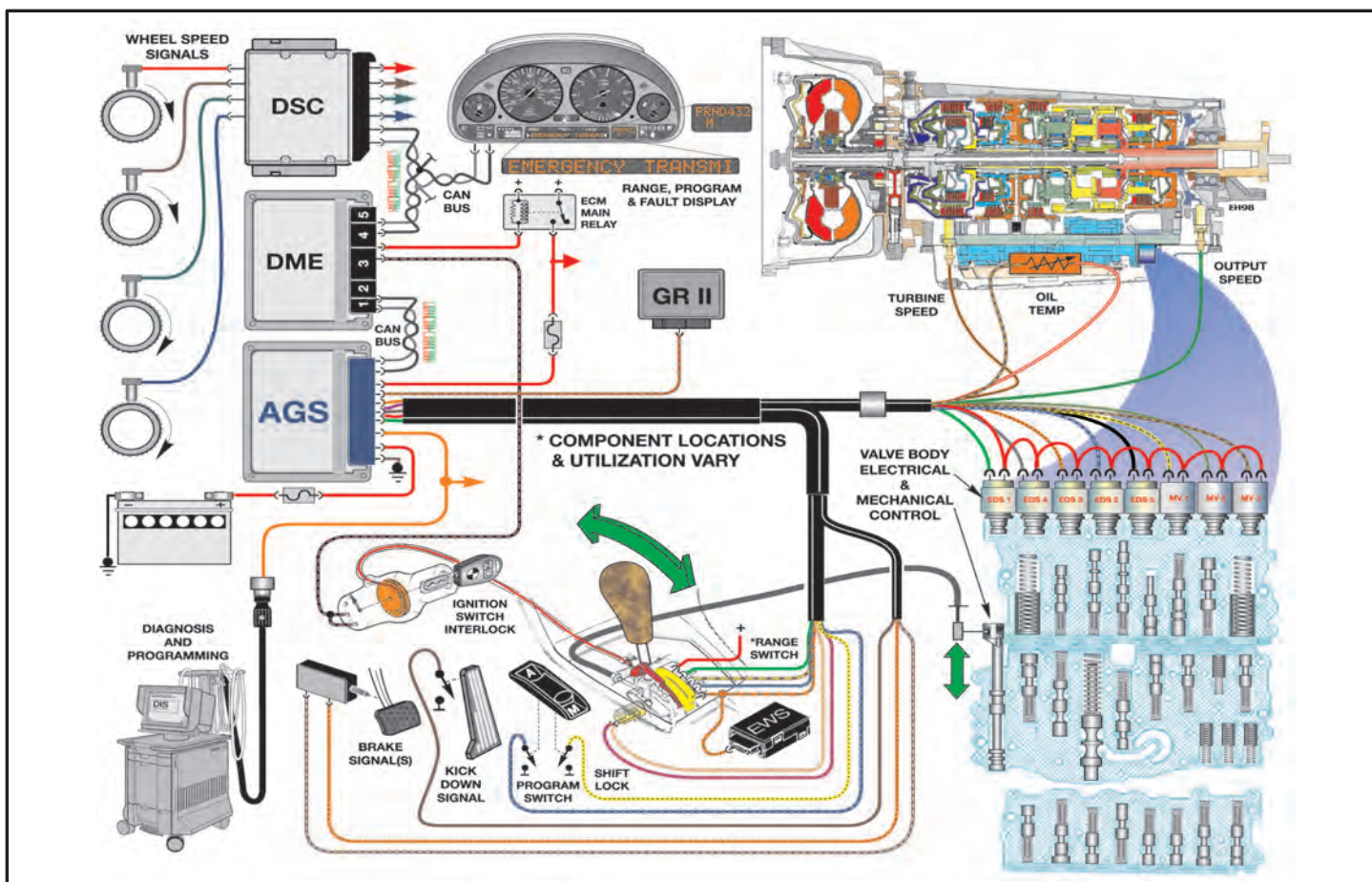


BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

Bus communication has been a necessary and vital aspect to vehicle operation. It began with manufacturer specific communication protocols such as SCP (Standard Corporate Protocol), SCI (Serial Communication Interface), CCD (Chrysler Collision Detection), PCI (Programmable Communication Interface), UART (Universal Asynchronous Receiver Transmitter) and Class 2 Data Bus to name a few. As more modules were being introduced to the network, the need to reduce wiring arose. Controller Area Network (CAN), was originally developed by Intel and Bosch to do just that, decrease the sizes of wiring harnesses. Additionally, since automakers shared the same subcontractors to provide the computers and wiring, this also caused a need for standardization. The CAN protocol Intel and Bosch developed was widely received and became the most used bus communication method in the automotive industry. Its open architecture provided flexibility for the automakers and was a welcome solution for subcontractors.

This system of communication was further refined by the International Organization for Standardization otherwise known as ISO. Although there has been standardization, vehicles use more than one protocol of communication. It's up to the technician to determine which protocol is used. Not knowing the type of communication protocol that is having a problem makes it very difficult to know your diagnostic approach.

The aim of this presentation in ATSG's 2017 seminar is to get you acquainted with the various communication protocols to assist you in diagnosing them.





Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

Diagnosing BUS communication issues begins with understanding the various means by which a manufacturer chooses to have their on-board computer systems speak to each other. BUS Communication malfunction is difficult for many to diagnose due to one or more of the following possibilities:

1. Not being familiar or comfortable with using a scope. This is a necessary tool for diagnosing BUS communication issues. It is imperative that one takes the time to learn how to use scope.
2. Not familiar with Bus Communication terminology
3. Not able to distinguish the difference between a scan tool communication issue with a system communication issue
4. Not understanding the various BUS communications in existence.
 - a) Through the years various BUS communication methods were used among manufacturers.
 - b) Even after BUS communication has been standardized, vehicles use more than one type of BUS communication
 - c) Without understanding the type of BUS communication that is having a problem, it is impossible to be able to diagnose it.

Vocabulary

1. Protocol: A set of rules or a standard used between computers (electronic control modules). This includes the type of electrical connectors, voltage levels and frequency of the transmitted messages. In short, the hardware and software needed to communicate between modules.
2. Network: a group or system of interconnected people or things
3. Bus: A term used to describe a communications network
4. Serial Data Bus: Serial communication is the process of sending data one bit at a time, sequentially, over a communication channel (computer bus).
 - a) Class A: 10Kbps (kilobits per second) – Low speed communication
 - b) Class B: Between 10Kbps and 125Kbps – Medium speed communication
 - c) Class C: Between 10Kbps and 1,000Kbps – High speed communication
5. Master/slave: In computer networking, master/slave is a model for a communication protocol in which one device or process (known as the master) controls one or more other devices or processes (known as slaves). Once the master/slave relationship is established, the direction of control is always from the master to the slave(s). Being that this phrase may be offensive, equipment manufacturers may use the term primary and secondary modules.
6. Multiplexing: a method of sending multiple signals or streams of information over a communications link at the same time in the form of a single, complex signal. The receiver recovers the separate signals, a process called demultiplexing.
7. Node: A connection point, a redistribution point, or a communication end point (an electronic device that is attached to the network: See figure 1).
8. Binary: Binary describes a numbering scheme in which there are only two possible values for each digit: 0 and 1 (Figure 2).
9. Bit: Short for binary digit. It is the smallest unit of data in a computer. A bit has a single binary value of either 0 or 1 (Figure 2).
10. Bus Arbitration: A method used to decide who has control over the BUS
11. Gateway: a network node equipped with interfacing with another network that uses different protocols (speeds).
12. Terminating Resistors: Resistors in the can bus communication network to prevent reflections or ringing in the electrical signal.



Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

13. Encoding: The process of putting a sequence of characters (i.e. numbers) into a specialized format for efficient transmission or storage. Decoding is the opposite process – the conversion of an encoded format back into the original sequence of characters. Microprocessors only recognize binary code 0 and 1. If a digital signal is transmitted. The voltage changing must be interpreted by the receiver. For the receiver to extract the data it must know the defining conditions that make the bus voltage change to 1 or 0
14. Topology: the arrangement or structure of the various nodes in a computer network. It may be in reference to its physical structure or to its logical structure.
15. Data Frame: a binary structure packet which arbitrates, delivers data, has error detection methods and looks for the acknowledgment that the information was received.
16. ISO (International Standards Organization): A popular name for International Organization For Standardization. ISO is an independent, non-governmental international organization with a membership of 161 national standards bodies. They define the various protocols in vehicle communications.
17. Layer: the different aspects that make up the communication system in both hardware and software which is standardized by ISO.
18. Keyword: Commands or parameters.
19. Synchronous: A way to define BUS access, or time divisions between the nodes. This type of communications has a known timing event between the modules. A clock signal known to both transmitters and receiver sets up events. Since this timing signal is more susceptible to radiated emission it is not used in vehicle networking.
20. Asynchronous: A way to define BUS access, or time division that takes place between the nodes. On this BUS arrangement there is not a common clock. The nodes are event driven so no node knows when to expect messages. Transmitters provide their own clocking, and receivers recover bit timing off of the edges of the signal. Summary: Synchronous and asynchronous transmissions are two different methods of transmission synchronization. Synchronous transmissions are synchronized by an external clock, while asynchronous transmissions are synchronized by special signals along the transmission medium.
21. Bit Stuffing: To ensure enough transitions to maintain synchronization, a bit of opposite polarity is inserted after five consecutive bits of the same polarity. This practice is called bit stuffing, and is necessary due to the non-return to zero (NRZ) coding used with CAN. The stuffed data frames are de-stuffed by the receiver.

EXAMPLE OF NODES

- | | |
|-------------------|---------------------------|
| • Engine | • Power Seat Controls |
| • Transmission | • Tilt/telescope Steering |
| • Brakes | • Theft Deterrent |
| • Suspension | • Horn |
| • Radio | • Trunk Lock |
| • Amplifier | • Headlights |
| • Cd Player | • Turn Signals |
| • Remote CD | • Courtesy Lights |
| • Power Antenna | • Brake Light |
| • Cellular | • Trip Computer |
| • Window Switches | • Navigation |
| • Door Locks | • Instrument Cluster |
| • Power Mirrors | • Air Conditioning |
| • Cruise Control | • Electronic Diagnostics |

Figure 1

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

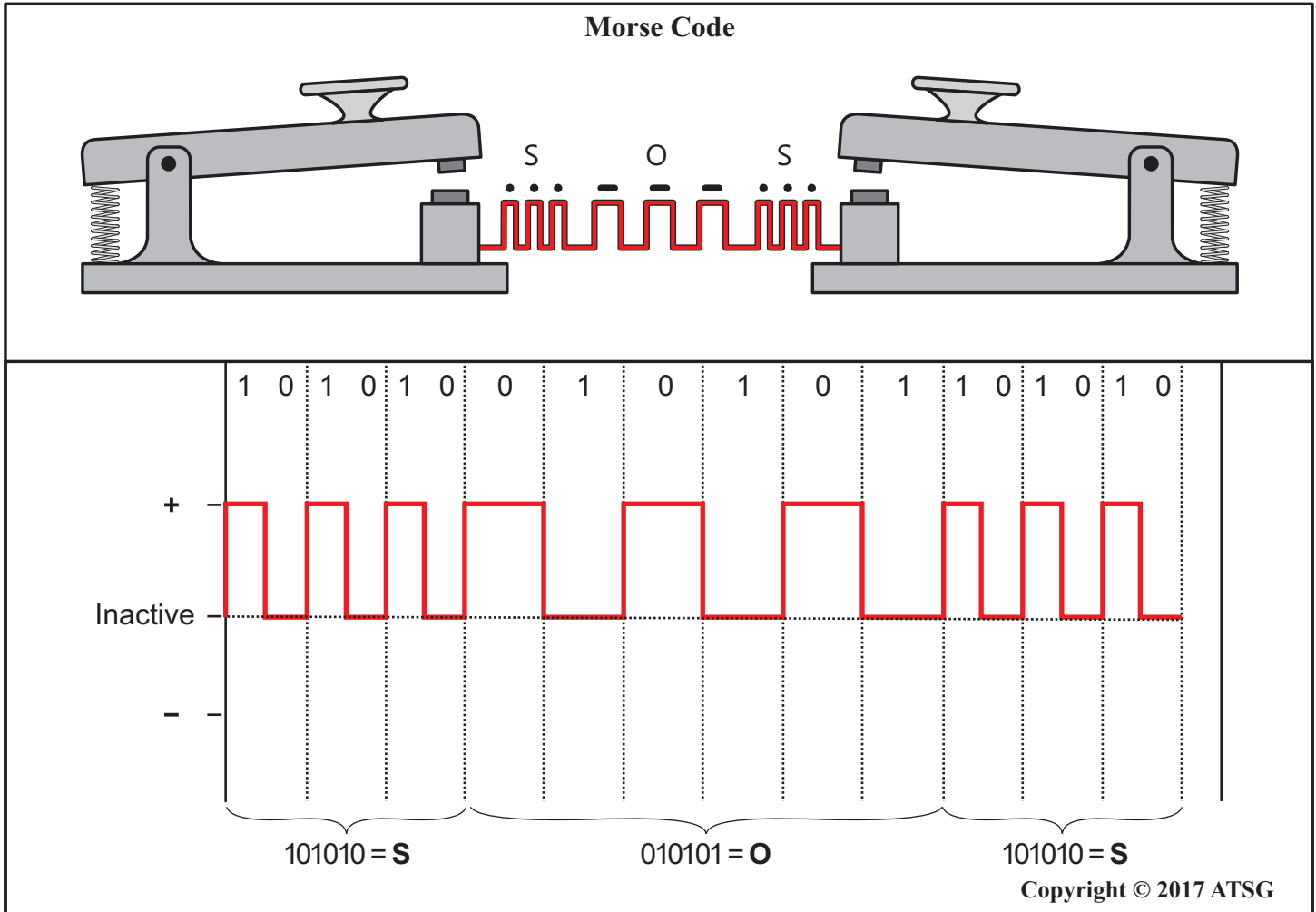


Figure 2

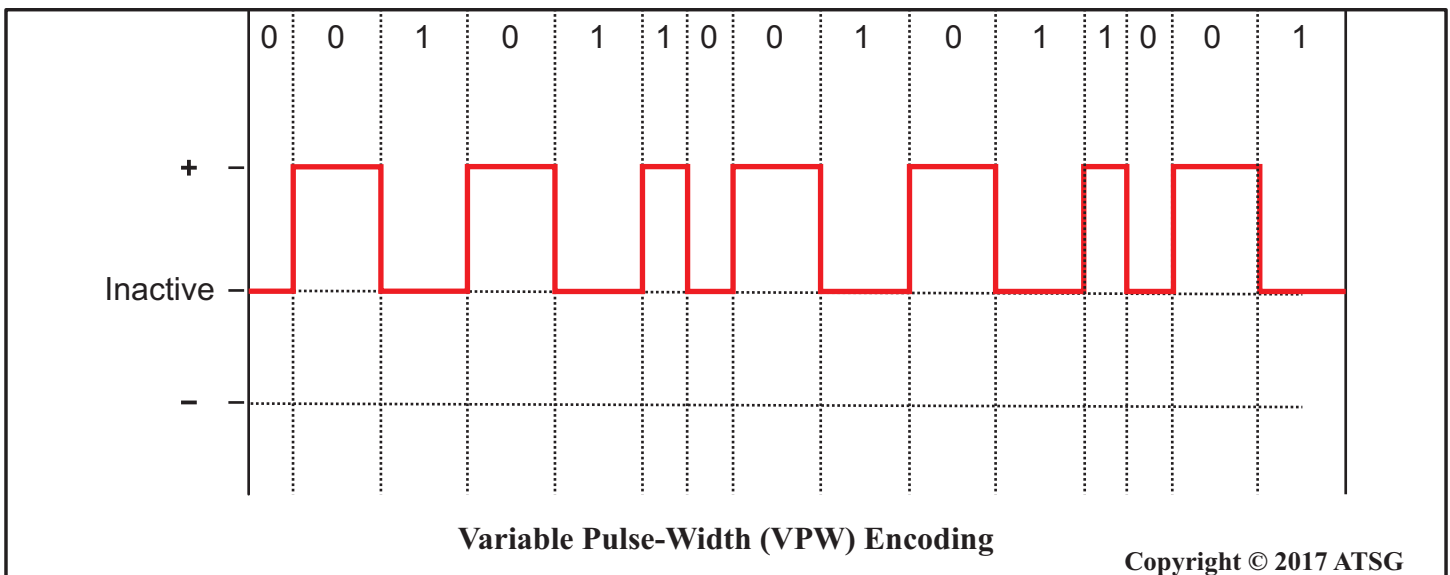


Figure 3

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

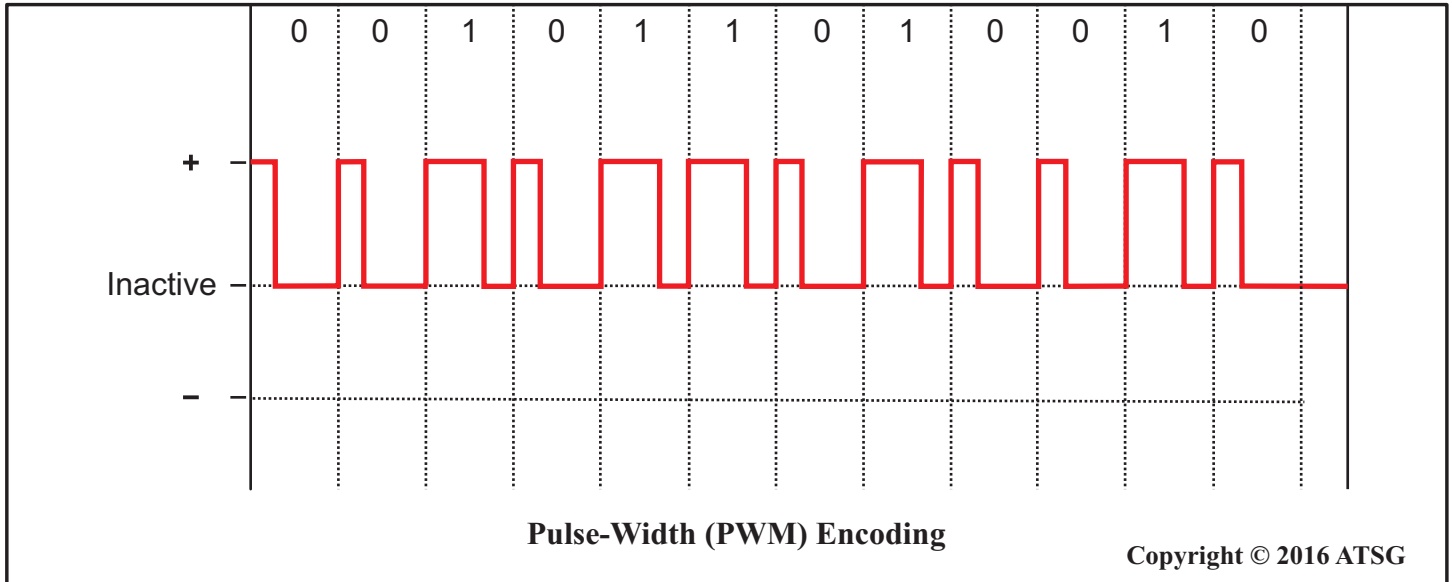


Figure 4

Physical Layer Differences Between VPW & PWM J1850

	VPW	PWM
Bit rate	10.4 Kbps	41.6 Kbps
Bit pulse width	Variable	Constant
Media	Single wire	Dual wire

The PWM messaging structure works just like a standard PWM with the level of the signal representing a logic 1 or 0. VPW messaging is quite different. Not only does the state of the bus determine a logic 1 or 0, but also the width of the pulse. A VPW bus operates in two states: Active, where the bus is driven between 6.25V and 8.00 V. Passive, where the bus is pulled down between 1.5V and 0V. As each bit of a message is transmitted, there is always a transition between states. Therefore, the message is made up of a series of high, low, high, low, etc. pulses. Logic 0s and 1s are uniquely encoded into both the active and passive states by varying the width of the pulse. Only two pulse widths are used when encoding data, either a short of 64 μ s or a long of 128 μ s.

