HIL simulator is intended to represent a generic vehicle network.

During the early stages of the test equipment procurement task, it was necessary to clearly understand and document how each system's sensors and actuators/valves would be emulated or driven to ensure that the system functioned properly in the lab environment. Software development work to control and communicate with the various ECUs also presented challenges due to the input precision needed and real-time data flow requirements. For example, emulating the crankshaft and camshaft timing pulses was extremely complex due to the multi-channel output needed to satisfy the engine ECU. This required custom software driver work. Section 2.0 provides more details on these and other simulator construction challenges.

Truck and bus OEMs produce many of the required components as integral parts of the complete vehicle assembly, which complicated the process of selecting and procuring ECUs. Therefore, we conducted a search of catalogs and databases and interviewed sales and engineering personnel to identify the appropriate parts and vendors. In some cases, parts were not available to the general public or required custom fabrication. The procurement process required a significant level of effort to establish OEM and vendor contacts with the various system suppliers. The OEM and suppliers were supportive of the effort and extremely generous in providing technical assistance. Software loads, simulation programs, engineering drawings, schematics, and other information were exchanged. Numerous conversations with the OEM engineers were necessary to determine how to integrate each ECU into the test bed. It was also necessary to determine the correct signals, sensors, peripheral components, and power levels to allow the ECUs to function on the test bed.

While the identification and procurement of the actual J1939 system hardware required considerable effort, it provided valuable insight into the network communication issues facing the heavy-duty vehicle industry. This in-depth interaction with each manufacturer established relationships with manufacturer's product engineering personnel supporting the test bed integration and reduced the technical risk and cost of producing a high-fidelity J1939 network test.

2. OVERVIEW OF TEST BED SETUP

2.1. SIMULATOR DESIGN

The simulator is intended to emulate a well-equipped, state-of-the-practice Class 8 truck currently manufactured for the U.S. market. The ECUs chosen are all J1939 capable, and as implemented, require the network to provide their full range of function. Exhibit 2.1 shows the test bed developed to test J1939.

Exhibit 2.1 - HIL Simulator Test Bed



The simulator was developed with a high degree of modularity to facilitate the simulation of different truck hardware configurations. This modularity is present in both the hardware and software relationships of the simulator. The simulator utilizes a distributed computing environment where each ECU is connected to a single target computer. The target computers exchange data and timing information on a private (secondary) network, operating independently of the J1939 network. Using modular components facilitates the addition or replacement of ECUs and their associated hardware.

For example, replacing the ABS ECU portion of the simulator with an ECBS ECU would only require the hardware exchange of the ABS interface box for an ECBS interface box. Similarly, the software changes needed would only require that the ABS plant target model be swapped for the ECBS plant target model. The remainder of the simulator hardware and software would remain unchanged.

2.1.1. Hardware

The simulator integrates all of the ECUs found in a “typical” well-equipped heavy truck available in the marketplace as of the 2002-2003 timeframe. The specific truck ECUs that are integrated into the HIL include:

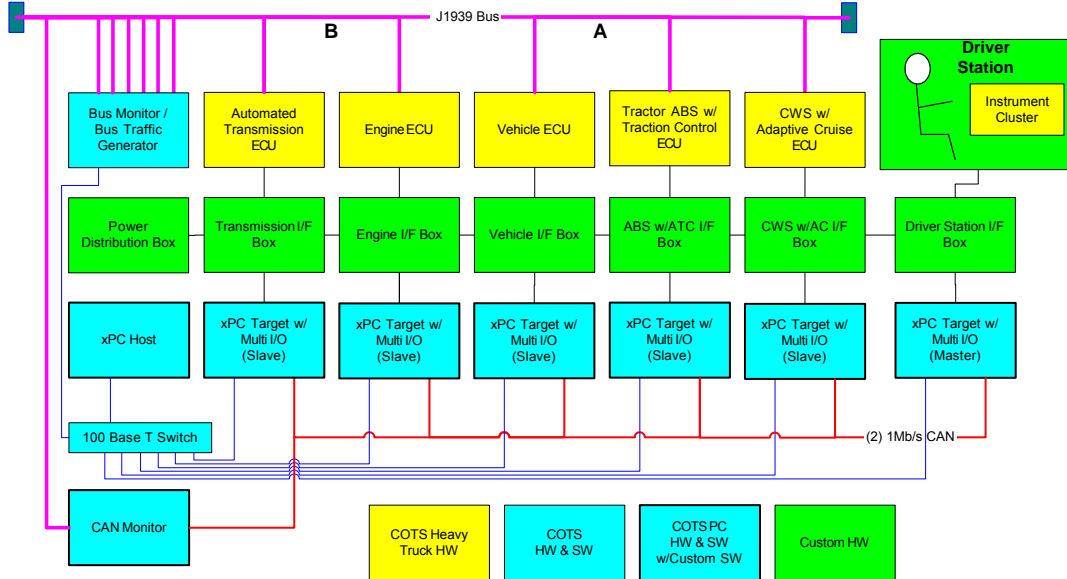
- Automated transmission
- Engine
- Vehicle (dash and warning)
- ABS with automatic traction control (ATC)
- CWS with adaptive cruise control (ACC)

In addition to the production ECUs used in the test bed, a number of other heavy truck hardware components are used in the HIL. This hardware includes:

- Transmission Components: shift servos and range valve
- Vehicle ECU Components: speed sensor
- ABS Components: wheel speed sensors
- Engine Components: fuel injectors
- ABS Components: ABS and ATC valves
- CWS Components: CWS front end radar

Exhibit 2.2 presents a block diagram of the simulator. The yellow boxes denote truck hardware. These components were purchased from truck parts suppliers in order to be as representative of hardware on the road as possible. The boxes in blue denote the hardware that was purchased as COTS equipment. The green boxes denote the hardware that was custom designed and built for this program. A fault induction generator was inserted into the network at physical fault test point either “A” or “B” in the test bed setup.

Exhibit 2.2 - HIL Test Bed Simulator Block Diagram



Each ECU is interfaced to a general purpose personal computer (PC) with input/output (I/O) cards through an interface box. The interface boxes are custom designed and contain all of the power, signal conditioning, and switchgear required to convert the signals in and out of the ECU to allow it to be interfaced with the target computer. In addition to the HIL hardware, the test bed includes equipment for simulating an additional 12 ECUs as well as a CAN analysis tool.

The interface boxes also contain circuit protection for each of the DC power lines supplied to the ECU. In addition, a J1587/1708 connector is provided on the front of each interface box to permit the use of a J1587 service tool.

The general-purpose computers used in the HIL utilize an Asus A7V8X motherboard with an AMD Athlon XP2100 Processor and 512 KB PC2700 memory in a rack mount case.

2.1.2. Software

The software environment chosen to develop the heavy-truck simulator was the MathWorks Development Environment. This toolset consists of a number of components including the following:

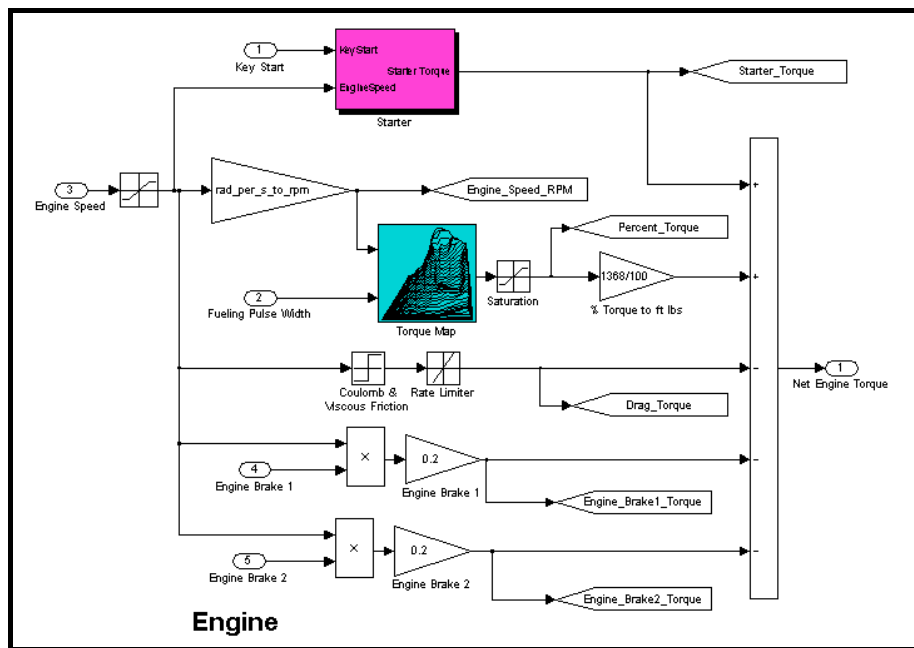
- MATLAB - Provides high-level modeling/scripting language
- Simulink - Provides visual modeling environment
- Real-Time Workshop - Compiles Simulink models for real-time applications
- xPC - Enables use of PC hardware and COTS data acquisition cards as a real-time target

The computers directly interfaced to each of the ECUs ran xPC Target, a real-time operating system that runs on the widely-used x86 Intel architecture. A "target" or, more fully, a "Real-Time Hardware Target" contains a computer processor that runs a real-time operating system

for deterministic performance. The target computer can integrate a wide array of input/output PCI bus hardware that can scale to accommodate high-channel-count control and signal conditioning. In this study, six rack-mounted personal computers are used as targets. Each target runs a set of simulation models under a real-time operating system and interfaces through I/O cards to a single ECU. The individual targets exchange model data at a rate of 1,000 Hz over a high speed CAN network, and together “run” the overall model of the tractor-trailer. The targets boot into xPC from a floppy disc, and the compiled models are downloaded from the host across the private ethernet (secondary) network, operating independently of the J1939 network. The target computers are networked together with a 1 Mbps CAN network. This network passes model parameters between the target computers and times the execution of the targets. The remainder of the development environment resided on the host computer. This computer is similar to the target computer except that it runs Windows 2000.

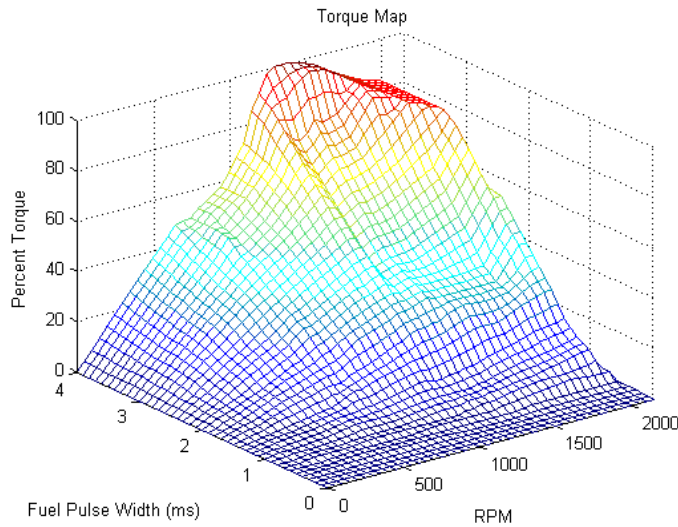
A separate software simulation model of each physical subsystem (“plant model”) was designed for each ECU’s target PC. The plant models were developed in MATLAB/Simulink, compiled in Real-Time Workshop with xPC drivers in preparation for download to the xPC target computers. Exhibit 2.3 illustrates the top level of the engine model used in the simulation.

Exhibit 2.3 – Engine Model



One of the key elements of this model is the torque map that provides the percentage of maximum torque developed by combustion based on engine RPM and the fueling pulse width measured at the fuel injectors. Exhibit 2.4 presents this map, which was generated using the plotting functions in MATLAB.

Exhibit 2.4 – Engine Model Torque Map



2.1.3. Data Capture and Analysis

For the J1939 test bed, the CAN monitoring and analysis was performed using the CANalyzer software package from Vector Informatics. This software permits use of a two-channel PC card interface for simultaneous monitoring and recording of the J1939 data bus and inter-target CAN (1 Mbps) bus. This allows correlation between the plant model I/O and J1939 messaging. A Softing CAN card was attached to the network for the first twenty physical fault tests. When it was determined that it provided redundant data to the CANalyzer tool, it was removed from the network and not used on the remainder of the tests.

Physical signal monitoring was also performed using a Tektronix THS720P digital oscilloscope with integral data logging capability.

2.1.4. Driver Station

The driver station permitted HIL operation and the capability to record and play back driver inputs. Exhibit 2.5 provides a picture of the driver station. The driver station consisted of the following:

- Keyed ignition switch (accessory, off, on, start)
- Accelerator, brake, and clutch potentiometer pedals
- Transmission shifter and console with gear indicator
- Vehicle speed and engine tachometer gauges
- Malfunction indicator lamps for engine malfunction, driver alarm, ABS, and ATC
- Indicator lamps for shutdown, exhaust wastegate, engine brake low and high, brake pedal activation, trailer, exhaust brake, and fan clutch

- Tractor and trailer parking brake switches
- Switches to control master lighting, air conditioning, quick to neutral (transmission shift directly to neutral), power take offs one and two, speed (cruise) control, speed control set and resume, engine brake low and high, overdrive (on/off), ATC, ABS diagnostics, and off road.
- Headway controller in cab unit with audio and visual indicators
- Operator seat
- Switch to record or playback operator inputs

This equipment was mounted on a moveable base, and all driver station wiring terminated in the driver station target PC.

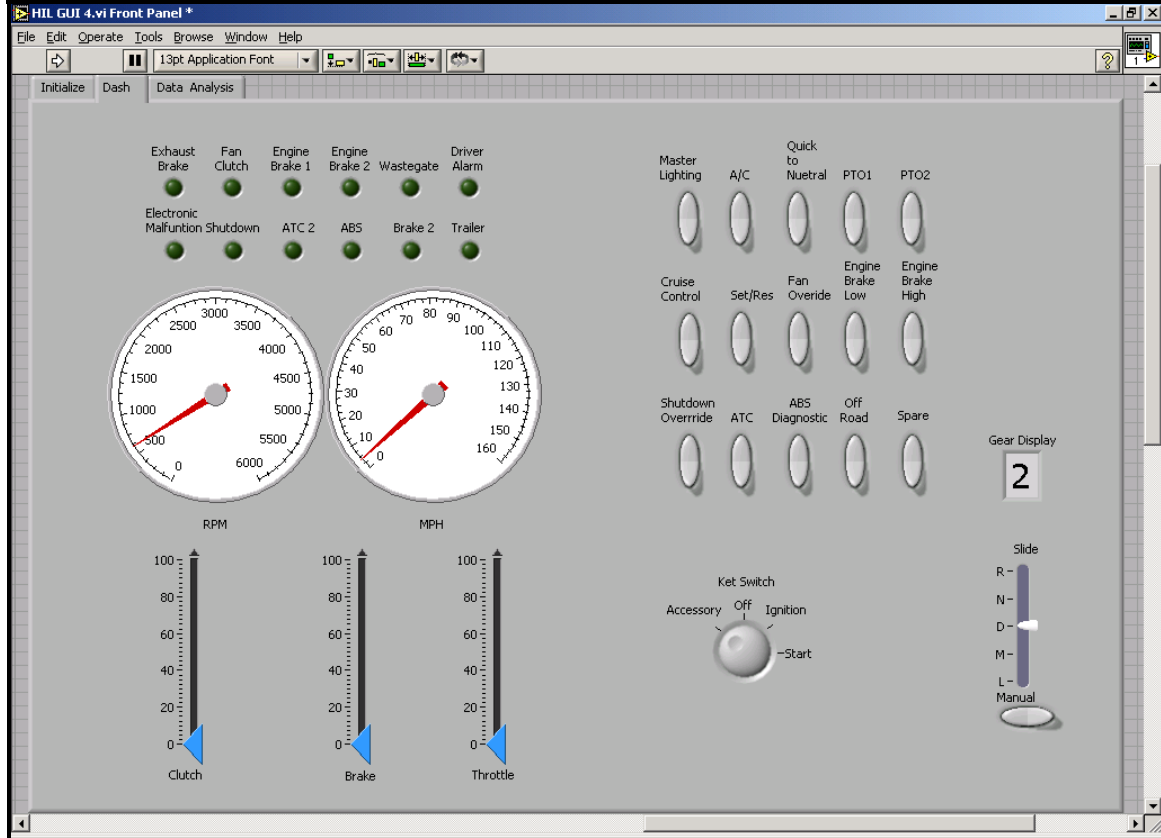
Exhibit 2.5 - Driver Station



2.1.5. Graphical User Interface (GUI)

A GUI was also developed to provide the project team with an effective and efficient tool to interpret data, especially during the process of the simulator validation. The GUI was built using a LabView interface, which could collect and display data from up to six xPC target PCs. The GUI aggregated and logged the data for each test run, and supported a minimal level of automated testing. Exhibit 2.6 provides a picture of the GUI.

Exhibit 2.6 – Graphical User Interface



2.2. SIMULATOR DESIGN AND FABRICATION ISSUES

The project team overcame several challenges to the design and fabrication of the HIL simulator, including:

- Engine simulator reengineering
- Limited inter-target bandwidth
- Generation of crank and cam sensor signals
- Supplier cooperation with plant modeling
- Difficulty in obtaining ECU connector matching mating connectors and tooling

2.2.1. Engine Simulator Reengineering

Originally, the team intended to use a previously developed “engine simulator” developed for internal use by an OEM. After significant study, the team found this existing engine/vehicle ECU simulator, which incorporated its own simulated transmission would not be able to provide the functionality the desired additional subsystem ECUs would require. The project team then decided that a new approach was necessary to be able to incorporate a production transmission ECU (TECU) and ABS ECUs into the test bed. The project team first carefully

examined the engine simulator to gain an understanding of how it functioned. This was a substantial undertaking, which required:

- Acquiring service documentation for the exact model engine simulated
- Tracing circuits and developing wiring charts and schematics for each discrete signal in the simulator
- Determining how various operator inputs affected the simulator performance
- Reverse engineering the algorithms used to simulate a real truck environment based on the inputs and outputs of the printed circuit board built into the engine simulator
- Developing a discrete wire management and wiring database

As work progressed on this effort, it became apparent that this existing engine/vehicle ECU simulator, which incorporated its own simulated transmission, was not suitable for expansion with additional COTS ECUs.

The team then worked with a major supplier of automotive transmissions to duplicate an existing automated manual transmission simulator that was constructed for product development purposes. This simulator consisted of a COTS transmission ECU, X-Y shifting assembly, associated position and vehicle speed sensors, a transmission plant model, and a simplified software plant model of the engine. The supplier provided both the simulator design and the assistance of its engineers. Once completed, this automated manual transmission simulator became the foundation for development of the complete COTS ECU HIL simulator used in this program.

The integration of the automated manual transmission allowed a phased approach to the development of the HIL simulator, which increased confidence in the final product and allowed the team to better manage the development risk along the way. The first phase of the effort required the development of a duplicate transmission simulator, which included both the setup of the hardware and integration of the software for this simulator. The incorporation of the production transmission simulator reduced the development effort in integrating the automated manual transmission ECU into the test bed. The transmission model was modified in anticipation of the planned separation of each subsystem plant model onto separate target PCs. A driver station, described in Section 2.1.4, was concurrently designed and fabricated.

Once the functionality of the existing transmission simulator was duplicated, the second phase of development involved creating a virtual engine model. This engine model was first verified on the same target PC as the transmission, so that no inter-target communication (communications between the “targets” or “real-time hardware targets” that contain a computer processor that runs a real-time operating system (OS) for deterministic performance of each system ECU) was required. The engine model was then loaded onto a separate target PC, and the inter-target communication was successfully incorporated.

The third phase involved modifying the engine plant model to allow the use of the COTS engine and vehicle ECUs, each running on their own target PCs. This required considerable effort, especially on the crank/cam signal generation (as described in Section 2.2.4 and the inter-target communications (as described in Section 2.2.3). The driver station functions were also

routed through a dedicated target PC. This target became the gatekeeper for the simulator's outer plant control loop. Once the transmission, engine, and vehicle ECUs, and the driver station and their models were fully functional and their performance verified, the bulk of the simulator design and fabrication effort was complete.

Phases four and five involved adding the ABS with ATC and then the headway controller (HWC) with ACC, and presented fairly straightforward development efforts. These systems had fewer inputs and outputs compared to the subsystems in phases one through three. Also, the plant model and hardware interface development process was well established in earlier phases. The completed tractor HIL simulator was verified by comparing the network data generated by the simulator to that of a similarly configured tractor (see Section 2.3.2).

For the J1939-specific testing, the project team used a Windows PC running a COTS CAN monitoring tool (Vector CANalyzer). This allowed monitoring of the J1939 network inter-ECU traffic, as well as the simulator inter-target control loop traffic. A COTS virtual ECU terminal was added to the network that could simulate up to 12 additional ECUs for the loading test. The network also allowed adding a Gaussian white noise generator for the noise testing portion of the study.

2.2.2. HIL Simulator Wiring Database

The integration of commercially available, heavy-duty truck ECUs into the test bed presented significant challenges in managing the physical wiring (5,000 discrete wires) between the following components:

- ECU hardware
- Associated physical hardware that could not be emulated (e.g., the fuel injectors, shift bar housing, ABS pressure modulator valves, etc.)
- The simulation computer
- Other subsystems in the test bed
- Power distribution units

A database was designed to track each wire, its associated connections, and the discrete signal it carried (e.g., tachometer pulse, brake pedal activation, etc.). The database was designed to allow the tracing of wire connections within and between simulators (e.g., engine, transmission, ABS, etc.). The database functioned as a tool to assist in the assembly of the test bed and reduced the risk that an improper connection would damage an ECU or simulation computer as components were connected during testing. It also helped in troubleshooting faults on the network.

2.2.3. Limited Inter-Target Bandwidth

In order for the ECUs to function properly in the HIL simulator, the target computers must exchange data and timing information on a private (secondary) network, operating independently of the J1939 network. The simulator utilizes a distributed computing environment where each ECU is connected to a single target computer. Initially in the

simulator design process, this private (secondary) inter-target communication network was planned to utilize the user datagram protocol (UDP) over a 100 Mbps ethernet LAN network. Using UDP, programs on networked computers can send short messages known as datagrams to one another. UDP does not provide the reliability of other protocols; however, UDP is faster and more efficient for many lightweight or time-sensitive applications. The project team determined that the interrupt priority of the UDP ethernet support within the individual targets was too low to guarantee real-time execution. The real-time execution requirement mandated a change to a high-speed, 1 Mbps CAN network between the targets where the real-time execution could be ensured. This CAN network was not part of the J1939 network, and did not carry any J1939 message traffic. It was used solely to pass inter-target plant model variable information on the simulator's outer control loop. The constraints of this inter-target data network required considerable additional effort to minimize the length of each target's message. As used in this test program, the inter-target network utilization was 84 to 86 percent. The network was used in a synchronous manner, with each target PC transmitting its message in a predetermined sequence at one-millisecond intervals. This allowed an outer loop control rate of 1,000 Hz, and nearly eliminated the chances of an inter-target message collision.

2.2.4. Generation of Crank and Cam Sensor Signals

A major challenge in developing the interface boxes was in generating the signals normally produced by the crank and cam sensors. Counter-timer cards were purchased to generate the cam and crank signals; however, the set produced output glitches when transitioning to a new pulse rate. This issue was solved by replacing them with cards from a different vendor. With the crank- and cam-timing diagram provided by the engine manufacturer, these signals were replicated using seven counter-timer channels and custom-developed circuitry. The seven channels were needed due to the nature of crank and cam signals used by the engine to determine engine timing and each of the six cylinder's top dead center (TDC).

Each signal has a different base pulse rate, which is modified to create a zeroing position. The crank signal dropped two pulses each revolution at a known angular distance relative to Cylinder 1's TDC. The cam signal added a single additional pulse for the same purpose. The dropped and added pulses allowed the circuitry to simulate the missing and additional teeth on the toothed wheels read by the cam and crank sensors that allow the engine to determine TDC. A single counter-timer channel was not capable of generating either of these irregular pulse trains with missing or extra pulses. A base rate, high-frequency channel was used to synchronize all the other counter-timer channels and the final output signals. Three channels for each of the crank signal and the cam signal were required. These were the base rate pulse for each signal – a cylinder one TDC delay count, and a cylinder one TDC null pulse (crank) or added pulse (cam). The base rate pulses and the null/added pulse were then fed through a NAND/NOR circuit to output correctly timed and formatted crank and cam signals.

Generating these seven synchronized pulse trains required the development of a custom driver. The drivers for each of these cards did not support some of the advanced functions required to generate the cam and crank sensor signals. The board hardware supported the generation of these signals with missing notched pulses and additional pulses for indexing, but they were not accessible with the xPC driver set. These functions were added to the drivers with considerable software development effort.

2.2.5. Supplier Cooperation with Plant Modeling

ECUs are tested to very tight tolerances to detect malfunctioning subsystem components. Duplicating the expected input and output signals necessary for proper operation requires comprehensive plant knowledge. Some ECU system suppliers were very generous in providing proprietary technical documentation, schematics, and engineer support to enable the models to closely replicate production equipment and systems. Other suppliers were unable to do so, or required extended negotiations before they could participate in discussions. For those components for which only limited vendor cooperation was available, the project team performed extensive testing and research to derive their operational parameters to provide the proper input to the HIL simulated ECUs and software.

2.2.6. ECU Connectors

The mating connectors and tooling for many of the electrical signals used on the ECUs were difficult for the project team to obtain. Many of the connectors were not available from typical electronic suppliers and had to be either ordered through truck part suppliers or obtained directly from manufacturers. The tooling necessary to assemble the connectors was even more problematic, given that most was developed for production-line applications. After working with OEMs, subsystem vendors, and connector suppliers, all of the correct connectors and tooling were identified and procured.

2.3. SIMULATOR CORRELATION AND VALIDATION

In any project where simulation results will be used to make qualitative or quantitative statements about the performance of a particular “real world” system, it is critical to correlate the simulation environment and the real-world implementation of the same system. The extent to which this is possible increases the confidence that the simulation is responding as the actual system would in simulated conditions not easily tested on the real system. Fortunately for this testing program, a production truck-tractor with similar system components and configuration to the HIL simulator was made available to the team for data collection. Exhibit 2.7 shows a picture of the tractor test bed used to obtain correlation data.

Exhibit 2.7 – Tractor Test Bed



2.3.1. Network Data Collection from Tractor Test Bed

The test tractor ECU configuration was nearly identical to simulator ECU configuration. The tractor engine ECU was an updated version of the unit used in the HIL, and the vehicle ECU, which generates the instrument panel data, had a different software load. The HIL engine ECU was changed out to match the test tractor, and the vehicle ECU was reprogrammed to match the test tractor, thus eliminating the variations. The HIL modifications also allowed full use of the CWS system including ACC, and updated the HIL to improve its fidelity. The manufacturers of the ABS on the test truck and on the HIL were different, but both vehicles used a four-modulator/four-sensor ABS.

The test tractor J1939 network was monitored and raw message data collected while operating the tractor in a variety of situations (see Exhibit 2.8). Step throttle inputs, while stationary, were used to derive the engine damping and inertial parameters to tune the engine model for a better real-world performance match. Shifting performance data was collected while driving at a variety of speeds. These included part-throttle and full-throttle up-shifting and braking-induced downshifting. The ABS, ATC, and CWS/ACC were used during a series of subsystem driving events to evaluate the bus loading while the tractor was driven in conditions likely to “stress” the network (e.g., heavy loading, several ECUs requiring coordinated operation). The ABS was activated on dry, wet, and icy pavement conditions, as was the ATC. A sufficient number of events were recorded in which the ABS was activated to provide a comprehensive database for correlation. On the road, CWS ACC events were also recorded.

Test Tractor Data Collection Test Plan

The test plan was performed on an OEM test tractor with a nearly identical ECU and hardware configuration to the HIL simulator. All of the testing was performed without a trailer. The J1939 network message data was collected for all of the series except series 1. Video data, from both in the cab while driving on the highway and outside during the traction control and ABS events, was taken to correlate the driving events with the J1939 network message data.

