Center for Automotive Science & Technology at Weber State University

Controller Area Network (CAN) for Vehicle Emissions Data Communication

Prior to 1996 Model Year (MY) vehicles, communication between the on-board emissions control module and an off-board computer system was not standardized between the different vehicle Original Equipment Manufacturers (OEMs). In fact, there was no requirement for federally certified vehicles to even have emissions data communication available between an on-board and off-board computer system. With the advent of On-Board Diagnostics (OBD) for 1996 and newer vehicles, emissions related serial data communication between the emissions control module/modules (generally referred to as the Powertrain Control Module or PCM) and off-board computer systems such as OBD I/M test equipment or diagnostic scan tools is required and has been limited to 3 general communication protocols, each with variations possible within the protocol:

- SAE J1850
- ISO 9141
- ISO 14230 (more commonly known as KWP2000)

> Note: A chart that details which communication protocols are used by the vehicle manufacturers is freely available for download at http://www.etools.org Select the Public Files link (currently on the left side of the web page) and then select the link for Current and Future Use of CAN. On the right side of the page will be links to various files that detail communication protocols used by Make, Model and Year since 1996.

Note: A Serial Data Voltage Waveform Comparison page is provided at the end of this article for a general reference of each protocol type.

To further reduce the number of possible variations in emissions related data communication, the Controller Area Network (CAN) protocol is required to be implemented on passenger vehicles and light duty trucks by the 2008 MY. A small number of 2003 MY vehicles were CAN equipped, but phase in is actually required from 2004 through 2007 MY vehicles.

There are many reasons for adapting the CAN protocol for emissions related OBD functions:

- The protocol is well established; even though CAN is just now being phased in for emissions data communication, CAN has been in use with other computer systems, both on and off the vehicle for many years. The protocol is based on the International Standards Organization (ISO) 11898 standard with specific automotive application standards in the Society of Automotive Engineers (SAE) J2284 Recommended Practice documents. Refer to www.sae.org www.iso.org and http://www.can-cia.de/ for the standards and other detailed information on the CAN protocol.

- CAN allows for a wide range of data bus speeds: from 10,000 bits per second (10k bit/s) to 1,000,000 bits per second (1M bit/s). This means the CAN protocol is able to accommodate the needs for faster data transmission rates as well as increased amounts of data. Coinciding with the CAN protocol phase in, federal EPA and the California Air Resources Board (CARB) are requiring vehicle manufacturers to include additional data parameters to be transmitted. The specifics of these requirements can be found at the CARB website: http://arbis.arb.ca.gov/msprog/obdprog/obdregs.htm under Final Regulation Order Section 1968.2.

General Comparison of Bit Rate and Bit Times

Bit Rate	Nominal Bit-Time (microseconds)
1 Mbit/sec	**1μS**
500 kbit/s	**2μS**
250 kbit/s	**4μS**
125 kbit/s	**8μS**
20 kbit/s	**50μS**
10 kbit/s	**100μS**

Note: other bit rate and times are also available for use within the CAN protocol

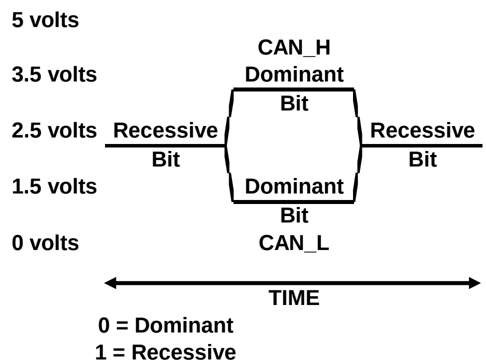
- CAN incorporates many of the positive features other protocols have used, such as:

- Message Prioritization/Bus Arbitration (the module with the highest priority message controls data transmission until that message is complete, then the module with the next priority message transmits)
- Multicast reception (one module sends a message that several other modules use)
- Remote data request (one module requests information from another module)
- Redundant data circuits for increased circuit fault tolerance capability and superior noise filtering capability

- CAN also includes advanced features such as:
  - Module Auto-Off if the module becomes faulty and may possibly disrupt communication
  - Additional modules can be added to the network without an entire system reconfiguration
  - 3 different voltage states that represent 0 and 1 data bits on two circuits for redundancy (increased fault tolerance) and increased noise filtering capabilities

Changes to hardware and software of off-board computer systems for CAN compatibility are required because of the addition of the two CAN data circuits in the Data Link Connector (DLC), voltage states used to transmit data and the amount of time per data bit:

- Prior to CAN, DLC terminals 6 & 14 were open for any use by the vehicle manufacturers (some restrictions apply – for details refer to SAE J1962), but as CAN is implemented on the vehicle for emissions data communication, DLC terminal 6 is reserved for the CAN High (CAN_H or CAN+) circuit and terminal 14 is reserved for the CAN Low (CAN_L or CAN-) circuit. Since not all OBD I/M test equipment or scan tool cables were constructed with these two circuits, older cables may have to be replaced with updated cables that have the appropriate circuitry.
  Important note: Terminals 6 and 14 are associated with the CAN communication network responsible for transmitting emissions related data. There may be other non-emissions related CAN networks on the vehicle that connect to the DLC at other terminals.