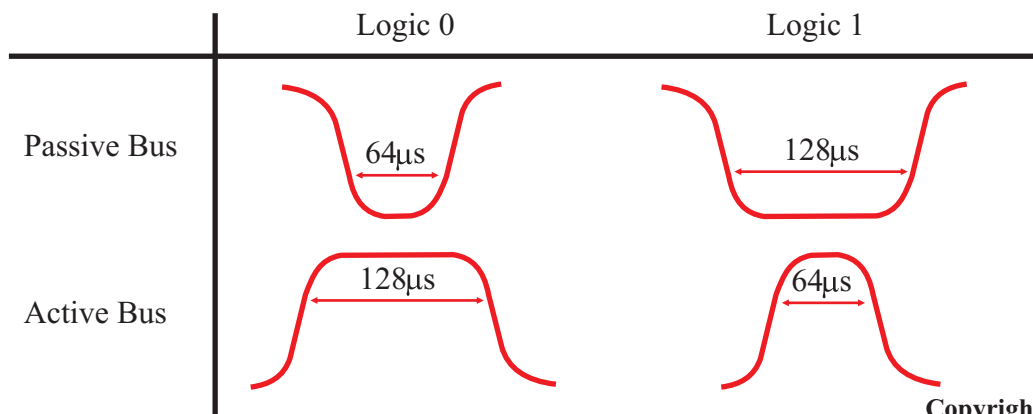


Figure 5

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

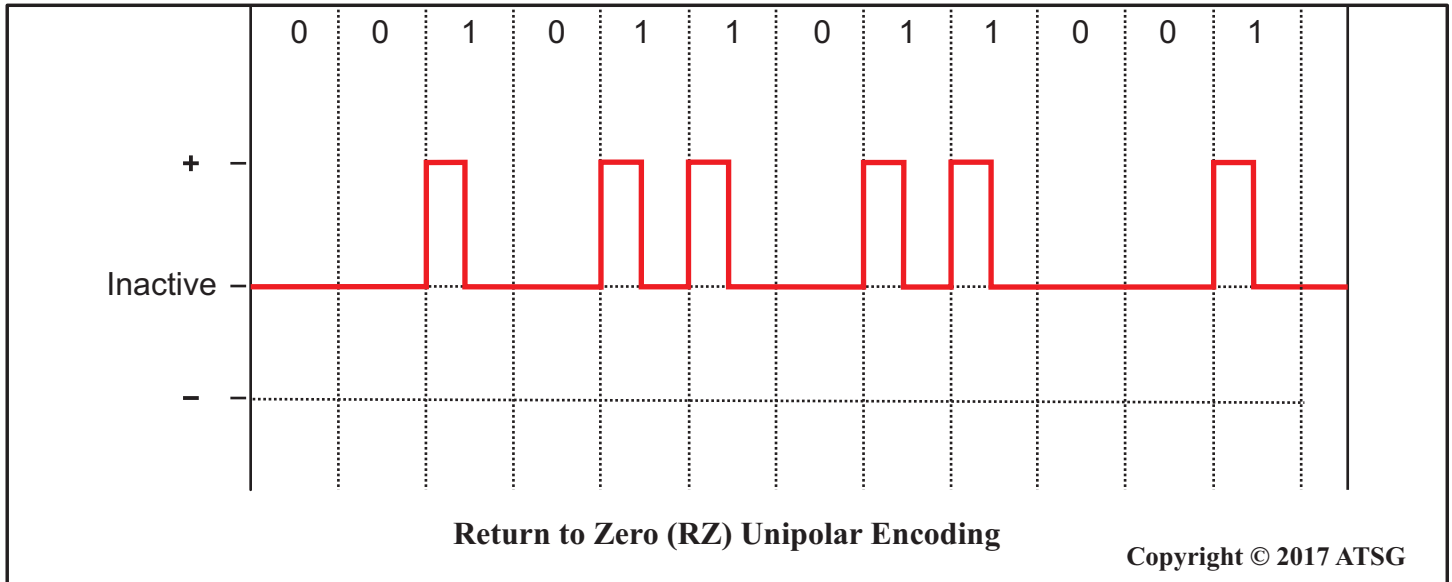


Figure 6

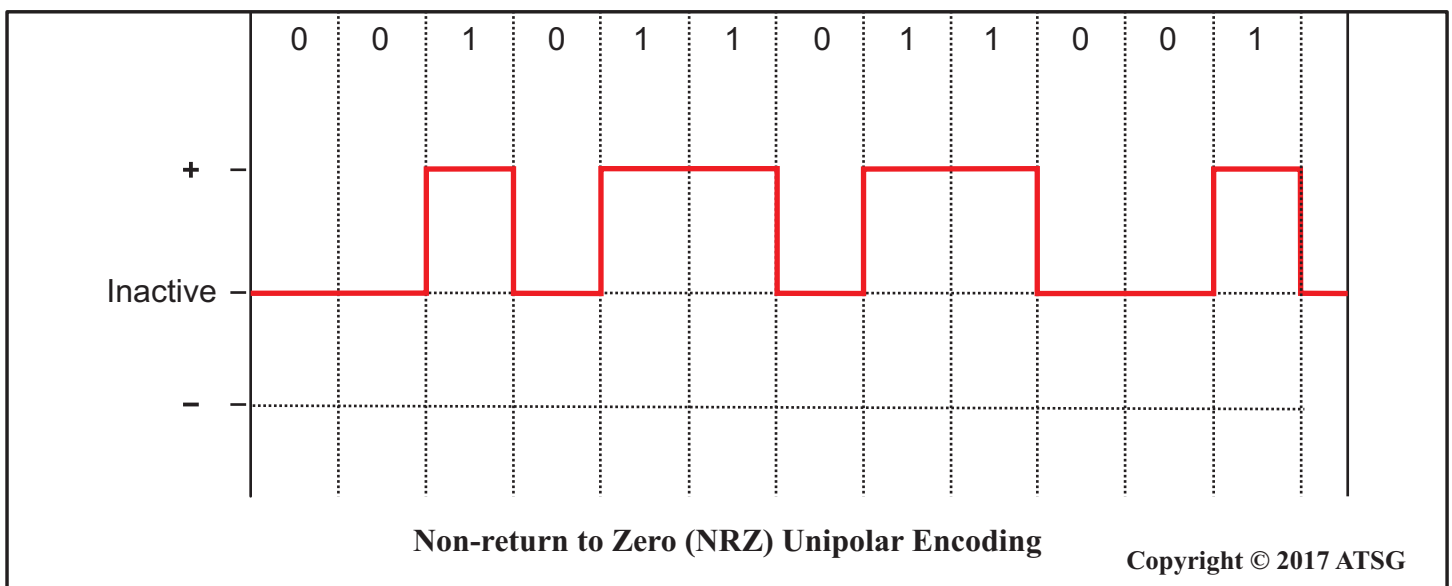


Figure 7

NRZ(Non-Return-to-Zero): Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme, in which the positive voltage defines bit 1 and the negative voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit.

Unipolar encoding is a line code. A positive voltage represents a binary 1, and zero volts indicates a binary 0. It is the simplest line code, directly encoding the bitstream, and is analogous to on-off keying in modulation.



Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

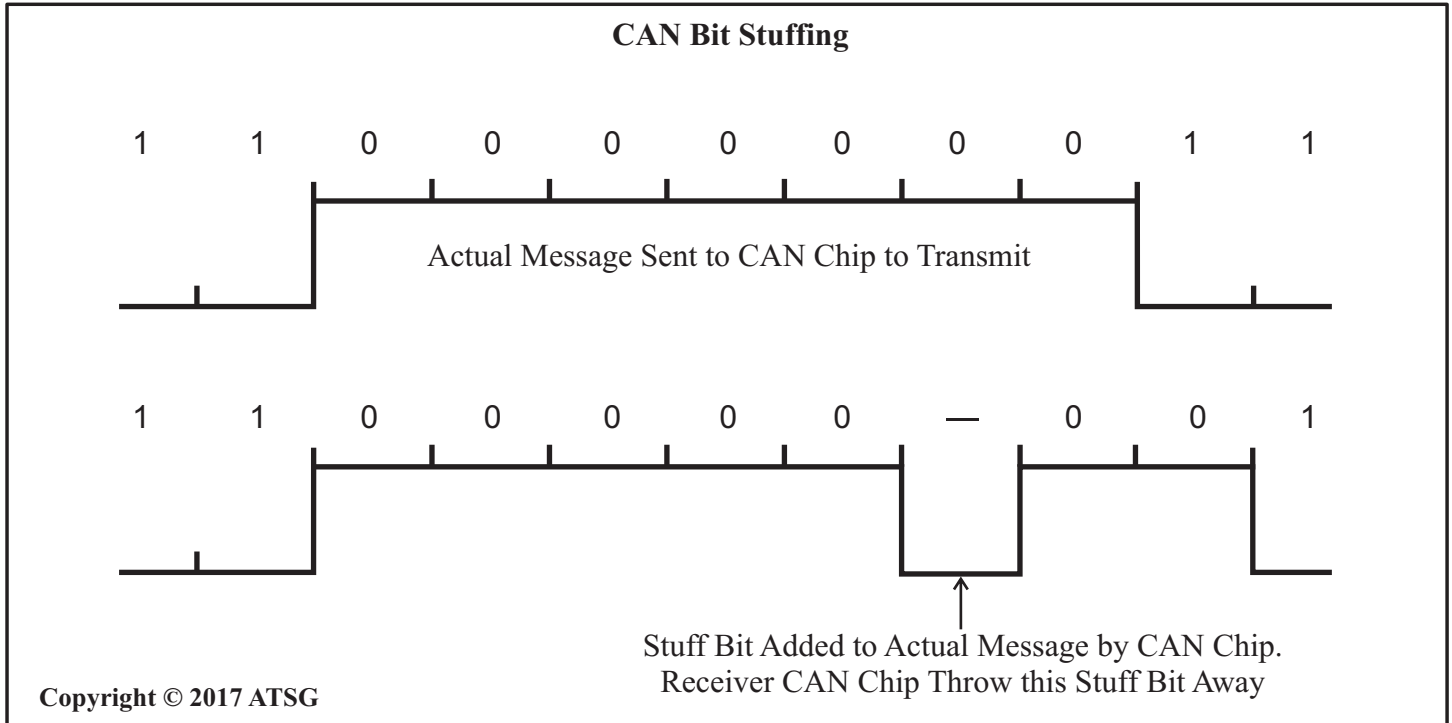


Figure 8

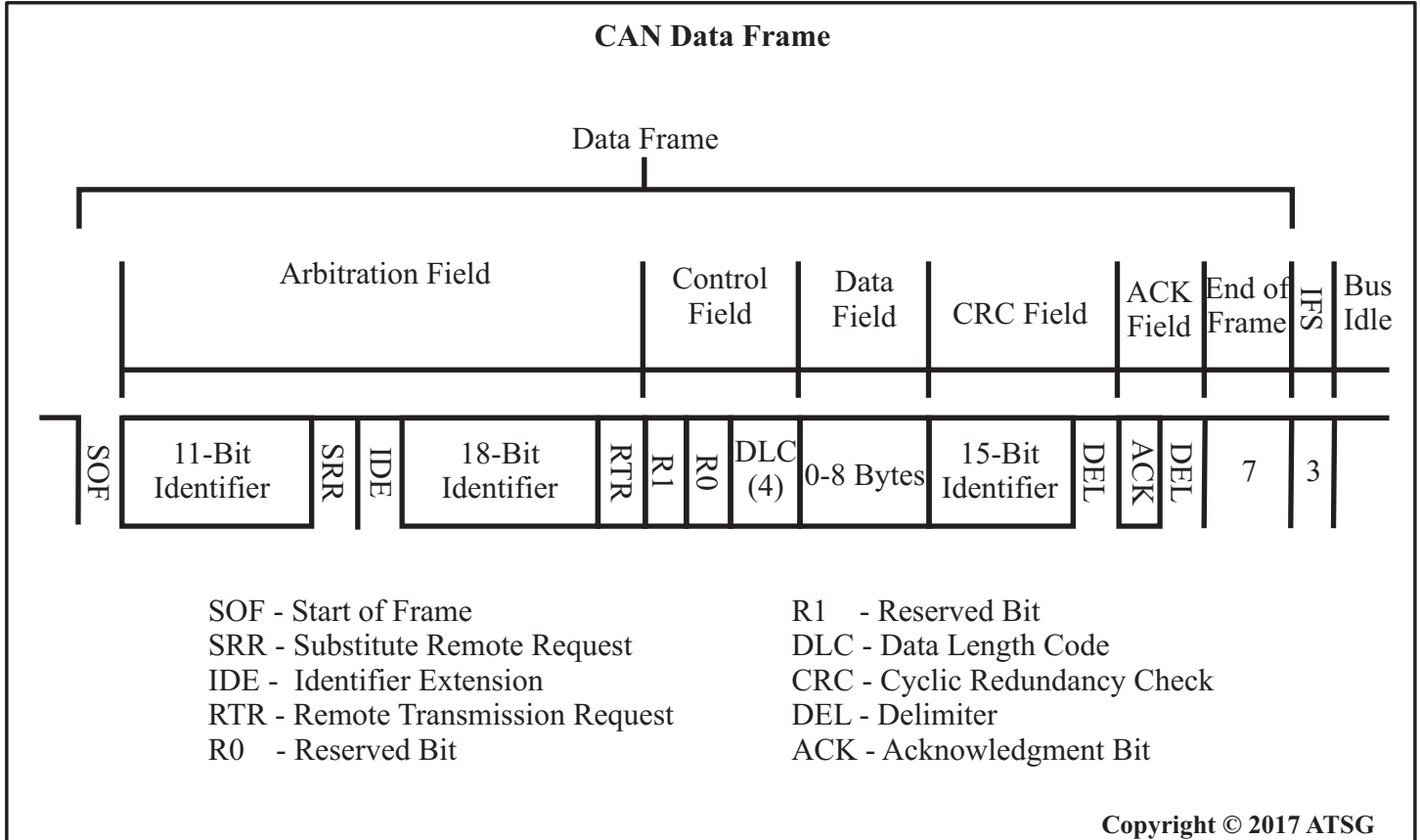


Figure 9



Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS

COMMUNICATION SYSTEMS

Ford computer history:

EEC-I	– 1978: Cars only
EEC-II	– 1979: Cars only – both were a 12 bit processor
EEC-III/DS-III	– 1980: Cars and pickups
MCU/DS-II	– 1981: 4.9L in California (Microprocessor Computer)
EEC-IV/TFI-IV	– 1984: All 50 States

EEC III computers supplied sensors with 9 volts. Aerospace did the same thing with their computer systems. This suggests that Ford aerospace may have had a hand in the design of the EEC-III computer. Ford then came out with MCU (Microprocessor Computer commonly referred to as the Mickey Mouse Control Unit) – they put the two together and came out with the EEC IV system. The EEC-IV supplied sensors with 5 volts.

Ford's communication systems:

SCP (Standard Corporate Protocol): 1988-1995 OBD-I. This is an unshielded two wire, twisted pair network. If 1 of the 2 wires is open, shorted to voltage or to ground the bus will still communicate over the other wire.

Bus + ...circuit # 914....and is found on Pin 2 of the DLC
Bus – ...circuit # 915....and is found on Pin 10 of the DLC
The voltage at “Rest” for Bus + is 0-.2 v.
The voltage at “Rest” for Bus – is 5 v.

Newer Fords use Medium and High speed CAN and a K-Line. SCP and UART Based Protocol (UBP) has been retained for some modules.

MS CAN +...circuit #VDB06...and is found on Pin 3 of the DLC
MS CAN – ...circuit #VDB07...and is found on Pin 11 of the DLC
HS CAN +...circuit #VDB04...and is found on Pin 6 of the DLC
HS CAN – ...circuit #VDB05...and is found on Pin 14 of the DLC
K-Line (ISO 9141) circuit VDB10 is found on Pin 7 of the DLC

Chrysler Communication Systems:

SCI (Serial Communication Interface): Uses two wires, one to transmit and one to receive for PCM and TCM Communication.