Exhibit 2.8 – Test Tractor Data Collection

Series	Description		
1	Tractor Warm Up		
	<i>Description</i>	Warm up truck engine and transmission	
	<i>Type</i>	Road test for 10 minutes	
	<i>Purposes</i>	Bring tractor systems to stabilized temperature and operating conditions	
		Verify tractor ECU configuration using J1587 service tool	
		Familiarize project team on CAN analyzing software package	
	<i>Condition</i>	Normal start, idle, and moderate speed driving and braking	
2	Step Throttle Increase		
	<i>Description</i>	Use 100% throttle pedal. Accelerate from 0 to 2,000 RPM and then release	
	<i>Type</i>	Static test (no vehicle motion, no gear engaged)	
	<i>Purpose</i>	Data collection to calibrate engine plant model – acceleration	
2.1	<i>Condition 1</i>	Transmission in neutral, clutch in	
		Engine brake off	Five repetitions
		Engine brake low	Three repetitions
		Engine brake high	Three repetitions
2.2	<i>Condition 2</i>	Transmission in neutral, clutch out	
		Engine brake off	Three repetitions
		Engine brake low	One repetition
		Engine brake high	One repetition
3	Step Throttle Decrease		
	<i>Description</i>	Establish stable 2,000 RPM. Use 0% throttle pedal to 0 RPM.	
	<i>Type</i>	Static test (no vehicle motion, no gear engaged)	
	<i>Purpose</i>	Data collection to calibrate engine plant model – deceleration	
3.1	<i>Condition 1</i>	Transmission in neutral, clutch in	
		Engine brake off	Five repetitions
		Engine brake low	Three repetitions
		Engine brake high	Three repetitions

Series	Description	
3.2	Condition 2	Transmission in neutral, clutch out
		Engine brake off
		Engine brake low
		Engine brake high
		Three repetitions
		One repetition
		One repetition
4	Nominal Performance Drive	
	Type	Road test to observe nominal acceleration, speed control, and deceleration
	Purpose	Data collection to calibrate system plant models – nominal operations
		Data collection to calibrate J1939 network traffic – nominal operations
	Condition 1	Accelerate from 0 to 60 mph under part throttle
		Observe transmission upshifts from 2nd through 10th gear
	Condition 2	Establish speed control at speed limit
	Condition 3	Decelerate from 0 to 60 mph with normal braking
		Observe transmission downshifts from 10th through 2nd gear
5	Maximum Performance Drive	
	Type	Road test to observe maximum acceleration and deceleration
	Purpose	Data collection to calibrate system plant models – maximum operations
		Data collection to calibrate J1939 network traffic– maximum operations
	Condition 1	Accelerate from 0 to 60 mph under full throttle
		Observe transmission upshifts from 2nd through 10th gear
	Condition 2	Decelerate from 0 to 60 mph with heavy braking (no ABS activation)
		Observe transmission downshifts from 10th through 2nd gear
6	Traction Control	
	Type	Road test to observe an ATC activation
	Purpose	Data collection to calibrate J1939 network traffic – ATC event
	Condition	Maximum acceleration over partially icy driving surface from 0 to 25 mph
7	Anti-lock Braking Event	
	Type	Road test to observe an ABS activation
	Purpose	Data collection to calibrate J1939 network traffic – ABS event
	Condition	Maximum deceleration over partially icy driving surface from 25 mph
8	Headway Controller Event	
	Type	Road test to observe HWC and ACC operation
	Purpose	Data collection to calibrate J1939 network traffic – HWC and ACC events
	Condition 1	Establish HWC with ACC with no targets within the separation distance
	Condition 2	Observe effects of traffic entering the separation distance

Series	Description	
	Condition 3	Observe HWC re-establish separation distance with down then up shifts

The cooperation of the truck OEM, whose engine ECU was used in the HIL simulator, was extremely valuable. The data collected from the test truck were used to tune and improve HIL simulation fidelity. The operational profiles used in the data collection of the test truck were matched using the HIL simulator. The engine model, in particular, was greatly refined in this process. Once these changes were incorporated into the HIL simulator, direct correlation data runs were then collected from the simulator.

2.3.2. Correlation HIL Simulator Versus Actual Truck

With the data collected from the tractor test bed, it was possible to compare the quality and quantity of J1939 message traffic between an actual heavy truck and the HIL simulator. Exhibits 2.9 – 2.12 illustrate a comparison of network data samples for both vehicle and HIL simulator accelerating from zero to nearly 39 miles per hour. The tractor took approximately 21 seconds, while the HIL took 25. The difference is primarily the result of the HIL simulator having a virtual, lightly loaded trailer. From this data, it is possible to make several observations.

Exhibit 2.9 – HIL Test Bed Wheel Speed During Acceleration

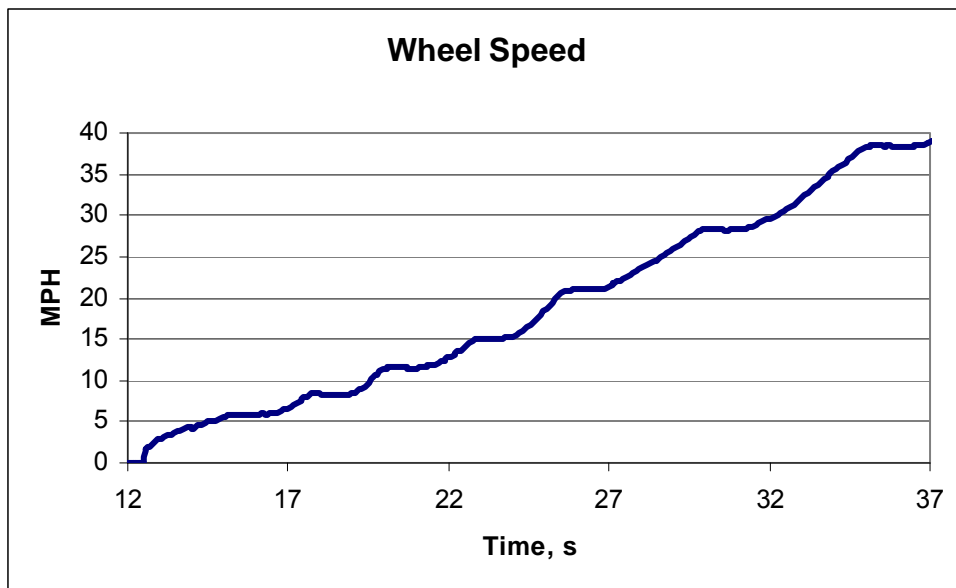
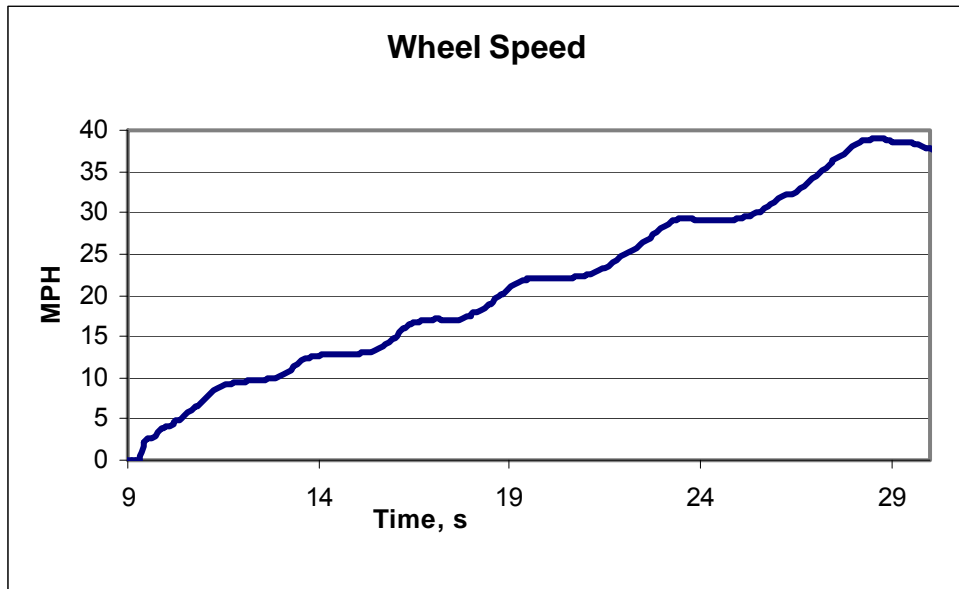


Exhibit 2.10 – Tractor Test Bed Wheel Speed During Acceleration



The vehicle and HIL simulator performance characteristics were similar. The acceleration profiles, with the slight speed dip during and just after a gear change, correlated well, as shown in Exhibit 2.9 and Exhibit 2.10. The Torque/Speed Control 1 (TSC1) message rates and intervals showed similar characteristics and trends. There was comparable functionality of the automated transmission, the collision warning system, the adaptive cruise control, the antilock braking system, and the automatic traction control.

The J1939 network loading during the acceleration shows very good correlation between the actual versus the simulated tractor for similar events. Exhibit 2.11 and Exhibit 2.12 provide a comparison of the actual and simulated J1939 network bus load during the same vehicle acceleration. These show that both peak at 25 to 26 percent of network capacity during shifting, and run a similar 18-percent load during non-TSC1 event periods.

Together, this data confirmed that the HIL simulator was accurately utilizing the J1939 network. This meant that testing results on overall network loading for specific driving event scenarios would be an excellent indicator for the overall network loading levels of actual trucks under similar circumstances.

Exhibit 2.11 - HIL J1939 Network Load During Acceleration

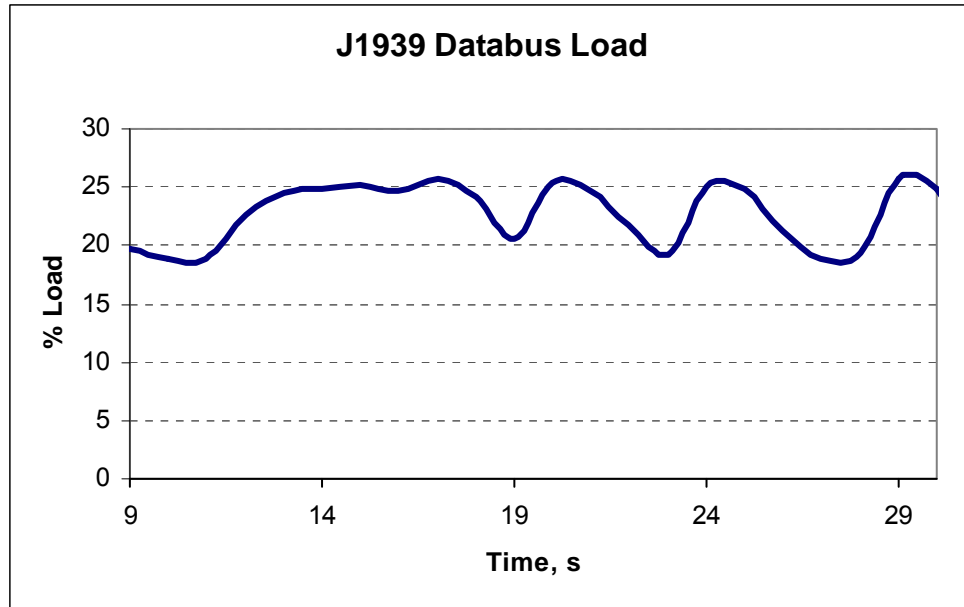
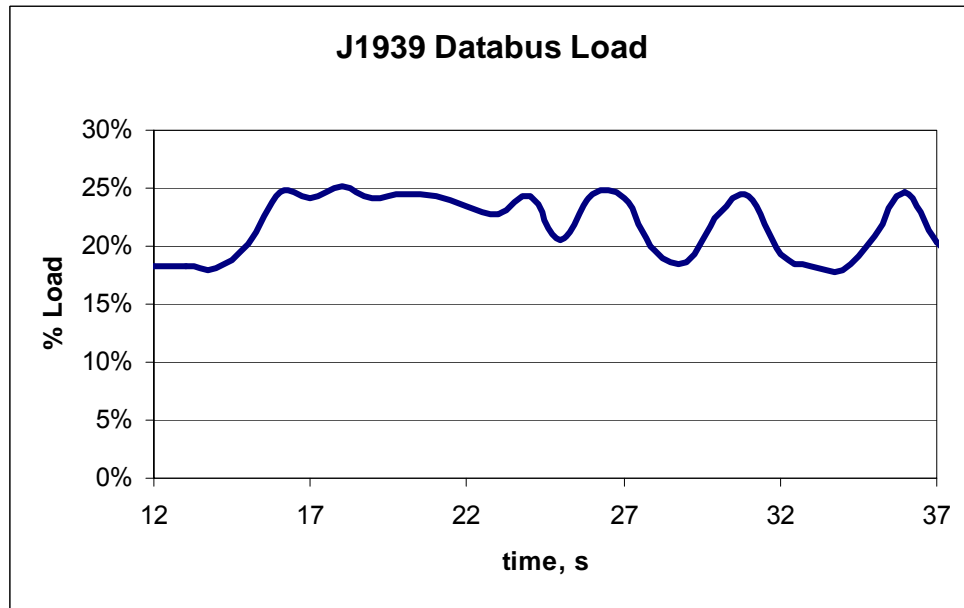


Exhibit 2.12 - Tractor J1939 Network Load During Acceleration



While the overall network utilization correlation was very good, specific performance characteristics highlighted differences in the HIL simulator and the actual tractor performance. Exhibit 2.13 and Exhibit 2.14 show the engine speed in RPM extracted from the electronic engine control EEC1 message from both the HIL and the tractor. The overall RPM range and shift profiles are very similar. However, the HIL exhibits much sharper corners at the gear transition points. This is the result of slightly imperfect modeling of the end-to-end dynamics

from the engine crankshaft to the actual wheels. The HIL does not fully capture all of the damping present in the real world, especially at clutch plate release and engagement.

Exhibit 2.13 - HIL Test Bed EEC1 Engine Speed During Acceleration

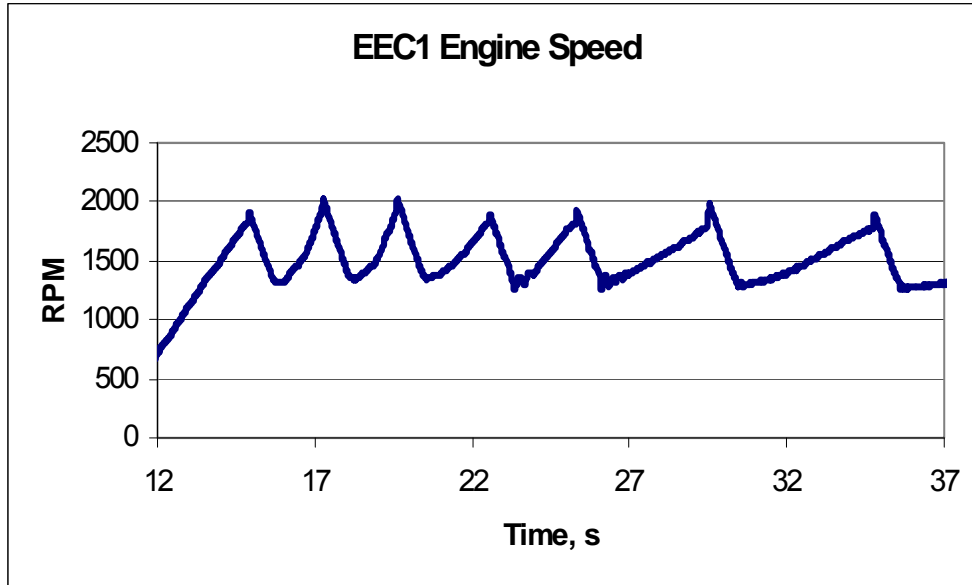
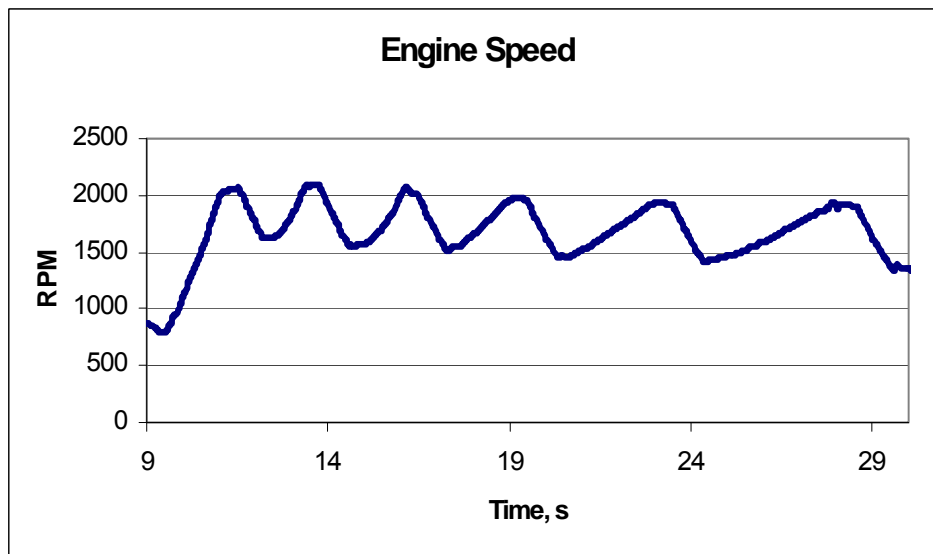


Exhibit 2.14 - Tractor EEC1 Engine Speed During Acceleration



As shown in the J1939 network loading exhibits, these inevitable modeling errors did not meaningfully detract from the overall excellent correlation between the simulator and a real truck. Additional correlation and validation data is found in Appendix A. With the HIL simulator validated by this data comparison, the project then progressed to the network-testing phase.

3. TEST RATIONALE AND SERIES

The objective of this task order was to test the performance of the J1939 network under a variety of conditions designed to “stress” the network. These were planned to generate high network load levels and to simulate safety-critical actions, failure of network harness components, and a physical deterioration of the network backbone. The project team developed a test plan to address the various operational parameters, which was reviewed by the project sponsor and by volunteer members of the SAE committees developing J1939 communications standards. The initial test plans followed accepted network testing protocols but produced a test matrix that was determined to be overly complex and included many trivial test points. Preliminary testing further refined the test matrix and involved:

- Testing a ‘steady’ driving scenario
- Injecting Intermediate traffic levels
- Varying the amount and priority mix of simulated ECU/CWS messages
- Recording and playing back test scenarios
- Injecting the noise at more than one location on the network
- Categorizing which of the five J1939 error types occurred

During testing, three ‘complex’ driving scenarios were utilized. These were all similar but had variations of injected network traffic or noise. The ‘steady’ scenario did not meaningfully stress the network and was eliminated after preliminary testing. Due to the divergent subsystems reactions to the different physical faults, an identical set of driver inputs could not be easily used. As one fault might cripple a particular a subsystem, some recorded driver inputs would then be impossible for the simulator to complete. Therefore driver inputs during driver scenarios during the testing were real-time as opposed to played back.

Also in preliminary testing, partial maximum bus loading had no impact on network performance. It was decided to run all network load tests at the maximum added traffic that the simulator set up could produce. The load testing was performed with an added traffic level at 74% of maximum bus capacity using six simulated ECUs with twelve simulated controller applications transmitting the same, high priority/highest repetition rate message. Noise was injected at one location.

The detailed test procedures and test matrix are listed in Appendices E and F. The Appendix E scenarios list the actions taken with the simulator, when data collection began for each test, when injected network load was added, and when injected noise was established. As a result of the test matrix reviews and preliminary testing, a final set of combined parameters was used to establish three main test series – physical fault, network loading, and injected noise tests.

3.1. VARIOUS TEST PARAMETERS

The testing involved various parameters, including:

- Number of ECUs on network
- Network complexity
- Virtual ECUs (message priority and type)
- Cable type (shielded versus unshielded)
- Network physical integrity (physical faults)
- Driving scenario (safety-critical actions)

3.1.1. Number of ECUs on Network - COTS and Virtual

The simulator was equipped with up to 5 COTS ECUs at any given time, and had the capacity to simulate up to an additional 12 yet-to-be-invented J1939 ECUs. A network with all five COTS ECUs was considered to represent a well-equipped, modern truck with an automated manual shifting transmission, engine, vehicle (instrument panel), ABS with ATC, and HWC. The project team estimated that an additional 12 virtual ECUs would be an appropriate number to simulate a high-end, well-equipped truck manufactured over the next two decades. Those additional virtual ECUs could incorporate non-safety-related functions such as cab lighting or entertainment functions, or they could be safety-related, such as jackknife and rollover prevention and additional systems monitoring and maintenance functions (e.g., tire pressure, wireless inspection).

3.1.2. Network Complexity

Network complexity increases with the number of ECUs that require a high level of interaction with other system ECUs in order to function properly. Safety-related ECUs (headway control and network active ABS) add a significant amount of network traffic for the short time periods when their systems must take action, as compared to the majority of the time when they only monitor the vehicle status. These bursts of network traffic have a high probability of occurring concurrently with other safety-related actions, such as during a headway control event that took place concurrently with an ABS event and automated shift of the transmission. To better capture the effect of adding complex, safety-related ECUs on the network, as compared to adding ECUs that have less interaction with other vehicle ECUs, a limited set of tests were run without the HWC in operation.

3.1.3. Simulated ECUs - Message Priority and Type

The type and priority of messages generated by the simulated ECUs were varied to maximize the loading of the network. Preliminary testing indicated the network was quite robust, even at very high network utilization levels. This meant the types of messages, which could meaningfully stress the network, were limited to those with the lowest transmission repetition time periods.

3.1.4. Cable Type – Shielded Versus Unshielded

Both shielded, twisted pair (J1939-11 or STP) and unshielded, twisted pair (J1939-15 or UTP) cables were examined. While the shielded cable was expected to perform better due to higher induced noise tolerance, the unshielded cable offers significant advantages in harness assembly and overall cost. For these reasons, the unshielded cable was tested more extensively than the shielded cable – with the assumption that shielded would be at least as capable in a given test scenario.

3.1.5. Network Physical Integrity – Physical Faults

The failure cases listed in J1939-11 Section 7.4 (summarized in Exhibits 3.1 and 3.2) were the basis for the physical network faults used in most testing. Additionally, injected Gaussian noise testing was conducted to provide an overall perspective on how minor physical degradation would affect the network. Factors such as excessive wear and environmental effects on the network harness and connectors might cause a degraded network.

3.1.6. Driving Scenario – Safety-Critical Actions

The initial approach to determining which driving scenario to use was based on the assumption that both a simple, steady-state scenario and a more complex, multiple high-network-demand events scenario would be of interest. However, as preliminary testing progressed, it became obvious that the network was quite robust, and only the most stressful scenario would have a meaningful chance of highlighting any systemic weaknesses. As a result, a complex driving and event scenario was selected for all of the test series.

The scenario began with a normal start, manual clutch activation to engage the starting gear, a rapid acceleration to 60 mph using automated manual shifting, and the establishment of cruise or adaptive cruise control. When steady cruise speed was established, two sequential, adaptive cruise headway control events were initiated, followed immediately with an emergency braking event requiring ABS activation. The HIL was then accelerated again to 60 mph and cruise/adaptive cruise resumed, if possible. After another short period of stable cruise, the test sequence was completed with a normal deceleration to a full stop and the ignition turned off. Physical faults, additional message traffic, and/or injected noise were added depending on the specific test series run. Appendix E lists the specific driving/test scenarios used in each test series.

3.2. PHYSICAL FAULT TESTS

3.2.1. Faults and Location

The physical faults (outlined in SAE J1939 Section 7.4 and ISO-11898 Table 19) that were tested are shown graphically in Exhibit 3.1 and summarized in Exhibit 3.2. In order to perform these tests, a fault induction generator was fabricated. The fault induction generator was inserted into the network at physical fault test point either “A” or “B” in the test bed setup (see Exhibit 2.2). The fault generator could induce physical faults one through nine at the selected location. Fault 10 (topology parameter violation) was created by adding additional network cable

segments to the nominal network. Fault 10 was only induced during injected noise tests, since the effect of excessive network length reduces overall network signal-to-noise ratio.

Exhibit 3.1 - Physical Fault Case Schematic

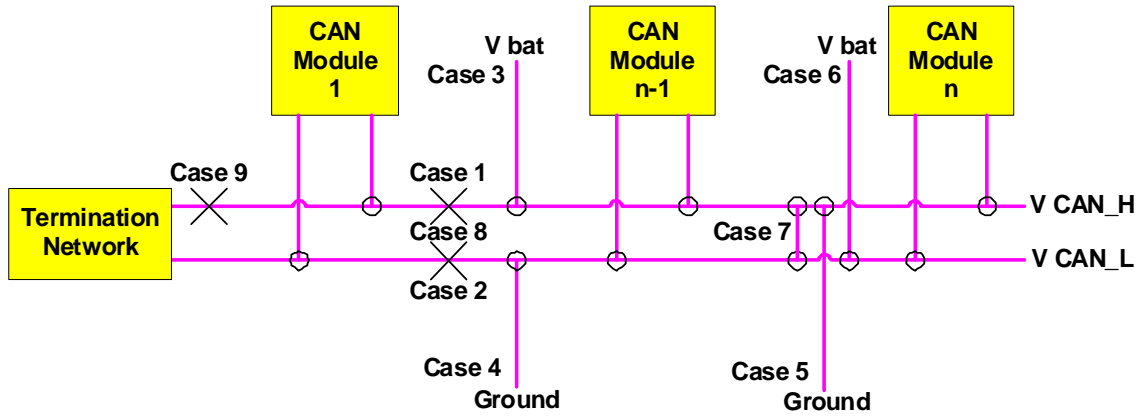


Exhibit 3.2 - Physical Fault Case Description

Fault #	Description	J1939-11	ISO-11898
0	No Fault	-	-
1	CAN_H Interrupted	No communication across fault. S/N reduced.	Communication continues. S/N decreased.
2	CAN_L interrupted	No communication across fault. S/N reduced.	Communication continues. S/N decreased.
3	CAN_H to Vbat	No communication possible.	Communication continues. S/N decreased
4	CAN_L to Ground	Communication possible. Reduced S/N.	Communication continues. S/N decreased
5	CAN_H to Ground	No communication possible.	Communication continues. S/N decreased
6	CAN_L to Vbat	No communication possible.	Communication continues. S/N decreased
7	CAN_H to CAN_L	No communication possible.	Communication continues. S/N decreased
8	CAN_H & CAN_L interrupted	No communication across fault. S/N reduced.	No communication across fault. S/N reduced.
9	Loss of Termination	Communication possible with reduced S/N.	Communication with reduced S/N.
10	Topology Parameter	Communication possible with reduced S/N.	N/A

3.2.2. Physical Fault Tests - Data Collection

Each ECU was cleared of active faults prior to the start of each test using the SAE J1708 service tool. The physical fault test driving scenario was repeated for each test and completed to the extent possible after initiation of the physical fault. Driver observable indicators of vehicle status and vehicle performance characteristics were recorded. Each ECU was queried for active and inactive fault codes after the network physical fault was initiated and after it was cleared. J1939 CAN message data was collected for each test as indicated in the test driving scenario.

3.2.3. Physical Fault Tests - Data Presentation

Exhibit 3.3 illustrates how the physical fault testing results were recorded. Under "Indicators," an "X" means the warning indicator illuminated once the fault was initiated. An "X" in the row labeled "Clear" means the warning indicator remained illuminated after the physical fault was cleared. The remaining results detail system functions and specific ECU fault codes (i.e., under "ABS " the code "17-3", etc.) observed during the J1939 network testing. These results are classified using a modification of the failure mode severity classification from Annex A of ISO 7637-1:1990(E). The specific definitions of these classifications are listed in Exhibit 3.4. All individual physical fault test results, and ECU fault code definitions are listed in Appendix B.

Exhibit 3.3 - Example of Physical Fault Testing Results

Test #	PF #	State	Indicators						Function					ABS			Headway Control					EECU & VECU			TECU								
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2			
PF01	0	Fault																															
		Clear																															
PF02	1	Fault	X	X	X	X			B	B	D			C	C			D	C		C	C			D								
		Clear			X	X				B	D							D						D									

Exhibit 3.4 - Failure Mode Classification

Failure Classification	Description (<i>italics indicates modification from ISO 7637-1</i>)
Class A <i>or Blank</i>	All functions of a device/system perform as designed during and after exposure to the physical fault. <i>ECU fault code is not activated at any point during the test.</i>
Class B	All functions of a device/system perform as designed during exposure; however, one or more functions can go beyond specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain Class A. <i>ECU fault code is intermittently activated during fault exposure and clears when exposure is removed.</i>
Class C	A function of a device/system does not perform as designed during exposure but returns automatically to normal operation after exposure is removed. <i>ECU fault code is activated during fault exposure and clears when exposure is removed.</i>
Class D	A function of a device/system does not perform as designed during exposure, <i>or ECU fault code activates</i> , and does not return to normal operation, <i>or ECU fault code inactivates</i> , until exposure is removed and the device system is reset by simple "operator/use" action.

Class E	One or more functions of a device/system do not perform as designed during and after exposure, <i>or ECU fault code activates</i> , and cannot be returned to proper operation, <i>or ECU fault code inactivated</i> , without repairing or replacing the device/system.
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3.2.4. Physical Fault Tests – Pass/Fail Criteria

The network was considered to have passed a physical fault test if it met or exceeded the requirements as listed in Exhibit 3.2, and when no ECU hardware had a failure classification of Class E, damage requiring repair or replacement, in Exhibit 3.4. All ECUs needed to revert to completely nominal operations after the fault was cleared and vehicle ignition was cycled. Listed below are the specific criteria to “Pass” a Physical Fault Test (All fault numbers refer to Exhibit 3.2.).

Fault free tests (Fault number 0)

No operator or J1708 service tool observable faults, warnings or other MIL indicators. Operation of the vehicle is nominal including HWC and ACC when part of the network.

Signal-to-Noise reducing faults (Fault numbers 4 and 9)

Same as fault free, above.