- In the past, data protocols used a 0 volt state and then a voltage high state; some protocols use 5 volts, other protocols use 7 volts while others use 12 volts or system voltage. The high speed CAN protocol uses 2.5 volts to represent a recessive bit which is translated as a 1 data bit. A 0 data bit is represented by a dominant bit; on the CAN_H circuit a dominant bit is at 3.5 volts and on the CAN_L circuit the dominant bit is at 1.5 volts. Note: CAN voltage values referenced in this article are based on nominal values as listed in ISO 11898. Each circuit has a range of acceptable voltage levels and the voltage difference between CAN_H and CAN_L during a dominant bit can range from 1.2 volts to 3.0 volts with 2.0 volts being specified as nominal.

- To achieve higher speed communication, the amount of time a voltage state exists to represent a data bit must decrease. Many of the vehicle OEMs are using the 500,000 bit/second (500k bit/s) speed which means the bit width in time is 2 microseconds (2 µS or 0.000002 seconds per bit – to verify this time, divide 1 by 0.000002 and the answer should be 500,000 bit/second or 1 divided by 500,000 = 0.000002 seconds/bit). Currently the 500k bit/s system is being referred to as "High Speed CAN" by many of the vehicle manufacturers.

Because of these differences, hardware and software of the off-board computer systems must be updated for CAN communicate to be possible.

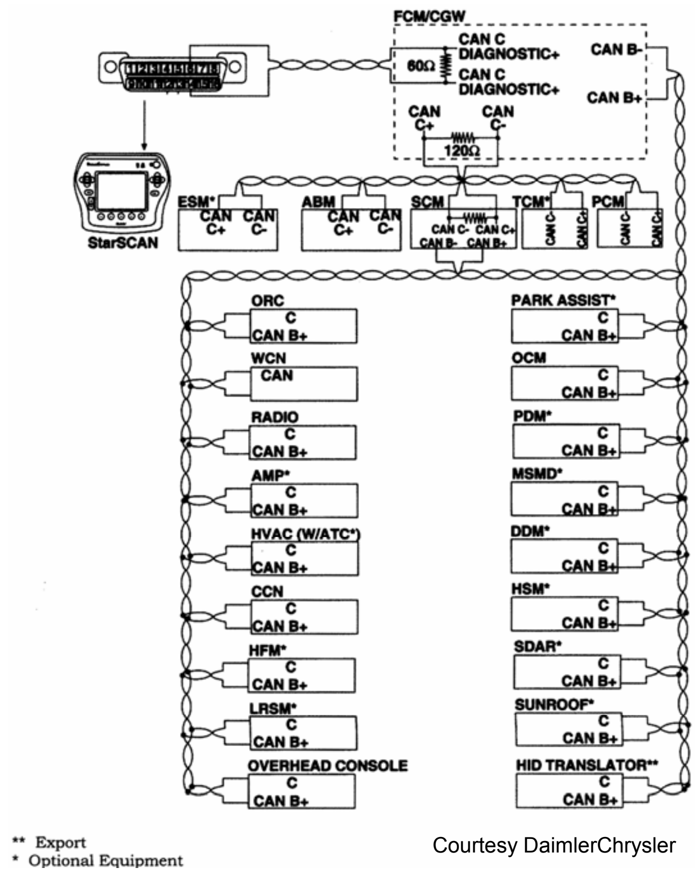
CAN System Fault Tolerance

Since the CAN system is designed to use two circuits, it is possible to have the system communicate on only one circuit (with degraded signal to noise ratio) if the other circuit has a fault such as an open, short to ground or B+. This type of fault tolerance is recommended in the related CAN specifications, but fault tolerance is not required at this time. As a result, some CAN systems will be able to communicate when a short to ground or power exists on one or the other CAN circuit, yet other CAN systems will not be able to communicate when a fault condition exists on either CAN circuit. Fault tolerant CAN systems may also be able to continue communications with the two CAN circuits shorted together, similar to SAE J1850 Pulse Width Modulation (PWM) systems.