EARLY SCI Tx & Rx

SCI Tx (Transmit) to PCM and TCM through pin 7 in the data link connector
SCI Rx (Receive) from PCM through pin 6 in the data link connector
SCI Rx (Receive) from TCM through pin 14 in the data link connector

LATE SCI Tx & Rx

SCI Tx (Transmit) to PCM through pin 7 in the data link connector
SCI Rx (Receive) from PCM through pin 12 in the data link connector
SCI Tx (Transmit) to TCM through pin 9 in the data link connector
SCI Rx (Receive) from TCM through pin 15 in the data link connector



Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS COMMUNICATION SYSTEMS

CCD (Chrysler Collision Detection) – Introduced in 1988, it was a module to module bus communication system which included the scan tool. 1998 to 2003 was its phase out period – 2 wire (twisted pair)

CCD + through pin 3 in the data link connector

CCD – through pin 11 in the data link connector

PCI Programmable Communication Interface: Uses a single wire pulse-width modulated signal to communicate between modules. Introduced in 1998 on LH vehicles (including the scan tool)

PCI through pin 2 in the data link connector

Single wire bus communication with a baud rate of 10,400 bits per second. It can support up to 32 different modules (the BCM can act as a central connecting point or through a splice called the Diagnostic Junction Port). It is held low and driven high (7.5 volts).

Newer Chrysler, Dodge and Jeep vehicles will use several protocols using a combination of several from the following: Diagnostic Can-C, Can-C, IHS Can-C (Interior High Speed Can), Can-B or LIN.

GM Communication Systems:

UART (Universal Asynchronous Receiver Transmitter): UART was a binary language with the on or off values controlled by a zero volt or 5 volt signal. The 5 volts was pulled low to talk and all bits were equal width. Messages were sent as a continuous stream. Early systems communicated at 1,024 bits per second with the later systems reaching 8,192 bps. The UART Line was generally wired in series with Data In and Data Out lines.

Class 2 Data: Began in 1995 this Class 2 data system used a pulsed signal that was different than UART in that the resting voltage was 0 and was pulled high to around 7 volts to talk. Messages were sent in packets having priorities so more than one controller can send messages simultaneously. The baud rate compared to the UART system increased to 10,400 bps. Class 2 modules could also be programmed at 41,600 bps. Class 2 Data was generally wired with a star topology.

E&C (Entertainment and Comfort): Similar to UART in that it had the same baud rate but was at 12 volts at rest and was pulled low to communicate. Signals were driver initiated (turn on the radio). In some cases the HVAC (Heated, Ventilation and Air Conditioning) module acted as a gateway for Class 2 Data

SPI (Serial Peripheral Interface): A 12 to 0 volt communication system between the Body Function Module (BFC) and the PCM with the BFC being the master on this bus line.

UART eventually faded out and Class 2 Data became to low speed Communication network. While the domestic automakers were developing UART and Class 2, the European industry was developing a system that operates on the CAN (Controller Area Network) protocol.

Here in the U.S., CAN vehicles were phased in starting about 2005 increased about 8% a year to get up to speed by about 2008. A variety of new terminologies for Can Bus circuits can be found with vehicles between 2008 and present (2016). Can-B is called the Interior Bus, but then there is also Can Interior High Speed or CAN IHS (PowerNet), CAN-AT for Audio and Telematics and MOST (Media Oriented Systems Transport) and FlexRay to name a few.



Technical Service Information

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS COMMUNICATION SYSTEMS

With the introduction of GMLAN, which also uses the CAN protocol, a common architecture now permits sharing of components from both sides of the ocean.

CAN (Controller Area Network): Uses a twisted pair of wires to communicate between modules

GMLAN (General Motors Local Area Network): The GMLAN supports three separate buses: low-speed (33.33 kilobits per second), mid-speed (95.2 kilobits) and high-speed (500 kilobits). Each bit is 2 microseconds, compared to 5-6 milliseconds on a Class 2 line. High-speed serial data is transmitted on two twisted wires to reduce interference. When active, one line goes high (3.5 volts) and the second line goes low (1.5 volts). Modules that need real-time communication are attached to the high-speed network. In most vehicles, the BCM is the gateway that translates the serial data messages between the GMLAN high-speed bus and other types of serial data communication.

K-Line: An ISO 9141 and 14230-1 compliant bi-directional one-wire-bus interface for data transfer. There are three versions: Keyword 81, 82 and 2000. Keyword 82 operates at a rate of 8,192 bps, similar to UART, and keyword 2000 operates at a baud rate of 10,400 bps (the same as Class 2 communicator). 0-12 volt pulse can be observed on this circuit.

L-Line: Optional communication line working in conjunction with the K-Line and both are operated in unidirectional mode (sends a wake up call to the ECU). These lines are utilized predominately for external communication, i.e. scan tool communication to provide onboard diagnostics.

OBD II SPECIFICATIONS AND CONNECTIONS

On Board Diagnostics, OBD-II, is required on all automobiles and light trucks in Canada and the United States from 1996 onward. OBD-II is a set of specifications for monitoring and reporting on engine emissions, monitoring and performance in modern automobiles.

The OBD-2 connector must have pins 4, 5 for ground connections and pin 16 for 12 volt power supply from the vehicle battery. Prior to OBD, auto manufacturers did not standardize DTCs (diagnostic trouble code). OBD-I begins standardized DTC's. OBD-II added specific tests to determine the vehicle's emission performance OBD-III adds more features, and is in the regulatory development phase.

If the vehicle's onboard diagnostic system detects a malfunction, a DTC corresponding to the malfunction is stored in the vehicle's specific and related controller, as well as real-time data from the sensors connected to the on-board computer. In addition, the OBD-II interface provides a means to clear the DTCs once maintenance, service and repairs have been completed. A field technician can retrieve the DTC, using a generic scan tool, and take appropriate action to resolve the malfunction. Prior to the introduction of digital powertrain controllers, repairing a vehicle relied solely upon the technician's skill and service information from the auto manufacturer. Generic scan tools do not offer total controller access or scans, be aware of that when purchasing scan equipment.

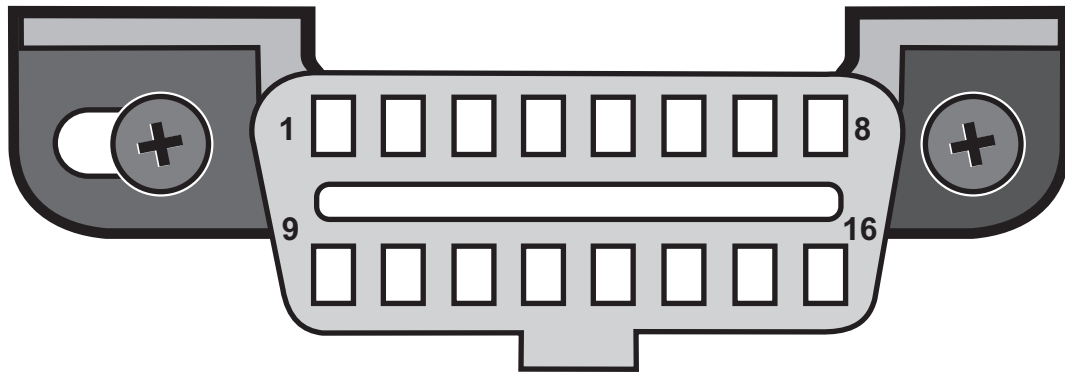
BUS COMMUNICATION

UNDERSTANDING VARIOUS PROTOCOLS

OBD II SPECIFICATIONS AND CONNECTIONS

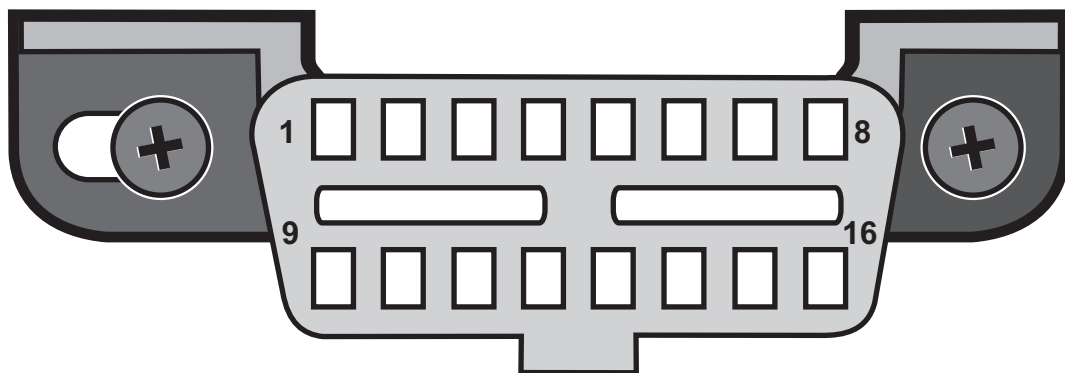
The OBD-II specification provides for a standardized hardware interface, the female 16-pin (2x8) J1962 connector. Unlike the OBD-I connector, which may have been placed anywhere the vehicle, the OBD-II connector is located on the driver's side of the passenger compartment near the center console.

There are two types of diagnostic link connectors (DLCs) defined by SAE J1962 - Type A and Type B, shown in Figures 10 and 11, respectively. The main difference between the two connectors is in the shape of the alignment tab.



According to J1962, Type A DLC "shall be located in the passenger or driver's compartment in the area bounded by the driver's end of the instrument panel to 300 mm (~1 ft) beyond the vehicle centerline, attached to the instrument panel and easy to access from the driver's seat. The preferred location is between the steering column and the vehicle centerline."

Figure 10

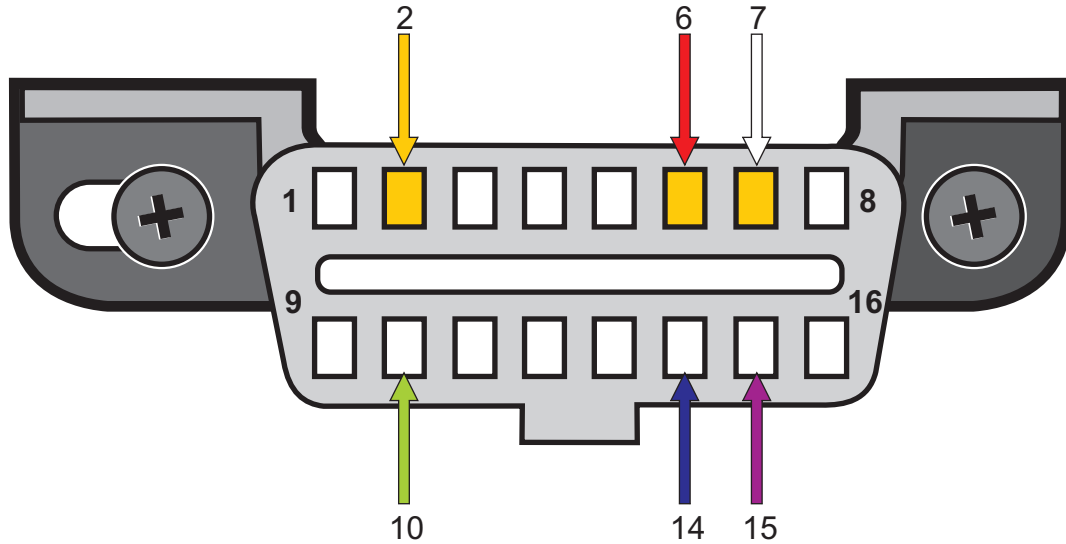


Type B DLC "shall be located in the passenger or driver's compartment in the area bounded by the driver's end of the instrument panel, including the outer side, and an imagined line 750 mm (~2.5 ft) beyond the vehicle centerline. It shall be attached to the instrument panel and easy to access from the driver's seat or from the Co-drivers seat or from the outside. The vehicle connector shall be mounted to facilitate mating and un-mating.

Figure 11

BUS COMMUNICATION UNDERSTANDING VARIOUS PROTOCOLS OBD II SPECIFICATIONS AND CONNECTIONS

As a general rule, you can determine which protocol your vehicle is using by looking at the pinout of the DLC:



1	Discretionary
2	Bus positive line of SAE J1850
3	Discretionary
4	Chassis ground
5	Signal ground
6	CAN-H line of ISO 15765-4
7	K-Line of ISO 9141-2 and ISO 14230-4
8	Discretionary

9	Discretionary
10	Bus negative line of SAE J1850
11	Discretionary
12	Discretionary
13	Discretionary
14	CAN-L line of ISO 15765-4
15	L-Line of ISO 9141-2 and ISO 14230-4
16	Permanent positive voltage

Assignment of contacts 1, 3, 8, 9, 11, 12 and 13 in the vehicle connector is left to the discretion of the vehicle manufacturer.

Note: for contacts 2, 6, 7, 10, 14 and 15 the related diagnostic communication assignments are shown. These contacts may also be used for alternate assignments in the vehicle connector.

Figure 12

Technical Service Information

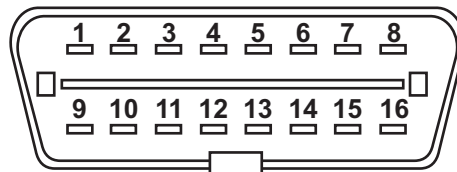
BUS COMMUNICATION

UNDERSTANDING VARIOUS PROTOCOLS

OBD II SPECIFICATIONS AND CONNECTIONS

The following table explains how to determine the protocol:

PIN 2	PIN 6	PIN 7	PIN 10	PIN 14	PIN 15	Standard
Must have	—	—	Must have	—	—	J1850 PWM
Must have	—	—	—	—	—	J1850 VPW
—	—	Must have	—	—	Must have*	ISO9141 ISO14320
—	Must have	—	—	Must have	—	ISO15765 (CAN)



* Pin 15 (also called the "L-line") is optional in newer vehicles that use the ISO9141-2 or ISO14230-4 protocols.

In addition to pins 2, 7, 10, and 15, the connector should have pins 4 (Chassis Ground), 5 (Signal Ground), and 16 (Battery Positive).

This means that:

PWM The connector must have pins 2, 4, 5, 10, and 16

VPW The connector must have pins 2, 4, 5, and 16, but not 10.

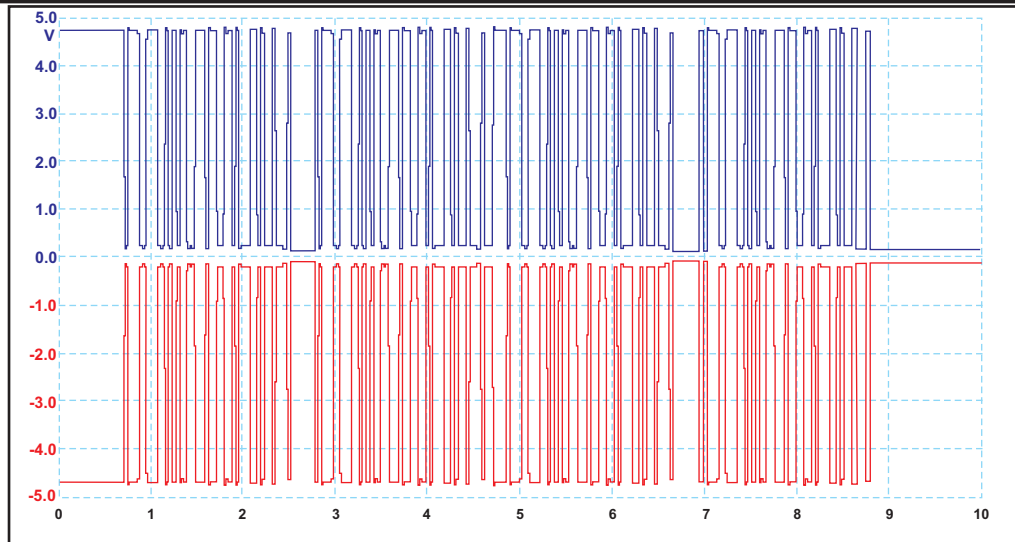
ISO The connector must have pins 4, 5, 7, and 16. Pin 15 may or may not be present.