Network Segmenting Faults (Fault numbers 1, 2, and 8)

The network operates in a fault free manner until initiation of the physical fault. Upon fault initiation, MIL indications and/or ECU fault codes on all affected subsystems needing to communicate across the fault location. Segmented subsystems revert to stand-alone or independent operation. Acceptable vehicle malfunctions: Transmission shifting degraded or not possible if network segmented in location B. Adaptive Cruise Control and ABS engine/retarder control not possible if the network segmented in location A. No Class E failure classification of any hardware.

Network Failure Faults (Fault numbers 3, 5, 6, and 7)

The network operates in a fault free manner until initiation of the physical fault. Upon fault initiation MIL indications and/or ECU fault codes on all affected subsystems using the J1939 network. Subsystems revert to stand-alone or independent operation. Acceptable vehicle malfunctions: Transmission shifting may be degraded or not possible. Adaptive Cruise Control and ABS engine/retarder control may not be possible. No Class E failure classification of any hardware.

3.3. NETWORK LOADING TESTS

3.3.1. Traffic Levels and Priority

The simulated ECUs could be programmed to produce a variety of message types and priorities to progressively load the network. Tire Pressure Control Unit Current Pressures (TP3/PGN65146) is an example of a low-priority, low-data-rate message that causes little interaction with other ECUs. The TSC1 message (Torque/Speed Control #1/PGN0) is an example of a high-rate, high-priority message that can directly affect multiple vehicle systems.

Vehicles with an automated transmission, engine and vehicle ECUs, an ABS ATC, and an HWC are considered to be complex vehicles for the purpose of this study. The network loading was approximately 18 percent for a complex vehicle while under headway control with no vehicle traffic within the minimum headway separation distance. The network load increased to 24 percent when simulated vehicle traffic entered the minimum separation and the HWC issued TSC1 commands to the engine and engine retarder. Under the most adverse operational scenario consisting of an HWC retarding event combined with ABS and retarder events that cause multiple automated shifts, the highest network peak traffic level observed by testing personnel was approximately 42 percent during a single, one-second average traffic level measurement by the Vector CANalyzer software tool.

Load testing started with an assumption that the asynchronous network might start to show signs of breakdown starting at or slightly above 60 percent of maximum capacity. This assumption meant that to achieve the minimum additional traffic necessary to begin the load tests, an additional 20 percent of total network capacity bus loading had to be artificially added.

Because low-rate, low-priority messages add trivial busloads (well below one-tenth of one-percent), the TSC1 message was chosen as the primary means to increase bus loading. The TSC1 message is a standard length, eight data byte message, which is broadcast at 10 ms intervals. Each TSC1 message added approximately 6 percent to total network loading.

The HIL test bed had six simulated ECUs, each capable of generating two simultaneous TSC1 message streams. The total network traffic that could be artificially added to the J1939 network was approximately 74 percent of the total rated capacity of the network. This meant the theoretical peak traffic level that the HIL simulator could generate was approximately 110 percent of rated J1939 capacity. In practice, the maximum requested load rates ranged from 95 to 104 percent.

3.3.2. Bus Arbitration

The CAN (ISO-11898) is the basis for the bus arbitration functions implemented in J1939. Under this CAN, a "1" is defined as a recessive bit, and "0" is defined as the dominant bit. The test bed HIL ECUs used the 29-bit J1939 identifier. This identifier is packaged into a CAN, four-byte arbitration field as part of the large CAN extended frame. All CAN arbitration is completed during the transmission of the 29-bit J1939 identification within the arbitration field. If two or more ECUs attempt to simultaneously transmit, an ECU will cease transmission when it detects a dominant "0" bus state while it is transmitting a recessive "1." This indicates another ECU is transmitting a message with higher arbitrated rank. Subsequent data bytes will then be transmitted only by the single ECU, which "wins" the arbitration.

An example of these J1939 message frames is shown in Exhibit 3.5. The exhibit lists 13 consecutive messages recorded during Load Test 119 (see Appendix C). The far right column lists their respective arbitrated "rank" if the ECUs had each attempted to simultaneously transmit them. At transmitted bit number seven (7), ECU ID 23 (Instrument Cluster) transmitting PGN 65281 and ECU ID 3 (Transmission) transmitting PGN 61442 would cease

transmission, since their CAN controllers would see the dominant “0” bus state when they attempted to transmit the recessive “1.”

Since all of the other messages are PGN 0/TSC1, Priority 3, Destination 0 (Engine #1), they are identical until broadcasting their source address, transmitted bits #25 through #32. At RX 12.4042, this means that the Virtual ECU ID 2 (Turbocharger) has the highest arbitrated rank, as it has the lowest J1939 preferred address.

Exhibit 3.5 – Bus Arbitration Illustration

RX Start	PGN	Priority	Source	Destination	CAN 29 Bit ID Position																												Arbitrated Rank	
					28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		0
					J1939 Frame Bit Position																													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32			
12.4002	0	3	3	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	
12.4007	65281	3	23	-	0	0	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	13	
12.4013	0	3	19	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	10	
12.4019	0	3	7	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	
12.4025	0	3	10	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	6	
12.4030	0	3	13	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	7	
12.4036	0	3	14	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	8	
12.4042	0	3	2	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
12.4048	0	3	6	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	3
12.4053	0	3	8	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
12.4059	0	3	18	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	9
12.4065	0	3	42	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	11
12.4070	61442	3	3	-	0	0	1	1	0	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	12

The effects of bus arbitration mean that during all the load tests, there were many opportunities for the 15 ECUs (12 virtual and 3 COTS ECU) to simultaneously begin TSC1 message transmission up to the 26th transmitted bit.

3.3.3. Network Load Tests – Data Collection

Load tests were conducted in a similar manner to physical fault tests with the addition of artificially added J1939 network traffic. The driving scenario in Appendix E shows the load test sequence of events, including the start and termination of virtual ECU-generated network traffic. Specific network load levels were recorded throughout the test runs.

3.3.4. Network Load Tests – Data Presentation

Exhibit 3.6 illustrates how the network load testing results were recorded. The exhibit and the classification of the severity are identical to the physical fault testing exhibit (see Exhibit 3.3). Four added columns record the “Network” nominal load (in percent of maximum), peak load (in percent of maximum), total CAN errors recorded during data collection, and the name of the raw recorded CAN data file (CFile #). Complete network load test results are listed in Appendix C.

Exhibit 3.6 - Example of Load Test Results

Test #	PF #	State	Indicators							Function				ABS			Headway Controller				EECU & VECU				TECU		Network											
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man. Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2	Load, Ave	Load, Pk	Errors	CFile #				
LT01	0	Fault																																				
		Clear																																				
LT02	1	Fault	X	X	X	X			B	B	D			C	C	D	C	C	C																			
		Clear			X	X			B	B	D					D																						

3.3.5. Network Load Tests - Pass/Fail Criteria

Network load test pass/fail criteria included all the criteria used in physical fault pass/fail criteria.

3.4. INJECTED NOISE LEVEL

Exhibit 3.7 shows the J1939 test setup block diagram used for the noise testing. Both J1939-11 and J1939-15 harnesses were tested. They are described in Exhibit 3.8.

Exhibit 3.7 - Noise Test Setup Block Diagram

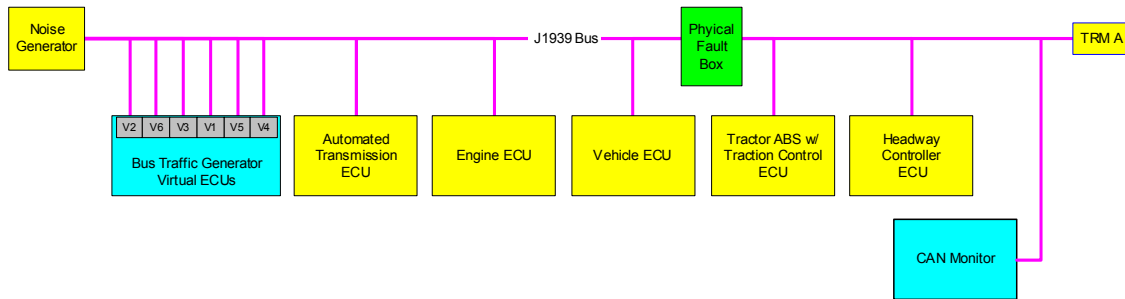


Exhibit 3.8 - Test Harness Lengths (meters)

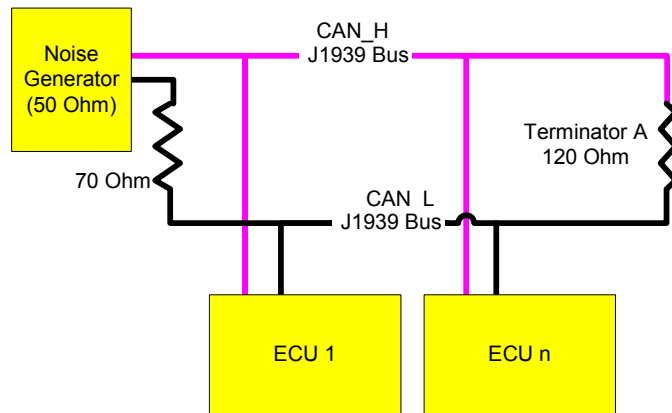
Harness Type	J1939-11		J1939-15	
	Bus	Stub	Bus	Stub
Noise Generator	0.90		0.91	
Virtual ECU 2	0.89	0.91	0.89	0.91
Virtual ECU 6	0.55	0.94	0.56	0.94
Virtual ECU 3	0.25	0.84	0.25	0.84
Virtual ECU 1	0.20	0.74	0.30	0.74
Virtual ECU 5	0.17	0.76	0.74	0.94
Virtual ECU 4	0.23	0.84	2.03	0.97
Transmission ECU	5.00	0.91	2.77	1.45
Engine ECU	7.00	0.86	3.68	1.70
Vehicle ECU	5.70	0.84	1.17	1.20
Physical Fault Box	0.23		0.23	
ABS	3.95	0.99		1.05
Headway Controller	0.18	1.02	0.30	1.14
Can Monitoring Card	0.03	0.86	0.64	1.73
Terminator A		0.03	0.28	
Total Length, meters	25.24	10.54	14.76	10.51

Two network cable harness assemblies were fabricated for this project. The first was a J1939-11 cable set (shielded twisted pair or STP) with an end-to-end length of 25.24 meters. The second set was fabricated to the J1939-15 specification (unshielded twisted pair or UTP) with a length of

14.76 meters. When combined, the total bus length was 40 meters, the longest specified under J1939-11/15. An additional J1939-15 cable segment of 20.00 meters could be added to both the J1939-11 harness and the combined harness. This resulted in bus lengths of 45.24 and 60.00 meters, respectively, both of which exceed the J1939 standard.

Noise was injected directly into the network using an arbitrary function generator producing Gaussian white noise from 1,000 Hz through 10 MHz. The injection point was in place of one bus terminator. Tests were conducted at a matched terminating resistance equal to the nominal 120-Ohm terminator (see Exhibit 3.9).

Exhibit 3.9 - Noise Test Termination



The nominal bus peak-to-peak voltage (VPP) was 1.80 VPP. One series of the noise tests was conducted with an injecting termination of 50-Ohms, which lowered network signal voltage levels to 1.20 VPP, the minimum specified by SAE J1939.

The noise level was adjusted before each test and remained constant for the duration of each test. The noise level was raised to determine the threshold where the network error rate caused a vehicle operator observable system malfunction indication (e.g., any malfunction light) and/or an improper and unexpected vehicle operation (e.g., no automated manual shifting).

3.4.1. Injected Noise Tests - Data Collection

Injected noise tests were conducted in a similar manor to physical fault tests. Appendix D shows the driving scenario and test sequence of events used for these tests.

3.4.2. Injected Noise Tests - Data Presentation

Exhibit 3.10 illustrates how the injected noise testing results were recorded. The test number and CAN data file are administrative information. The arbitrary function generator noise level and net noise level on the network are shown in millivolts root-mean-square (RMS). Load and peak are the network traffic load percentages. The errors per second are the average error level during the CAN data collection. The S/N ratio represents the energy level of the J1939 signal divided by the noise energy level. The number of virtual ECUs was recorded, as well as whether they were transmitting during the test.

A “Pass” result indicates no driver observable effect on vehicle performance, including no warning or malfunction indicators (even intermittent ones), and no active or intermittently active ECU fault codes. A “Fail” result means some or all vehicle functions were impaired and/or indicators or active ECU fault codes presented themselves. The classification of the effects on the HWC, ABS, TECU, and the combined vehicle (or cab) ECU (VECU) and engine ECU (EECU) are the same as used in physical fault and load tests (see Exhibit 3.4). Unlike the physical fault and load tests, which used a single entry, the effect classification was recorded at four phases of the driving scenario, since the noise would usually affect the more complex and highly loaded driving phases before it interfered with the ignition on and start phases. All individual injected noise test results are listed in Appendix D.

Exhibit 3.10 - Example of Injected Noise Test Results

Test #	CFile #	ARB mVrms	Net mVrms	Load Ave	Load Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N006	390	180	180	17.33	25.64	5.5	14.3	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				

3.4.3. Injected Noise Tests - Pass/Fail Criteria

With no SAE J1939 specified tolerance level for injected noise, these tests were meant to give a relative quantitative evaluation of the effects of a degraded network, which might then allow qualitative statements on the overall robustness of the network to electromagnetic interference. The degradation simulated was less than a level sufficient to allow network fault classification under the failures listed in Exhibit 3.2 (SAE J1939 Section 7.4).

Specifically, for those physical faults specified only to reduce the signal-to-noise ratio of the network, the testing allowed a quantitative evaluation of the relative difference between nominally-configured, fault-free networks and those with physical faults which produced no observable effects under the previously accomplished physical fault and load tests. These faults were number 4 (CAN_L to Ground), number 9 (loss of termination), and number 10 (topology parameter, i.e., excessive network bus and/or stub lengths). Additionally, more bus cross signal wire resistance was added for some tests to simulate a partial shorting of the signal wires

of the network, but one which had not reached a level of shorting to be classified as a full fault number 7 (CAN_H to CAN_L).

The network was considered to “pass” an injected noise test when no operator observable or ECU faults, warnings, or other MIL indicators were present. Operation of all vehicle systems was nominal, including HWC and ACC when present on the network.

The network was considered to “fail” when any warning indicator, ECU fault and/or abnormal operation was observed. However, this failure does not mean the J1939 network failed to meet some specification; it merely demarcates the injected noise tolerance for that particular configuration/physical fault vs. a nominal network.

The network would have been considered to “fail” specification, if an in-specification network topology had failed with no injected noise.

3.5. APPLICATION LAYER ISSUES

During testing, one specific anomalous behavior occurred without any warning to the operator. When the TECU was segmented from the EECU by a physical fault, which did not corrupt the voltage level of the entire network (faults number one, two, and eight in Exhibit 3.2) neither ECU would report a network error to the operator. In this situation, all transmission shifting methods were inoperative. This included automated manual shifting, manual shifting, and the selection of neutral/reverse.

The vehicle would remain in the gear that it was in when the fault occurred. The operator would only observe an anomaly if an attempt was made to accelerate or decelerate out of the normal vehicle speed range for that gear. Slowing the vehicle caused the engine to stall as the speed dropped below engine idle RPM for that gear. Accelerating would cause the engine to reach maximum RPM without an up shift. Restarting the stalled engine in this condition could be accomplished by pushing the clutch pedal. However, acceleration again from a full stop of the tractor would only be possible if the transmission locked in a low gear. If the transmission was locked in a relatively high gear, the operator might be able to slip the clutch to accelerate the tractor to a speed range appropriate to the locked gear. Once the fault was corrected, even without cycling the ignition, the transmission exhibited normal behavior and function.

Both the engine and transmission recorded a J1939 fault in the ECU, but did not report this to the operator through any of the warning indicators in the dashboard display. The information could be retrieved in real-time or after shutdown through the use of a J1708 service tool.

This issue highlights the fact that no particular ECU is “responsible” for the J1939 network status. Each ECU may report network errors, as the manufacturer deems necessary, for the safe operation of its particular system.

3.6. CONNECTOR DIVERSITY

As stated previously, the SAE J1939-11 documentation specifies the Deutsch 3-pin connector (part number DT06-3S-E008) is to be used for interconnection within the vehicle. This 3-pin connector is used to link an ECU to the backbone of the network. The use of non-standard connectors could have an adverse effect on network performance. All of the COTS ECUs used in the simulator incorporated the J1939 network wiring via their existing interface connectors. None of the five OEM connectors on the COTS ECUs were of the same type, nor were their connectors specifically identified in the J1939 standard. In total, there were four different connector manufacturers. Furthermore, the connectors from the two ECUs, which utilized connectors from the same manufacturer, sourced the connectors from different connector families within that manufacturer's product line.

Standard cable termination for the connectors is also specified for the J1939 network. Appendix B of both SAE J1939-11 and J1939-15, details the recommended cable termination procedures for both J1939-11 (shielded twisted pair) and J1939-15 (unshielded twisted pair). That document specifies that insulation is to be stripped 7 mm +/- 0.8 mm from the data wires. For J1939-15, the maximum distance between data wires is 3 mm, and a resumption of data wire twist should occur within 50 mm. A summary of the strip lengths, signal wire separation in the connector and the in-connector length where the cable could not begin to twist (as compared to the J1935-15 specification) is listed in Exhibit 3.11. That said, there appeared to be little or no degradation of the network as a result of this diversity of implementation of J1939 connector standards.

Exhibit 3.11 - Connector Summary

ECU	Wire Strip Length	Pin Separation	Cable Untwist Length
TECU	4.0 mm	4.6 mm	9.3 mm
EECU	4.7 mm	10.0 mm	7.0 mm
VECU	5.9 mm	5.3 mm	2.0 mm
ABS	7.0 mm	9.1 mm	12.0 mm
HWC	5.0 mm	3.0 mm	5.0 mm
J1939	7 mm	3 mm (-15)	50 mm (-15)

4. TESTING RESULTS

4.1. PHYSICAL FAULT TEST RESULTS

During the physical fault testing, the network reacted to physical failures as discussed in SAE J1939-11, Section 7.4 (summarized in Exhibit 3.2).

Deviations in network performance caused by individual ECU variation from J1939 in connector type and wiring were not observed (see Section 3.6). An anomalous vehicle operational mode was repeatedly observed when the transmission ECU was segmented from the EECU. However, this is an application layer-based implementation anomaly and not J1939 standards-related (see Section 3.5).

In the physical fault testing, there are three primary classes of bus faults:

1. Signal-to-noise ratio reduction, but communications still possible
2. Segmenting faults that prohibit/inhibit communication across the fault location
3. Network failure faults that cause loss of communications over the entire network

A total of eight network configurations were tested against physical faults. The network configurations were chosen to stress the networks in realistic manner by varying the complexity of the ECU hardware, adding virtual ECUs and failing the network in specific locations. The HWC was viewed as a “complex” network addition. The HWC provides ACC functionality and issues high rate TSC1 messages. The HWC also directly controls vehicle deceleration and reacceleration without operator intervention. The number of virtual ECUs added to the network was decided upon in consultation with industry. The four additional ECUs resulted in an 80% increase over the complex network (with HWC) and a 100% increase over the “simple” network (without HWC). Faults inserted (see Exhibit 2.2) at the “A” location separates the ABS and HWC from the engine, and forces these systems into independent operation if the physical fault causes segmentation or loss of communication on the network. Faults at the “B” location can disrupt the communication between the automated shifting transmission and the engine ECUs. This has a greater potential for crippling the vehicle operation by making shifting sporadic or impossible.

Each test configuration was tested for physical faults one through nine (see Exhibit 3.2) and included a nominal test at the beginning of each new test series to determine proper network functionality before inducing physical faults. A total of 80 physical fault tests were conducted, the results of which are listed in Appendix B with each test numbered sequentially from 1-80.

4.1.1. Fault-Free Tests

The eight physical network configurations used in physical fault testing were first tested for error-free operation on all ECUs connected to the network and for proper vehicle operations (see Exhibit 4.1). The data from the physical fault tests with no induced faults are listed in

Appendix B, specifically tests PF01,PF11, PF21, PF31,PF41, PF51, PF61, and PF71. With no induced faults, all configurations operated nominally.

Exhibit 4.1 – Physical Fault Tests: Network Configurations

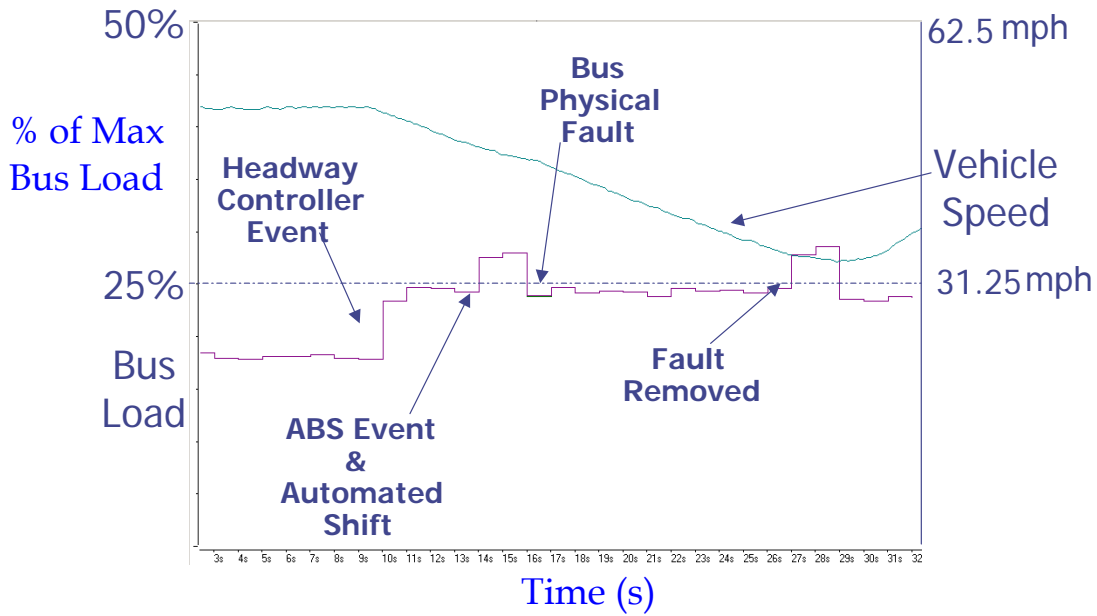
Test Series	Network Configuration Description	Virtual ECUs	Cable Type	Physical Fault Location
Tests PF01-10	Tractor with HWC	4	-11 STP	A
Tests PF11-20	Tractor with HWC	4	-11 STP	B
Tests PF21-30	Tractor with HWC	0	-11 STP	A
Tests PF31-40	Tractor with HWC	0	-11 STP	B
Tests PF41-50	Tractor without HWC	0	-11 STP	B
Tests PF51-60	Tractor without HWC	0	-11 STP	A
Tests PF61-70	Tractor with HWC	4	-15 STP	B
Tests PF71-80	Tractor with HWC	4	-15 STP	A

Appendix B details the specific devices and network configuration for each test series.

4.1.2. Signal-to-Noise Reducing Faults

Sixteen tests of S/N reducing faults were performed. The number of S/N reducing faults is a function of the number of physical fault test series performed. Eight series were performed. Each consisted of 10 tests, two of which are S/N reducing. The J1939 standard states that fault type 4 (CAN_L to ground) and type 9 (loss of terminator) both decrease overall bus S/N ratio, but may allow the network to function normally. In all tested cases, network and vehicle operation was nominal. There were no operator observable or ECU-reported faults or unexpected operation (see Exhibit 4.2). Operation was equivalent to the fault-free tests conducted at the beginning of each configuration series. The effects of the decreased S/N on network performance were insignificant as measured by the bus loading. The test data from the S/N reducing faults are listed in Appendix B (PF04 and PF10, PF14 and PF20, PF24 and PF30, PF34 and PF40, PF44 and PF50, PF54 and PF60, PF64 and PF70, PF74 and PF80). The details of the effects of decreased S/N are discussed in Section 4.3.

**Exhibit 4.2 - HIL Bus Loading During a Physical Fault Causing Reduced S/N
(Headway Controller Engaged, CAN_L to Ground, Fault Location A)**

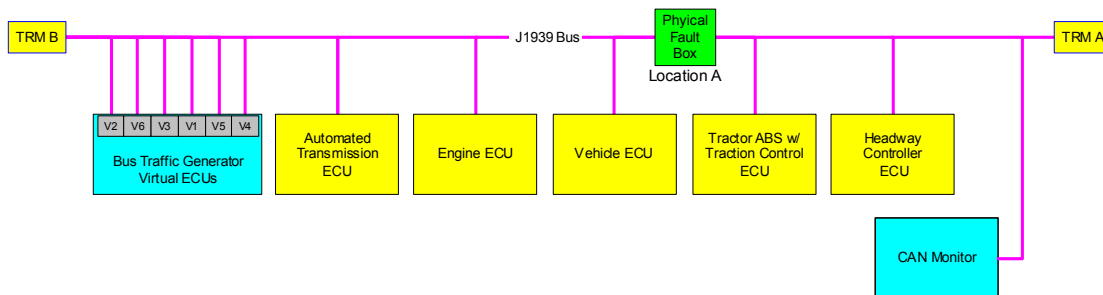


4.1.3. Segmenting Faults

Twenty-four tests of segmenting faults were performed. The number of segmenting faults is a function of the number of physical fault test series performed. Eight series were performed. Each consisted of 10 tests, three of which are segmenting. The test data from the segmenting fault tests are listed in Appendix B (PF02, PF03 and PF09, PF12, PF13 and PF19, PF22, PF23 and PF29, PF32, PF33 and PF39, PF42, PF43 and PF49, PF52, PF53 and PF59, PF62, PF63 and PF69, PF72, PF73 and PF79). The standard states that fault types 1 (CAN_H interrupt), 2 (CAN_L interrupt), and 8 (CAN_H & L interrupt) will cause the network to operate as if it were divided into independent segments. The standard indicates communications should be possible on either side of the network fault, at reduced S/N, but not across the fault location.

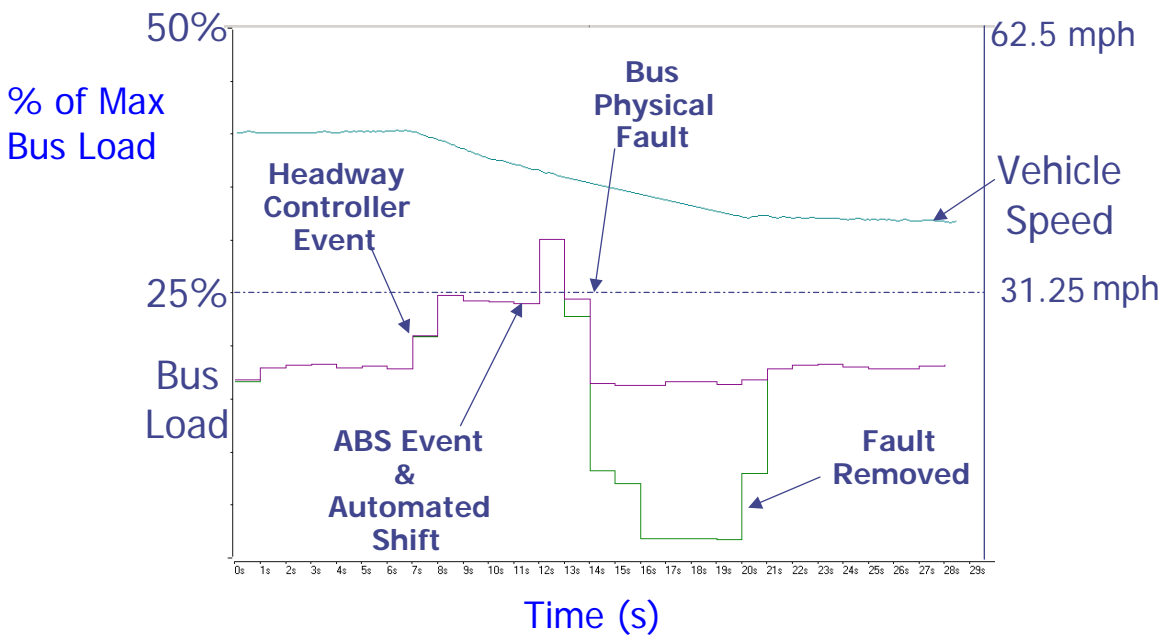
Initiating any segmenting fault for any test at location "A" (see Exhibit 4.3) caused immediate notification to the vehicle operator via multiple fault indicators.