CAN System Configurations
Single and Two Circuit Systems

Within the CAN specifications there exists many different possible configurations. For example, manufacturers may have a single circuit CAN application; however, these systems are currently used with non-emissions related systems such as headlamp or other body control modules, climate control systems, radios, etc. The single circuit systems operate at a speed much lower than the 500k bit/s two circuit (CAN_H and CAN_L) system being used for emissions related data transmission since noise suppression and filtering capabilities with a single wire are reduced. Some manufacturers also use a two wire, lower speed CAN system for non-emissions related data that is typically fault tolerant. Non-emissions related CAN systems may also use voltage levels other than those specified for the emissions related high speed CAN systems.
Both the single and two data circuit configurations are permitted to operate within a range of speeds (refer to the General Comparison table listed previously) with the understanding that a system will use only one speed. Some vehicles use multiple CAN systems with each operating at different speeds. To facilitate data transfer from one system to another (for example; vehicle speed (VS) data on the high speed system may also be required by an audio system for vehicle speed volume compensation), an interface module (may also be referred to as a cross-over, gateway, or bridge) is needed and becomes an integral part of both the high speed and low speed CAN data networks.

SAMPLE CAN WIRING DIAGRAM WITH TWISTED PAIR CIRCUITS & TERMINATING RESISTORS



Courtesy DaimlerChrysler

Shielded and Non-Shielded Twisted Pair Systems

Different methods exist to help reduce electromagnetic interference (EMI) from components (other wiring, modules, coils, etc.) near the CAN data circuit or circuits. If the data circuits are shielded, the shield drain circuit is to be grounded on only one end that should be identified in the related service information wiring diagram. This is a typical requirement to avoid creating a possible ground current loop between modules with slightly different ground voltage levels. As an important reminder, if the shield or drain circuit becomes damaged, proper repair procedures must be followed to ensure shield and drain circuit continuity is maintained so the signal to noise ratio is correct.
Instead of using a shield and drain configuration, the two circuit CAN system may have the insulated circuits twisted together throughout the wiring harness as a method to reduce EMI. By twisting the two circuits together, external noise induced on the two circuits is effectively cancelled. The unshielded twisted pair must have a twist rate

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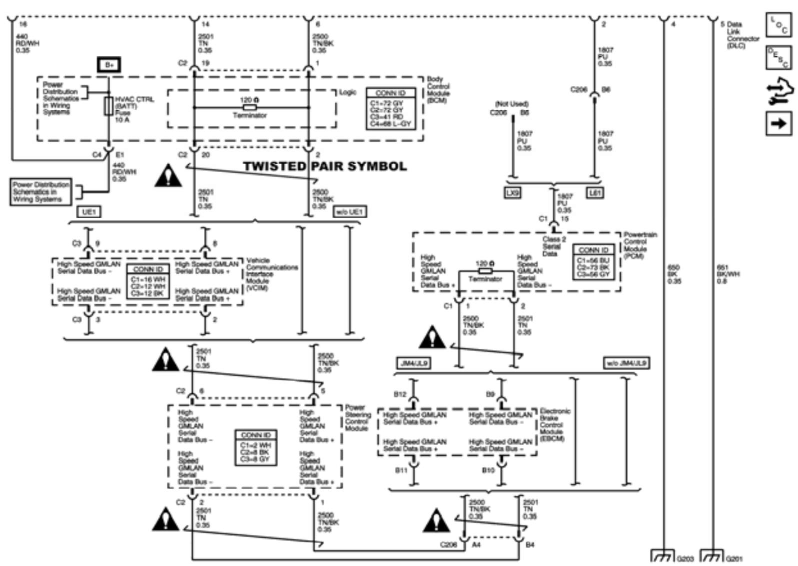


Courtesy General Motors Co.

between 33 and 50 twists/meter. If the twisted pair becomes damaged, repair procedures must include maintaining the twist rate specified in the appropriate service information.