CAN The connector must have pins 4, 5, 6, 14, and 16

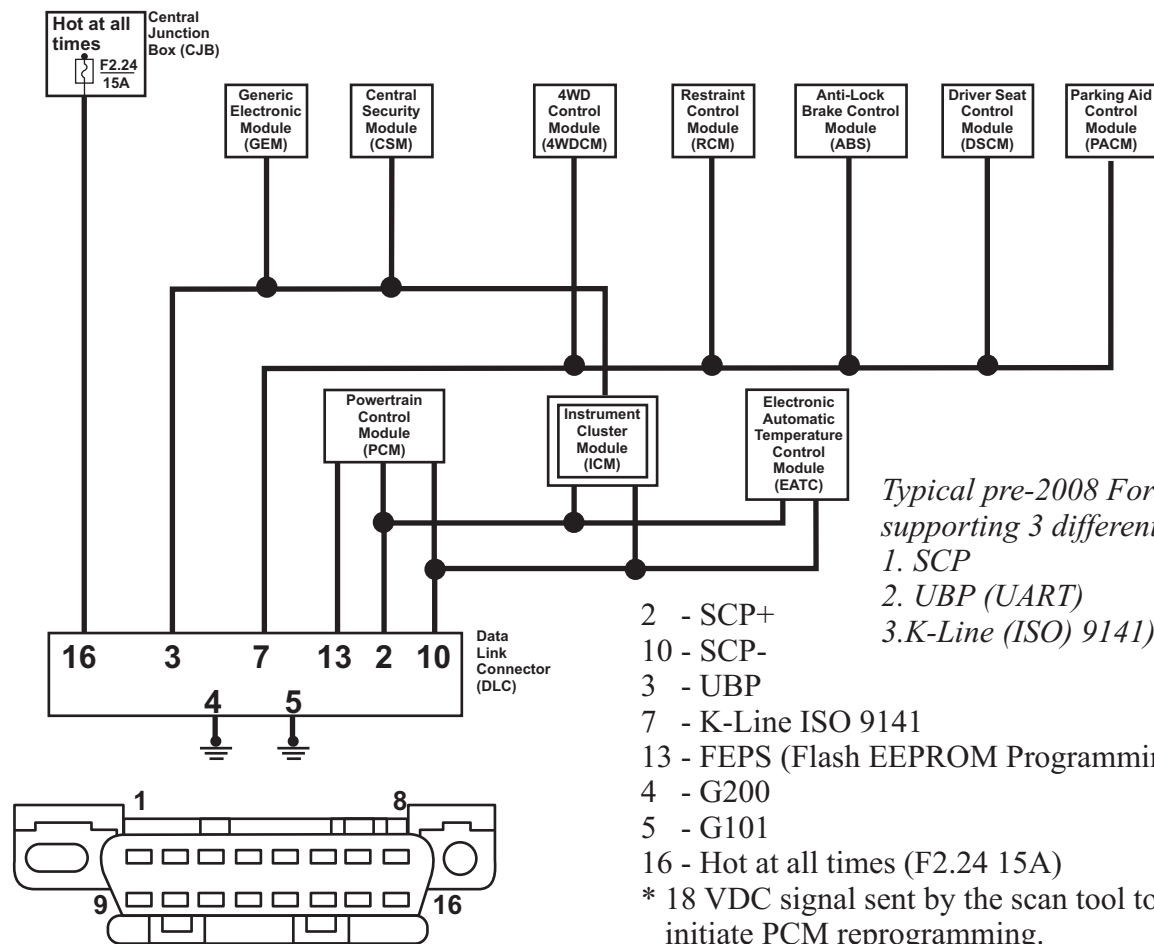
Figure 13

BUS COMMUNICATION

STANDARD CORPORATE PROTOCOL (SCP)



SCP + : terminal 2 in the DLC } Twisted pair of wires. If one goes down the other will
 SCP - : terminal 10 in the DLC } continue communications 0-5V - mirror image signal



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Figure 14



Technical Service Information

BUS COMMUNICATION

STANDARD CORPORATE PROTOCOL (SCP)

COMPLAINT: A 2002 Ford Explorer had no real driveability issues but failed a state emissions inspection as their scan tool could not communicate with the PCM. The vehicle was brought to the shop for repairs so it would pass inspection. The tech discovered a similar problem. Using his aftermarket scan tool he had an intermittent connection to the PCM and at times no communication at all to the PCM. Ford's IDS factory scan tool was obtained and it had no issues. Since the state's inspection center uses an aftermarket scan tool, the vehicle needs to be diagnosed and repaired so that an aftermarket scan tool will communicate with the PCM.

A break out box (BOB) for the data link connector (DLC) was installed so that an oscilloscope can be used for diagnostics (figure 15). This particular vehicle supports three different network protocols. The protocol used to communicate with the PCM is called SCP for Standard Corporate Protocol. This is an unshielded two wire, twisted pair network. If 1 of the 2 wires is open, shorted to voltage or to ground the bus will still communicate over the other wire. These two wires go to terminals 2 and 10 at the DLC and the 0 to 5 volt signals they produce mirror each other (figure 14).

Once an oscilloscope was attached, two things were quickly observed (figure 16). The first was a bad 5 volt amplitude signal. Secondly, terminal 10 was full of activity while terminal 2 was erratic. A closer look revealed that when terminal 2 had a signal it did mirror terminal 10 but the signal was sloppy and the amplitude for both was too low (figure 17).

Three Modules are on the SCP as the wiring diagram shows in figure 14. Each one of these modules could be the cause. The first thing to check is to see if there are any type of aftermarket devices installed such as an alarm or remote start tied into the SCP. Interestingly enough there were and they were disconnected but the problem remained.

CAUSE: In the process of looking for an aftermarket device, an examination was made with the DLC. It was noticed that terminal 2 looked spread out more than the others (figure 18). In fact all the terminals on the top row are spread open. This was caused by years of scan tools being put on the DLC and then yanked off at an angle spreading the terminals apart, especially so since the DLC is mounted vertically.

CORRECTION: A gentle squeeze was made for each of the terminals and checked with a male pin taken from an old connector for a proper drag. A recheck was made with the scope and it showed a perfect signal (figure 19). An aftermarket scan tool was then connected and it was able to communicate with the PCM. The reason is the aftermarket scan tool now works is that it initiates communication through terminal 2. Whereas the IDS is designed to read both 2 and 10 making it much more forgiving than an aftermarket scan tool. Remember, the engineers designed this two wire communication protocol to be redundant. Should one circuit go down the other will still communicate. Their dedicated scan tool is designed to read both circuits. If one is down, it will read the one that talks to it.

Note: If the DLC was not the problem, each module on the SCP would need to be disconnected to see which module was causing the problem.

A special thank you to John Rogers from JRW Automotive Diagnostics.

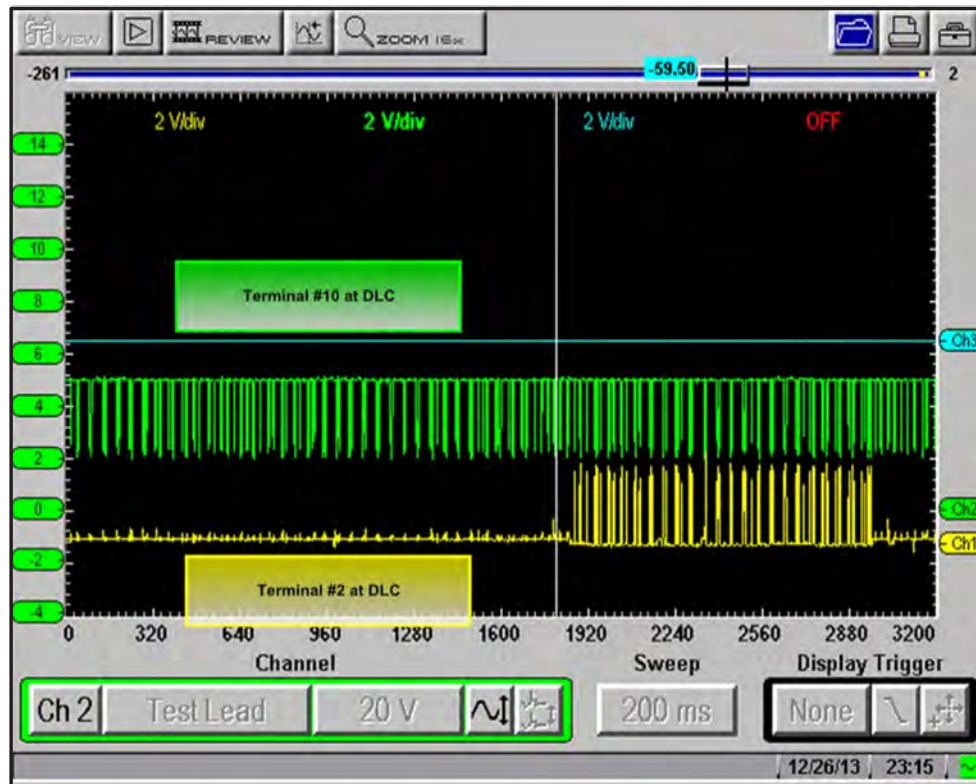
BUS COMMUNICATION STANDARD CORPORATE PROTOCOL (SCP)



<http://www.automotivetestsolutions.com/dlc-breakout-box.html>

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Figure 15



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Figure 16

BUS COMMUNICATION STANDARD CORPORATE PROTOCOL (SCP)

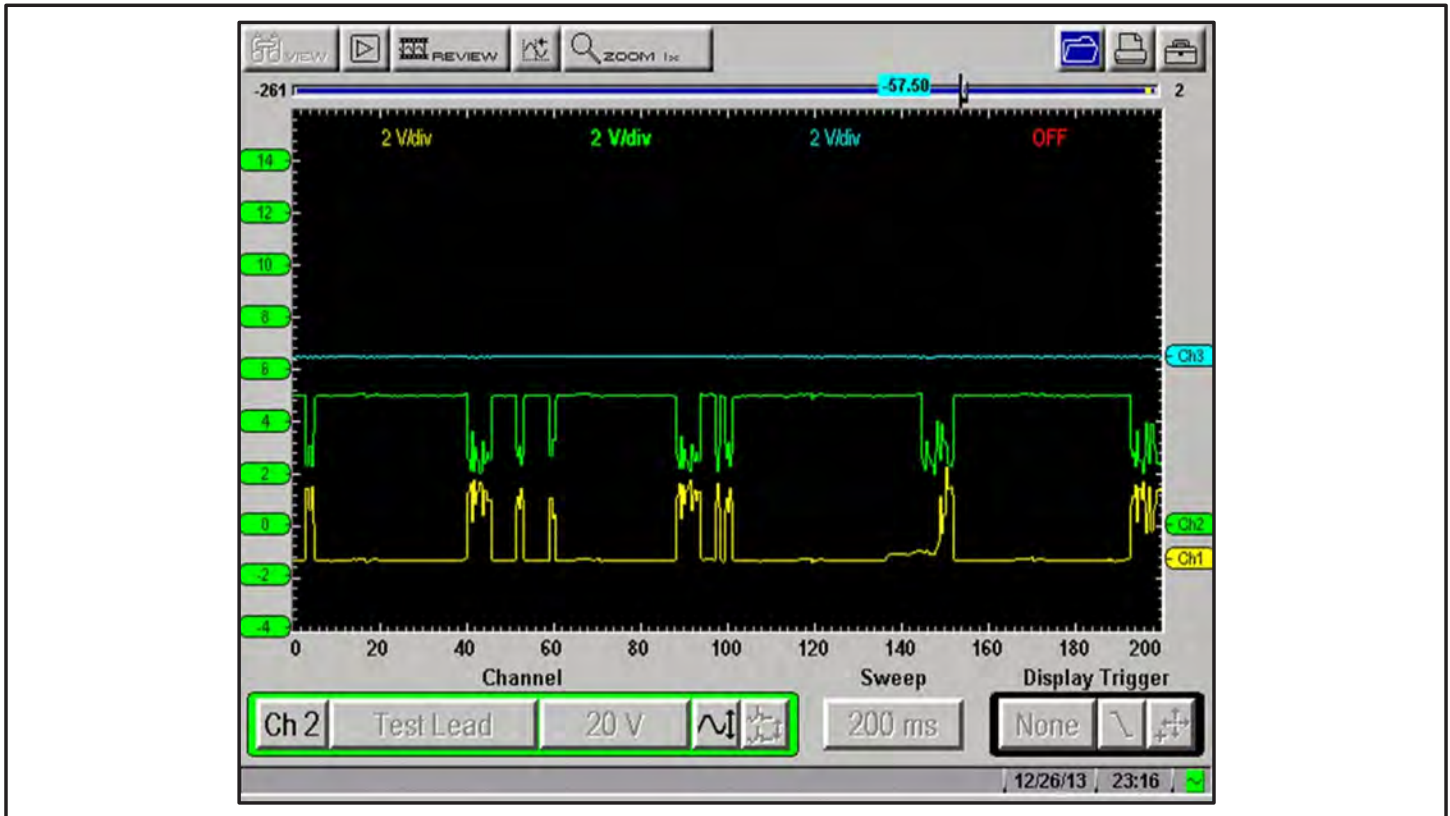
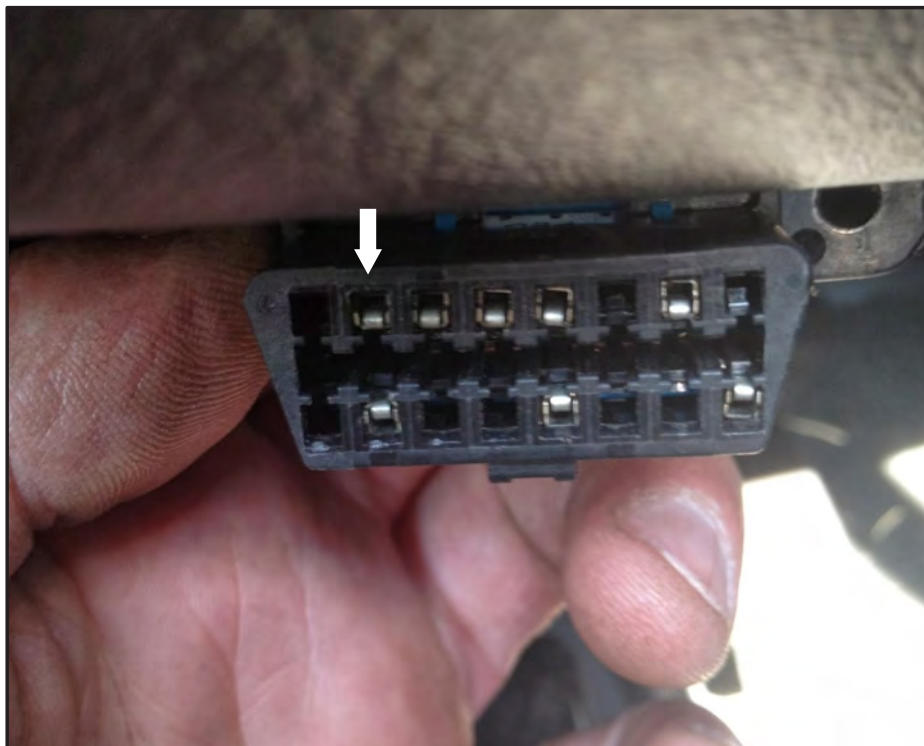


Figure 17

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Figure 18

BUS COMMUNICATION STANDARD CORPORATE PROTOCOL (SCP)

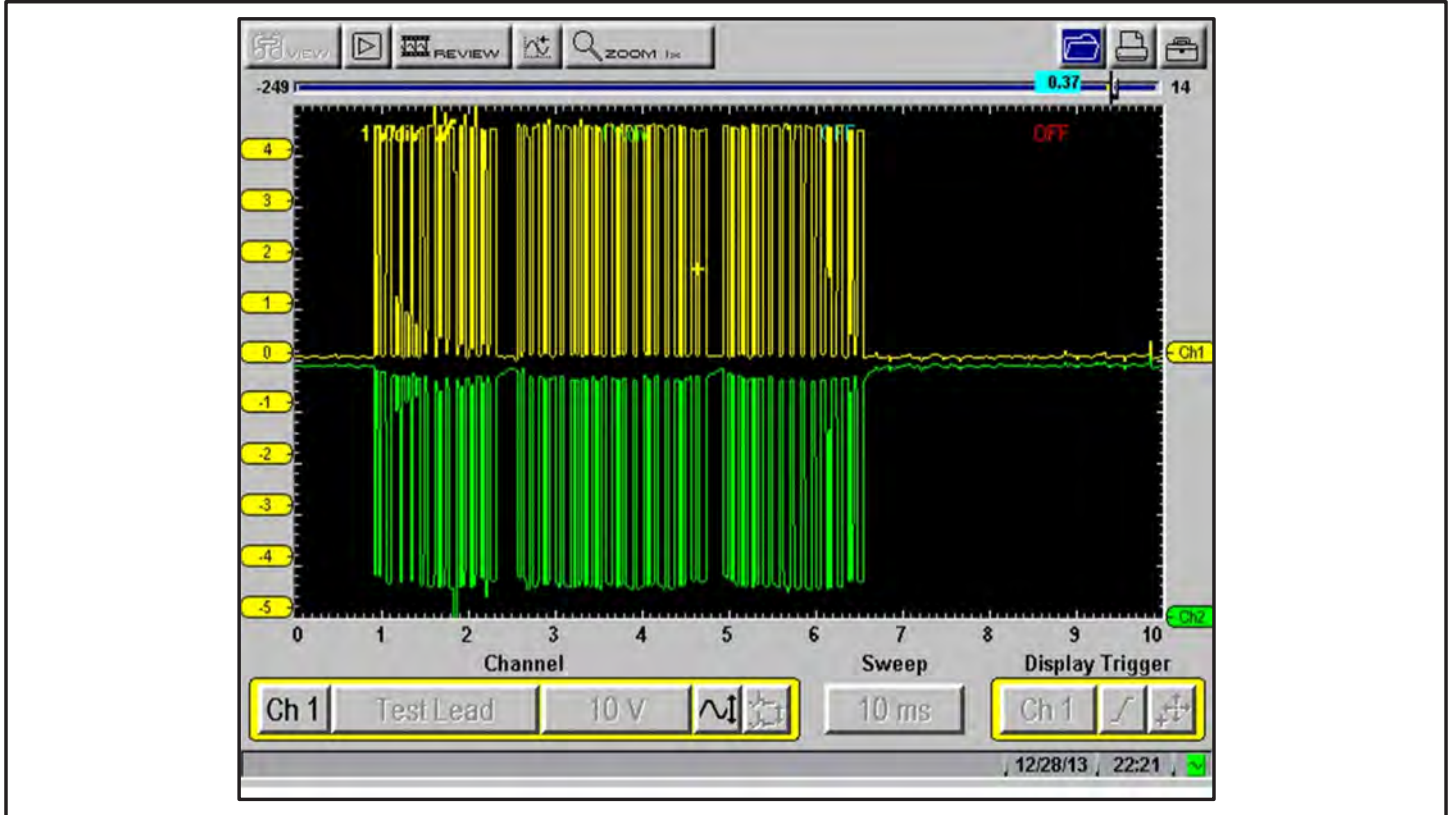


Figure 19

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TYPICAL COMMUNICATION FAULTS

Poor connection to the data link connector:

- Backed out pins
- Poor terminal tension

Monitor behavior:

- Forced in
- Yanked out

Connections:

- Unplug and reconnect – clean terminals – always torque connector bolt to spec
- Check for possible water intrusion

Feeds and Grounds:

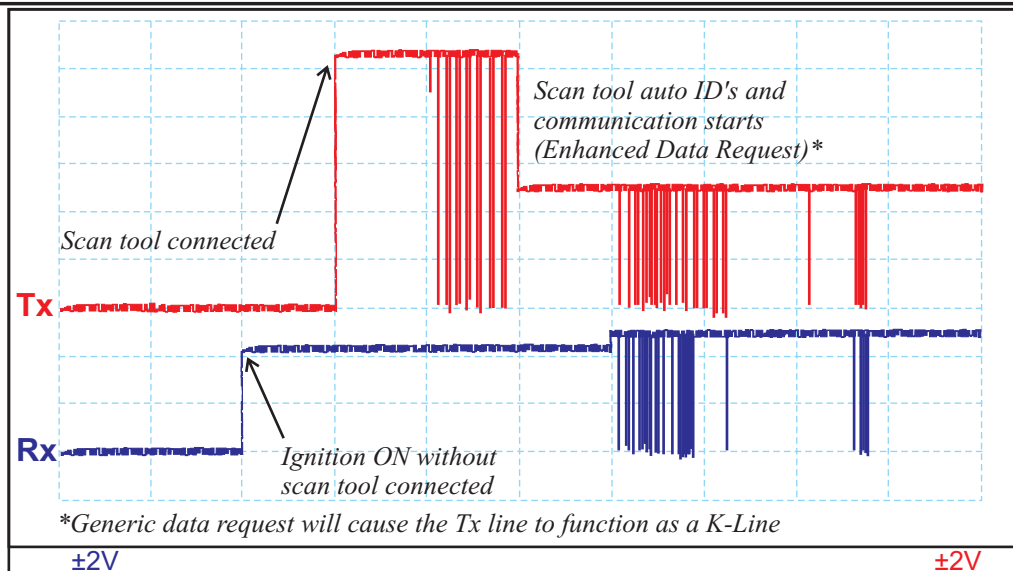
- Open, short or high resistance
- Perform wiggle test

Serial Data:

- Corruption of Data: EMI/RFI, defective wiring, connectors or module
- Aftermarket accessories
- Perform wiggle test

BUS COMMUNICATION

SERIAL COMMUNICATION INTERFACE (SCI)



Dual wire, non-multiplexed serial communication interface

Supports both low-speed diagnostic command (7812.5bps) and high-speed interrogation command (62,500K bps)

Supports both diagnostics and flash re-programming. During flash the scan tool raises voltage on the Rx circuit to 20 volts

Transmit (Tx) refers to the module transmitting data to the scan tool. The scan tool supplies bias to the module on the Tx line and the module pulls the voltage low to transmit data to the scan tool

Receive (Rx) refers to the module receiving data from the scan tool. The module supplies bias on the Rx circuit and the scan tool pulls the voltage low to send data to the module

With the key ON without a scan tool attached:

- There should be 5 volts to DLC at the Rx circuit
- There should be 0 volts to the DLC at the Tx circuit

With the key ON with a scan tool attached:

- There should be 12 volts to the DLC at the Tx circuit. Once a selection is made by the scan tool the tool will turn off the 12 volts and apply 5 volts to attempt SCI communications

Early SCI Tx: terminal 7 in the DLC (PCM & TCM)

Early SCI Rx: terminal 6 in the DLC (PCM)

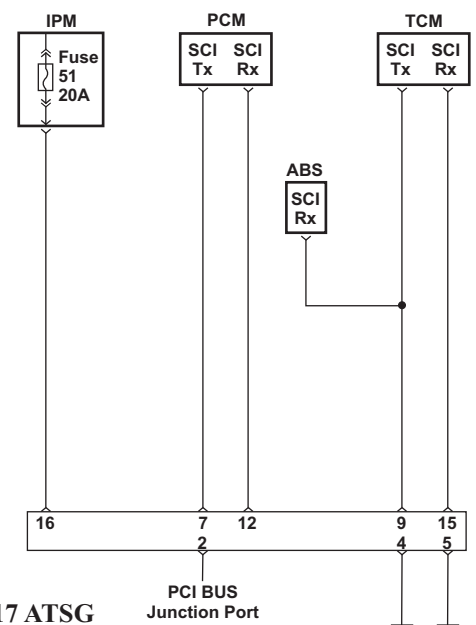
Early SCI Rx: terminal 14 in the DLC (TCM)

Late SCI Tx: terminal 7 in the DLC (PCM)

Late SCI Rx: terminal 12 in the DLC (PCM)

Late SCI Tx: terminal 15 in the DLC (TCM)

Late SCI Rx: terminal 9 in the DLC (TCM)

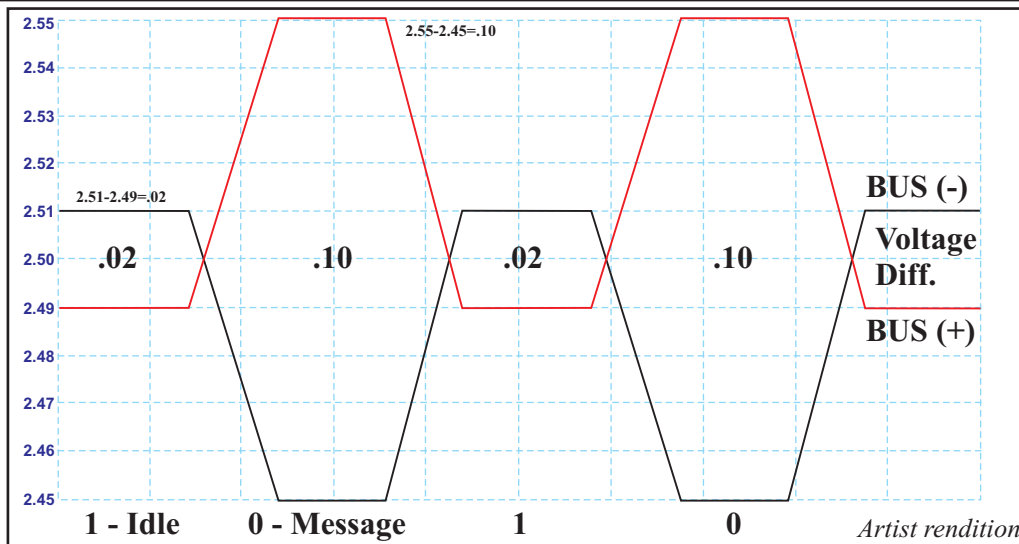


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Figure 20

BUS COMMUNICATION

CHRYSLER COLLISION DETECTION (CCD) PROTOCOL



Twisted pair of wires which changes state in the voltage providing a voltage differential

Modules communicate like a conference call

5 volts pass through a 13K ohm resistor to the CCD wire

The module providing biasing voltage (1.8-2.3) also provides the ground for the CCD bus through a 13k ohm resistor

Two modules contain 120 ohm terminating resistor placed across the CCD wires:
3 & 11 = 60 ohms

Scan tool communicates with the modules through the CCD bus

CCD + : terminal 3 in the DLC
CCD - : terminal 11 in the DLC

(Switch DC signal to AC couple)

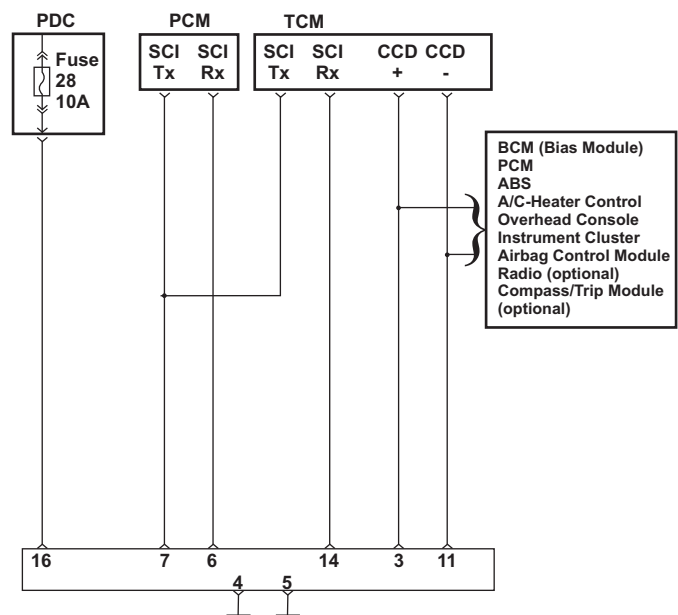
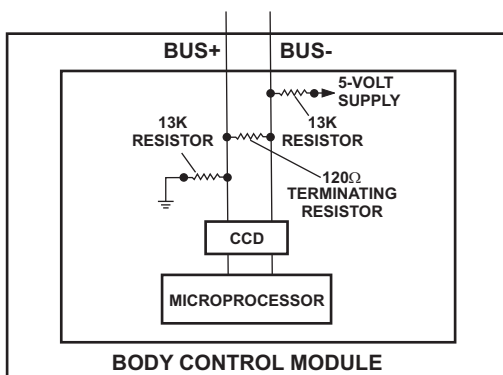
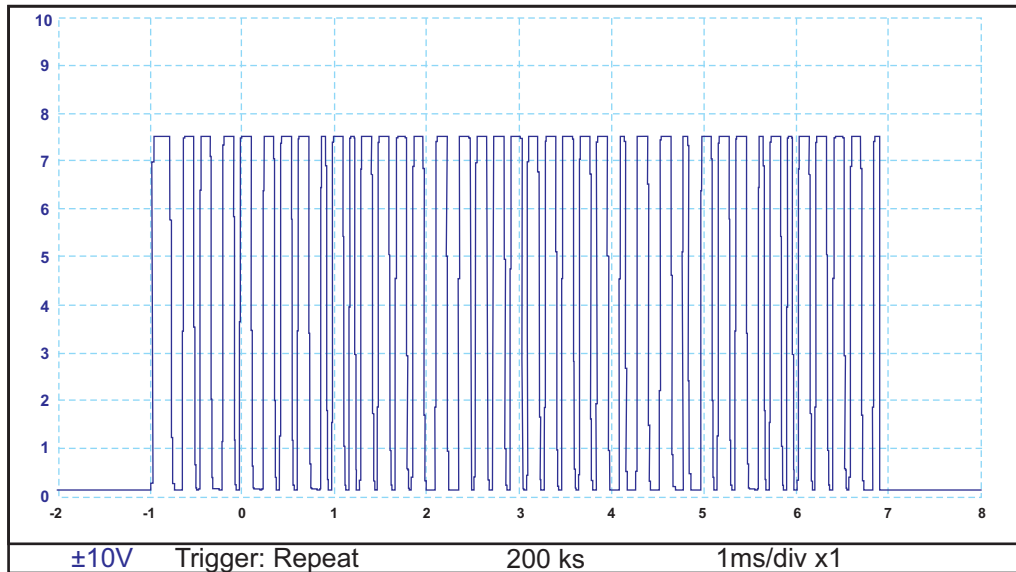


Figure 21

BUS COMMUNICATION

PROGRAMMABLE CONTROLLER INTERFACE (PCI)



Programmable Controller Interface (PCI): Terminal 2 in the DLC

Single wire bus communication with a baud rate of 10.4 K bps

This bus can support up to 32 different modules connected in parallel to each other

There may be a central connection point for the PCI bus which can be the BCM or a splice known as a Diagnostic Junction Port

To minimize circuit loading, termination resistors and capacitors are connected in parallel to the transceiver circuit within the module

When monitoring voltage on the PCI bus wire, it is normally held low and can be driven as high as 7.5 to 8 volts. In other words, when there is no communication, the system is at rest and will show almost 0 volts. This near 0 voltage reading is not an indication that the wire is being grounded because each module on the system is capable of providing its own pull-up voltage for transmitting data. This means that each module is capable of reading and transmitting bus messages.

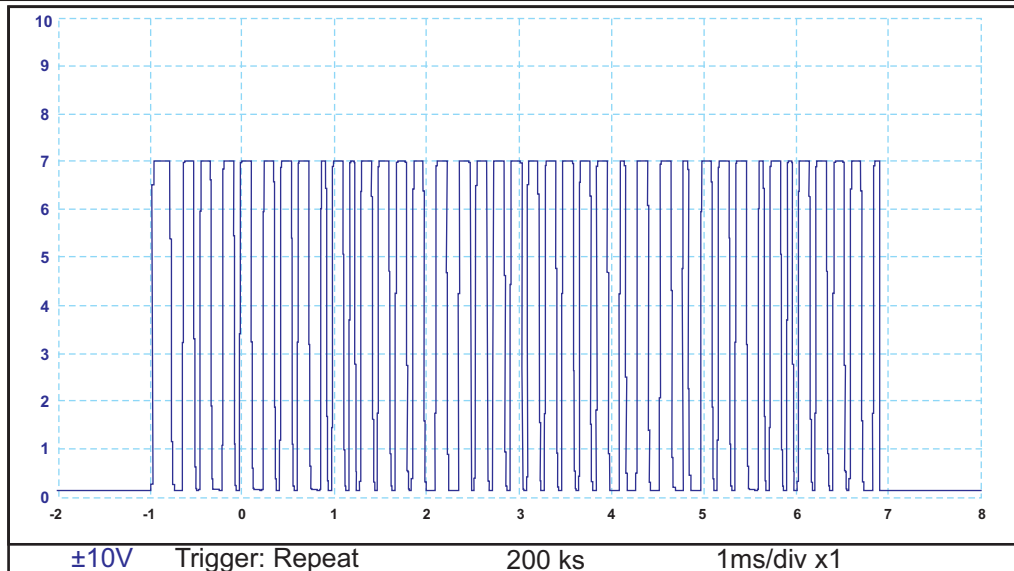
This means that each module is capable of reading and transmitting bus messages. SAE International published J1850 VPW DC Parameters where it is learned that the Output Low Voltage range on the PCI bus wire is 0 to 1.5 volts and the range for the Output High Voltage is 6.25 to 8 volts. Minimum network resistance can be as low as 315 ohms and as high as 1,575 ohms depending on the amount of modules on the network

For those of you who had attended or own ATSG's 2006 Seminar Manuals, for an extensive understanding of this system and how to diagnose it refer to the Red Manual pages 87 to 110.

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Figure 22

BUS COMMUNICATION GM CLASS 2 COMMUNICATION



Class 2 Data: Terminal 2 in the DLC

Single wire bus communication with a baud rate of 10.4 K bps.

Voltage at rest is 0 and is pulled high to around 7 volts to talk. Messages are sent in packets having priorities so more than one controller can send messages simultaneously.

Class 2 Data could be wired in a ring (loop) arrangement or in a star arrangement with the use of a splice pack bus bar or "comb". A combination of the two is a Hybrid topology.

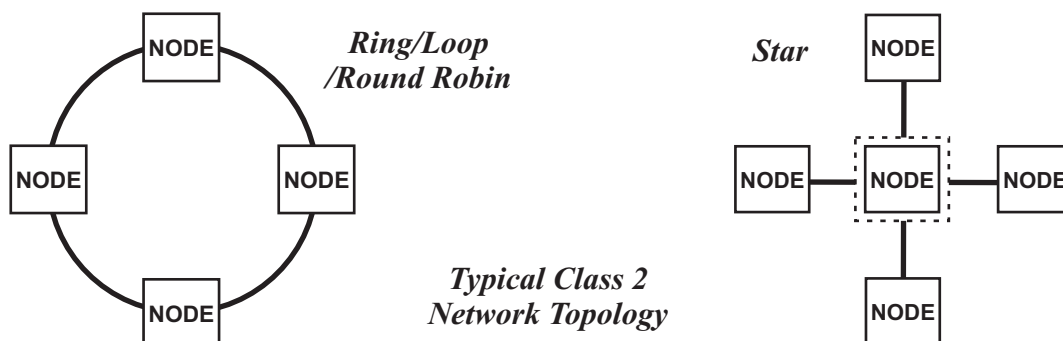
The advantage of a ring arrangement is the built in redundancy. There are 2 bus wires to each module; therefore, one open wire does not affect bus operation.

The disadvantage of a ring arrangement is the difficulty in diagnosis (short to ground or a short to power).

?

The advantage of a star arrangement is the relative ease in diagnosis using the splice pack.

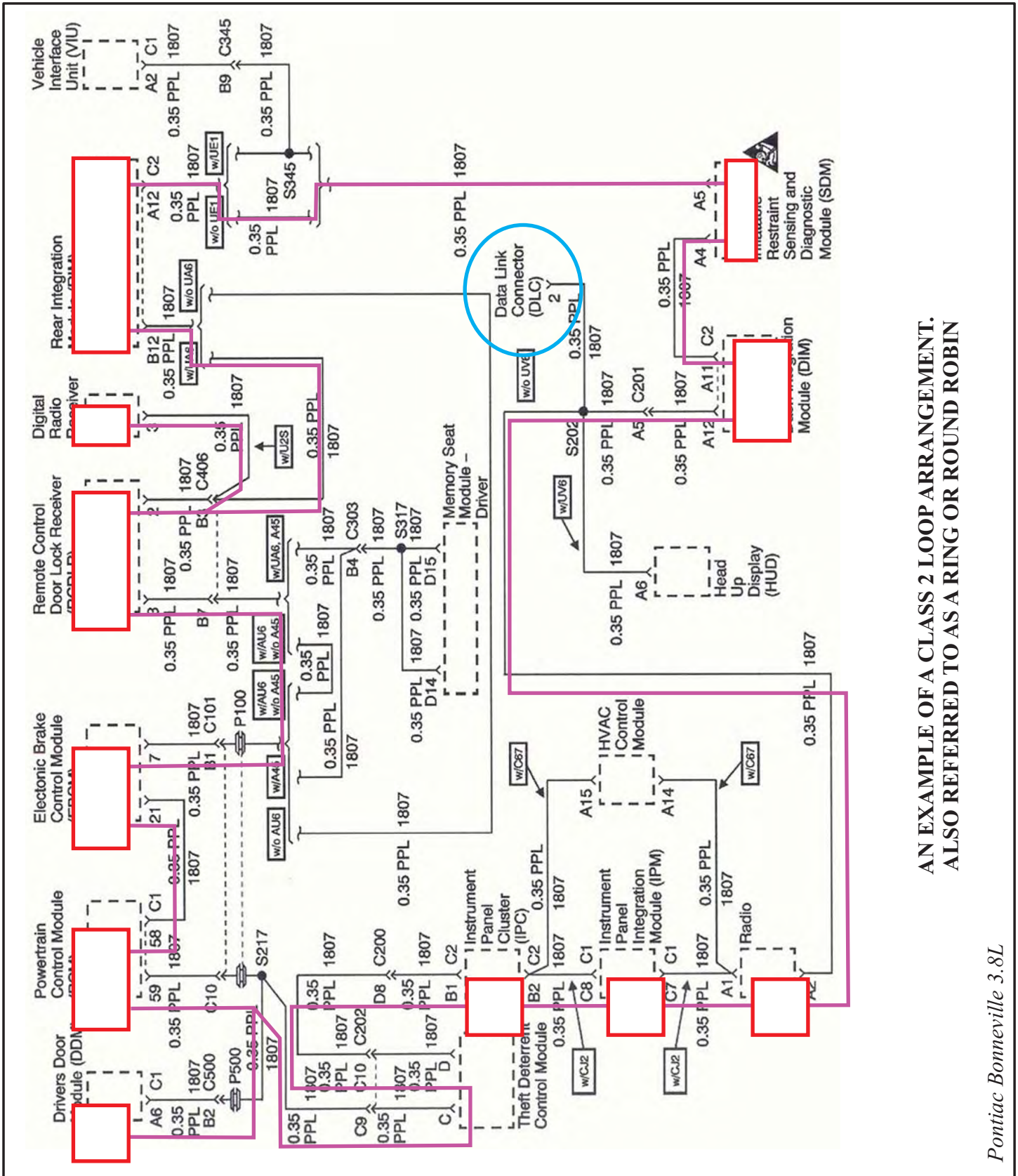
The disadvantage of a star arrangement is the lack of built in redundancy. If a bus wire to a module opens, that module can no longer communicate on the bus.