Exhibit 4.3 - Fault Location A: Between VECU and ABS



These notifications included illumination of the ABS lamp, ATC lamp, HWC fail lamp and audio warning, and the engine malfunction lamp. The ABS and HWC reverted to independent system operation. Cruise control with or without headway control was inoperative. Transmission operation was nominal in both manual and automated manual shifting. The engine and HWC ECUs reported error codes during the active J1939 bus fault and retained a subset of these as active after the fault was cleared. The ABS reported active J1939 faults during the active fault, but these became inactive once the fault was cleared. The transmission and vehicle ECUs did not report any error codes during these tests (see Exhibit 4.4 for an example of network activity on both sides of a segmenting fault). The two traces on Exhibit 4.4 track together until the fault causes the network to segment, during which time one segment shows low bus loading until the fault is removed and the network recovers.

**Exhibit 4.4 - HIL Bus Loading During a Segmenting Physical Fault
Headway Controller Engaged, CAN_H Open, Fault at Location A**

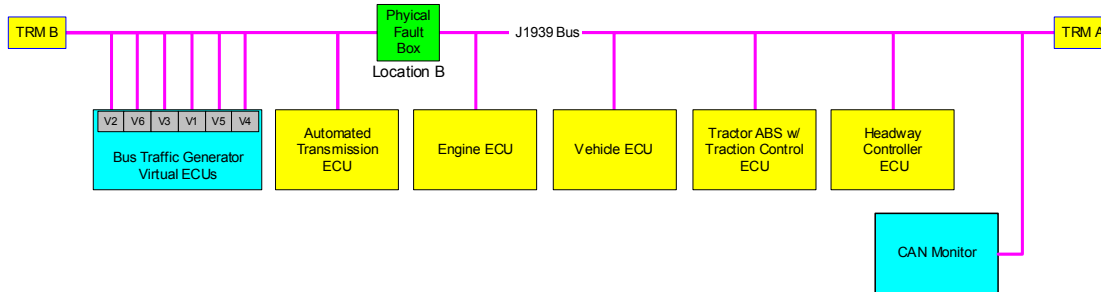


Exceptions occurred when testing a simplified network – without HWC or virtual ECUs connected to the network. During these three tests, the vehicle responded as described above, except that the engine malfunction lamp did not illuminate, and there were no engine ECU fault codes reported.

Segmenting faults at location “B” (see Exhibit 4.5) caused no notification to the vehicle operator. Transmission operation was abnormal, resulting in the vehicle being stuck in the current gear regardless of shifter position or engine RPM (see Section 3.5, Application Layer Issues). The TECU reported active J1939 errors, but did not indicate these to the vehicle operator via the transmission fault light on the shift console. Therefore, the vehicle operator had no indication that a transmission fault or failure had occurred until the transmission failed to shift. When the

fault was cleared, transmission operation immediately returned to nominal and its ECU bus faults became inactive.

Exhibit 4.5 – Fault Location B – Between EECU and TECU at Location B



Exceptions occurred during J1939-11 testing with four virtual ECUs connected to the network. During these two tests, the HWC ECU reported a “data link erratic intermittent” fault code. However, all HWC functions, including headway control, remained nominal during the fault.

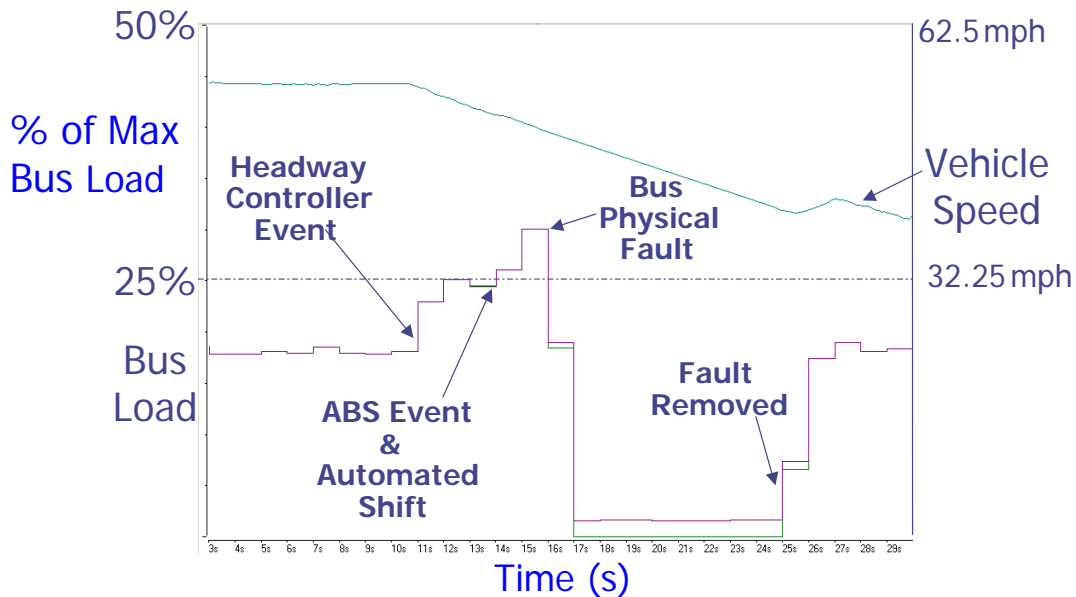
4.1.4. Network Failure Faults

Thirty-two tests of network failure faults were performed. The number of network failure faults is a function of the number of physical fault test series performed. Eight series were performed. Each consisted of 10 tests, four of which are segmenting. The test data from the network failure faults are listed in Appendix B (PF04, PF06, PF07, and PF08; PF14, PF16, PF17, and PF18; PF24, PF26, PF27, and PF28; PF34, PF36, PF37, and PF38; PF44, PF46, PF47, and PF48; PF54, PF56, PF57, and PF58; PF64, PF66, PF67, and PF68; and PF74, PF76, PF77, and PF78). Fault types 3 (CAN_H to Vbat), 5 (CAN_H to Ground), 6 (CAN_L to Vbat), and 7 (CAN_H to CAN_L) can all be expected to cause total network breakdown with no communications possible (see Exhibit 3.2).

4.1.5. Fault location A: Between VECU and ABS

Initiating any network failure fault at location “A” caused immediate notification to the vehicle operator via multiple fault indicators. These include the ABS lamp, ATC lamp, HWC fail lamp and audible warning, and the engine malfunction lamp. The ABS and HWC reverted to independent operation. Cruise control with or without headway control was inoperative. Transmission operation was abnormal in both manual and automated shifting. The test data from fault location A are listed in Appendix B (PF04, PF06, PF07 and PF08, PF24, PF26, PF27 and PF28, PF54, PF56, PF57 and PF58, PF64, PF66, PF67 and PF68). Exhibit 4.6 illustrates the network traffic on both sides of a bus failure fault with the two traces from the network segments displaying a similar low level of bus activity until the fault is removed.

**Exhibit 4.6 – HIL Bus Loading During a Physical Fault Causing Bus Failure
Headway Controller Engaged, CAN_L to CAN_H, (Fault at Location A)**



Engine and HWC ECUs reported error codes during the active J1939 bus fault and retained a subset of these as active after the fault was cleared. The ABS, transmission, and vehicle ECUs reported active J1939 faults during the active fault, but these became inactive once the fault was cleared. Returning the vehicle to nominal operation required the fault to be cleared, the vehicle stopped, and the ignition cycled.

4.1.6. Fault Location B: Between EECU and TECU

Network failure faults induced at location “B” caused nearly identical results to those induced at location “A.” Operator notification and vehicle functionality were the same as at fault location A (see Section 4.1.5) with some variation on the specific network faults reported by the ECUs. The test data from fault location B are listed in Appendix B (PF14, PF16, PF17, and PF18; PF36, PF37, and PF38; PF44, PF46, PF47, and PF48; and PF74, PF76, PF77, and PF78).

4.1.7. Overall Physical Fault Testing Results

The J1939 network operated within the SAE specifications during all physical fault tests. The only non-nominal operation without operator notification is discussed in Section 3.5: Application Layer Issue, but this is an application layer rather than a network standards implementation issue.

4.2. NETWORK LOADING TEST RESULTS

A total of 60 network loading tests were conducted. Six different network configurations were tested and each series of physical fault and load testing consisted of ten tests. As discussed in Section 3.3.1, TSC1 messages were injected into the network using an ECU simulator. The

network operated robustly up to 100 percent of rated loading. The results of the network loading tests are presented in Appendix C, where each test is numbered sequentially from LT01 to LT60.

4.2.1. Network Response to Physical Faults While Under High Traffic Load

Inducing physical faults while under high network loading produced network responses that conformed to J1939 specifications. These were qualitatively identical to the network responses for tests run at nominal network load levels described in Section 4.1, Physical Fault Tests.

Two load tests, numbers 31 (LT31) and 06 (LT06), which are representative of the entire load test series, are discussed in detail below and highlight the overall results from the load test series.

4.2.2. Load Test LT31

Exhibit 4.7 shows a typical load test run with no physical faults. Data logging commenced with the vehicle at a stable speed of 87 kph (54 mph) with adaptive cruise control engaged.

The tested scenario has the engine, an ABS/ECBS, and HWC simultaneously broadcasting TSC1 messages, and does not represent any specific shift command scenario. The TSC1 message was chosen solely for its high repetition rate. The test bed used up to 6 simulated ECUs. Each of these could simulate two "Controller Applications," such as the EECU, which runs controller applications engine (ID 0) and retarder (ID 15). These 6 virtual (or emulated) ECUs were utilized to run 12 controller applications. At the 3.87-second point, the 12 simulated ECU TSC1 messages commence on 40-millisecond spacing. Each TSC1 message was broadcast continuously for 20 seconds. At the 9.48-second point, the HWC in adaptive cruise commences TSC1 engine and engine retarder commands to maintain proper spacing behind an object placed in the path of the headway radar unit. At the 11.75-second point, the transmission begins to issue TSC1 commands in preparation for a downshift, culminating in a peak one-second network load of 99.3 percent when the shift actually occurs between the 12- and 13-second points.

An ABS event and additional ACC events occur through the 22-second point. The 12 simulated ECUs cease TSC1 transmission beginning at 23.87 seconds on 40-millisecond intervals. The HWC, engine, and transmission then resume the set cruise control vehicle speed, which included two up shifts, for the remainder of the data collection.

Exhibit 4.7 - LT31 Network Loading

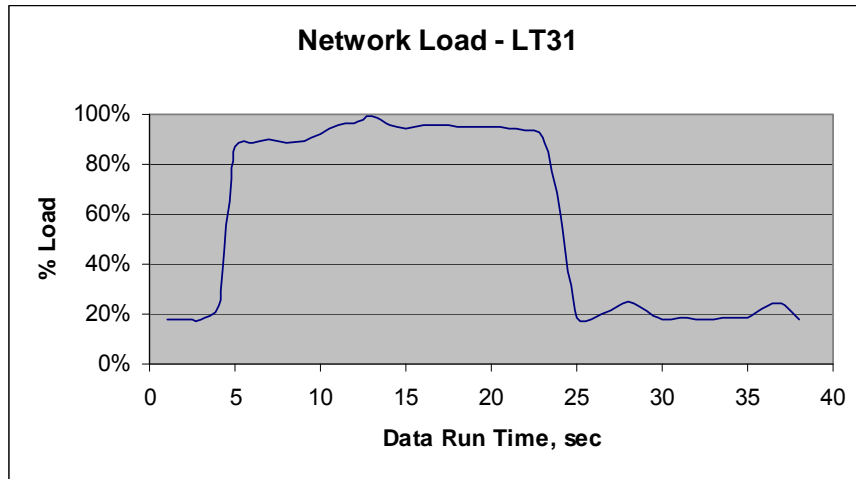
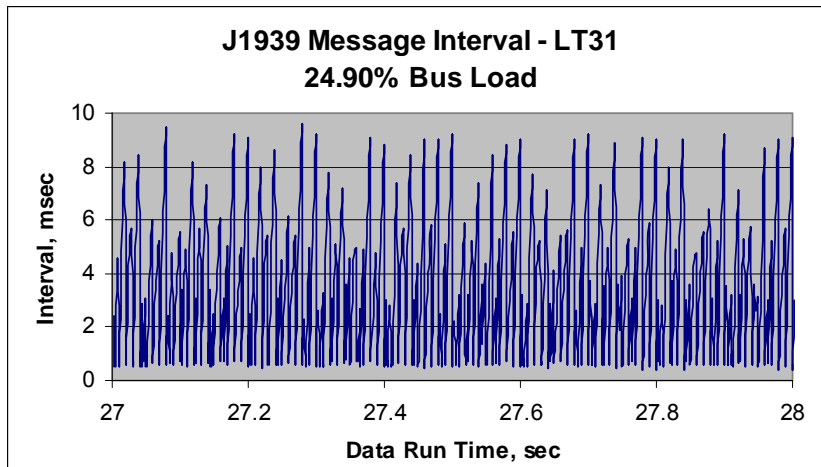


Exhibit 4.8 shows the typical time interval between message starts for the HIL recovering its cruise speed from the combined HWC and ABS event with no simulated messages broadcasting. The 24.90% bus load was typical during a transmission up or down shift, whereas a typical of steady state bus load was 18.8% as seen in the first three seconds of Exhibit 4.7. The message start interval gap routinely reached lengths greater than six milliseconds. The time resolution of the data logger was 0.1 millisecond. The message time interval was used since it is a good graphical indication of J1939 bus utilization. An individual J1939 message is approximately 0.55 to 0.60 milliseconds long - maximum of 151 bit times at 0.004 milliseconds per bit. Comparing low vs. high bus utilization message time intervals, as shown in Exhibit 4.8 and 4.9, dramatically shows the bus reaching full capacity. The CANalyzer tool could only provide measurements to the nearest 0.1 of a millisecond, and the average message length was approximately 0.58 milliseconds. When the bus was near full capacity, the message time intervals would jump between 0.5 and 0.6 milliseconds.

Exhibit 4.8 - LT31 Message Interval at 24.90% Load



During this same data collection period, between the 12- and 13-second points, the network traffic level reached 99.30 percent over a time period of 1.0019 seconds. The message start intervals recorded during this period are shown in Exhibit 4.9. This level of network utilization implies significant periods of 100-percent network utilization. Based on the messages broadcast during this time period and their transmission repetition rate from J1939-71, the potential existed for message transmission requests to exceed 100 percent. The 99.30-percent network load implies an average message length of 0.572 milliseconds or 142.6 bits, including the 3-bit inter-frame spacing. Message intervals of 0.6-milliseconds or less made up 98.56 percent of the message intervals during this period.

Exhibit 4.9 - LT31 Message Interval at 99.30% Load

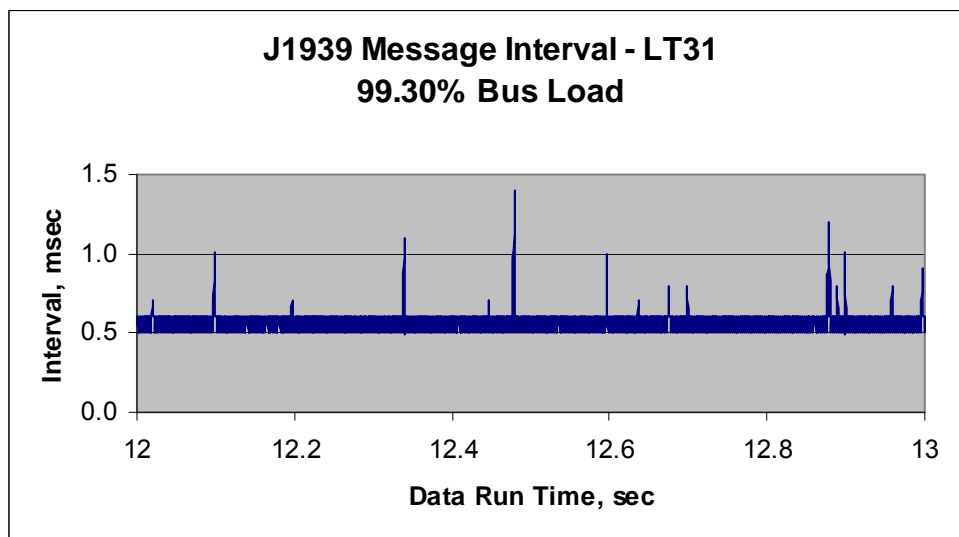
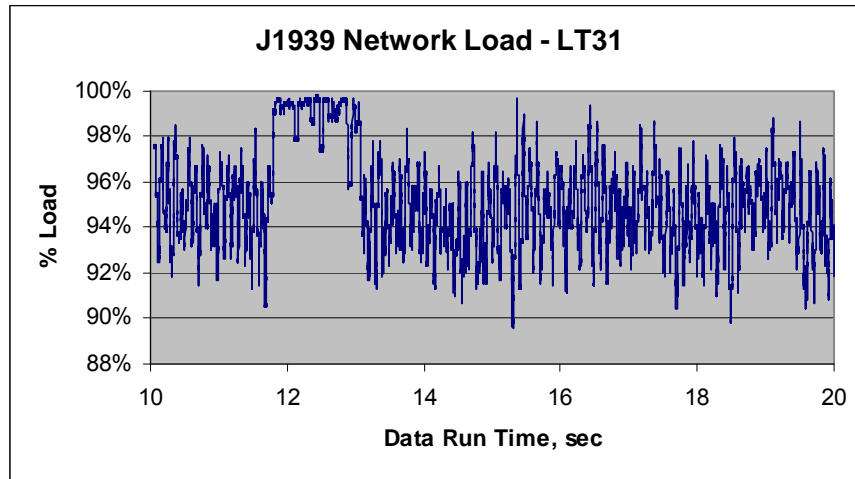


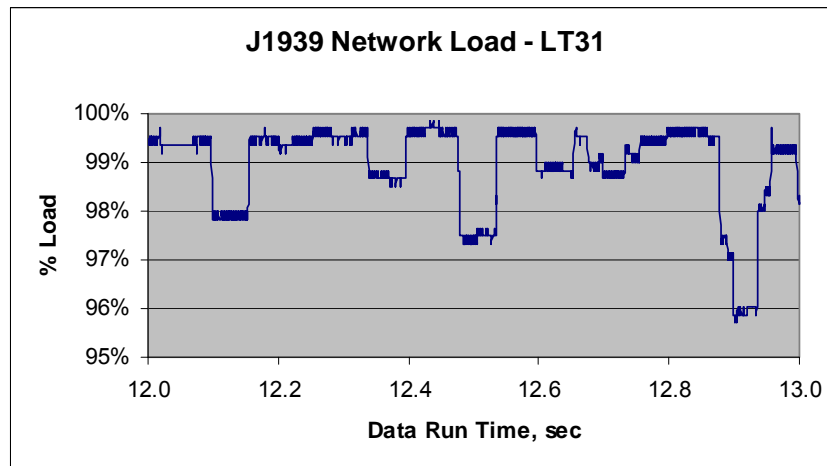
Exhibit 4.10 shows the running network load level for the previous 100 messages. The average duration of this interval was of 57.2-milliseconds. At 11.87 seconds, the transmission begins the request to the engine for an RPM change in anticipation of a downshift. The TSC1 message used by the transmission adds approximately 6.14 percent of total network capacity to the existing network load level.

Exhibit 4.10 – LT31 Network Load – From 10 to 20 seconds



Taking a more detailed look at the very high load data interval, Exhibit 4.11 shows the average network load concentrating on the highest loaded second of the data log. The network repeatedly runs up to the theoretical limit of the bus of 250 Kbps.

Exhibit 4.11 – LT31 Network Load – From 12.0 to 13.0 seconds



The effect on message regularity caused by near 100-percent bus loadings is illustrated in Exhibit 4.12, Exhibit 4.13, and Exhibit 4.15. This data is from the same one-second interval from Exhibit 4.11. The time intervals for TSC1 messages at three different addresses during the same elapsed data run time (12 s to 13 s) are presented. Each subsequent graph is from an ECU/TSC1 message of lower-arbitrated rank. The three messages shown are all TSC1, Throttle Speed Control #1. In decreasing priority, the three address messages are: (7) Power Takeoff (Main or Rear), (19) Steering Control, and (42) Headway Control. The (7) and (19) address messages were generated by the virtual ECU simulator. The (42) HWC messages were generated by the COTS HWC ECU. The lower-ranked messages show less regularity and longer periods between subsequent TSC1 messages. Despite this effect on the HWC's messages

(displayed in Exhibit 4.14), the human operator did not observe an effect on vehicle performance.

Exhibit 4.12 - LT31 Address 7 Message Intervals

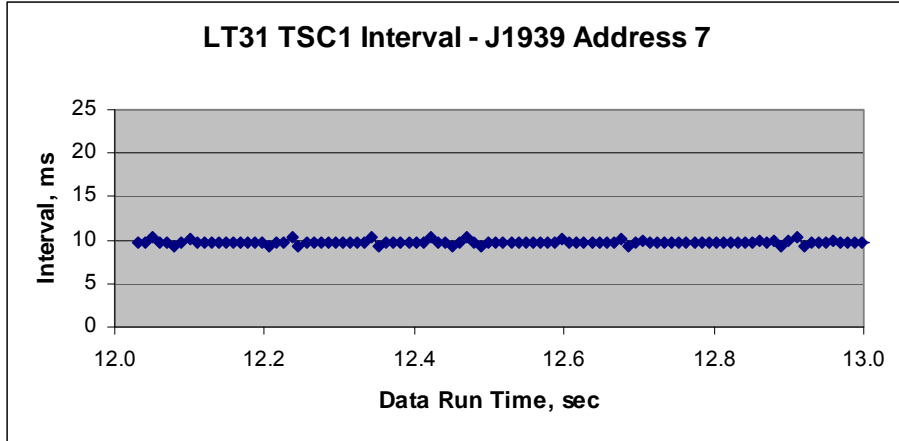


Exhibit 4.13 - LT31 Address 19 Message Intervals

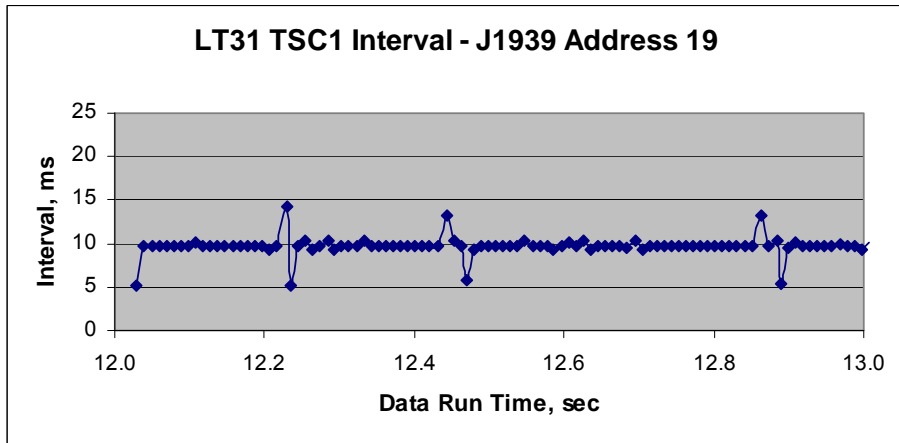
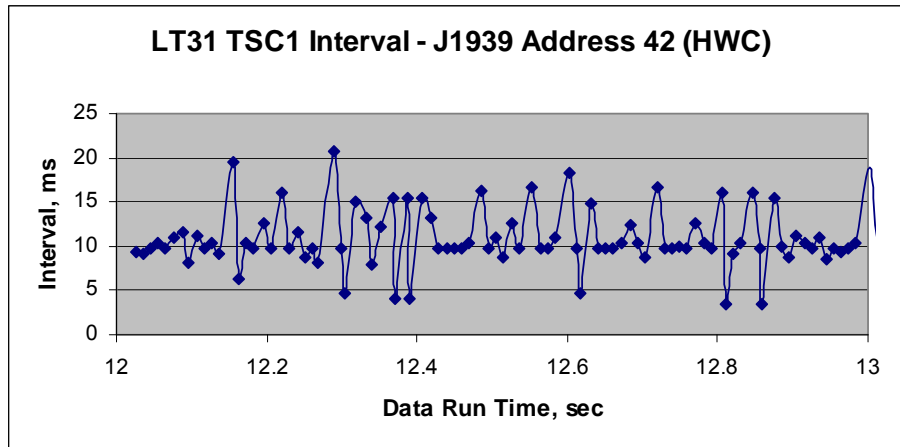


Exhibit 4.14 - LT31 Address 42 Message Intervals



The specified and actual message intervals for the high load network traffic period shown in Exhibit 4.11 through Exhibit 4.14 are listed in Exhibit 4.15. Exhibit 4.16 translates the parameter group numbers (PGNs) and Source/Destination ID numbers and provides further detail on each of the messages in Exhibit 4.15 listed by rank. This time period began at the 11.9999-second point of the data logging, and lasted for 1001.9 milliseconds.

In the two exhibits, "Rank" indicates the CAN arbitrated rank of the message. Each CAN message is referenced by a unique number known as the PGN, under SAE J1939-71, and "TX ECU" and "RX ECU" are the transmitting and receiving ECUs. The specified interval is the transmission repetition rate specified in J1939-71 (italics indicate no rate specified or a flexible rate). "Average interval" was the average message start interval recorded during the sample period. "Percent of specified" is the average interval divided by the specified interval. Percentages below 100 percent indicate the message is repeating faster than specified. Standard deviation is the deviation around the average interval. Messages recorded are the number of messages of that particular rank recorded during the period.

Exhibit 4.15 - LT31 High Load Period

Rank	PGN	TX ECU	RX ECU	Specified Interval	Average Interval	Percent of Specified	Standard Deviation	Messages Recorded
1	0	2	0	10 ms	9.77 ms	97.7%	29.6%	103
2	0	3	0	10 ms	10.00 ms	100.0%	21.1%	101
3	0	4	0	10 ms	9.77 ms	97.7%	2.6%	102
4	0	5	0	10 ms	9.77 ms	97.7%	3.1%	102
5	0	6	0	10 ms	9.77 ms	97.7%	11.1%	103
6	0	7	0	10 ms	9.77 ms	97.7%	2.4%	103
7	0	8	0	10 ms	10.72 ms	107.2%	44.9%	93
8	0	9	0	10 ms	9.67 ms	96.7%	34.5%	102
9	0	10	0	10 ms	9.77 ms	97.7%	4.6%	103
10	0	13	0	10 ms	9.78 ms	97.8%	10.4%	103
11	0	14	0	10 ms	9.75 ms	97.5%	15.4%	103
12	0	18	0	10 ms	9.77 ms	97.7%	7.5%	102
13	0	19	0	10 ms	9.76 ms	97.6%	11.9%	103
14	0	42	0	10 ms	10.74 ms	107.4%	30.3%	92
15	0	3	15	50 ms	45.52 ms	91.0%	16.6%	6
16	0	42	15	50 ms	53.85 ms	107.7%	11.2%	16
17	65135	42		100 ms	107.23 ms	107.2%	6.2%	9
18	61440	15		100 ms	99.93 ms	99.9%	29.6%	10
19	61441	11		100 ms	100.84 ms	100.8%	19.2%	10
20	61442	3		10 ms	9.95 ms	99.5%	39.1%	100
21	61443	23		50 ms	48.85 ms	97.7%	39.5%	20
22	61444	0		20 ms	20.12 ms	100.6%	28.9%	50
23	61445	3		100 ms	100.38 ms	100.4%	9.2%	10
24	65146	51		250 ms	242.00 ms	96.8%	7.1%	5
25	65215	11		100 ms	102.48 ms	102.5%	23.2%	10
26	65226	0		1000 ms				1
27	65247	0		250 ms	245.27 ms	98.1%	2.2%	4
28	65252	23		1000 ms				1
29	65262	0		1000 ms				1
30	65263	0		500 ms	461.70 ms	92.3%		2
31	65265	23		100 ms	293.40 ms	293.4%		2
32	65270	0		500 ms	481.30 ms	96.3%		2
33	65281	23		20 ms	20.83 ms	104.1%	42.3%	48
34	65282	0		250 ms	190.38 ms	76.2%	10.5%	5
35	65283	23		250 ms	295.00 ms	118.1%		2
Total message in the data run interval of 1001.9 milliseconds:								1732
Percent of Max Load for Interval:								99.30%

Note:
TX ECU is Transmitter (check with acronym list and throughout doc. ECU
RX ECU is Receiving (check with acronym list and throughout doc. ECU
PGN is Parameter Group Number

Exhibit 4.16 - Description of Parameter Group Numbers (PGNs) and Source (TX ECU)/Destination (RX ECU) ID numbers

Rank	PGN	Description	Source	Destination
1	0	Torque/Speed Control #1	Turbocharger	Engine #1
2	0	Torque/Speed Control #1	Transmission #1	Engine #1
3	0	Torque/Speed Control #1	Transmission #2	Engine #1
4	0	Torque/Speed Control #1	Shift Console - Primary	Engine #1
5	0	Torque/Speed Control #1	Shift Console - 2nd	Engine #1
6	0	Torque/Speed Control #1	Power Take Off	Engine #1
7	0	Torque/Speed Control #1	Axle - Steering	Engine #1
8	0	Torque/Speed Control #1	Axle - Drive #1	Engine #1
9	0	Torque/Speed Control #1	Axle - Drive #2	Engine #1
10	0	Torque/Speed Control #1	Brakes - Drive Axle #1	Engine #1
11	0	Torque/Speed Control #1	Brakes - Drive Axle #2	Engine #1
12	0	Torque/Speed Control #1	Fuel System	Engine #1
13	0	Torque/Speed Control #1	Steering Controller	Engine #1
14	0	Torque/Speed Control #1	Headway Controller	Engine #1
15	0	Torque/Speed Control #1	Transmission #1	Retarder - Engine
16	0	Torque/Speed Control #1	Headway Controller	Retarder - Engine
17	65135	Adaptive Cruise Control	Headway Controller	
18	61440	Electronic Retarder Controller #1	Retarder - Engine	
19	61441	Electronic Brake Controller #1	Brakes - System Controller	
20	61442	Electronic Transmission Controller #1	Transmission #1	
21	61443	Electronic Engine Controller #2	Instrument Cluster	
22	61444	Electronic Engine Controller #1	Engine #1	
23	61445	Electronic Transmission Controller #2	Transmission #1	
24	65146	Tire Pressure CU Current Pressure	Tire Pressure Controller	
25	65215	Wheel Speed Information	Brakes - System Controller	
26	65226	Diagnostic Message #1	Engine #1	
27	65247	Electronic Engine Controller #3	Engine #1	
28	65252	Shutdown	Instrument Cluster	
29	65262	Engine Temperature #1	Engine #1	
30	65263	Engine Fluid Level/Pressure #1	Engine #1	
31	65265	Cruise Control/Vehicle Speed	Instrument Cluster	
32	65270	Inlet/Exhaust Conditions	Engine #1	
33	65281	Proprietary B	Instrument Cluster	
34	65282	Proprietary B	Engine #1	
35	65283	Proprietary B	Instrument Cluster	

4.2.3. Load Test LT06

Load test LT06 was conducted by inducing physical fault 5 (CAN_H to Ground) while the virtual ECUs were transmitting the artificially generated TSC1 messages. This fault makes communications impossible under the J1939-11/15 specifications, and this was the result obtained during this test. Exhibit 4.17 shows the network load level for the duration of the data collection run. As with test LT31, the vehicle begins the test with ACC engaged while traveling at a stable velocity of 87 kph (54 mph).

At approximately 3 seconds, the virtual ECUs begin transmitting the 12 TSC1 message streams, each commencing on 20 millisecond intervals. At 9 seconds, the HWC begins to respond to an object within the separation distance by commanding the engine to throttle back. This action produces two downshifts. The object then clears or leaves the target zone, and the HWC attempts to resume set cruise speed, producing one up shift. Before the set cruise speed is established again, the physical fault is induced and ABS event occurs at 23.4 seconds. The physical fault brings the network communications to an ineffective level by the 24.7-second point of the data run.

Exhibit 4.17 - LT06 Network Loading

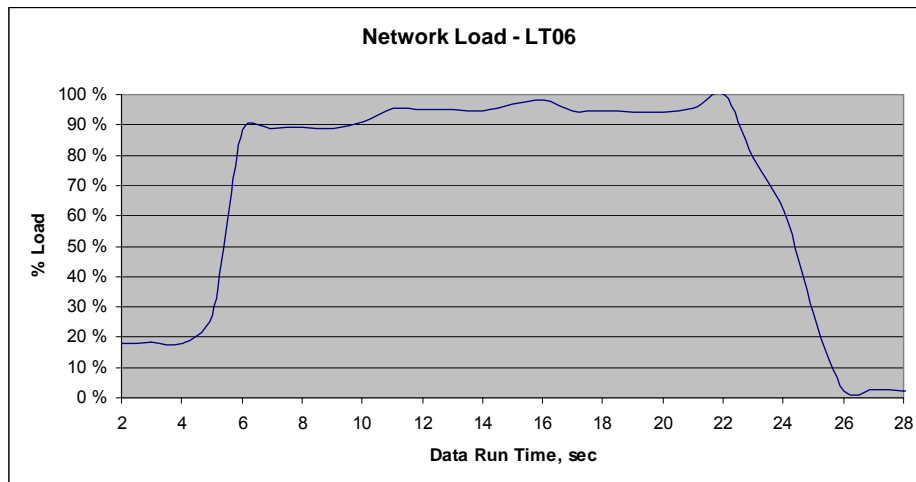


Exhibit 4.18 shows the subsequent message start interval when the vehicle is operating at a load of 18.38 percent of maximum during the 2- to 3-second point. No TSC1 messages, artificially generated or nominal, are being broadcast, and message intervals regularly reach up to 10 milliseconds.

Exhibit 4.18 - LT06 Message Interval at 18.38% Load

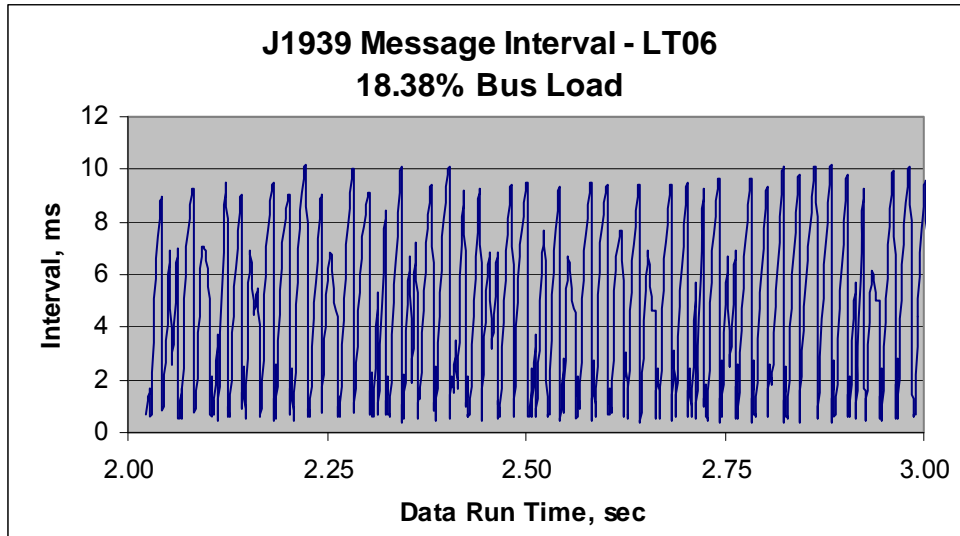


Exhibit 4.19 shows the message start intervals for the period from 13.2 to 22.2 seconds from Exhibit 4.17. All 12 artificially generated TSC1 messages are being broadcast. During this interval, average network load levels were above 90 percent, and the maximum message interval does not exceed 2.5 milliseconds. The last second of this exhibit is the most highly loaded time period recorded in all the load test series.

Exhibit 4.19 - LT06 Message Interval - From 13.2 to 22.2 seconds

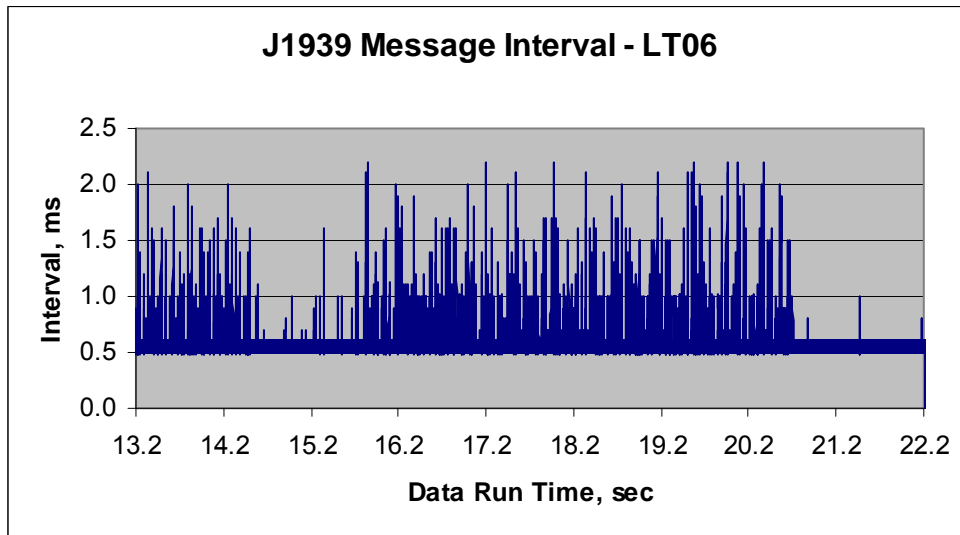


Exhibit 4.20 shows the message start intervals for a 0.2-second section of this highest loaded time period. All are between 0.5 and 0.6 milliseconds. The resolution of the measurement system was 0.1 seconds, and the average message duration was 0.575 milliseconds. The bus loading over this time period was 99.94 percent.

Exhibit 4.20 - LT06 Message Interval at 99.94% Load

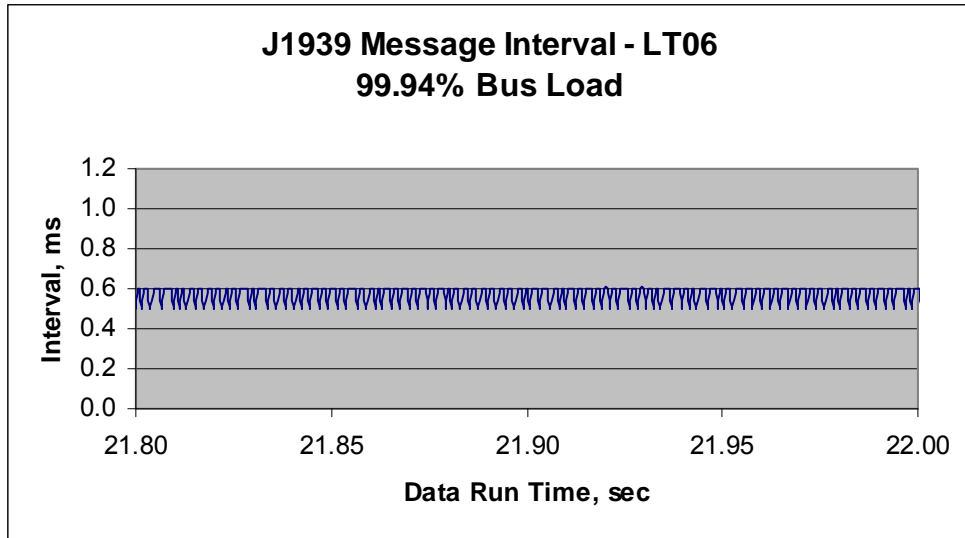


Exhibit 4.21 and Exhibit 4.22 are based on the same data as Exhibit 4.19 and Exhibit 4.20 except “% Load” instead of “Interval (between messages), ms” is expressed as a function of “Data Run Time”. The network load bumped against the 100-percent limit around the 15- and 21-second points. These were both shift events, where the transmission sends out TSC1 commands to the engine to match the engine RPM to the next desired gear, either down or up shift.

Exhibit 4.21 - LT06 Network Load - From 13.2 to 22.2 seconds

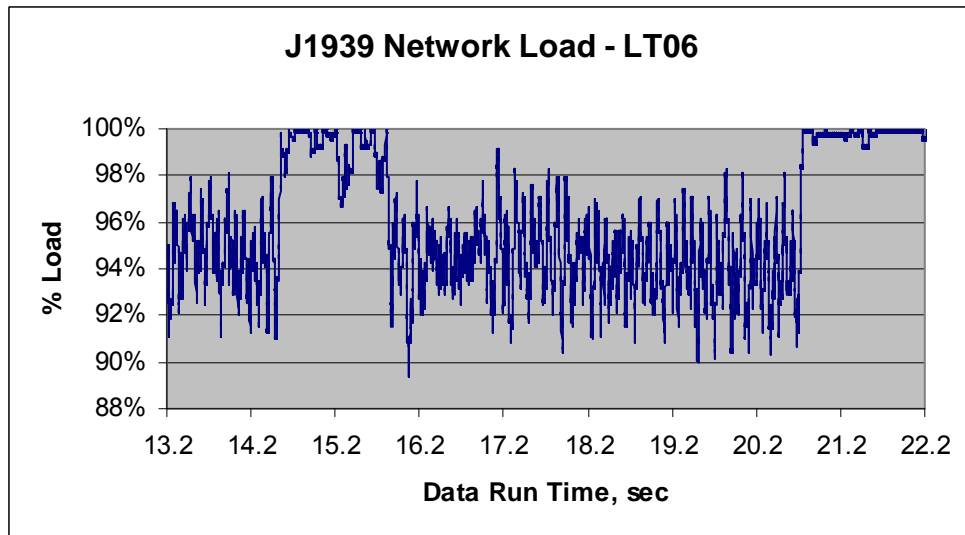
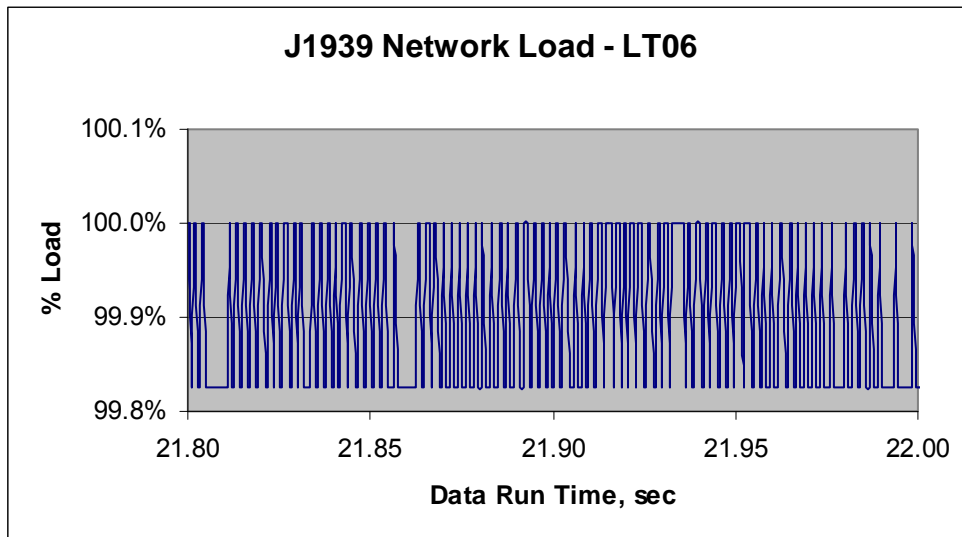


Exhibit 4.22 - LT06 Network Load - From 21.8 to 22.0 seconds



As in LT31, the vehicle operated nominally even under these extremely high network loads levels. Only when a physical fault was induced did the network cease to effectively function.

Exhibit 4.23 details the messages transmitted during the highest loaded time period of test LT06, a 1020-millisecond period commencing at 21.0001 (as shown in Exhibit 4.17). This was also the highest sustained network load for any comparable period of any test conducted under this study. The specified and average message intervals for the highest load network traffic period are also listed in Exhibit 4.23. (To translate the PGNs and Source and Destination ID numbers according to rank refer to Exhibit 4.24.)

Rank indicates the CAN arbitrated rank of the message. PGN is the parameter group number under J1939-71. TX and RX ECU are the transmitting and receiving ECUs. The specified interval is the transmission repetition rate specified in J1939-71 (*italics indicate no specified or flexible rate*). Average interval was the average message start interval recorded during the sample period. Percent of specified is the average interval divided by the specified interval. Percentages below 100 percent indicate the message is repeating faster than specified. Standard deviation is the deviation around the average interval. Messages recorded are the number of messages of that rank recorded during the period.

Exhibit 4.23 - LT06 High Load Period

Rank	PGN	TX ECU	RX ECU	Specified Interval	Average Interval	Percent of Specified	Standard Deviation	Messages Recorded
1	0	2	0	10 ms	9.69 ms	96.9%	34.1%	105
2	0	3	0	10 ms	10.00 ms	100.0%	34.3%	101
3	0	4	0	10 ms	9.76 ms	97.6%	2.9%	104
4	0	5	0	10 ms	9.77 ms	97.7%	2.4%	105
5	0	6	0	10 ms	9.76 ms	97.6%	3.3%	104
6	0	7	0	10 ms	9.76 ms	97.6%	5.0%	105
7	0	8	0	10 ms	9.76 ms	97.6%	5.6%	104
8	0	9	0	10 ms	9.72 ms	97.2%	28.5%	105
9	0	10	0	10 ms	9.77 ms	97.7%	2.3%	105
10	0	13	0	10 ms	9.76 ms	97.6%	4.5%	104
11	0	14	0	10 ms	9.77 ms	97.7%	5.9%	104
12	0	18	0	10 ms	9.76 ms	97.6%	9.3%	104
13	0	19	0	10 ms	9.76 ms	97.6%	9.9%	105
14	0	42	0	10 ms	10.61 ms	106.1%	26.1%	96
15	0	3	15	50 ms	50.30 ms	100.6%	6.0%	21
16	60160	0	all					1
17	60416	0	all					1
18	61440	15		100 ms	100.92 ms	100.9%	64.5%	10
19	61441	11		100 ms	103.11 ms	103.1%	12.3%	9
20	61442	3		10 ms	9.97 ms	99.7%	42.1%	101
21	61443	23		50 ms	43.48 ms	87.0%	33.9%	23
22	61444	0		20 ms	19.93 ms	99.6%	27.2%	52
23	61445	3		100 ms	100.14 ms	100.1%	9.2%	10
24	65135	42		100 ms	104.56 ms	104.6%	8.0%	10
25	65146	51		250 ms	244.15 ms	97.7%	3.5%	5
26	65215	11		100 ms	103.02 ms	103.0%	22.5%	10
27	65247	0		250 ms	241.20 ms	96.5%	13.5%	3
28	65252	23		1000 ms	137.84 ms	13.8%	61.4%	6
29	65263	0		500 ms	472.60 ms	94.5%		2
30	65265	23		100 ms				1
31	65270	0		500 ms	493.40 ms	98.7%		2
32	65281	23		20 ms	20.45 ms	102.2%	37.2%	50
33	65282	0		200 ms	197.58 ms	98.8%	39.6%	5
34	65283	23		1000 ms				1
Total Messages in the data run interval of 1,020 milliseconds:								1,774
Percent of Maximum Load for Interval:								99.95%

Note:

TX ECU is Transmitter ECU

RX ECU is Receiving ECU

PGN is Parameter Group Number

Exhibit 4.24 - LT06 High Load Period

Rank	PGN	Description	Source	Destination
1	0	Torque/Speed Control #1	Turbocharger	Engine #1
2	0	Torque/Speed Control #1	Transmission #1	Engine #1
3	0	Torque/Speed Control #1	Transmission #2	Engine #1
4	0	Torque/Speed Control #1	Shift Console - Primary	Engine #1
5	0	Torque/Speed Control #1	Shift Console - 2nd	Engine #1
6	0	Torque/Speed Control #1	Power Take Off	Engine #1
7	0	Torque/Speed Control #1	Axle - Steering	Engine #1
8	0	Torque/Speed Control #1	Axle - Drive #1	Engine #1
9	0	Torque/Speed Control #1	Axle - Drive #2	Engine #1
10	0	Torque/Speed Control #1	Brakes - Drive Axle #1	Engine #1
11	0	Torque/Speed Control #1	Brakes - Drive Axle #2	Engine #1
12	0	Torque/Speed Control #1	Fuel System	Engine #1
13	0	Torque/Speed Control #1	Steering Controller	Engine #1
14	0	Torque/Speed Control #1	Headway Controller	Engine #1
15	0	Torque/Speed Control #1	Transmission #1	Retarder - Engine
16	60160	Transport Protocol - Data Transfer	Engine #1	all
17	60416	Transport Protocol - Connection Management	Engine #1	all
18	61440	Electronic Retarder Controller #1	Retarder - Engine	
19	61441	Electronic Brake Controller #1	Brakes - System Controller	
20	61442	Electronic Transmission Controller #1	Transmission #1	
21	61443	Electronic Engine Controller #2	Instrument Cluster	
22	61444	Electronic Engine Controller #1	Engine #1	
23	61445	Electronic Transmission Controller #2	Transmission #1	
24	65135	Adaptive Cruise Control	Headway Controller	
25	65146	Tire Pressure CU Current Pressures	Tire Pressure Controller	
26	65215	Wheel Speed Information	Brakes - System Controller	
27	65247	Electronic Engine Controller #3	Engine #1	
28	65252	Shutdown	Instrument Cluster	
29	65263	Engine Fluid Level/Pressure #1	Engine #1	
30	65265	Cruise Control/Vehicle Speed	Instrument Cluster	
31	65270	Inlet/Exhaust Conditions	Engine #1	
32	65281	Proprietary B	Instrument Cluster	
33	65282	Proprietary B	Engine #1	
34	65283	Proprietary B	Instrument Cluster	

4.3. INJECTED NOISE TEST RESULTS

A total of 115 noise tests were conducted. Injected Gaussian white noise tolerance appears consistent with other networks, which have specifications for injected noise tolerance (such as MIL-STD-1553). Ten configuration-fault combinations were tested for noise tolerance. The first several test series involved more tests than the latter, since the level of noise tolerance was not known. Once the noise tolerance level was established in these first series, subsequent series started at these levels and eliminated low noise tests thus reducing the number of tests in those configurations. The arbitrary function generator was adjusted in 30 mV RMS steps for most test series. Finer steps than this were considered excessive for these tests, since they are not conducted against any specific standard. The tests were meant to show a general comparison between configurations/faults and other known specifications. Exhibit 4.25 summarizes these testing results. Appendix D lists the results for each individual noise test, which is numbered sequentially from N001 to N115.

Each test series was conducted on the harness described by the cable type. Any physical fault (from Exhibit 3.5) present during the series is listed under the Fault column. Also under the Fault column, "50 ohms TrmB" is where the terminating resistance of the noise generator replaced one end bus terminator. This is equivalent to a fully loaded network where the cumulative ECU terminations reduce the CAN VPP to the minimum of 1.20 Volts, or to a mild short between CAN_H and CAN_L. In test series one through nine, all J1939 CAN signals had a CAN_H to CAN_L VPP of 1.80 Volts. The tested lengths of the main J1939 bus listed under Bus Length in Exhibit 4.24 are a combination of one, two, or three harnesses. These harnesses consist of the J1939-15 at 25.24 meters, the J1939-11 at 14.76 meters, and the 20 meter J1939-15 extension cable. Two S/N levels are listed. S/N Fail is the noise level where anomalies occurred that inhibited full vehicle function and/or activated driver observable warning indicators. S/N Pass is the highest level of noise where the HIL simulator had no driver observable anomalies.

Exhibit 4.25 - Noise Tolerance Summary

Series	Cable Type	Fault	Bus Length	S/N Fail	S/N Pass
1	J1939-15 (UTP)	None	14.76 m	6.00 dB	6.30 dB
2	J1939-11 (STP)	None	25.24 m	6.00 dB	6.30 dB
3	J1939-11 & J1939-15	None	40.00 m	6.30 dB	6.60 dB
4	J1939-11 & J1939-15 Extension	PF 10	45.24 m	6.60 dB	6.81 dB
5	J1939-11 & J1939-15 + Extension	PF 10	60.00 m	7.82 dB	8.19 dB
6	J1939-11	PF 9	25.24 m	11.11 dB	11.65 dB
7	J1939-11 & J1939-15 + Extension	PF 9 & 10	60.00 m	12.22 dB	12.65 dB
8	J1939-11	PF 4	25.24 m	8.70 dB	9.10 dB
9	J1939-11 & J1939-15 + Extension	PF 4 & 10	60.00 m	45.1 dB*	NA
10	J1939-15 (1.2VPP signal)	50 Ohms TrmB	14.76 m	20.0 dB	21.0 dB

Note: PF 4 is CAN_L to Ground, PF9 is a missing terminating resistor, and PF 10 is a topology (length) fault. *Lowest noise level possible from test equipment.

4.3.1. Effect of Network Length on Noise Tolerance

Noise test series 1 through 5 show the effect of increasing network harness length on noise tolerance. A J1939-15 harness of 14.76 meters and a J1939-11 harness of 25.24 meters (36.9 percent and 63.1 percent, respectively, of the maximum specified length of maximum length of 40 meters) show excellent and similar tolerance to injected noise. A maximum specified length network harness of 40 meters is within 0.3 dB of the sub-maximum length harnesses. Exceeding the maximum length by 13.1 percent, or 45.24 meters total length, produced another 0.3 dB lower tolerance than the maximum. Exceeding the maximum length by 50 percent, or 60 meters total length, reduced tolerance by 1.59 dB compared to a maximum length harness. While the drop off in noise tolerance with excessive harness length is somewhat significant, these results show the network has good injected noise tolerance of topology length faults.

4.3.2. Comparison of J1939-11 (STP) vs. J1939-15 (UTP)

Noise test series 1 and 2 show the results for an all J1939-11 (STP) harness versus an all J1939-15 (UTP) harness. While the lengths of the harnesses vary, both wire types produced identical results within the resolution of this test series, 0.3 dB.

4.3.3. Improper Termination Effects

One bus terminator was removed for test series 6 and 7. This physical fault is supposed to reduce overall S/N ratio, and the test results confirmed this. Compared to the identical harness with the terminator in place, a nominal length J1939-11 (STP) of 25.24 meters lost 5.35 dB of noise tolerance. For the harness 60 meters long, 50-percent above specified maximum, the noise tolerance dropped an additional 4.46 dB beyond that due to excessive length. These results indicate that improper termination has a much larger adverse effect on network performance than excessive length alone (5.05 dB vs. 1.59 dB, respectively, for a network of maximum specified length).

Test series 10 replaced one of the nominal 120-Ohm harness terminators with the equivalent of 50 Ohms of termination. This lowered overall J1939 CAN_H to CAN_L differential bus voltage to 1.2 VPP. This is the lowest differential level specified in J1939-11/15 with a range of 1.2 VPP (minimum), 2.0 VPP (nominal), and 3.0 VPP (maximum). This level may approximate a network overloaded with devices; one with one or more ECUs with excessive internal termination; or one that has a mild short due to environmental wear or improper installation or repair of the harness, factory ECUs, or aftermarket ECUs. This lower terminating resistance, even though the differential voltage was with specification, caused a very large reduction of noise tolerance of 14.7 dB. This again emphasizes that proper termination is more important than topology in increasing network noise tolerance.

4.3.4. CAN_L Short to Vehicle/Battery Ground

Test series 8 and 9 examined the effect of another physical fault, CAN_L to Ground. This fault decreases the network S/N ratio, which increases the likelihood of bit errors and invalid messages. For a nominal length, 25.24-meter, harness of J1939-11 (STP), the fault decreased noise tolerance by 2.8 dB. On the excessively long harness of 60 meters, the fault caused network breakdown at the lowest noise level the generator could produce, a S/N ratio of 45.1 dB. The failure occurred as the ignition switch was rotated from "ON" to "Start."

5. CONCLUSIONS

5.1. ROBUSTNESS OF THE J1939 NETWORK

5.1.1. Physical Fault Response

The network responded to physical faults as specified in J1939. Faults resulting in reduced network S/N ratio allowed the network to function nominally with no operator observable loss of function. For physical faults where the standard states that no network communication should be possible, the network failed in all instances.

Faults that could be expected to segment the network did allow communication on either side of the physical fault. The operator-observed vehicle malfunctions and the active ECU fault codes were determined by the specific ECUs grouped together on either side of the fault. For example, a fault that grouped the transmission, engine, and vehicle ECUs on one side and the ABS and CWS ECUs of the other allowed the engine and transmission to communicate nominally. However, the CWS and ABS both reverted to independent operation and activated observable malfunction indicators. All segmenting fault network responses were within the J1939 standard.

One application layer issue was observed where segmenting faults prevented the transmission from shifting gear. The details of this application layer issue are discussed in Section 3.5 Application Layer Issues.

5.1.2. High Bus Loading Response

The network handled loads of up to 100 percent of rated capacity without adverse effects and its performance remained nominal under these conditions. To produce a bus loading of up to 100 percent, six virtual ECUs were required and each had to transmit two high-rate TSC1 messages. This artificially added traffic represented a 150-percent increase over the maximum observed network load of the nominally operating HIL simulator test bed – even under adverse conditions, such as simultaneous demands for engine, transmission and ABS communications generated while a CMV is traveling down a wet or icy road. Physical faults induced during high bus loading produced qualitatively similar results to those observed in the physical fault test series.

The HIL simulator/vehicle response appeared identical to the operator under high network loads when compared to nominal load conditions. Analysis of the CAN message traffic indicated that the lower-arbitrated TSC1 messages did have a higher occurrence of missed or skipped messages, on the order of two to five percent. However, due to the high rate and repetitive nature of these messages, there appeared to be no degradation of vehicle performance due to these missed messages.

5.1.3. Injected Noise Response

While J1939 does not have a specified tolerance to injected Gaussian white noise, its tolerance to it appears consistent with other, similar communications networks, which do have

specifications for injected noise tolerance (such as MIL-SPEC-1553). Both the J1939-11 (STP) and the J1939-15 (UTP) test harnesses performed equally well, as might be expected for injected, rather than induced, noise. The noise tolerance for a harness of the maximum specified length (40 meters) was within 0.3 dB of the noise tolerance demonstrated by harnesses that were 14.8 meters (37 percent of maximum) and 25.2 meters (63 percent of maximum) in length.