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Figure 23

BUS COMMUNICATION GM CLASS 2 COMMUNICATION



AN EXAMPLE OF A CLASS 2 LOOP ARRANGEMENT.
ALSO REFERRED TO AS A RING OR ROUND ROBIN

Pontiac Bonneville 3.8L

Figure 24



BUS COMMUNICATION GM CLASS 2 COMMUNICATION

COMPLAINT: A 2003 Pontiac Montana 3.4L will not crank and will not communicate with the scan tool. A volt meter is placed on pin 2 for Class 2 and pin 4 for ground. Class 2 when at rest is 0 volts and when there is communication 7 volts is seen. With the Key On and Engine Off, the meter showed 9.69 volts confirming that Class 2 was shorted to power. By looking at a wiring diagram it is determined that the system is configured with splice pack 205 for a Class 2 star topology. This splice pack is located behind the end of the dash. Terminal 2 at the DLC for Class 2 goes to terminal A in splice pack 205. By removing the "comb" from the splice pack the volt meter went to 0 volts confirming there is short to power beyond terminal A at the splice pack.

CAUSE: While keeping the volt meter connected to terminals 2 and 4 in the DLC, a jumper wire is used at the splice pack from circuit A to each of the other Class 2 circuits. As each circuit was checked, the volt meter remained at 0 volts until circuit E. Circuit E is for the Electronic Brake Control Module (EBCM) where the meter reported over 11 volts on that circuit.

CORRECTION: The EBCM module was defective. Once it was replaced all issues were resolved.

This was more of an exercise in diagnosing a short to power with Class 2 Star topology using the splice pack to isolate the offending circuit.

Special thank you to John Thornton from Pro-Tech Auto.



Figure 26

BUS COMMUNICATION GM CLASS 2 COMMUNICATION

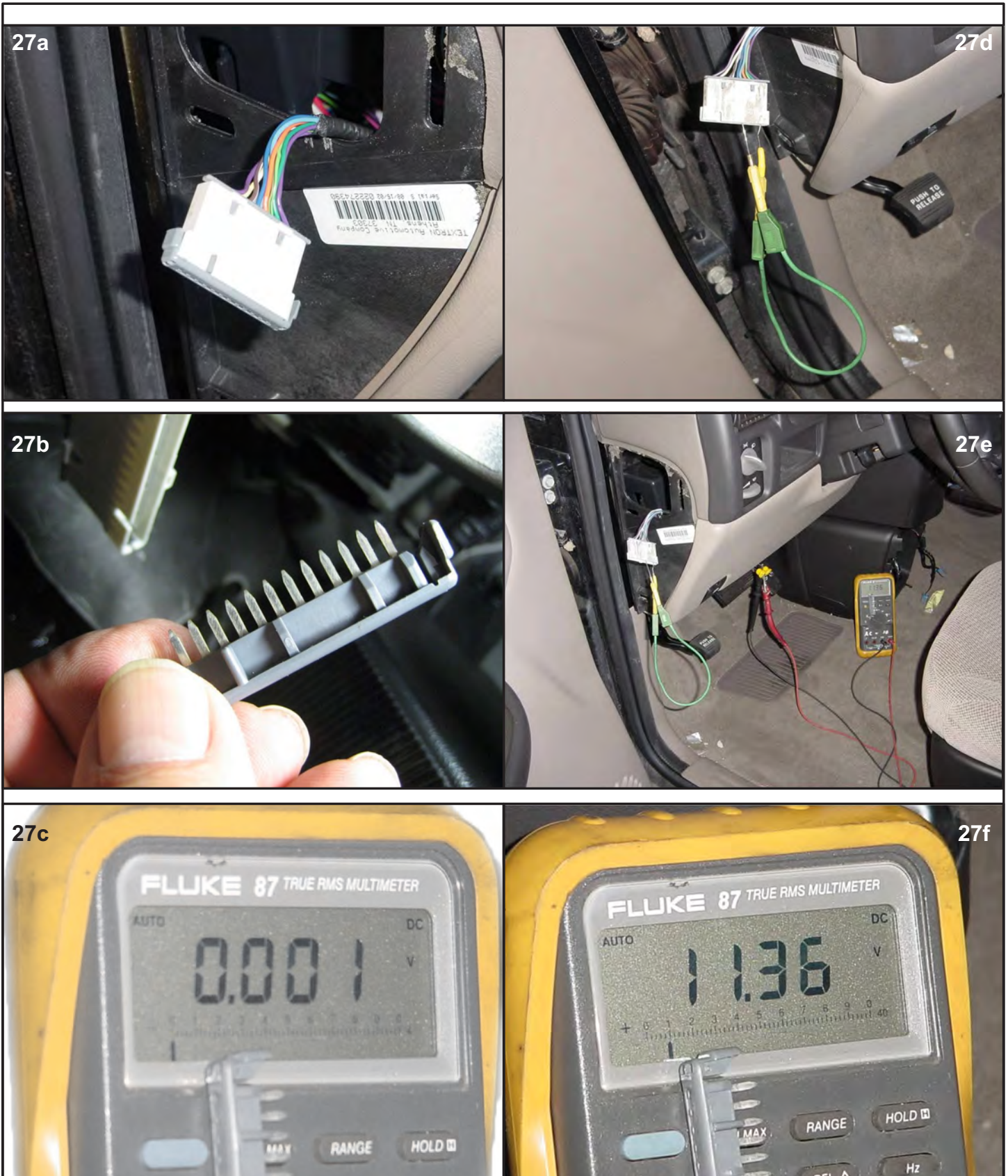
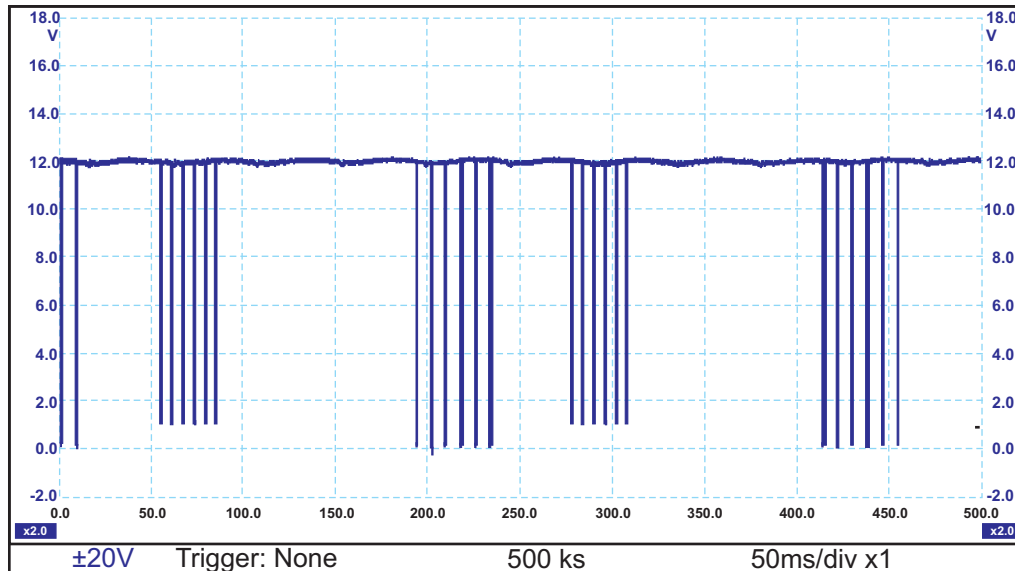


Figure 27

BUS COMMUNICATION

K-LINE



K-Line: Check wiring for terminal location in the DLC*

The K-Line Is a dedicated bi-directional one-wire-bus interface for data transfer operating at a baud rate of 10,400 bps on terminal 7 in the DLC. This is specifically used for scan tool communication. A 0-12 volt pulse (minimum voltage is 10) can be observed on this circuit when the scan tool is requesting information. When the modules on the K-line transmits information to the scan tool, the 12 volts are not fully pulled to ground.

L-Line: Check wiring for terminal location in the DLC*

The optional L-Line is unidirectional, and is only used to pass address information from the diagnostic tester to the ECUs during initialization. The L-Line is in a 1 state during all other events. The K-Line will mimic the L-Line's address initialization. This optional L-Line is not to be confused with LIN (12 volt single-wire 20kbps).**

*A 2001 Hyundai Tiburon uses a K-Line at terminal 2 and an L-Line at terminal 10 in the DLC. Later models the K-Line is housed at terminal 7 in the DLC while the L-Line may be found at terminal 15.

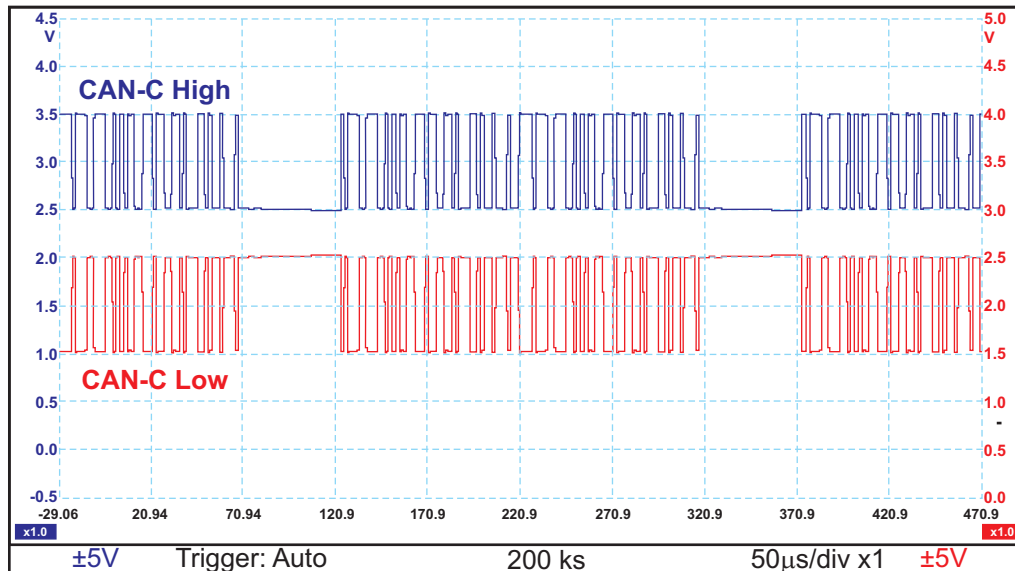
**The LIN Bus (Local Interconnect Network) is a serial networking system.

The development of the LIN Bus arose out of the need for a cheap serial network in automobiles as the number of items within a vehicle that needed to sense conditions or requiring control increased. An earlier system called the CAN bus was too expensive to implement for every component in the car. As a result European car manufacturers started using different serial communication topologies, and this led to compatibility problems. The LIN Bus aimed to reduce costs and thereby enable a single system to be used across the industry and hence fewer compatibility issues.

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Figure 28

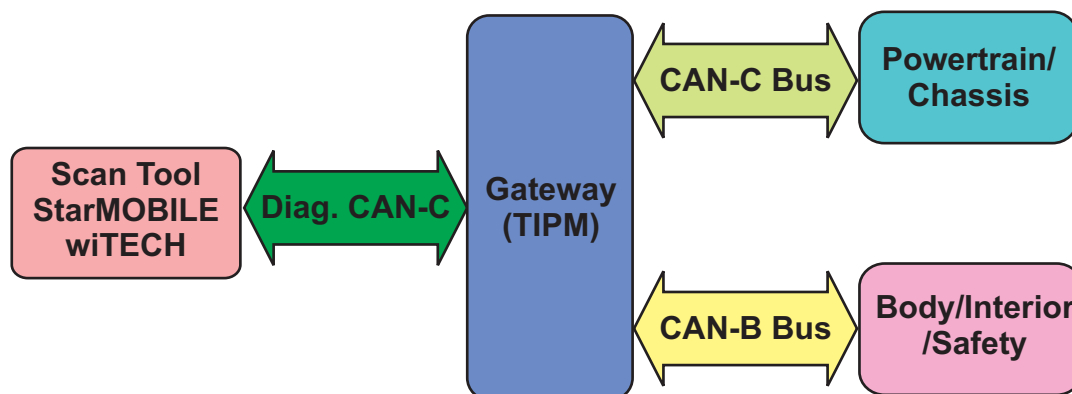
BUS COMMUNICATION HIGH SPEED CAN-C BUS



CAN-C BUS: HS Can-C Bus + is terminal 6 in the DLC
HS Can-C Bus - is terminal 14 in the DLC

It is imperative to consult a wiring diagram to determine if terminals 6 and 14 in the DLC is directly connected to the High Speed (HS) CAN-C circuit or not. Chrysler for example, typically connects to a gateway called a Front Control Module (FCM) or, the Intelligent Power Module (IPM) as seen below. Should any diagnostics be required using an oscilloscope, it will need to be checked at the gateway or by one of the modules on the High Speed network.

Two terminating resistors are usually used at either end of the circuits to ensure that reflection does not occur in the transmission signal. This is accomplished by matching the termination to the impedance of a node to the impedance of the transmission line being used. When the source, transmission line and load impedance are equal, reflections are eliminated.



Typical Chrysler Topology

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Figure 29



Technical Service Information

2003 SATURN L300 3.0L V-6

K-LINE, CLASS II & INTERIOR CAN

COMPLAINT: A 2003 Saturn L300 came in with CAN BUS communication problems producing codes U1000 and a U2105. U1000 is a Class II Data Link code. One explanation given for this code by G.M. is that should this code be set in history with other DTCs set in "current or history", to diagnose these codes or code first. This means DTC U2105 could be the cause of code U1000 and will need to be diagnosed and resolved first. It is learned that code U2105 will set if the BCM or TCM lost CAN communications with the ECM.

A multiplex network module status feature of the Tech 2 scan tool performs a module scan to see who is online and who is off line. When this feature is performed, it is learned that the TCM is down.

If a Tech 2 scan tool is not available, a generic scan tool can be used to see which modules can be accessed. It will be discovered that the ECM and BCM can be accessed but not the TCM.

A network wiring diagram was then pulled and examined (figure 30). The wiring diagram reveals that three different protocols are used; a K-line, a Class 2 line and an internal high speed CAN bus network. The K-line allows scanner communication to the ECM and TCM. If equipped, there is an additional K-line for the Electronic Brake/Traction Control Module. Class 2 allows scanner communication to the BCM which acts as a gateway for the scanner to access enhanced data to the ECM.

The wiring diagram also revealed dedicated can bus wires running from the ECM to BCM as well as from the ECM to the TCM. This means the twisted pair of wires from the ECM to the TCM could be a problem.

With the ECM sitting on top of the engine, it allowed for a fast visual inspection of the connector and can bus wires which all proved to be good. The next step would be to go to the TCM but to get to it would entail removing the right side cowl cover. This prompted taking a look at a wire diagram to see which fuses supply power to the TCM. As figure 31 shows, there are two 10 amp fuses, one hot at all times and one ignition supply going to the TCM. When these fuses were inspected and found to be good, gaining access to the TCM now became necessary.

Once the cowl was removed the problem was immediately discovered. Evidence of a rodent was present and upon further investigation, the wire going to terminal 1 at the TCM was gnawed through. After the wire was repaired, a scan tool was now able to read the TCM. The code was erased but returned immediately after the vehicle was started. Regardless of how many times the code was erased, it would return upon start up.

CAUSE: Code U2105 is a type A code when it relates to the TCM. It is a type C code when it related to the BCM.

CORRECTION: The type A code in this vehicle requires three complete drive cycles turning the ignition off after each trip. If the problem is not seen after the third ignition cycle, the code is eliminated and the MIL light will turn off.



Technical Service Information

2003 SATURN L300 3.0L V-6

K-LINE, CLASS II & INTERIOR CAN

CLASS II CIRCUIT DESCRIPTION

Class II serial data is a 0 to 7 volt variable pulse width message scheme (logic 0's and logic 1's) used to communicate information between modules and for communication to an off-board Scan tool. Contained in each module memory is a list of serial data messages and default actions taken by the module if one of the important messages is not received. One of the most important messages is the state of health (SOH) message used to inform each module that other modules on the Class II link are functioning correctly.

Each module on the Class II link must first "learn" all modules connected to the Class II link every time the ignition is turned On. Each message that a module sends out on the link contains a source identifier used to identify where the information came from. Once a module receives information, it will store the attached controller ID. If this same information is not received later in the ignition cycle, lost communications with a specific controller DTC will set. DTC U1000 sets when a controller does not receive specific information when the source identifier was not learned.