The noise tolerance for networks longer than the maximum specified decreased more significantly when compared to differences of harness lengths within the specified maximum of 40 meters. Several physical faults also lowered noise tolerance even further. These faults are listed in order of increasing degradation:

- Grounding CAN_L to ground
- Removal of one of the end terminators
- Mild short circuit across CAN_L to CAN_H

The network; however, recovers within 100 milliseconds when the injected noise ceases regardless of harness length, physical fault, and/or mild short circuit.

5.2. SUMMARY OF KEY RESULTS AND RECOMMENDATIONS

Based on the network testing conducted for Task Order 4, the COTS ECUs used in the network testing, which are representative of a generic and complex network on a commercial truck, implemented J1939 well within the standards.

Network data during actual test truck operation displayed bus loads with 24-26 percent peaks for most TSC1 activities which was similar to the testing conducted on the HIL simulator. However, a single one-second average of 29.70 percent was recorded during the test truck data run when a simultaneous HWC event and automated gear shift occurred. Network loadings of approximately 42% are mathematically possible and were observed intermittently under combinations of HWC, ABS, and transmission ECU commands on top of the base level of traffic when the HIL was operating. However, none of the documented tests in Appendixes B-D, attempted to replicate these results. The tests produced frequent HWC/TECU and/or ABS/TECU TSC1 message combinations, but no sustained combination of all three. The results from the HIL simulator indicate the network appears to have 2.5 to 3 times the capacity currently used by the majority of commercial heavy vehicles in the United States.

This study provides quantitative information concerning the validity of the current design philosophy that combines safety-critical and non-safety-critical data communications devices and paths. The COTS ECUs used in this network-testing program, demonstrated excellent adherence to J1939 network specifications and performed well, even when network loading reached 100 percent.

This study also presents a quantitative measure of the network's capacity to accommodate additional safety-critical networked devices. Even a relatively well-equipped heavy truck, as represented by the HIL simulator, can potentially load the J1939 network only up to a peak of 42 percent capacity. This result indicates there is significant room for additional networked

devices. Examples of networked system controllers, which this study indicates might be safely added to the J1939 network, may include:

- Electronic stability control with sensors to detect un-commanded vehicle yaw. These systems use automatic braking of individual wheels to prevent the vehicle's heading from changing too quickly (spinning out or over-steering) or not quickly enough (plowing out or under-steering).
- Rollover/jackknife prevention with electronic stability control systems to help prevent rollovers and loss of control crashes that may include jackknives. With a combination-unit truck, an over-steer situation may lead to a vehicle jackknife. These systems will require network extensions to the trailer(s) for full implementation.
- Wireless vehicle inspection by using data already on the network to update a central memory file with Federal and state-mandated inspection criteria. This may include adding specific Individual Status Monitors, which could be directly connected to the network.

Additionally, the results of this study provide quantitative information to designers and manufacturers of the components, connectors, and systems to improve their physical and operational integrity for better performance and safer operation. In particular, the study identified non-standard implementation of the J1939 connector standards and an application level issue that resulted in degraded transmission performance during a network segmenting fault. Discussions with industry have highlighted issues with J1939 bus failures and fault indications to the vehicle operator. The original work accomplished in developing the HIL simulator has attracted industry attention, and may be incorporated into commercial products as a tool for engine/vehicle simulation.

The industry could benefit from further work focused on improving or standardizing the physical fault indication and recovery characteristics of the system ECUs. Most J1939 network physical faults invoke multiple failure codes in the ECUs, which can be hard to diagnose. Also, some systems that enter into a degraded mode as the result of a network fault do not recover unless power is cycled, which is not possible while the vehicle continues driving. Most concerning are systems that could enter into a severely degraded mode due to a loss of network with no indication to the operator of equipment problems. Some of these issues are related to the apparent "non-ownership" of the vehicle's J1939 network. The J1939 network cabling is installed by the vehicle OEM and utilized by systems from various manufacturers. Currently there is no system responsible for monitoring the physical condition or performance of the network and alerting the operator or maintenance personnel of failures.

APPENDIX A: SIMULATOR VALIDATION - ADDITIONAL DATA

Additional data is presented below that was collected to validate the data types and network loading of the HIL simulator versus an actual heavy truck test bed of similar configuration. These show good correlation, particularly on the overall network loading – the key focus of this study.

Exhibit A.1 and Exhibit A.2 show a comparison of TSC1 message traffic during vehicle acceleration for the HIL simulator and a similarly equipped tractor.

Exhibit A.1 - HIL TSC1 Messages during Acceleration

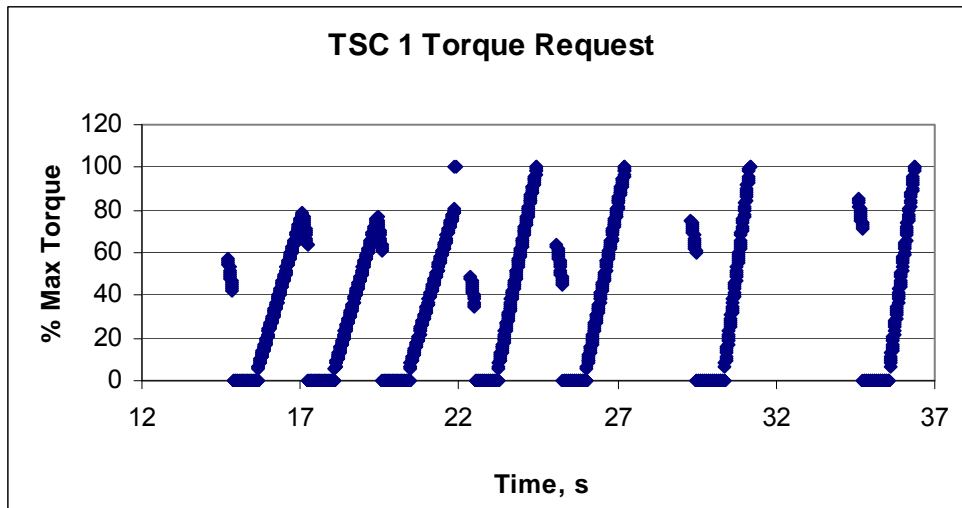
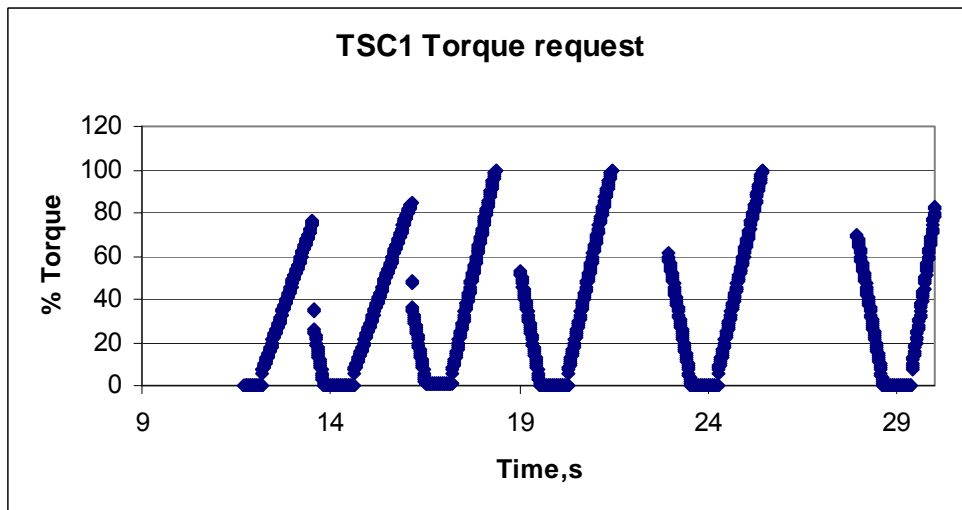


Exhibit A.2 - Tractor TSC1 Messages during Acceleration



HIL SIMULATOR DURING ADAPTIVE CRUISE CONTROL EVENTS

Exhibits A.3 through A.6 display data extracted from the HIL simulator J1939 message traffic while at speed and under adaptive cruise control for a period of 25 seconds. Two headway control events occur during this sequence. This data shows the interaction of the ECUs, and allows comparison of how each is interpreting the same simulation environment presented to them by the vehicle software models running on the target PCs.

Exhibit A.3 shows the accelerator pedal position and percent load at the current speed the engine is producing as reported in the J1939 Electronic Engine Controller #2 (EEC2) message, Suspect Parameter Numbers (SPNs) 91 and 92. Electronic Engine Controllers #1 and #2 are different messages (PGNs 61444 and 61443, respectively). They may or may not refer to separate ECUs or Controller Applications. In this set up, EEC2 originates from the VECU and EEC1 from the EECU. At the three-second point, the cruise control is set. At the 14- and 17.5-second points, the headway controller is commanding the engine to zero load to establish again proper spacing with an object in the path of the HWC radar unit.

Exhibit A.3 - HIL EEC2 Message Data while Under Headway Control

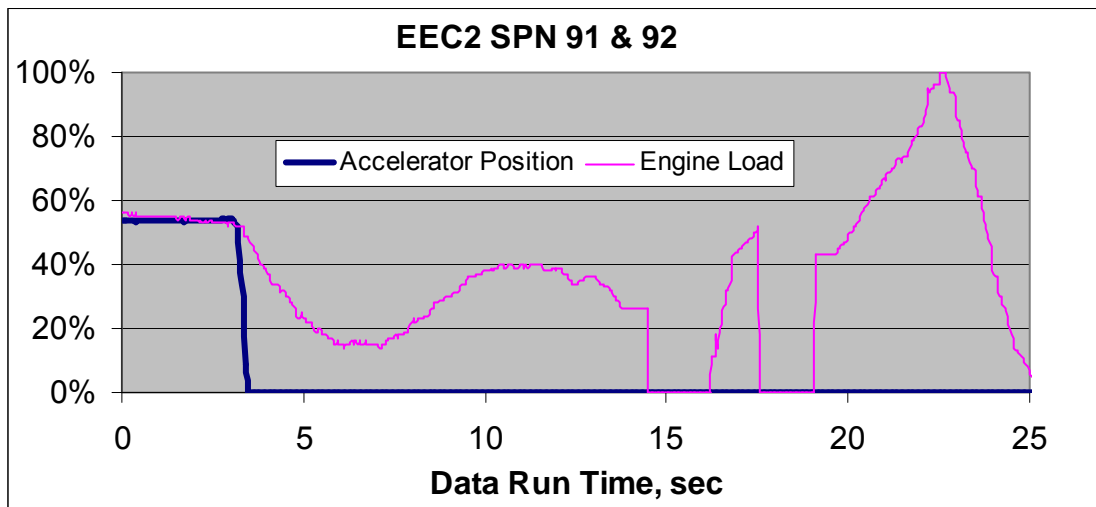


Exhibit A.4 shows a composite of data on the engine torque mode, the percent of actual engine torque, the percent of demanded engine torque, and the engine speed. These are transmitted in the J1939 EEC1 message. See Exhibit A.5 for the specific SPNs displayed.

Exhibit A.4 - HIL EEC1 Data under Headway Control

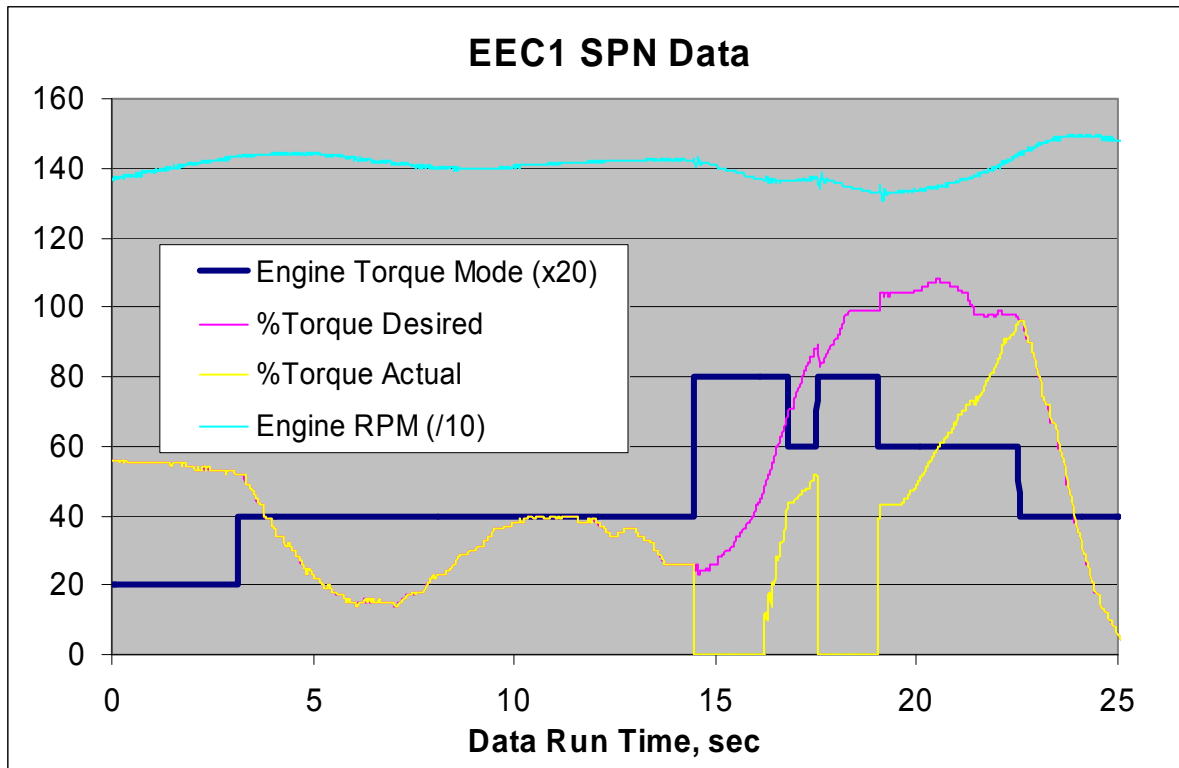


Exhibit A.5 - EEC1 Message SPNs in Exhibit A.4

Message	PGN
EEC1: Electronic Engine Controller #1	61444
SPN Descriptions displayed in Exhibit	SPN
Engine Torque Mode	899
Driver's Demand Engine – Percent Torque	512
Actual Engine – Percent Torque	513
Engine Speed	190

The engine torque mode has thirteen defined bit states in J1939-71. Only four states were transmitted during the 25 seconds of data displayed in Exhibit A.4. Exhibit A.6 translates the four torque mode bit states into the values displayed in Exhibit A.4. The “value” in Exhibit A.6 is dimensionless, translating the bit state to a value that could be displayed in combination with the other values in Exhibit A.4. The percent of commanded and actual engine torque are shown in a zero-to-one hundred scale. The engine speed is translated into engine RPM in tens.

Exhibit A.6 - EEC1 Torque Mode - SPN 899

Bit State	Engine/Retarder Torque Mode	Value
0001	Accelerator Pedal/Operator Selection	0.2
0010	Cruise Control	0.4
1000	Torque Limiting (by HWC)	0.6
1110	Other (resuming cruise set speed)	0.8

Exhibit A.7 displays the time interval between subsequent EEC1 message starts. The time interval is displayed in milliseconds. The message's transmission repetition rate is engine speed dependant, so engine RPM in hundreds is shown below the start interval data.

Exhibit A.7 - HIL EEC1 Start Intervals and Engine RPM

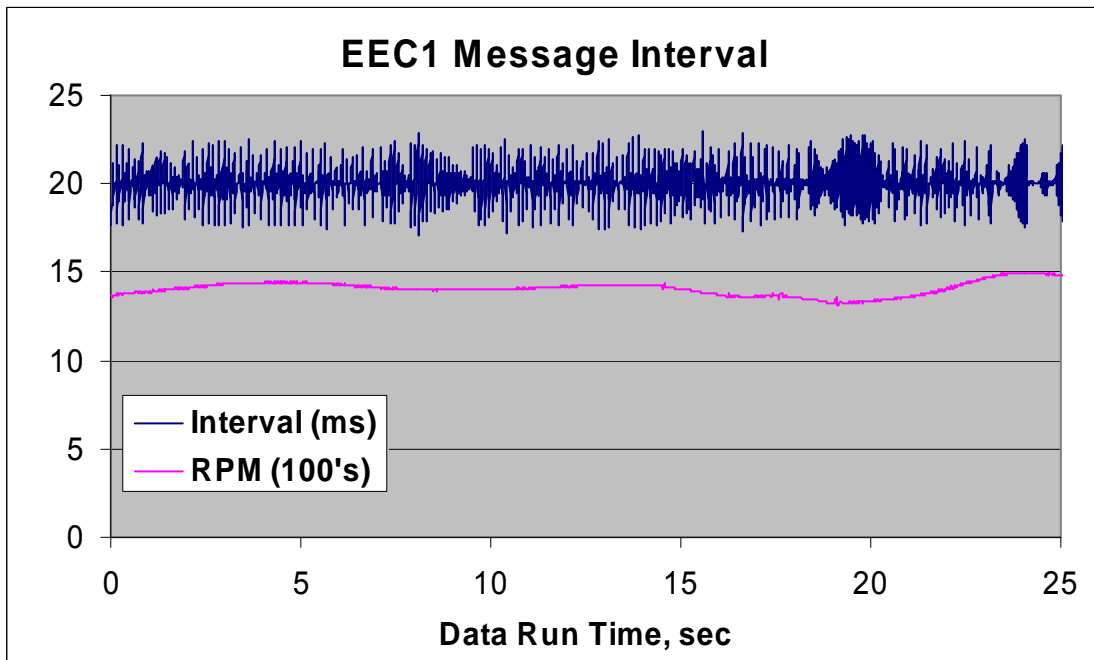


Exhibit A.8 shows data from the ACC1 message, SPN 1590 - Adaptive Cruise Control Mode. Exhibit A.9 translates the "Mode" values shown in the figure to the ACC mode from the SPN. The "Value" in Exhibit 4.9 is arbitrary. It was created to provide a graphical display of ACC mode vs. time. Comparing the ACC mode to the EEC1 engine torque mode shows that the two ECUs responsible for these messages are working together as specified.

Exhibit A.8 - HIL Adaptive Cruise Control Mode

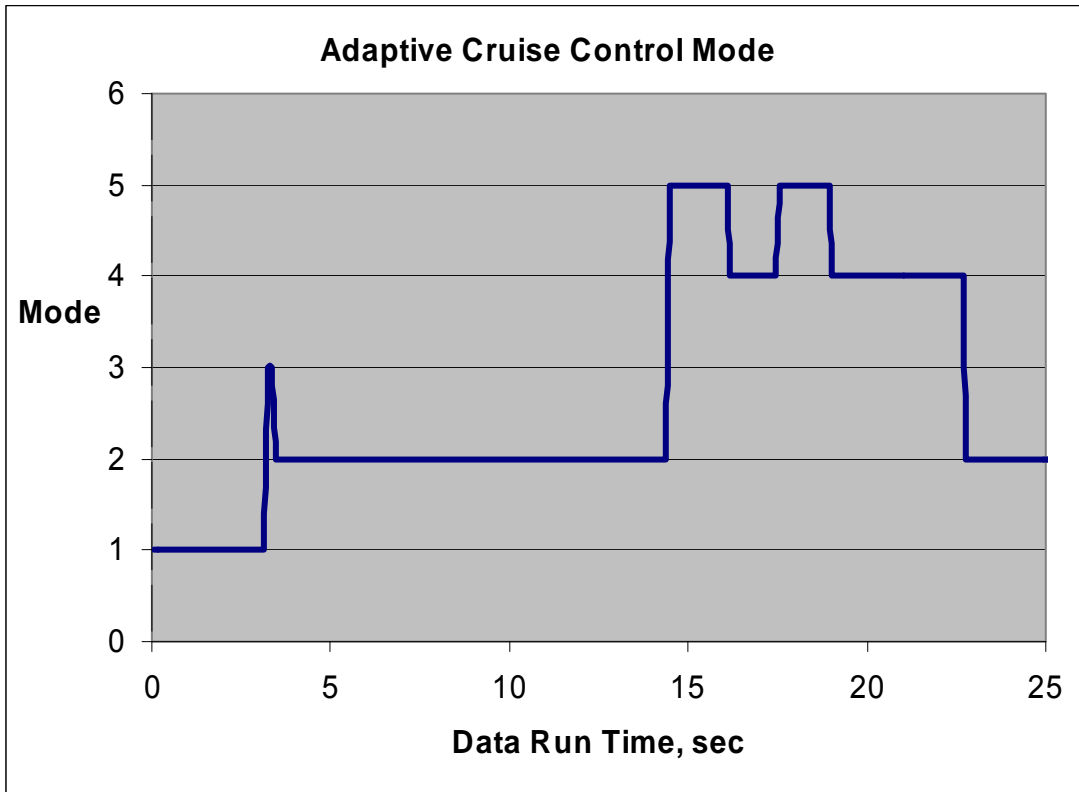
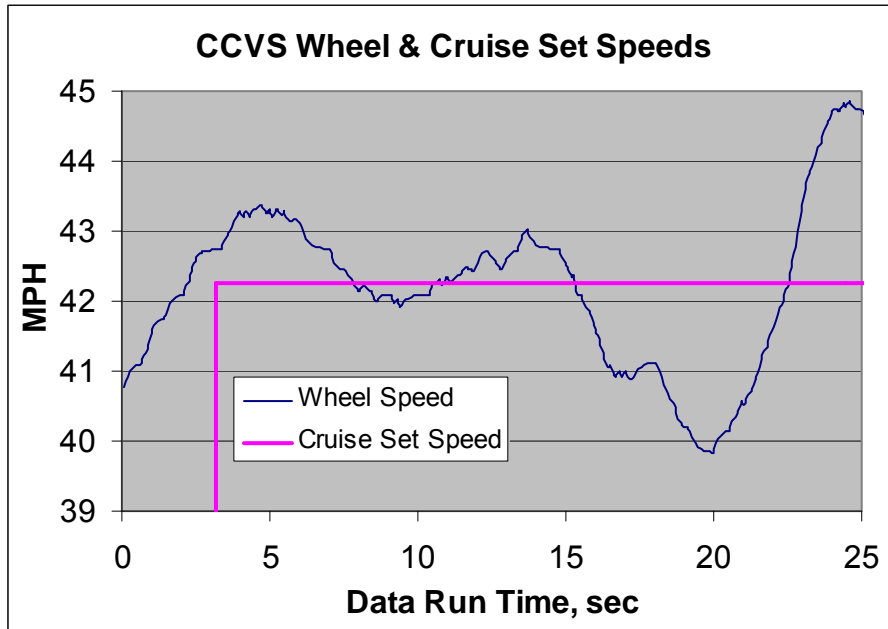


Exhibit A.9 - ACC Modes

ACC Mode	Exhibit A.8 Value
Off (Standby, Enabled, Ready for Action)	1
Speed Control Active	2
Overtake Mode	3
Finish Mode	4
Distance Control Active	5

Exhibit A.10 displays data on wheel speed and cruise control set point during the data run. These are transmitted as part of the Cruise Control/Vehicle Speed (CCVS) message, SPNs 84 and 86. The vehicle was accelerating into the start of cruise control at the three-second point. The controller attempts to establish the speed to the set point, but is interrupted by the ACC commands at the 14- and 17.5-second points. Exhibit A.10 demonstrates that the HIL was responding correctly to ACC mode state and HWC commands. At 3 seconds, the cruise is engaged and the VECU begins to slow and stabilize the speed at the set point. At 15 and 17 seconds (approximately), the HIL decelerates under headway retarding commands. At 16 and 18 seconds, the HWC begins to restore vehicle speed to the set point. At 23 seconds, the HWC returns speed control to the VECU as the speed accelerates past the set point.

Exhibit A.10 - HIL CCVS Wheel Speed and Cruise Set Point



APPENDIX B: PHYSICAL FAULT TEST DATA

Tests	J1939-11 or –15	Network Complexity	Virtual ECUs	Fault Location
PF01-10	J1939-11	Complex	4	A
PF11-20	J1939-11	Complex	4	B
PF21-30	J1939-11	Complex	0	A
PF31-40	J1939-11	Complex	0	B
PF41-50	J1939-11	Simple	0	B
PF51-60	J1939-11	Simple	0	A
PF61-70	J1939-15	Complex	4	A
PF71-80	J1939-15	Complex	4	B

PHYSICAL FAULT TEST DATA KEY	
Data Label	Description
X	Under “Indicators,” an “X” means the warning indicator illuminated once the fault was initiated. An “X” in the row labeled “Clear” means the warning indicator remained illuminated after the physical fault was cleared.
A or Blank	All functions of a device/system perform as designed during and after exposure to the physical fault. ECU fault code is not activated at any point during the test.
B	All functions of a device/system perform as designed during exposure; however, one or more functions can go beyond specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain Class A. ECU fault code is intermittently activated during fault exposure and clears when exposure is removed.
C	A function of a device/system does not perform as designed during exposure but returns automatically to normal operation after exposure is removed. ECU fault code is activated during fault exposure and clears when exposure is removed.
D	A function of a device/system does not perform as designed during exposure, or ECU fault code activates, and does not return to normal operation, or ECU fault code inactivates, until exposure is removed and the device system is reset by simple “operator/use” action.
E	One or more functions of a device/system do not perform as designed during and after exposure, or ECU fault code activates, and cannot be returned to proper operation, or ECU fault code inactivated, without repairing or replacing the device/system.

Physical Fault Test ECU Diagnostic Codes

The descriptions of the ABS, headway controller, engine, vehicle, and transmission ECU fault codes in the physical fault test data headers are listed below:

ABS ECU Diagnostic Fault Codes

17-3: MID 136 SID 231 MFI 002; J1939 data link not functioning; datalink (retarder) no communications

14-12: MID 136 SID 231 MFI 002; Time-out or no connection to engine link (J1939); Location - Data Link; engine interface timeout, no signal

17-4: MID 136 SID 231 MFI 002; J1939 data link time out; datalink (retarder) timeout

Headway Controller ECU Fault Codes

S216F11: SID 216 FMI 11 - Fail mode not identified

S231F14: SID 231 FMI 14 - J1939 Datalink special instructions

S231F2: SID 231 FMI 2 - J1939 Datalink erratic intermittent

6-2: SID 6 FMI 2 - Speedometer input erratic, intermittent

S254F12: SID 254 FMI 12 - Controller 1 bad intelligence device

S254F14: SID 254 FMI 14 - Controller 1 special instructions

S231F12: SID 231 FMI 12 - J1939 datalink bad intelligence device

Vehicle and Engine ECU Fault Codes

S216F12 6-9: SID 216 MID 142 FMI 12 - Other ECU affecting operation; possible HWC failure; other ECU failure

S231 F8 6-4E: SID 231 MID 128 FMI 8 - J1939 Link; J1939 Abnormal frequency pulse width or period; link abnormal frequency

S231 F8 6-4V: SID 231 MID 142 FMI 8 - J1939 Abnormal frequency pulse width or period; link abnormal frequency

S231 F12: SID 213 FMI 12 - J1939 link, bad intelligent device or component

S216 F11: SID 216 FMI 11 - Other ECU affecting operation, failure mode not identifiable

Transmission ECU Fault Codes

S231 F14: SID 231 FMI 14 - Loss of J1939 communication from the engine; J1939 datalink special instructions

S231F2: SID 231 FMI 2 - J1939 data link (with engine), J1939 datalink erratic intermittent

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician: GSL

Cable Type: J1939-11

Test Mode: PFT

Test Equip: TTX, VC

Equipment: PL

Lgth (net/stb): 25.24 10.54

HW: TrmB V6 V5 V3 V1 TECU EECU VECU PF A ABS CM 1 CC HWC TrmA
 TX: N N N N N

Test #	PF #	State	Indicators					Function					ABS			Headway Control				EECU & VECU			TECU											
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2				
PF01	0	Fault																																
		Clear																																
PF02	1	Fault	X	X	X	X			B	B	D		C	C		D	C		C	C			D											
		Clear			X	X				B	D					D								D										
PF03	2	Fault	X	X	X	X			B	B	D		C	C		D	C		C	C			D											
		Clear			X	X				B	D					D								D										
PF04	3	Fault	X	X	X	X			B	B	D		C			D	C		C	C			D									C		
		Clear			X	X				B	D					D								D										
PF05	4	Fault																																
		Clear																																
PF06	5	Fault	X	X	X	X			B	B	D		C										D										C	
		Clear			X	X				B	D					D							D											
PF07	6	Fault	X	X	X	X			B	B	D		C			D			C				D	C	C							C		
		Clear			X	X				B	D					D								D										
PF08	7	Fault	X	X	X	X			B	B	D		C			D			C				D	C	C							C		
		Clear			X	X				B	D					D								D										
PF09	8	Fault	X	X	X	X			B	B	D		C	C		D	C		C	C			D											
		Clear			X	X				B	D					D								D										
PF10	9	Fault																																
		Clear																																

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician: GSL

Test Mode: PFT

Equipment: PL

Cable Type: J1939-11

Test Equip: TTX, VC

Lgth (net/stb): 25.24 10.54

HW: TrmB V6 V5 V3 V1
TX: N N N N

TECU PF B EECU VECU

ABS CM 1

CC
N

HWC TmA

Test #	PF #	State	Indicators						Function					ABS			Headway Control					EECU & VECU				TECU											
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2							
PF11	0	Fault																																			
		Clear																																			
PF12	1	Fault																																			
		Clear																																			
PF13	2	Fault																																			
		Clear																																			
PF14	3	Fault	X	X	X	X			B	B	D	C	C	C		D	C	C	C	C				D	C	C									C		
		Clear			X	X				B	D						D								D												
PF15	4	Fault																																			
		Clear																																			
PF16	5	Fault	X	X	X	X			B	B	D	C	C	C												C	C									C	
		Clear			X	X				B	D														D		D										
PF17	6	Fault	X	X	X	X			B	B	D	C	C	C												C	C									C	
		Clear			X	X				B	D															D		D									
PF18	7	Fault	X	X	X	X			B	B	D	C	C	C		D		C								C	C									C	
		Clear			X	X				B	D						D									D		D									
PF19	8	Fault																																			C
		Clear																																			
PF20	9	Fault																																			
		Clear																																			

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician: GSL

Test Mode: PFT

Equipment: PL

Cable Type: J1939-11

Test Equip: TTX, VC

Lgth (net/stb): 25.24 10.54

HW: TrmB

TECU

EECU

VECU

PF A

ABS

CM 1

HWC TrmA

TX:

Test #	PF #	State	Indicators						Function					ABS			Headway Control						EECU & VECU				TECU								
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2					
PF21	0	Fault																																	
		Clear																																	
PF22	1	Fault	X	X	X	X			B	B	D			C	C	D	C	C	C	C			D												
		Clear			X	X				B	D					D								D											
PF23	2	Fault	X	X	X	X			B	B	D			C	C	D	C	C	C	C			D												
		Clear			X	X				B	D					D								D											
PF24	3	Fault	X	X	X	X			B	B	D			C		D	C	C	C	C			D	C	C			C							
		Clear			X	X				B	D					D								D											
PF25	4	Fault																																	
		Clear																																	
PF26	5	Fault	X	X	X	X			B	B	D	C	C	C		D				C				C	C									C	
		Clear			X	X				B	D					D								D											
PF27	6	Fault	X	X	X	X			B	B	D	C	C	C		D				C				C	C									C	
		Clear			X	X				B	D					D								D											
PF28	7	Fault	X	X	X	X			B	B	D	C	C	C		D	C	C	C	C	C	C		C	C			C	C					C	
		Clear			X	X				B	D					D								D											
PF29	8	Fault	X	X	X	X			B	B	D			C	C	D	C	C	C	C			D												
		Clear			X	X				B	D					D								D											
PF30	9	Fault																																	
		Clear																																	

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician: GSL

Test Mode: PFT

Equipment: PL

Cable Type: J1939-11

Test Equip: TTX, VC

Lgth (net/stb): 25.24 10.54

HW: TrmB

TECU PF B EECU VECU

ABS CM 1

HWC TrmA

TX:

Test #	PF #	State	Indicators						Function					ABS			Headway Control					EECU & VECU				TECU																	
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2													
PF31	0	Fault																																									
		Clear																																									
PF32	1	Fault																																									
		Clear																																									
PF33	2	Fault																																									
		Clear																																									
PF34	3	Fault	X	X	X	X					B	B	D	C	C	C			D	C	C	C	C			D	C	C															
		Clear			X	X						B	D							D							D																
PF35	4	Fault																																									
		Clear																																									
PF36	5	Fault	X	X	X	X					B	B	D	C	C	C			D				C					C	C														
		Clear			X	X						B	D							D							D																
PF37	6	Fault	X	X	X	X					B	B	D	C	C	C			D				C					C	C														
		Clear			X	X						B	D							D								D															
PF38	7	Fault	X	X	X	X					B	B	D	C	C	C			D				C						C	C													
		Clear			X	X						B	D							D								D															
PF39	8	Fault																																									
		Clear																																									
PF40	9	Fault																																									
		Clear																																									

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician: GSL

Test Mode: PFT

Equipment: PL

Cable Type: J1939-11

Test Equip: TTX, VC

Lgth (net/stb): 25.24 10.54

HW: TrmB

TECU PF B EECU VECU

ABS CM 1

TrmA

Test #	PF #	State	Indicators					Function					ABS			EECU & VECU				TECU																																	
			ABS	ATC	Malfunction	Shift Service	Gear "F"	ABS			Auto Sft	Man Sft	17-3	14-12	17-4				S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2																												
PF41	0	Fault																																																			
		Clear																																																			
PF42	1	Fault	X	X					B																																												
		Clear																																																			
PF43	2	Fault	X	X					B																																												
		Clear																																																			
PF44	3	Fault	X	X		X			B				C	C	C																																						
		Clear																																																			
PF45	4	Fault																																																			
		Clear																																																			
PF46	5	Fault	X	X		X			B				C	C	C																																						
		Clear																																																			
PF47	6	Fault	X	X		X			B				C	C	C																																						
		Clear																																																			
PF48	7	Fault	X	X		X			B				C	C	C																																						
		Clear																																																			
PF49	8	Fault	X	X					B																																												
		Clear																																																			
PF50	9	Fault																																																			
		Clear																																																			

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/19/04

Technician GSL

Test Mode PFT

Equipment PL

Cable Type: J1939-11

Test Equip: TTX, VC

Lgth (net/stb): 25.24 10.54

HW: TrmB

TECU

EECU

VECU

PFA

ABS

CM1

TrmA

TX:

Test #	PF #	State	Indicators					Function					ABS			EECU & VECU					TECU			
			ABS	ATC	Malfunction	Shift Service	Gear "F"	ABS		Auto Sft	Man Sft	17-3	14-12	17-4				S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2
PF51	0	Fault																						
		Clear																						
PF52	1	Fault									C	C												C
		Clear																						
PF53	2	Fault									C	C												C
		Clear																						
PF54	3	Fault	X	X	X			B		C	C	C						C	C				C	
		Clear																						
PF55	4	Fault																						
		Clear																						
PF56	5	Fault	X	X	X			B		C	C	C						C	C				C	
		Clear																						
PF57	6	Fault	X	X	X			B		C	C	C						C	C				C	
		Clear																						
PF58	7	Fault	X	X	X			B		C	C	C						C	C				C	
		Clear																						
PF59	8	Fault								C	C													C
		Clear																						
PF60	9	Fault																						
		Clear																						

SAE J1939 CAN Network Hardware-in-Loop Heavy Truck Test Bed

Physical Fault Testing

Date: 10/29/04

Technician: G

Test Mode: PFT

Equipment: PL

Cable Type: J1939-15

Test Equip: TTX, VC

Lgth (net/stb): 14.76 13.61

HW: TrmB V6 V5 V3 V1

TECU PF B EECU VECU

ABS CM 1

HWC TrmA

TX: N N N N

Test #	PF #	State	Indicators						Function					ABS			Headway Control						EECU & VECU				TECU						
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2			
PF71	0	Fault																															
		Clear																															
PF72	1	Fault																															C
		Clear																															
PF73	2	Fault																															C
		Clear																															
PF74	3	Fault	X	X	X	X			B	B	D	C	C	C		D	C	C	C	C			D	C	C			C			C		
		Clear			X	X				B	D						D							D									
PF75	4	Fault																															
		Clear																															
PF76	5	Fault	X	X	X	X			B	B	D	C	C	C		D				C				C	C						C		
		Clear			X	X				B	D						D							D									
PF77	6	Fault	X	X	X	X			B	B	D	C	C	C		D				C				C	C						C		
		Clear			X	X				B	D						D							D									
PF78	7	Fault	X	X	X	X			B	B	D	C	C	C		D				C				C	C						C		
		Clear			X	X				B	D						D							D									
PF79	8	Fault													C	C																C	
		Clear																															
PF80	9	Fault																															
		Clear																															

APPENDIX C: NETWORK LOAD TEST DATA

Tests	J1939-11 or –15	Network Complexity	Virtual ECUs	Fault Location
LT01-10	J1939-11	Complex	6	A
LT11-20	J1939-11	Complex	6	B
LT21-30	J1939-15	Complex	6	A
LT31-40	J1939-15	Complex	6	B
LT41-50	J1939-15	Simple	6	A
LT51-60	J1939-15	Simple	6	B

LOAD TEST DATA KEY	
Data Label	Description
X	Under “Indicators,” an “X” means the warning indicator illuminated once the fault was initiated. An “X” in the row labeled “Clear” means the warning indicator remained illuminated after the physical fault was cleared.
A or Blank	All functions of a device/system perform as designed during and after exposure to the physical fault. ECU fault code is not activated at any point during the test.
B	All functions of a device/system perform as designed during exposure; however, one or more functions can go beyond specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain Class A. ECU fault code is intermittently activated during fault exposure and clears when exposure is removed.
C	A function of a device/system does not perform as designed during exposure but returns automatically to normal operation after exposure is removed. ECU fault code is activated during fault exposure and clears when exposure is removed.
D	A function of a device/system does not perform as designed during exposure, or ECU fault code activates, and does not return to normal operation, or ECU fault code inactivates, until exposure is removed and the device system is reset by simple “operator/use” action.
E	One or more functions of a device/system do not perform as designed during and after exposure, or ECU fault code activates, and cannot be returned to proper operation, or ECU fault code inactivated, without repairing or replacing the device/system.

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date: 1/28/08 & 1/31/05*

Technician: G

Cable Type: J1939-11

Test Mode: PFT

Test Equip: TTX, VC

Equipment: PL

Lgth (net/stb): 14.76 13.61

HW: TrB V2 V6 V3 V1 V5 V4 TECU PF B EECU VECU ABS CM 1 HWC TrA
 TX: Y Y Y Y Y Y

Test #	PF #	State	Indicators						Function					ABS			Headway Controller						EECU & VECU				TECU		Network																						
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2	Load, Ave	Load, Pk	Errors	CFile #																	
LT11	0	Fault																																		18.01	95.67	0	L099												
		Clear																																																	
LT12	1	Fault																																					17.83	89.41	1	L102									
		Clear																																																	
LT13	2	Fault																																							18.03	82.40	2	L103							
		Clear																																																	
LT14	3	Fault	X	X	X	X				B	B	D	C	C	C			D	C	C	C	C		D	C	C		C												18.01	99.54	73	L100								
		Clear			X	X					B	D						D						D																											
LT15	4	Fault																																									18.03	94.58	1	L101					
		Clear																																																	
LT16	5	Fault	X	X	X	X				B	B	D	C	C	C			D	C	C	C	C	D	C		C	C	D		C												17.90	80.31	152	L104						
		Clear			X	X					B	D						D					D		D																										
LT17	6	Fault	X	X	X	X				B	B	D	C	C	C			D				C			C	C			C														17.90	94.35	12085	L105					
		Clear			X	X					B	D						D					D		D																										
LT18	7	Fault	X	X	X	X				B	B	D	C	C	C			D	C	C	C	C	D	C		C	C			C														18.18	99.41	10	L106				
		Clear			X	X					B	D						D					D		D																										
LT19	8	Fault												D	D																															18.10	96.10	0	L107		
		Clear												D	D																																				
LT20	9	Fault																																														19.10	98.24	0	L108
		Clear																																																	

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date: 1/31/05

Technician: G

Test Mode: PFT

Equipment: PL

Cable Type: J1939-15

Test Equip: TTX, VC

Lgth (net/stb): 14.76 13.61

HW: TrB V2 V6 V3 V1 V5 V4 TECU EECU VECU PFA ABS CM 1 HWC TrA
TX: Y Y Y Y Y Y

Test #	PF #	State	Indicators						Function						ABS			Headway Controller						EECU & VECU				TECU			Network						
			ABS	ATC	HWC Fail	Malfunction	Shift Service	Gear "F"	ABS	HWC	ACC	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F11	S231 F14	S231 F2	6-2	S254 F12	S254 F14	S231F12	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2	Load_Ave	Load_Pk	Errors	CFile #			
LT21	0	Fault																																18.23	98.08	0	L109
		Clear																																			
LT22	1	Fault	X	X	X	X				B	B	D			C	C	D	C	C	C	C		D											18.01	95.91	4	L112
		Clear			X	X				B	B	D					D						D														
LT23	2	Fault	X	X	X	X				B	B	D			C	C	D	C	C	C	C		D											17.95	99.16	1	L113
		Clear			X	X				B	B	D					D						D				D										
LT24	3	Fault	X	X	X	X				B	B	D	C	C	C		D	C	C	C	C		D	C	C			C					18.05	92.02	2	L110	
		Clear			X	X				B	B	D					D						D														
LT25	4	Fault																																18.05	98.47	2	L111
		Clear																																			
LT26	5	Fault	X	X	X	X				B	B	D	C	C	C		D	C	C	C	C	D	C	D	C	C			C				18.03	99.83	174404	L114	
		Clear			X	X				B	B	D					D					D		D													
LT27	6	Fault	X	X	X	X				B	B	D	C	C	C		D	C	C	C	C	D	C		C	C			C				18.05	98.90	80343	L115	
		Clear			X	X				B	B	D					D					D		D													
LT28	7	Fault	X	X	X	X				B	B	D	C	C	C		D				D			C	C			C					17.92	92.74	9	L116	
		Clear			X	X				B	B	D					D					D															
LT29	8	Fault	X	X	X	X				B	B	D			C	C	D	C	C	C	C		D											17.96	96.38	1	L117
		Clear			X	X				B	B	D					D						D														
LT30	9	Fault																																18.09	96.32	0	L118
		Clear																																			

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date: 2/1/05

Technician: G

Test Mode: PFT

Equipment: PL

Cable Type: J1939-15

Test Equip: TTX, VC

Lgth (net/stb): 14.76 13.61

HW: TrB V2 V6 V3 V1 V5 V4 TECU PF B EECU VECU ABS CM 1 TrA
 TX: Y Y Y Y Y Y

Test #	PF #	State	Indicators					Function				ABS			Headway Controller							EECU & VECU				TECU			Network										
			ABS	ATC	Malfunction	Shift Service	Gear "F"	ABS	Cruise	Auto Sft	Man Sft	17-3	14-12	17-4	S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2	Load Ave	Load Pk	Errors	CFFile #														
LT41	0	Fault																																					
		Clear																																					
LT42	1	Fault									C	C																											
		Clear																																					
LT43	2	Fault									C	C																											
		Clear																																					
LT44	3	Fault	X	X		X			B		C	C	C	C					C	C																			
		Clear				X																																	
LT45	4	Fault																																					
		Clear																																					
LT46	5	Fault	X	X		X			B		C	C	C	C					C	C																			
		Clear																																					
LT47	6	Fault	X	X		X			B		C	C	C	C					D	C																			
		Clear				X															D																		
LT48	7	Fault	X	X		X			B		C	C	C	C					C	C																			
		Clear																																					
LT49	8	Fault									C	C	C																										
		Clear																																					
LT50	9	Fault																																					
		Clear																																					

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date: 2/3/05 & 2/4/05*

Technician: G

Test Mode: PFT

Equipment: PL

Cable Type: J1939-15

Test Equip: TTX, VC

Lgth (net/stb): 14.76 13.61

HW: TrB V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1
 TX: Y Y Y Y Y Y

TrA

Test #	PF #	State	Indicators					Function					ABS			Headway Controller						EECU & VECU			TECU		Network													
			ABS	ATC		Malfunction	Shift Service	Gear "F"	ABS		Cruise	Auto Sft	Man Sft	17-3	14-12	17-4								S216 F12 6-9	S231 F8 6-4 E	S231 F8 6-4 V	S231 F12	S216 F11	S231 F14	S231 F2	Load, Ave	Load, Pk	Errors	CFile #						
LT51	0	Fault																																17.65	97.49	0	L139			
		Clear																																						
LT52	1	Fault	X	X							B																								17.49	94.02	2	L142		
		Clear																																				*		
LT53	2	Fault	X	X							B																									17.81	93.74	3	L143	
		Clear																																						
LT54	3	Fault	X	X		X					B		C	C	C	C																				17.83	87.79	3	L140	
		Clear																																						
LT55	4	Fault																																		17.71	86.50	0	L141	
		Clear																																						
LT56	5	Fault	X	X		X					B		C	C	C	C																				17.33	94.42	192128	L144	
		Clear																																						
LT57	6	Fault	X	X		X					B		C	C	C	C																				17.32	90.85	22178	L145	
		Clear																																						
LT58	7	Fault	X	X		X					B		C	C	C	C																				17.69	84.80	6	L146	
		Clear																																					*	
LT59	8	Fault	X	X																																	17.81	92.81	3	L147
		Clear																																					*	
LT60	9	Fault																																			18.12	97.34	0	L148
		Clear																																						

APPENDIX D: INJECTED NOISE TEST DATA

Tests	J1939-11 or – 15	Network Complexity	Virtual ECUs	Physical Fault #s
N001-005	J1939-15	Complex	6	50 Ohm Terminator
N006-010	J1939-15	Complex	6	50 Ohm Terminator
N011-015	J1939-15	Complex	6	50 Ohm Terminator
N016	J1939-15	Complex	6	50 Ohm Terminator
N017-021	J1939-15	Complex	6	50 Ohm Terminator + #9 (both)
N022	J1939-15	Complex	6	50 Ohm Terminator + #9 (both)
N023-027	J1939-15	Complex	6	50 Ohm Terminator + #9
N028-031	J1939-15	Complex	6	-
N032-036	J1939-15	Complex	6	-
N037-041	J1939-15	Complex	6	-
N042-046	J1939-15	Complex	6	-
N048-052	J1939-15	Complex	6	-
N053-057	J1939-15	Complex	6	-
N058	J1939-15	Complex	6	-
N059-063	J1939-11	Complex	6	-
N064-68	J1939-11	Complex	6	-
N069	J1939-11	Complex	6	-
N070-074	J1939-11	Complex	6	#4 – CAN_L to Gnd
N075-079	J1939-11	Complex	6	#4 – CAN_L to Gnd
N080-081	J1939-11	Complex	6	#4 – CAN_L to Gnd
N082-086	J1939-11/15	Complex	6	#10 – topology
N087-089	J1939-11/15	Complex	6	#10 – topology
N090-094	J1939-11/15	Complex	6	#10 – topology
N095	J1939-11/15	Complex	6	#10 – topology
N096-100	J1939-11/15	Complex	6	#10 & #9
N101-102	J1939-11/15	Complex	6	#10 & #9
N103-107	J1939-11	Complex	6	#9 – terminator
N108	J1939-11	Complex	6	#9 – terminator
N109-112	J1939-11/15	Complex	6	#10 & #4
N113-115	J1939-11/15	Complex	6	#10

INJECTED NOISE TEST DATA KEY	
Data Label	Description
Y	“Yes”, virtual ECUs were transmitting during the test.
N	“No”, virtual ECUs were not transmitting during the test.
P	“Pass”, result indicates no driver observable effect on vehicle performance, including no warning or malfunction indicators (even intermittent ones), and no active or intermittently active ECU fault codes.
F	“Fail”, result means some or all vehicle functions were impaired and/or indicators or active ECU fault codes presented themselves.
A or Blank	All functions of a device/system perform as designed during and after exposure to the physical fault. ECU fault code is not activated at any point during the test. ,.
B	All functions of a device/system perform as designed during exposure; however, one or more functions can go beyond specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain Class A. ECU fault code is intermittently activated during fault exposure and clears when exposure is removed. Characters following the data label refer to conditions during failure. Numbers 0-8 indicate the transmission gear selected, “i” is during ignition, “st” is during start, “dr” is drive selected on the transmission, “nas” is loss of auto shift function.
C	A function of a device/system does not perform as designed during exposure but returns automatically to normal operation after exposure is removed. ECU fault code is activated during fault exposure and clears when exposure is removed. Characters following the data label refer to conditions during failure. Numbers 0-8 indicate the transmission gear selected, “i” is during ignition, “st” is during start, “dr” is drive selected on the transmission, “nas” is loss of auto shift function.
D	A function of a device/system does not perform as designed during exposure, or ECU fault code activates, and does not return to normal operation, or ECU fault code inactivates, until exposure is removed and the device system is reset by simple “operator/use” action. Characters following the data label refer to conditions during failure. Numbers 0-8 indicate the transmission gear selected, “i” is during ignition, “st” is during start, “dr” is drive selected on the transmission, “nas” is loss of auto shift function.
E	One or more functions of a device/system do not perform as designed during and after exposure, or ECU fault code activates, and cannot be returned to proper operation, or ECU fault code inactivated, without repairing or replacing the device/system. Characters following the data label refer to conditions during failure. Numbers 0-8 indicate the transmission gear selected, “i” is during ignition, “st” is during start, “dr” is drive selected on the transmission, “nas” is loss of auto shift function.
-	Data label remained unchanged from previous (cell to the left).

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/7/2005	Cable Type:	J1939-15	Term Impd:	27.3
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.2
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	0.936
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

TrB V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N001	385	30	30	17.90	28.71	0.0	29.9	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N002	386	60	60	17.93	29.90	1.4	23.9	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N003	387	90	90	18.27	25.29	2.7	20.3	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				
N004	388	120	120	18.83	25.63	4.5	17.8	6	N	F	HWC			Ddr	-
											ABS				
											TECU				
											V/EECU				
N005	389	150	150	17.99	25.49	7.5	15.9	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/7/2005	Cable Type:	J1939-15	Term Impd:	27.3
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.2
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	0.936
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

TrB V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N006	390	180	180	17.33	25.64	5.5	14.3	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				
N007	391	210	210	17.59	26.90	5.2	13	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				
N008	392	240	240	18.81	26.15	4.5	11.8	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				
N009	396	300	300	17.74	26.66	4.7	9.9	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				
N010	397	400	400	17.99	26.16	5.5	7.4	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/7/2005	Cable Type:	J1939-15	Term Impd:	27.3
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.2
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	0.936
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

TrB V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N011	398	600	600	22.41	29.87	180.4	3.9	6	N	F	HWC	D			
											ABS	C			
											TECU	C			
											V/EECU	C			
N012	399	500	500	18.21	27.35	29.3	5.4	6	N	F	HWC	D	-	-	-
											ABS				
											TECU				
											V/EECU				
N013	3102	550	550	18.13	29.05	92.4	4.6	6	N	F	HWC	D			
											ABS	C			
											TECU	C			
											V/EECU	C			
N014	3103	70	70	18.02	33.27	2.6	22.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N015	3104	80	80			1.3	21.4	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/7/2005	Cable Type:	J1939-15	Term Impd:	27.3
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.2
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	0.936
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

TrB V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N016		110	110				18.6	6	N	F	HWC			D7	-
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/9/2005	Cable Type:	J1939-15	Term Impd:	50
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.7
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	1.271
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N017	3109	120	120	17.88	30.44	0.0	20.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N018	3110	180	180	18.66	30.95	9.8	17.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N019		300	300				12.5	6	N	F	HWC	D	-	-	-
											ABS			C2	-
											TECU				
											V/EECU			C2	-
N020	401	240	240	14.71	27.03	35.7	14.5	6	N	F	HWC	D	-	-	-
											ABS			CR	C
											TECU				
											V/EECU			CR	C
N021	402	210	210	20.18	33.02	47.1	15.6	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				C

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/9/2005	Cable Type:	J1939-15	Term Impd:	50
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.7
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	1.271
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N022	403	200	200	18.66	30.95	59.2	16.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/9/2005	Cable Type:	J1939-15	Term Impd:	35.3
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.4
Test Mode:	INT	Noise Loc:	B TECU	J1939 mVrms:	1.047
Equipment:	HP 33120A	Sensor Loc:	B TECU	Lgth (net/stb):	14.76 13.61

HW:

TrB V2 V6 V3 V1 V5 V4 NG TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N023	408	270	270	19.36	30.84	62.5	11.8	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				C
N024	405	330	330	27.77	30.47	301.2	10.0	6	N	F	HWC	D	-	-	-
											ABS			C4	-
											TECU			C4	-
											V/EECU			C4	-
N025	406	180	180	18.54	33.08	0.2	15.3	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N026		240	240	18.29	31.54	0.8	12.8	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N027	404	300	300	22.39	32.31	121.4	10.9	6	N	F	HWC	D	-	-	-
											ABS			CR	-
											TECU			CR	-
											V/EECU			CR	-

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/10/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N028	4010	120	69	18.86	29.76	0.0	26.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N029	F11	200	114	22.71	30.70	82.4	21.6	6	Int	F	HWC	D	-	-	-
											ABS		C	-	-
											TECU				
											V/EECU		C	-	-
N030	F12	240	137	19.68	29.69	0.0	20.0	0	NA	P	HWC				
											ABS				
											TECU				
											V/EECU				
N031	F13	240	137	17.88	28.26	0.0	20.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/10/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N032	F14	240	183	18.37	30.53	0.0	17.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N033	F15	270	206	18.09	29.51	0.0	16.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N034	F16	300	229	17.94	29.43	0.0	15.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N035	F17	330	252	18.56	35.80	0.0	14.7	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N036	F18	360	275	17.94	34.26	0.0	14.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/10/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N037	F19	390	298	18.01	30.64	0.0	13.3	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N038	F110	420	321	18.07	29.42	0.0	12.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N039	F111	450	344	18.26	29.70	0.1	12.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N040	F112	480	367	18.20	28.15	0.1	11.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N041	F113	510	390	18.04	32.46	0.1	10.9	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/10/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N042	F114	540	413	18.33	29.83	0.3	10.4	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N043	F115	570	436	18.03	28.42	0.1	10.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N044	F116	600	459	17.97	28.21	0.0	9.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N045	F117	630	482	19.72	28.72	0.4	9.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N046	F118	660	504	18.06	32.41	0.6	8.7	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/10/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N047	F119	690	527	18.21	31.00	1.3	8.3	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N048	F120	720	550	17.94	30.25	2.5	7.9	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N049	F121	750	573	18.05	37.69	4.8	7.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N050	F122	780	596	18.34	31.45	7.4	7.2	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N051	F123	810	619	18.91	30.49	13.6	6.9	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N052	F124	840	642	18.99	31.68	23.5	6.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N053	F125	870	665	19.72	32.80	40.5	6.3	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N054	F126	900	688	20.11	31.19	64.4	6.0	6	N	F	HWC				D
											ABS				C
											TECU				
											V/EECU				
N055	F127	930	711	22.52	34.23	70.2	5.7	6	N	F	HWC			C	D
											ABS				
											TECU				
											V/EECU				D
N056	F128	960	734	23.49	30.88	101.7	5.4	6	N	F	HWC			D	-
											ABS			CI	-
											TECU				
											V/EECU			D4	-
N057	F130	990	757	24.52	33.89	143.6	5.2	6	N	F	HWC	D	-	-	-
											ABS		C	-	-
											TECU			C	-
											V/EECU			C2	-

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	14.76 13.61

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N058	DF131	1020	780	25.63	29.03	169.4	4.9	6	N	F	HWC	D	-	-	-
											ABS		C	-	-
											TECU			C	-
											V/EECU			D2	-
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N059	F132	10	8	18.39	28.96	0.0	45.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N060	F133	600	459	18.28	27.78	0.0	9.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N061	F134	700	535	17.98	29.76	0.6	8.2	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N062	F135	800	611	18.62	31.20	9.3	7.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N063	F136	870	665	20.17	31.60	39.5	6.3	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N064	F137	900	688	21.12	29.20	57.7	6.0	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				D
N065	F138	930	711	22.65	32.97	80.0	5.7	6	N	F	HWC			D9	-
											ABS			C	-
											TECU				
											V/EECU			C7	-
N066	F139	960	734	22.93	31.53	99.5	5.4	6	N	F	HWC			D7	-
											ABS			C8i	C
											TECU				
											V/EECU			C3i	C
N067	F140	990	757	23.78	35.41	140.1	5.2	6	N	F	HWC	D	-	-	-
											ABS		C0i	Ci	C
											TECU				
											V/EECU			C2i	C
N068	F141	1020	780	18.03	25.47	71.5	4.9	6	N	F	HWC				D
											ABS			C0i	C
											TECU			C2	-
											V/EECU			C0i	C

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	2/11/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N069	F142	10	8	18.33	95.79	0.0	45.1	6	Y	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/9/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54
				Fault:	4

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N070	F159	10	8	17.85	28.56	1.7	45.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N071	F160	600	459	21.23	32.57	51.1	9.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N072	F161	700	535	24.56	32.27	111.2	8.2	6	N	F	HWC			D7	D
											ABS			D8	D
											TECU				
											V/EECU			CiD7	D
N073	F162	730	558	24.09	34.19	114.8	7.8	6	N	F	HWC			Ddr	D
											ABS		C	C	-
											TECU				
											V/EECU			Ci5	
N074	F163	760	581	24.47	33.96	124.6	7.5	6	N	F	HWC		Dst	D	-
											ABS			C5	C
											TECU				
											V/EECU			C5	C