DTC PARAMETERS: DTC U1000 will set if the BCM, PCM, SDM, auto climate control module (if equipped) or ONSTAR CIM (if equipped) did not received information from another Class II module when:

- Condition exists for longer than 6 seconds for BCM, PCM or SDM and longer than 5 seconds for auto climate control module or ONSTAR CIM
- One of the above modules was not able to "learn" the source identifier of another Class II module that it relies on for information.
- Ignition is On Possible combinations for U1000:

- 6-CYL (L81)

- BCM cannot communicate with the I/P cluster, SDM or ONSTAR CIM
- SDM cannot communicate with the BCM, ECM** or I/P cluster
- Auto climate control module (if equipped) cannot communicate with the BCM or ECM
- ONSTAR CIM (if equipped) cannot communicate with the BCM, ECM**, I/P cluster or SDM

DTC U1000 diagnostic runs continuously with ignition On.

DTC U1000 is a type C DTC.

IMPORTANT: If only one other U-type DTC is set, diagnose that DTC first. If two or more different U-type DTCs are set, perform the "Vehicle On-Board Diagnostic System Check".

** L81 vehicles only: If the ECM is not communicating over the CAN link with the BCM as soon as the ignition is turned On, the SDM, auto climate control module (if equipped) and ONSTAR CIM (if equipped) will set U1000. If the ECM loses communication with the BCM after the ignition was turned On, these modules will set U1016 and the BCM will set U2105. Diagnose U2105 first. This DTC indicates that a module did not communicate with another module(s) when the ignition was first turned On.

The Class II circuit is in a ring configuration. An individual open in circuit 1807 will NOT affect communications. Check for module connector tightness and broken connector locks.

To locate an intermittent problem, use Scan tool to monitor each individual controller located under DIAGNOSTIC CIRCUIT CHECK---CLASS II MESSAGE MONITOR with ignition On, engine Off. If a controller is not communicating on the Class II link, either the controller name will not appear or INACTIVE will be displayed.



Technical Service Information

2003 SATURN L300 3.0L V-6 K-LINE, CLASS II & INTERIOR CAN

DTC U2105

DTC PARAMETERS: DTC U2105 will set if the BCM or TCM lost CAN communications with the ECM when:

- Condition exists for longer than 2 seconds for TCM, 3 seconds for BCM
- Ignition is On

DTC U2105 diagnostic runs continuously with ignition On.

DTC U2105 is a type A DTC for TCM.

DTC U2105 is a type C DTC for BCM.

DIAGNOSTIC AIDS FOR DTC U2105

IMPORTANT: If DTC U2100 is also set in the ECM, diagnose that DTC first. If a short to ground/voltage occurs on the CAN link, the BCM and TCM will set U2105.

The TCM sends the BCM vehicle speed for the speedometer over the CAN link. If an open exists in either CAN high or CAN low circuit between the ECM and TCM, the tachometer will be inoperative.

The ECM sends the BCM tachometer RPM over the link. If an open exists in either CAN high or CAN low circuit between the ECM and BCM, the tachometer and speedometer will be inoperative.

With ignition On, each CAN high or CAN low circuit should have between 1.5 and 3.5 volts measuring into a control module no matter how many modules are left connected.

An open anywhere in the CAN link will result in a least one controller not communicating.

If main relay voltage is not present at the ECM as soon as the ignition is turned On, the ECM will NOT communicate over the CAN link; however it will communicate with the Scan tool. As soon as main relay voltage is present, the ECM will communicate over the CAN link for the entire ignition cycle even if main relay voltage is later lost.

Check ECM mounting bolts for tightness and corrosion.



Technical Service Information

2003 SATURN L300 3.0L V-6

K-LINE, CLASS II & INTERIOR CAN

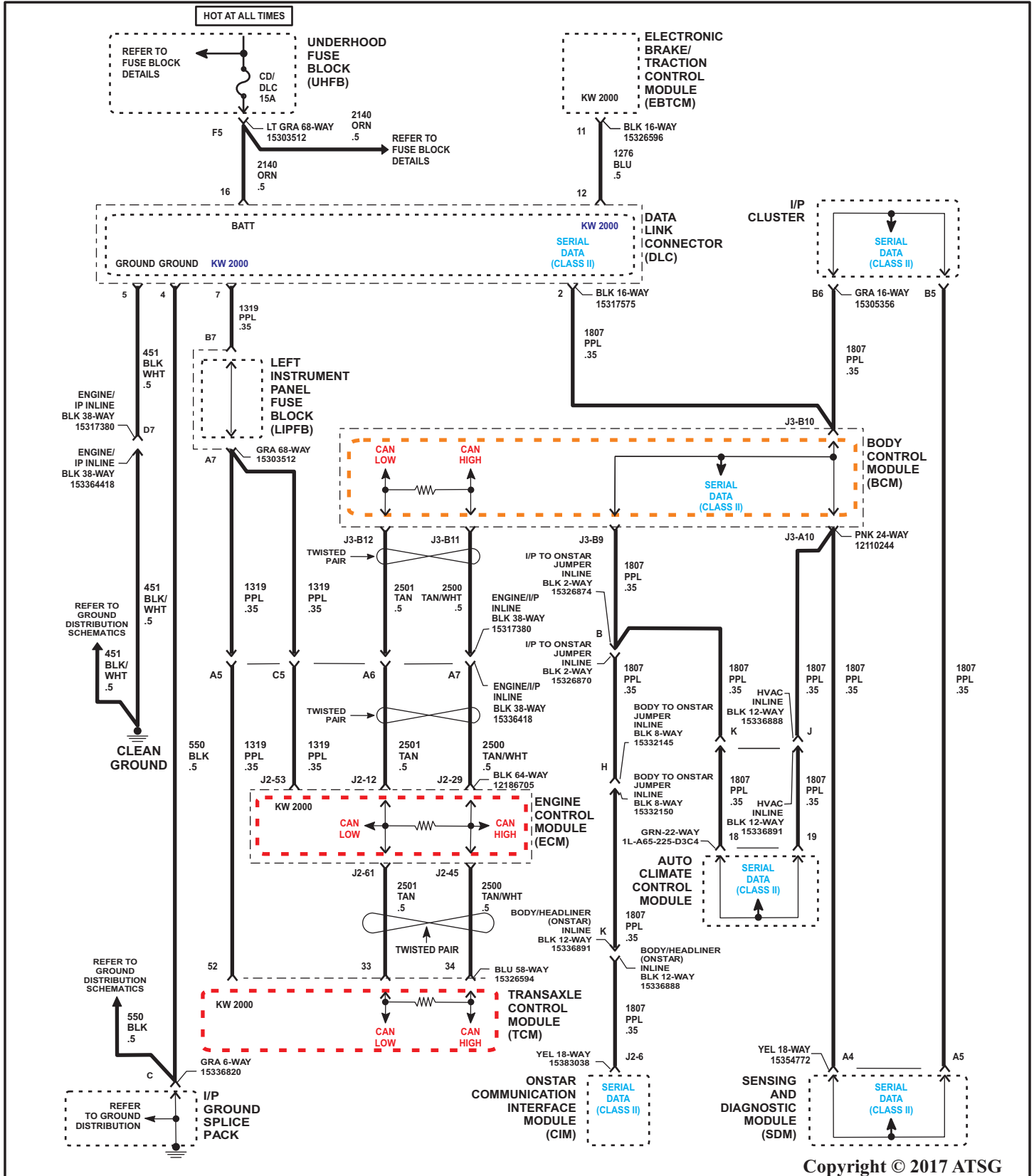


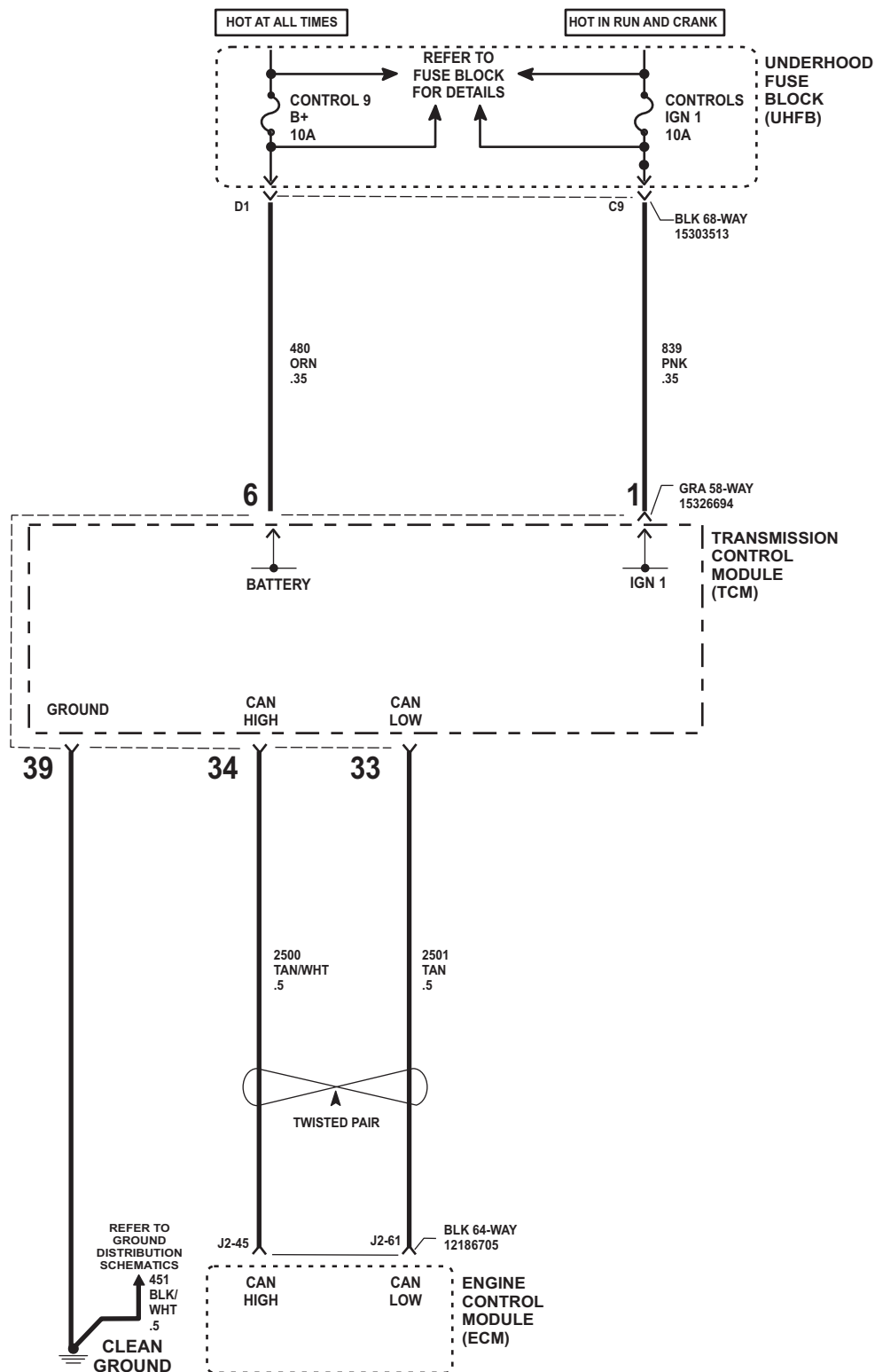
Figure 30



Technical Service Information

2003 SATURN L300 3.0L V-6

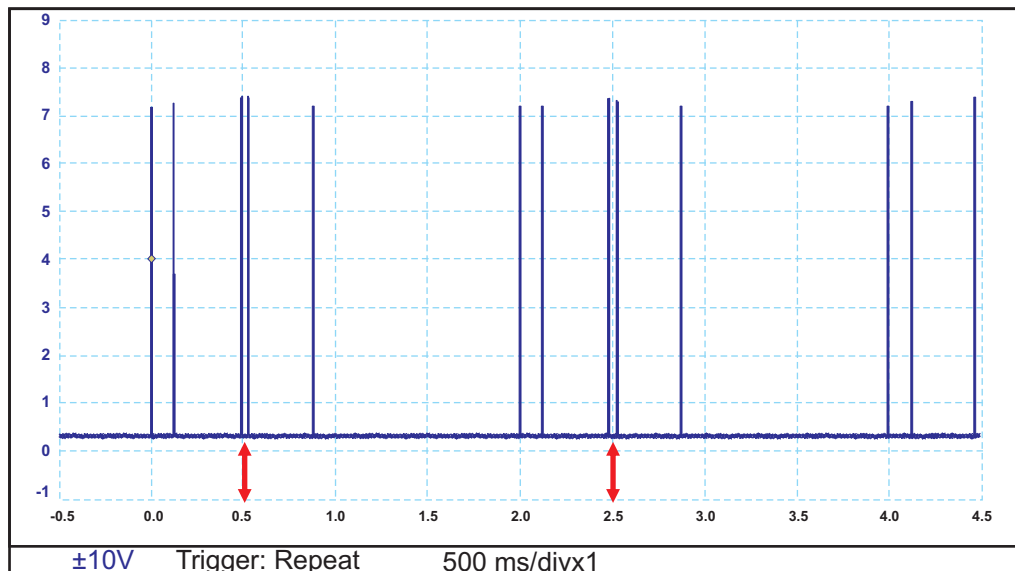
K-LINE, CLASS II & INTERIOR CAN



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Figure 31

2003 SATURN L300 3.0L V-6 K-LINE, CLASS II & INTERIOR CAN



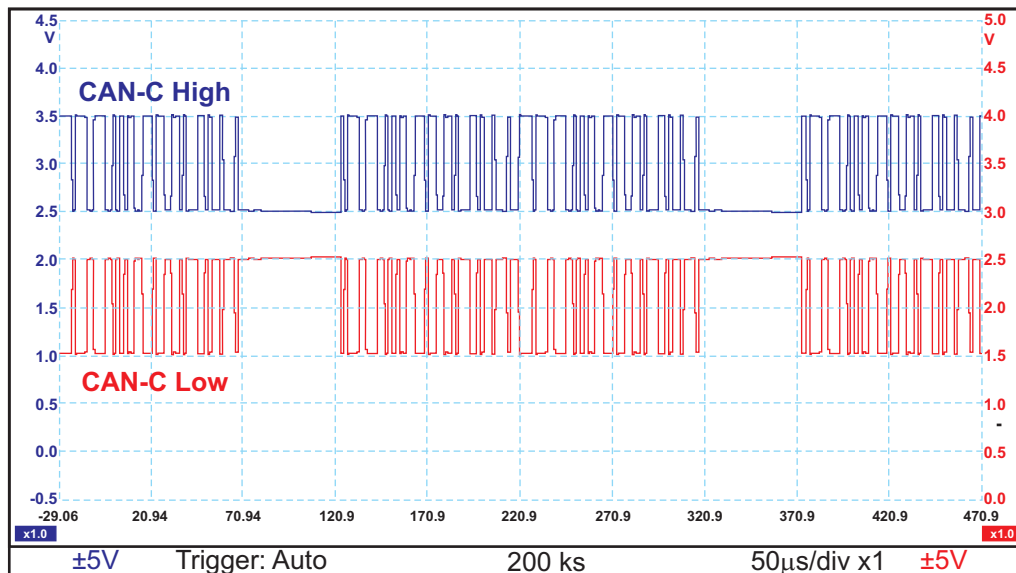
State of Health (SOH) messages are sent out every 2 seconds. If a module fails to send its SOH message two times in a row (5 seconds), a network DTC is set by the "OTHER" modules that required the information. The module containing the DTC is not necessarily the module with the fault.

Every module on the Class II BUS has its own unique ID number:

Powertrain Control Module (PCM): ID number: 016
 Body Control Module (BCM): ID number: 064
 Sensing and Diag. Module (SDM): ID number: 088
 Instrument Panel Cluster (IPC): ID number: 096
 Vehicle Comm. Module (VCIM): ID number: 151
 HVAC Control Module: ID number: 153

Six modules are scanned for codes, the BCM and the IPC come back storing code U1016. What module would be considered suspect?

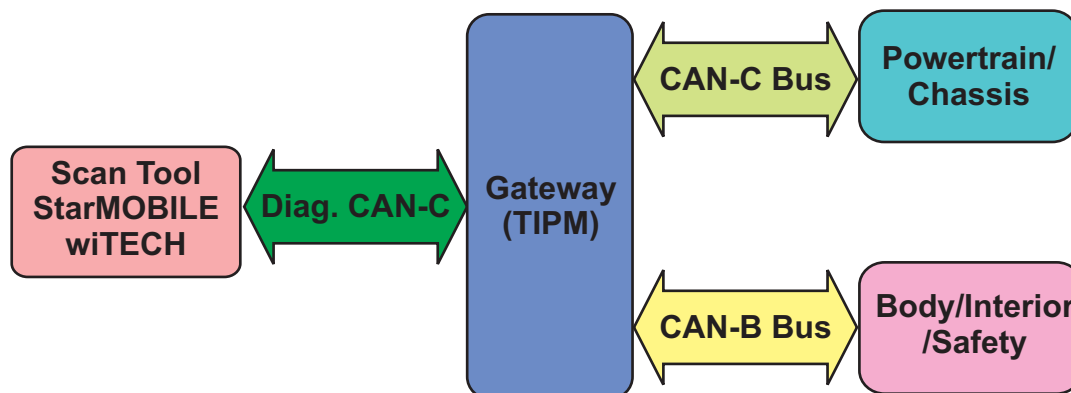
BUS COMMUNICATION HIGH SPEED CAN-C BUS



CAN-C BUS: HS Can-C Bus + is terminal 6 in the DLC
HS Can-C Bus - is terminal 14 in the DLC

It is imperative to consult a wiring diagram to determine if terminals 6 and 14 in the DLC is directly connected to the High Speed (HS) CAN-C circuit or not. Chrysler for example, typically connects to a gateway called a Front Control Module (FCM) or, the Intelligent Power Module (IPM) as seen below. Should any diagnostics be required using an oscilloscope, it will need to be checked at the gateway or by one of the modules on the High Speed network.

Two terminating resistors are usually used at either end of the circuits to ensure that reflection does not occur in the transmission signal. This is accomplished by matching the termination to the impedance of a node to the impedance of the transmission line being used. When the source, transmission line and load impedance are equal, reflections are eliminated.

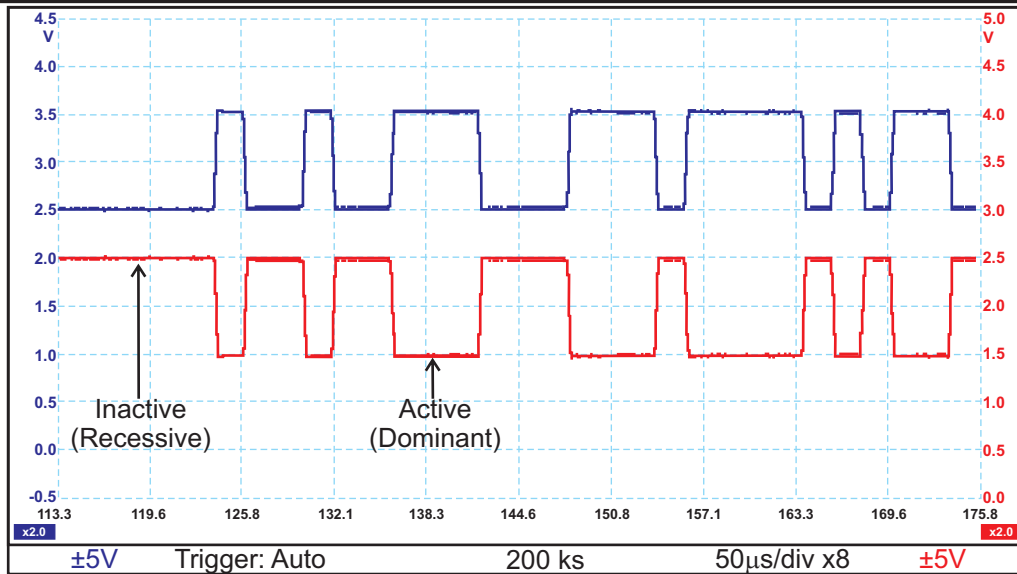


Typical Chrysler Topology

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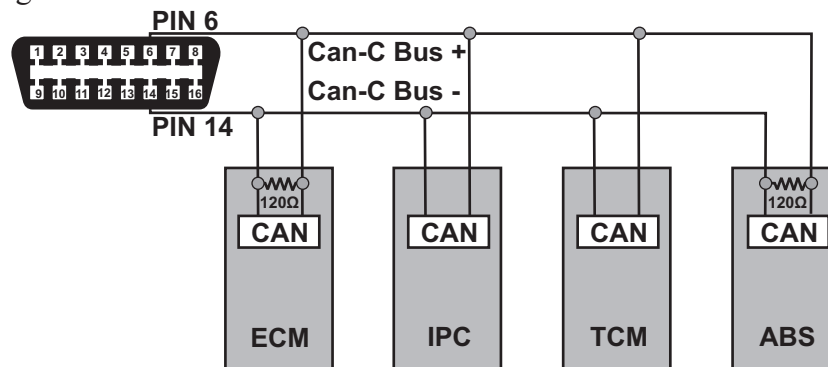
Figure 33

BUS COMMUNICATION HIGH SPEED CAN-C BUS



High Speed (HS) CAN-C uses a differential type of module communication where the voltage on one wire is the equal but opposite voltage on the other wire. When no communication is occurring, both wires have 2.5 volts applied. When communication is occurring, CAN H (high) goes up 1 volt to 3.5 volts and CAN L (low) goes down 1 volt to 1.5 volts.

To provide proper data transmission, the CAN bus is terminated at either end of the network with 120 Ω resistors. A simple check of the CAN bus would be to connect an ohm meter across pins 6 and pin 14 in the DLC. Due to the combined resistance of two 120 Ω termination resistors, the overall resistance should be read between 50 Ω to 70 Ω (60 Ω). The average 60 Ω measurement should be the same at any point on the network. If the value is below 50, be sure that there is not more than 2 terminating resistors in the circuit. Then check for shorts between CAN+ and CAN- wiring or for nodes with faulty receivers. If the value is higher than 70 Ω, look for opens in the wiring or for a defective terminating resistor.

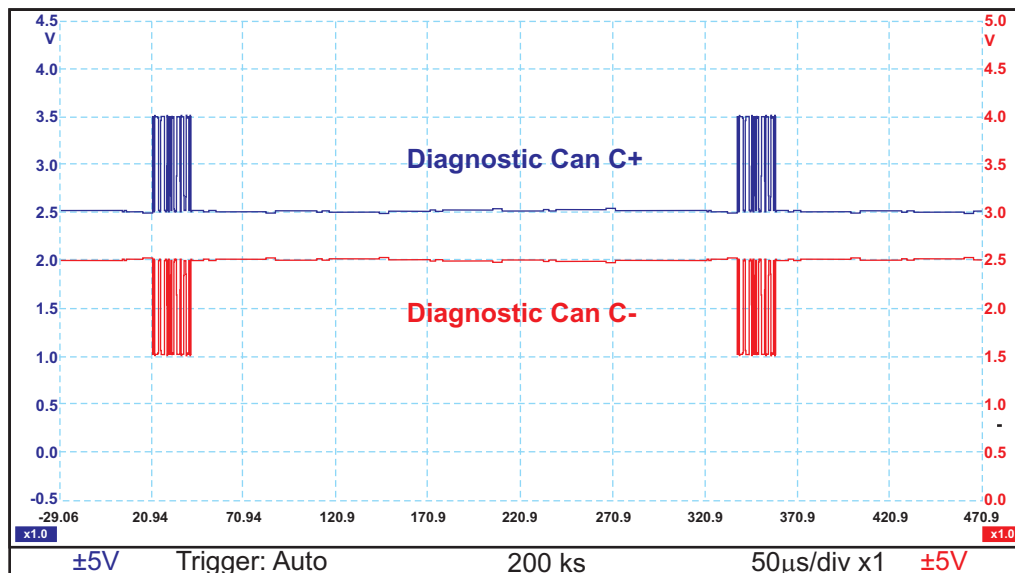


$$\frac{1}{\frac{1}{120} + \frac{1}{120}} = \frac{1}{\frac{2}{120}} = \frac{1}{.01666} = 60\Omega$$

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Figure 34

BUS COMMUNICATION DIAGNOSTIC CAN-C BUS



Looking at the Data Lines for a 2010 Volkswagen Jetta in figure 30, it can be seen that the scan tool communicates to the CAN-Bus through the Data Bus On Board Diagnostic Interface Module. This arrangement is similar to Chrysler's topology where they use the Front Control Module like Volkswagen uses the Data Bus On Board Diagnostic Interface Module (figure 27).

The Front Control Module and the Data Bus On Board Diagnostic Interface Module are known as gateways. They allow for the physical and electrical separation of the different bus protocols while still allowing all networks to share their information. It does this by coordinating their bi-directional information that it receives.

The short pair of twisted wires between the DLC and the gateway module is called the Diagnostic Can-C bus by Chrysler (Can-D with Mercedes). The same concept can be applied to Volkswagen as this separate bus circuit operates at the same high speed (500 kbps) as the CAN-C Bus but is solely used to transfer information from the gateway to the diagnostic scan tool.

When an oscilloscope is connected to the "Diagnostic Can-C bus" through terminals 6 (Can high) and 14 (Can lo) in the DLC, both circuits at rest will be at 2.5volts. When speaking, CAN High will go the 3.5 volts and CAN Low will go to 1.5 volts in the same way regular CAN-C bus communicates. The difference between Diagnostic Can-C bus and CAN-C bus is the amount of activity that will be observed. Compare the screen capture above with figure 27 to see the difference in activity.

Technician's note: There should be 0 volts at each of these terminals when the ignition is off and 2.5V when the ignition is on. If there is voltage when the ignition is off, it may indicate a module is not shutting down. A parasitic draw problem with the vehicle will keep modules awake.

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Figure 35



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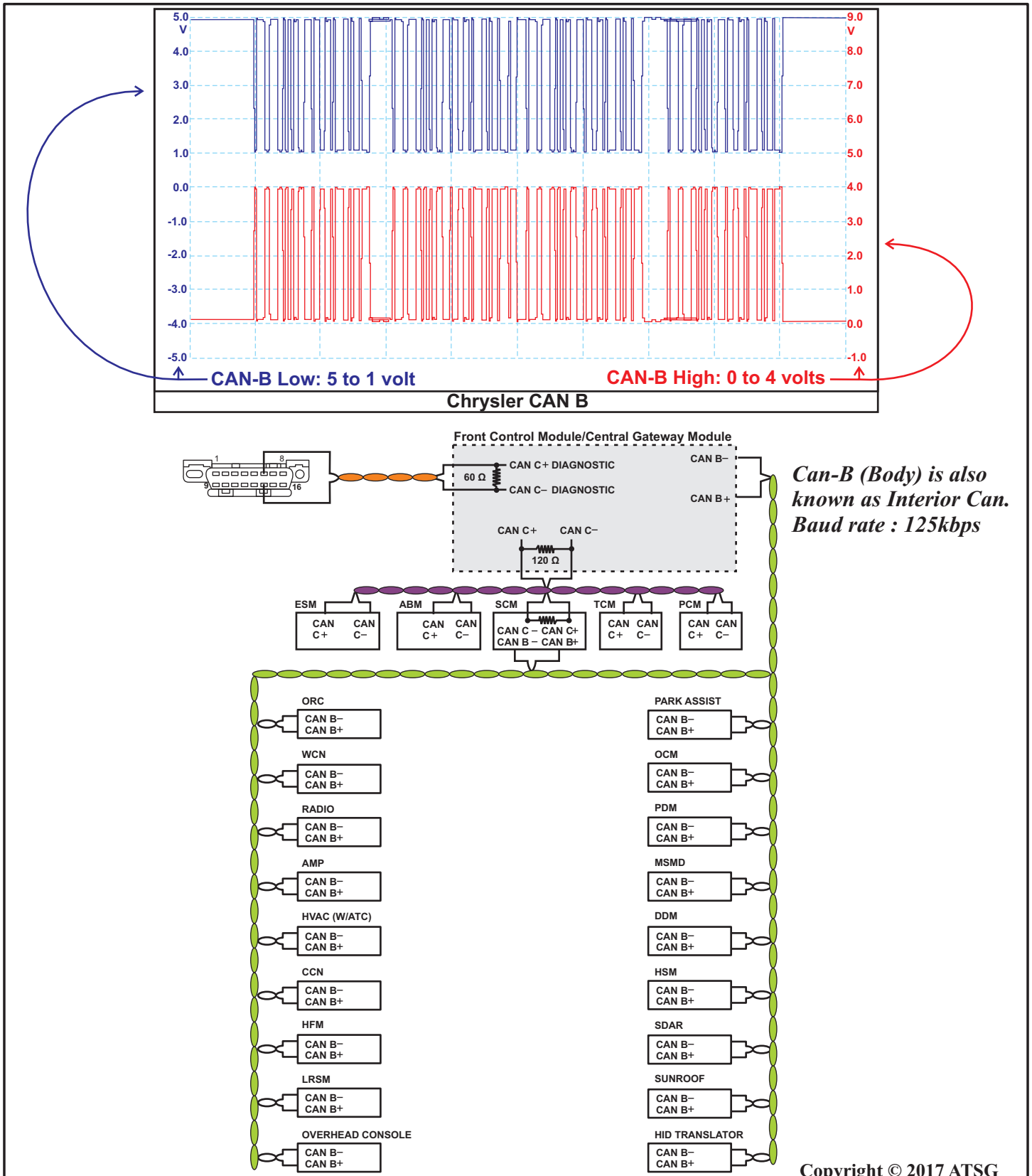
BUS COMMUNICATION

CAN-B BUS

CAN Bus Voltages (Normal Operation)								
CAN C Bus Circuits	Sleep	Recessive (Bus Idle)	Dominant (Bus Active)	CAN L Short to Ground	CAN H Short to Ground	CAN L Short to Battery	CAN H Short to Battery	CAN H Short to CAN-L
CAN-L (-)	0 V	2.4 - 2.5 V	1.3 - 2.3 V	0 V	0.3 - 0.5 V	Battery Voltage	Battery Voltage Less 0.75 V	2.45 V
CAN-H (+)	0 V	2.4 - 2.5 V	2.6 - 3.5 V	0.02 V	0 V	Battery Voltage Less 0.75 V	Battery Voltage	2.45 V
CAN-Interior Bus Circuits	Key-Off (Bus Asleep)		Key-ON (Bus Active)	CAN-L Short to Ground	CAN-H Short to Ground	CAN-L Short to Battery	CAN-H Short to Battery	CAN-H Short to CAN-L
CAN-L (-)	0.0 V		1.3 - 2.3 V	00W	0.3 - 0.5 V	Battery Voltage	Battery Voltage Less 0.75 V	2.45 V
CAN-H (+)	0.0 V		2.6 - 3.5 V	0.02 V	00W	Battery Voltage Less 0.75 V	Battery Voltage	2.45 V
Notes								
All measurements taken between node ground and CAN terminal with a standard DVOM								
DVOM will display average network voltage								
Total resistance of CAN-C network can also be measured (60 ohms). Total resistance of CAN-Interior varies, depending upon the number of optional non-dominant nodes on the BUS. CAN-Interior total resistance should range between about 60 ohms with the minimal number nodes, to about 42 ohms with the maximum number of nodes.								
<p>In order to minimize the potential effects of Ignition-OFF Draw (IOD), the CAN-Interior network employs a sleep strategy. However, a network sleep strategy should not be confused with the sleep strategy of the individual nodes on that network, as they may differ. For example: The CAN-C bus network is awake only when the ignition switch is in the ON or START positions; however, the TIPM, which is on the CAN-C bus, may still be awake with the ignition switch in the ACCESSORY or UNLOCK positions. The integrated circuitry of an individual node may be capable of processing certain sensor inputs and outputs without the need to utilize network resources.</p> <p>The CAN-Interior bus network remains active until all nodes on that network are ready for sleep. This is determined by the network using tokens in a manner similar to polling. When the last node that is active on the network is ready for sleep, and it has already received a token indicating that all other nodes on the bus are ready for sleep, it broadcasts a bus sleep acknowledgment message that causes the network to sleep. Once the CAN-Interior bus network is asleep, any node on the bus can awaken it by transmitting a message on the network. The TIPM will keep either the CAN-Interior or the CAN-C bus awake for a timed interval after it receives a diagnostic message for that bus over the Diagnostic CAN-C bus.</p>								
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Figure 37

BUS COMMUNICATION CAN-B BUS



*Can-B (Body) is also known as Interior Can.
Baud rate : 125kbps*

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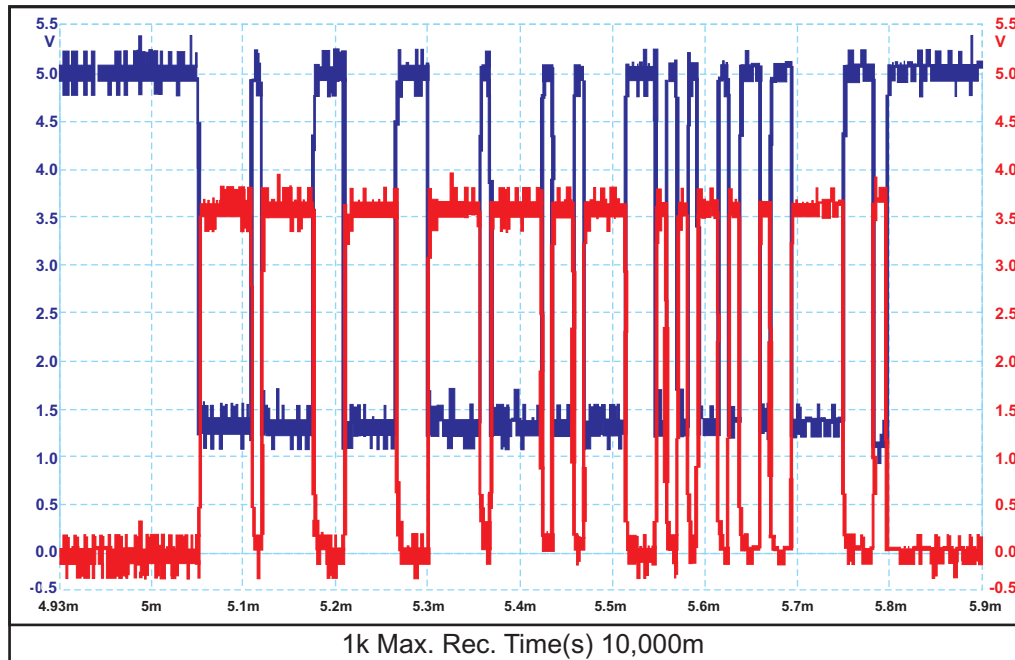
Figure 38



Technical Service Information

BUS COMMUNICATION

LOW SPEED CAN BUS



Both the Comfort (Convenience) and Infotainment Can Bus protocols operate at a data transfer rate of 100kbps. Similar to Can-C Bus, a pair of twisted wires are used with which the data is transferred. Logically, High Speed and Low Speed Can systems have differences in Baud Rate. High Speed works from 10kbit to 1Mbits/sec and Low Speed restricts to 125kbps (Low Speed Can offers baud rates from 40 kbps to 125 kbps).

Another major difference between the two Bus systems is "Termination Resistance". High Speed CAN requires 120 Ohm termination on the bus while Low Speed CAN devices are self terminated (Every Device has Termination). Termination Resistors are to avoid "Standing Waves" which would be significant in case of High Speed and Longer Bus lengths which is not significant in case of Low Speed CAN.

Another Difference is High Speed CAN won't work if there is problem in Wiring but Low Speed CAN can work on Asynchronous network as it is terminated/grounded at every node. That's why Low Speed CAN is called as "Fault Tolerant CAN".

The Can-high and Can-low signals are independent. There is no common medium voltage. The Can-high signal is 0 volts in a recessive state (rest state), and greater than or equal to 3.6 volts in a dominant state. For Can-low signal, the recessive level is 5 volts and the dominant level is less than or equal to 1.4 volts.

After differential build-up in the differential amplifier, the recessive level is 5 volts and the dominant level 2.2 volts (3.6-1.4). The combined difference in voltage between the recessive and dominant levels (voltage rise) is therefore greater than or equal to 7.2 volts.