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/9/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54
				Fault:	4

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N075	F164	790	604	26.37	34.19	129.8	7.1	6	N	F	HWC	D	-	-	-
											ABS	C	-	-	-
											TECU				
											V/EECU			C7	C
N076	F165	820	627	24.04	34.88	144.6	6.8	6	N	F	HWC	D	-	-	-
											ABS	C	-	-	-
											TECU			Cnas	-
											V/EECU			C8	-
N077	F166	850	650	27.21	30.58	151.4	6.5	6	N	F	HWC	D	-	-	-
											ABS	C	-	-	-
											TECU			Cnas	-
											V/EECU			C5	-
N078	F167	880	673	27.51	32.98	178.1	6.2	6	N	F	HWC	D	-	-	-
											ABS	D	-	-	-
											TECU			Cnas	-
											V/EECU			C5	-
N079	F168	910	696	27.29	31.24	198.6	5.9	6	N	F	HWC	D	-	-	-
											ABS	D	-	-	-
											TECU			Cnas	-
											V/EECU			C5	-

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/9/2005	Cable Type:	J1939-11	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54
				Fault:	4

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N080	F169	630	482	21.40	34.36	75.6	9.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N081	F170	660	504	22.06	35.62	97.2	8.7	6	N	F	HWC				
											ABS				
											TECU				
											V/EECU				B
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/10/2005	Cable Type:	J1939-11/15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	45.24 10.54 13.61
				Fault:	10

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N082	F171	10	8	17.93	30.18	0.0	45.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N083	F172	600	459	18.02	29.69	0.7	9.5	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N084	F173	790	604	18.30	30.86	12.0	7.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N085	F174	900	688	20.30	31.16	60.5	6.0	6	N	F	HWC			D7	D
											ABS				
											TECU				
											V/EECU			B6	
N086	F175	960	734	21.49	31.96	104.1	5.4	6	N	F	HWC		D	-	-
											ABS			B10	B
											TECU				
											V/EECU			B5	B

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/10/2005	Cable Type:	J1939-11/15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	45.24 10.54 13.61
				Fault:	10

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N088	F177	870	665	19.11	31.00	49.0	6.3	6	N	F	HWC			D0	D
											ABS				
											TECU				
											V/EECU				
N089	F178	840	642	18.69	31.62	43.4	6.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/10/2005	Cable Type:	J1939-11/15	Term Impd:	59.5			
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8			
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373			
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00	10.54	13.61	
				Fault:	10			

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N090	F179	790	604	18.29	24.99	11.2	7.1	6	N	F	HWC			D4	D
											ABS				
											TECU				
											V/EECU				
N091	F180	730	558	18.15	30.56	6.6	7.8	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				
N092	F181	700	535	18.10	30.84	6.9	8.2	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N093	-	870	665	-	-	-	6.3	6	N	F	HWC	D	na	na	na
											ABS		na	na	na
											TECU		na	na	na
											V/EECU		na	na	na
N094	-	840	642	-	-	-	6.6	6	N	F	HWC	D	na	na	na
											ABS		na	na	na
											TECU		na	na	na
											V/EECU		na	na	na

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/10/2005	Cable Type:	J1939-11/15	Term Impd:	59.5			
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8			
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373			
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00	10.54	13.61	
				Fault:	10			

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N095	-	810	619	-	-	-	6.9	6	N	F	HWC	D	na	na	na
											ABS		na	na	na
											TECU		na	na	na
											V/EECU		na	na	na
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/11/2005	Cable Type:	J1939-11/15	Term Impd:	118.2
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00 10.54 13.61
				Fault:	10 9

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N096	F182	10	8	18.11	29.86	0	45.1	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N097	F183	660	504	62.76	78.28	303.6	8.7	6	Y	F	HWC	D	-	-	-
											ABS		B	-	-
											TECU				
											V/EECU		B	-	-
N098	F184	400	306	17.97	29.85	7.0	13.0	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N099	F185	500	382	22.21	32.57	46.4	11.1	6	N	F	HWC			D3	D
											ABS				
											TECU				
											V/EECU				
N100	F186	470	359	19.82	29.96	20.5	11.6	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/11/2005	Cable Type:	J1939-11/15	Term Impd:	59.5			
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8			
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373			
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00	10.54	13.61	
				Fault:	10	9		

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N101	F187	440	336	18.91	30.74	19.7	12.2	6	N	F	HWC				D
											ABS				
											TECU				
											V/EECU				
N102	F188	420	321	18.49	31.04	11.4	12.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/11/2005	Cable Type:	J1939-11	Term Impd:	118.2
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54
				Fault:	9

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N103	-	700	535	-	-	-	8.2	6	N	F	HWC	D	na	na	na
											ABS	C	na	na	na
											TECU		na	na	na
											V/EECU	B	na	na	na
N104	-	600	459	-	-	-	9.5	6	N	F	HWC	D	na	na	na
											ABS	B	na	na	na
											TECU		na	na	na
											V/EECU		na	na	na
N105	F189	500	382	20.91	33.37	23.8	11.1	6	N	F	HWC				
											ABS				
											TECU				
											V/EECU			B7	B
N106	F190	470	359	19.03	29.75	11.8	11.6	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N107	F191	530	405	24.15	36.11	48.3	10.6	6	N	F	HWC				
											ABS			B5	B
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/11/2005	Cable Type:	J1939-11	Term Impd:	118.2
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	25.24 10.54
				Fault:	9

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N108	F192	570	436	32.59	40.53	79.1	10.0	6	N	F	HWC			D7	D
											ABS			B3	B
											TECU				
											V/EECU			B3	B
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/11/2005	Cable Type:	J1939-11/15	Term Impd:	59.5		
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8		
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373		
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00	10.54	13.61
				Fault:	10	4	

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event	
N109	-	700	535	-	-	-	8.2	6	N	F	HWC					
											ABS		B	-	-	
											TECU				D	-
											V/EECU		C	D2	-	
N110	-	600	459	-	-	-	9.5	6	N	F	HWC					
											ABS		B	-	-	
											TECU				D	-
											V/EECU		C	D2	-	
N111	-	500	382	-	-	-	11.1	6	N	F	HWC					
											ABS		B	-	-	
											TECU				D	-
											V/EECU		C	D3	-	
N112	-	10	8	-	-	-	45.1	6	N	F	HWC		D	-	-	
											ABS		C	-	-	
											TECU				C	-
											V/EECU		D	-	-	
											HWC					
											ABS					
											TECU					
											V/EECU					

Hardware-in-Loop Heavy Truck Test Bed

SAE-J1939 Network Testing

Date:	3/12/2005	Cable Type:	J1939-11/15	Term Impd:	59.5
Technician:	GGG	Test Equip:	TTX, VC	J1939 VPP:	1.8
Test Mode:	INT	Noise Loc:	TRMB	J1939 mVrms:	1.373
Equipment:	HP 33120A	Sensor Loc:	TRMB	Lgth (net/stb):	60.00 10.54 13.61
				Fault:	10

HW:

NG V2 V6 V3 V1 V5 V4 TECU EECU VECU PF A ABS CM 1 HWC TrA

Test #	CFile #	ARB mVrms	Net mVrms	Load, Ave	Load, Pk	Errors/s, Ave	S/N, dB	Sim ECUs	TX	Pass/Fail	ECU	Ignition On	Start	Drive	HWC Event
N113	-	840	642	-	-	-	6.6	6	N	F	HWC			D7	D
											ABS				
											TECU				
											V/EECU				
N114	F193	820	627	19.15	30.01	20.6	6.8	6	N	P	HWC				
											ABS				
											TECU				
											V/EECU				
N115	-	870	665	-	-	-	6.3	6	N	F	HWC			D4	D
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				
											HWC				
											ABS				
											TECU				
											V/EECU				

APPENDIX E: TEST SERIES DRIVING SCENARIOS AND TEST PROCEDURES

Detailed Test Procedures For All Driving Scenarios:

0. Determine test type (physical fault, load, or noise), desired network configuration and harness type.
1. Configure the network with proper J1939 network harness. The harnesses could consist of the J1939-11 harness (A), and/or the J1939-15 harness (B) [both listed in Exhibit 3.8] with/without a 20-meter extension made with J1939-15 cable (C).
 - a. Harness 1: (A) - Fault, Load, or Noise Testing, or
 - b. Harness 2: (B) - Fault, Load, or Noise Testing, or
 - c. Harness 3: (A) & (C) - Noise Testing only, or
 - d. Harness 4: (A) & (B) - Noise Testing only, or
 - e. Harness 5: (A), (B) & (C) - Noise Testing only
2. Configure the network as 'complex' or 'simple'. Attached the headway controller ECU to the network for complex. Remove it from the network for simple.
3. Place physical fault box in Location A or B as required. Ensure all switches are in nominal/no-induced -faults positions.
4. Connect simulated ECUs to the network as required. Physical Fault or Noise Tests: Establish Simulated ECUs as non-powered or monitoring-only as applicable. For Load Tests: active the simulated ECU's controller applications so they are waiting trigger. Ensure HOST computer triggering application for the simulated controller applications is running properly and the trigger control key set.
5. Noise Tests Only: Connect Gaussian noise injector to the network. Add additional resistor between CAN_H and CAN_L, as required. Establish injected noise at desired level. Measure effective bus noise level with digital oscilloscope and record.
6. CAN monitoring PC operational and monitoring program running awaiting data logging command.
7. Digital oscilloscope connected to the network and operating.
8. CAN card connected to the network and powered as required.
9. All target PCs on, target operating systems and applications loaded, and communications with HOST PC nominal.
10. Transmission shift controller to NEUTRAL.

11. Ignition switch to ON.
12. Observe that no inappropriate MIL or other indicators are active. Transmission X-Y shifter moves, if required, and indicates neutral. All ECUs pass self-tests.
13. Poll all COTS ECUs with J1587 service tool. Observe no active ECU faults. Clear or record the number and type of inactive ECU faults, as required.
14. Ignition switch to START HIL simulator. Observe nominal idling RPM, MIL, and other indicators. Depress brake pedal to complete ABS self-test if needed.
15. Release parking brake and trailer brake. Depress brake pedal and observe zero mph and brake light indicator.
16. Transmission shift controller to DRIVE. Observe no shift or gear indicator change.
17. Depress clutch and observe transmission shift to "2".
18. Release brake pedal, accelerate engine, and release clutch pedal to begin truck motion.
19. Rapid (full pedal deflection) acceleration to 60 mph. Observe nominal automated shifting from gears 2 through 10.
20. Passing 35 mph, turn cruise controller ON.
21. Established at 60 mph for at least five seconds, activate cruise control SET button.
22. Commence CAN data logging.
23. Load Tests only: Trigger Simulated controller applications to commence TSC1 message broadcasts.
24. Complex Network Tests only: Initiate collision warning/adaptive cruise control event.
25. Complex Network Tests only: When ACC begins to reaccelerate the truck after the CWS following-distance-all-clear, allow a partial velocity recovery.
26. Complex Network Tests only: At a velocity of 52-55 mph, initiate the second collision warning/adaptive cruise control event.
27. Initiate physical fault using the fault box or removal of terminating resistor if required. Complex Network Tests only: accomplish within 1 second of the CWS following-distance-all-clear.
28. Commence emergency (full pedal deflection) braking, within 1 second of physical fault initiation. Hold brake pedal until speed decreases to below 35 mph but above 25 mph

(cruise control cut off point). Observe ABS operation on break pedal relief valves upon initial activation.

29. Rapidly accelerate (full pedal deflection) to 60 mph if possible, or to maximum speed attainable without changing transmission shifter if less than 60 mph.
30. RESUME cruise control, if possible.
31. Allow cruise control to re-establish 60 mph if possible; otherwise, maintain highest speed possible with accelerator pedal up to 60 mph.
32. While maintaining speed from previous step, observe, and record all MIL and other indicators. Using the J1587 service tool, record all active ECU faults and any additional inactive faults since commencing the test run.
33. Check alternate transmission modes if automated shifting is malfunctioning. Check for independent ABS and CWS operation if they exhibit active faults or MIL indicators. Record results.
34. With truck reestablished in cruise control at 60 mph or manually held at highest speed possible up to 60 mph, clear physical fault, if applicable.
35. If not already at 60 mph, rapidly accelerate to 60 mph.
36. RESUME cruise control if possible.
37. Stop CAN data logging.
38. Record active MIL, other indicators and use J1587 service tool to record active faults, if any, and inactive fault type and count.
39. Normal deceleration using partial brake deflection to 0 mph. Observe no ABS operation.
40. Passing 700 RPM, depress clutch pedal. At 0 mph, observe transmission gear indicator reads "2".
41. Ignition switch to OFF. Wait 15 seconds.
42. Ignition switch to ON. Observe no active ECU faults.
43. Ignition switch to OFF. Test complete.

Physical Fault Test Scenario

1	Ignition ON
2	Start HIL simulator
3	Engine Idling
4	Transmission to Drive
5	Observe automated shift to "2"
6	Disengage clutch, accelerate engine, engage clutch
7	Rapid acceleration to 60 mph
8	Engage cruise control at 35 mph
9	Set cruise control at 60 mph
10	Data Collection ON
11	Collision Warning & Adaptive Cruise Control Event
12	Allow partial ACC velocity recovery
13	2 nd CWS & ACC Event
14	Physical Fault initiation
15	Emergency deceleration event activating ABS response
16	Rapid acceleration to 60 mph (if possible)
17	"RESUME" cruise control (if possible)
18	Reestablished at 60 mph (if possible)
19	Clear Physical Fault
20	Rapid acceleration to 60 mph (if possible)
21	"RESUME" cruise control (if possible)
22	Re-established at 60 mph (if possible)
23	Data Collection OFF
24	Normal deceleration to full stop
25	Ignition OFF

Loading Test Series

1	Ignition On
2	Start HIL simulator
3	Engine Idling
4	Transmission to Drive
5	Observe automated shift to "2"
6	Disengage clutch, accelerate engine, engage clutch
7	Rapid acceleration to 60 mph
8	Engage cruise control at 35 mph
9	Set cruise control at 60 mph
10	Data Collection ON
11	Initiate Virtual ECU TSC1 messages
12	Collision Warning & Adaptive Cruise Control Event
13	Allow partial ACC velocity recovery
14	2 nd CWS & ACC Event
15	Physical Fault initiation (if applicable)
16	Emergency deceleration event activating ABS response
17	Rapid acceleration to 60 mph (if possible)
18	"RESUME" cruise control (if possible)
19	Reestablished at 60 mph (if possible)
20	Clear Physical Fault (if applicable)
21	Rapid acceleration to 60 mph (if possible)
22	"RESUME" cruise control (if possible)
23	Re-established at 60 mph (if possible)
24	Data Collection OFF
25	Normal deceleration to full stop
26	Ignition OFF

Injected Noise Test Scenario

1	Establish injected noise level
2	Ignition On
3	Start HIL simulator
4	Engine Idling
5	Transmission to Drive
6	Observe automated shift to "2"
7	Disengage clutch, accelerate engine, engage clutch
8	Rapid acceleration to 60 mph
9	Engage cruise control at 35 mph
10	Set cruise control at 60 mph
11	Data Collection ON
12	Collision Warning & Adaptive Cruise Control Event
13	Allow partial ACC velocity recovery
14	2 nd CWS & ACC Event
15	Physical Fault initiation (if applicable)
16	Emergency deceleration event activating ABS response
17	Rapid acceleration to 60 mph (if possible)
18	"RESUME" cruise control (if possible)
19	Re-established at 60 mph (if possible)
20	Clear Physical Fault (if applicable)
21	Rapid acceleration to 60 mph (if possible)
22	"RESUME" cruise control (if possible)
23	Re-established at 60 mph (if possible)
24	Data Collection OFF
25	Normal deceleration to full stop
26	Ignition OFF

APPENDIX F: TEST MATRIX

Test Matrix Key	
Column Heading	Section Reference
Physical Fault	Physical fault number 0-10, Section 3.2.1, Exhibit 3.2
Physical Fault Location	A or B Section 3.2.1; Exhibits 2.2, 4.3, and 4.5
Injected Traffic	Simulated ECU network traffic in percent of bus capacity Section 3.3.1
COTS ECUs	Number of COTS ECUs on Network Sections 3.1.1 and 3.1.2, Exhibit 2.2
Simulated ECUs	Number of Simulated ECUs Network Sections 3.1.1 and 3.1.2, Exhibit 2.2
SimECU Non-Powered	Simulated ECU with no power
SimECU Monitoring Only	Simulated ECU with power, monitoring bus only
SimECU Active	Simulated ECU actively transmitting
SimECU Controller Apps	Total number of CA's transmitting on all Simulated ECUs
Network Complexity	Simple = No HWC; Complex = with HWC Section 3.1.2
Harness Type	-11 TSP or -15 UTP Section 3.1.4, Exhibit 3.8
Bus Length	End-to-end main J1939 bus length Exhibit 3.8
Stub Length	Sum of the individual ECU to main bus stubs Exhibit 3.8
Driving Scenario	Physical Fault, Load or Noise Driving scenario Section 3.1.6, Appendix E
Injected Noise	Gaussian noise injected at bus end Section 3.1.5 and 3.4
Noise Level	Effective injected noise level in millivolts RMS Section 3.4, Appendix D
CAN monitoring	Vector CANalyzer CAN monitor/recorder Section 2.1.3
Signal Monitoring	Tektronix oscilloscope on network Section 2.1.3
CAN card	Softing CAN card on network, not used for data collection

TEST MATRIX DATA KEY	
Data Label	Description
Y	Yes
N	No
PF	Physical Fault
LT	Load Test
NT	Noise Test
C	Complex
S	Simple

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
PF01	0	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	N	Y
PF02	1	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF03	2	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF04	3	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF05	4	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	N	Y
PF06	5	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF07	6	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF08	7	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF09	8	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF10	9	A	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	N	Y
PF11	0	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	N	Y
PF12	1	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF13	2	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF14	3	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF15	4	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	N	Y
PF16	5	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF17	6	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF18	7	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF19	8	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	Y	-	Y	Y
PF20	9	B	0	5	4	4	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF21	0	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF22	1	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF23	2	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF24	3	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF25	4	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF26	5	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF27	6	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF28	7	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF29	8	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF30	9	A	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
PF31	0	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF32	1	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF33	2	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF34	3	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF35	4	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF36	5	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF37	6	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF38	7	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF39	8	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF40	9	B	0	5	0	-	-	-	-	C	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF41	0	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF42	1	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF43	2	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF44	3	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF45	4	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF46	5	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF47	6	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF48	7	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF49	8	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF50	9	B	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF51	0	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF52	1	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF53	2	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF54	3	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF55	4	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y
PF56	5	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF57	6	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF58	7	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF59	8	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	Y	Y
PF60	9	A	0	4	0	-	-	-	-	S	-11	25.24	10.54	PF	N	-	Y	Y	N	-	N	Y

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
PF61	0	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y
PF62	1	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF63	2	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF64	3	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF65	4	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y
PF66	5	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF67	6	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF68	7	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF69	8	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF70	9	A	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y
PF71	0	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y
PF72	1	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF73	2	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF74	3	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF75	4	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y
PF76	5	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF77	6	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF78	7	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF79	8	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	Y	Y
PF80	9	B	0	5	4	4	-	-	-	C	-15	14.76	13.61	PF	N	-	Y	Y	N	-	N	Y

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
LT01	0	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT02	1	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT03	2	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT04	3	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT05	4	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT06	5	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT07	6	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT08	7	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT09	8	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT10	9	A	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT11	0	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT12	1	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT13	2	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT14	3	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT15	4	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT16	5	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT17	6	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT18	7	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT19	8	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	Y	Y
LT20	9	B	74	5	6	-	-	6	12	C	-11	25.24	10.54	LT	N	-	Y	Y	N	-	N	Y
LT21	0	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT22	1	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT23	2	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT24	3	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT25	4	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT26	5	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT27	6	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT28	7	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT29	8	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT30	9	A	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
LT31	0	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT32	1	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT33	2	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT34	3	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT35	4	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT36	5	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT37	6	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT38	7	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT39	8	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT40	9	B	74	5	6	-	-	6	12	C	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT41	0	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT42	1	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT43	2	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT44	3	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT45	4	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT46	5	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT47	6	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT48	7	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT49	8	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT50	9	B	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT51	0	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT52	1	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT53	2	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT54	3	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT55	4	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y
LT56	5	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT57	6	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT58	7	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT59	8	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	Y	Y
LT60	9	A	74	4	6	-	-	6	12	S	-15	14.76	13.61	LT	N	-	Y	Y	N	-	N	Y

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
N001	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	30	Y	Y	N	50 Ω	N	N/A
N002	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	60	Y	Y	N	50 Ω	N	N/A
N003	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	90	Y	Y	N	50 Ω	Y	N/A
N004	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	120	Y	Y	N	50 Ω	Y	N/A
N005	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	150	Y	Y	N	50 Ω	Y	N/A
N006	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	180	Y	Y	N	50 Ω	Y	N/A
N007	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	210	Y	Y	N	50 Ω	Y	N/A
N008	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	240	Y	Y	N	50 Ω	Y	N/A
N009	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	300	Y	Y	N	50 Ω	Y	N/A
N010	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	400	Y	Y	N	50 Ω	Y	N/A
N011	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	600	Y	Y	N	50 Ω	Y	N/A
N012	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	500	Y	Y	N	50 Ω	Y	N/A
N013	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	550	Y	Y	N	50 Ω	Y	N/A
N014	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	70	Y	Y	N	50 Ω	N	N/A
N015	0	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	80	Y	Y	N	50 Ω	N	N/A
N016	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	110	Y	Y	N	50 Ω	Y	N/A
N017	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	120	Y	Y	N	50 Ω	N	N/A
N018	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	180	Y	Y	N	50 Ω	N	N/A
N019	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	300	Y	Y	N	50 Ω	Y	N/A
N020	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	240	Y	Y	N	50 Ω	Y	N/A
N021	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	210	Y	Y	N	50 Ω	Y	N/A
N022	9,9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	200	Y	Y	N	50 Ω	N	N/A
N023	9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	270	Y	Y	N	50 Ω	Y	N/A
N024	9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	330	Y	Y	N	50 Ω	Y	N/A
N025	9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	180	Y	Y	N	50 Ω	N	N/A
N026	9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	240	Y	Y	N	50 Ω	N	N/A
N027	9	A	0	5	6	-	6	-	-	C	-15	14.76	13.61	NT	Y	300	Y	Y	N	50 Ω	Y	N/A
N028	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	69	Y	Y	N	-	N	N/A
N029	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	114	Y	Y	N	-	Y	N/A

Test #	Physical Fault SAE J1939 Section 7.4		Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
N030	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	137	Y	Y	N	-	N	N/A
N031	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	137	Y	Y	N	-	N	N/A
N032	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	183	Y	Y	N	-	N	N/A
N033	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	206	Y	Y	N	-	N	N/A
N034	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	229	Y	Y	N	-	N	N/A
N035	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	252	Y	Y	N	-	N	N/A
N036	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	275	Y	Y	N	-	N	N/A
N037	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	298	Y	Y	N	-	N	N/A
N038	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	321	Y	Y	N	-	N	N/A
N039	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	344	Y	Y	N	-	N	N/A
N040	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	367	Y	Y	N	-	N	N/A
N041	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	390	Y	Y	N	-	N	N/A
N042	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	413	Y	Y	N	-	N	N/A
N043	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	436	Y	Y	N	-	N	N/A
N044	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	459	Y	Y	N	-	N	N/A
N045	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	482	Y	Y	N	-	N	N/A
N046	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	504	Y	Y	N	-	N	N/A
N047	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	690	Y	Y	N	-	N	N/A
N048	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	550	Y	Y	N	-	N	N/A
N049	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	573	Y	Y	N	-	N	N/A
N050	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	596	Y	Y	N	-	N	N/A
N051	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	619	Y	Y	N	-	N	N/A
N052	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	642	Y	Y	N	-	N	N/A
N053	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	665	Y	Y	N	-	N	N/A
N054	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	688	Y	Y	N	-	Y	N/A
N055	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	711	Y	Y	N	-	Y	N/A
N056	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	734	Y	Y	N	-	Y	N/A
N057	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	757	Y	Y	N	-	Y	N/A
N058	0	A	0	5	6	6	-	-	-	C	-15	14.76	13.61	NT	Y	780	Y	Y	N	-	Y	N/A

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
N059	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	8	Y	Y	N	-	N	N/A
N060	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	459	Y	Y	N	-	N	N/A
N061	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	535	Y	Y	N	-	N	N/A
N062	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	611	Y	Y	N	-	N	N/A
N063	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	665	Y	Y	N	-	N	N/A
N064	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	688	Y	Y	N	-	Y	N/A
N065	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	711	Y	Y	N	-	Y	N/A
N066	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	734	Y	Y	N	-	Y	N/A
N067	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	757	Y	Y	N	-	Y	N/A
N068	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	780	Y	Y	N	-	Y	N/A
N069	0	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	8	Y	Y	N	-	N	N/A
N070	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	8	Y	Y	N	-	N	N/A
N071	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	459	Y	Y	N	-	N	N/A
N072	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	535	Y	Y	N	-	Y	N/A
N073	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	558	Y	Y	N	-	Y	N/A
N074	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	581	Y	Y	N	-	Y	N/A
N075	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	604	Y	Y	N	-	Y	N/A
N076	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	627	Y	Y	N	-	Y	N/A
N077	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	650	Y	Y	N	-	Y	N/A
N078	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	673	Y	Y	N	-	Y	N/A
N079	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	696	Y	Y	N	-	Y	N/A
N080	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	482	Y	Y	N	-	N	N/A
N081	4	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	504	Y	Y	N	-	Y	N/A
N082	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	8	Y	Y	N	-	N	N/A
N083	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	459	Y	Y	N	-	N	N/A
N084	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	604	Y	Y	N	-	N	N/A
N085	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	688	Y	Y	N	-	Y	N/A
N086	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	734	Y	Y	N	-	Y	N/A
N087	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	757	Y	Y	N	-	Y	N/A

Test #	Physical Fault SAE J1939 Section 7.4	Fault Location	Injected Network Traffic, % of max	COTS ECUs	Simulated ECUs	SimECUs Non Powered	SimECUs Monitoring Only	SimECUs Active	SimECU Controller Applications	Network: Complex or Simple	Harness Type: -11, -15 or mix	Bus Length, End-to-End meters	Stub Length, Sum Total meters	Driving Scenario: Physical Fault, Load or Noise	Injected Noise?	Noise Level, millivolts RMS	CAN Monitoring	Signal Monitoring	CAN card	Additional Impedance	Network Communications Failure(s)?	Complies with SAE J1939 Standards?
N088	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	665	Y	Y	N	-	Y	N/A
N089	10	A	0	5	6	6	-	-	-	C	Mix	40.00	24.15	NT	Y	642	Y	Y	N	-	N	N/A
N090	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	604	Y	Y	N	-	Y	N/A
N091	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	558	Y	Y	N	-	Y	N/A
N092	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	535	Y	Y	N	-	N	N/A
N093	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	665	Y	Y	N	-	Y	N/A
N094	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	642	Y	Y	N	-	Y	N/A
N095	10	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	619	Y	Y	N	-	Y	N/A
N096	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	8	Y	Y	N	-	N	N/A
N097	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	504	Y	Y	N	-	Y	N/A
N098	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	306	Y	Y	N	-	N	N/A
N099	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	382	Y	Y	N	-	Y	N/A
N100	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	359	Y	Y	N	-	Y	N/A
N101	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	336	Y	Y	N	-	Y	N/A
N102	10,9	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	321	Y	Y	N	-	N	N/A
N103	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	535	Y	Y	N	-	Y	N/A
N104	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	459	Y	Y	N	-	Y	N/A
N105	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	382	Y	Y	N	-	Y	N/A
N106	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	359	Y	Y	N	-	N	N/A
N107	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	405	Y	Y	N	-	Y	N/A
N108	9	A	0	5	6	6	-	-	-	C	-11	25.24	10.54	NT	Y	436	Y	Y	N	-	Y	N/A
N109	10,4	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	535	Y	Y	N	-	Y	N/A
N110	10,4	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	459	Y	Y	N	-	Y	N/A
N111	10,4	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	382	Y	Y	N	-	Y	N/A
N112	10,4	A	0	5	6	6	-	-	-	C	Mix	60.00	24.15	NT	Y	8	Y	Y	N	-	Y	N/A
N113	10	A	0	5	6	6	-	-	-	C	Mix	45.24	10.54	NT	Y	642	Y	Y	N	-	Y	N/A
N114	10	A	0	5	6	6	-	-	-	C	Mix	45.24	10.54	NT	Y	627	Y	Y	N	-	N	N/A
N115	10	A	0	5	6	6	-	-	-	C	Mix	45.24	10.54	NT	Y	665	Y	Y	N	-	Y	N/A



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