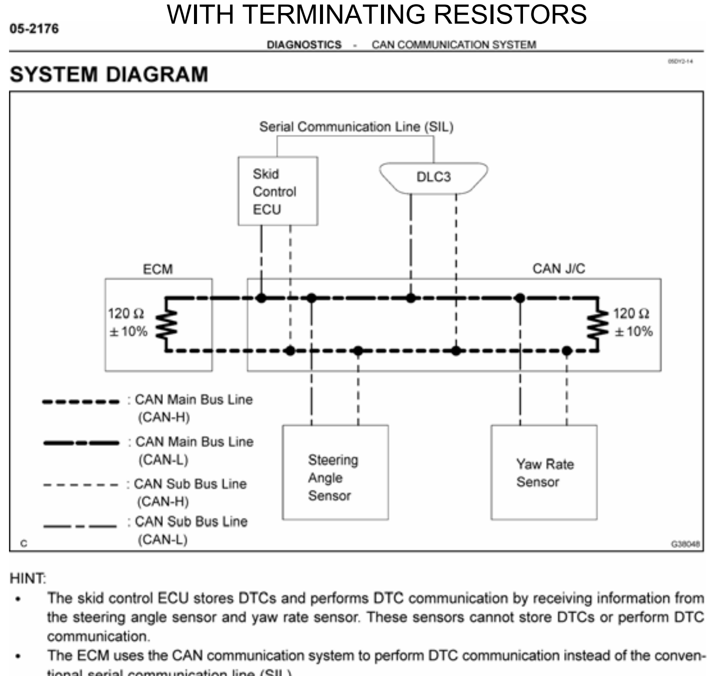
Terminating Resistors

Terminating resistors are used in the CAN system to create a proper electrical load between the CAN_H and CAN_L circuits. This load helps to reduce electrical noise on the data circuits, which in turn allows for a cleaner voltage signal.

Terminating resistors in the high speed CAN systems are required to be 120Ω (actual specified range is 118Ω - 132Ω) with lower speed CAN systems using other resistance values. Split termination implementations are allowed, which means there may be more than two terminating resistors in the system as long as the equivalent resistance between CAN_H and CAN_L is between approximately 60Ω and 130Ω. Terminating resistors may be physically located inside any of the modules connected to the CAN harness, within a CAN junction connector, or the resistors may be part of the wiring harness itself. Terminating resistors may or may not be identified in the vehicle wiring diagrams.

Because of the many variations related to terminating resistor configuration and locations, communication fault diagnostics for the specific vehicle must be precisely followed. <u>Do not attempt to conduct wiring diagnostic fault isolation procedures such as voltage or resistance tests without the proper service information and specifications.</u>

SAMPLE CAN WIRING DIAGRAM
WITH TERMINATING RESISTORS



Courtesy Toyota Motor Co.

CAN System Diagnosis

Diagnosing CAN communication errors requires the proper service information and diagnostic equipment. A CAN compatible scan tool as well as appropriate service information which includes an accurate wiring diagram of the CAN system being diagnosed should be considered essential. Always follow the appropriate fault isolation procedures published by the vehicle manufacturer. The following diagnostic suggestions are not intended to replace any vehicle manufacturer diagnostic procedure; rather, they are intended to supplement/enhance published procedures for communication system diagnosis:

- Verify whether or not your diagnostic scan tool is able to communicate with the PCM. *<u>Important note:</u> If the scan tool is able to communicate but the vehicle failed an OBD I/M test for no-communication, make sure the next three steps are completed. Many scan tools do not require B+ at DLC pin 16 or ground at pin 4 or pin 5 (ground must be present at one or the other) for communication, however, most OBD I/M test equipment do require proper circuit functionality at pins 16, 4 and 5 for communication.*
- Verify B+ is available at DLC pin 16; system voltage should be present at all times. Use a known good ground (battery negative if possible) to make this measurement. The best way to verify circuit functionality is to take voltage measurements while a scan tool is connected to the DLC, powered on if possible and requesting data. The DLC may have to be backprobed (carefully) to gain access to each circuit for diagnosis with the scan tool connected.
- Verify DLC pin 4 is properly grounded.
- Verify DLC pin 5 is properly grounded. After verifying proper ground at pin 5, use this circuit for reference low during any data circuit voltage measurements since this is the communication network reference low.
- With the ignition key on and scan tool disconnected from the DLC, measure voltage at DLC pin 6 (CAN_H) and pin 14 (CAN_L). If the communication circuits do not have a malfunction present, the measured voltage on most systems will be rapidly fluctuating and will be between 1.5 volts and 3.5 volts. If a short to ground exists, measured voltage will be lower than 1.5 volts and if a short to positive voltage exists the measured voltage will be above 3.5 volts. *<u>Important note:</u> Some CAN networks may use a separate CAN section for connection to off-board diagnostic computer systems such as scan tools or OBD I/M test equipment (refer to the previous DaimlerChrysler diagram). These diagnostic CAN circuits may be inactive until an off-board computer is connected to the DLC and requests data from CAN modules on the main*

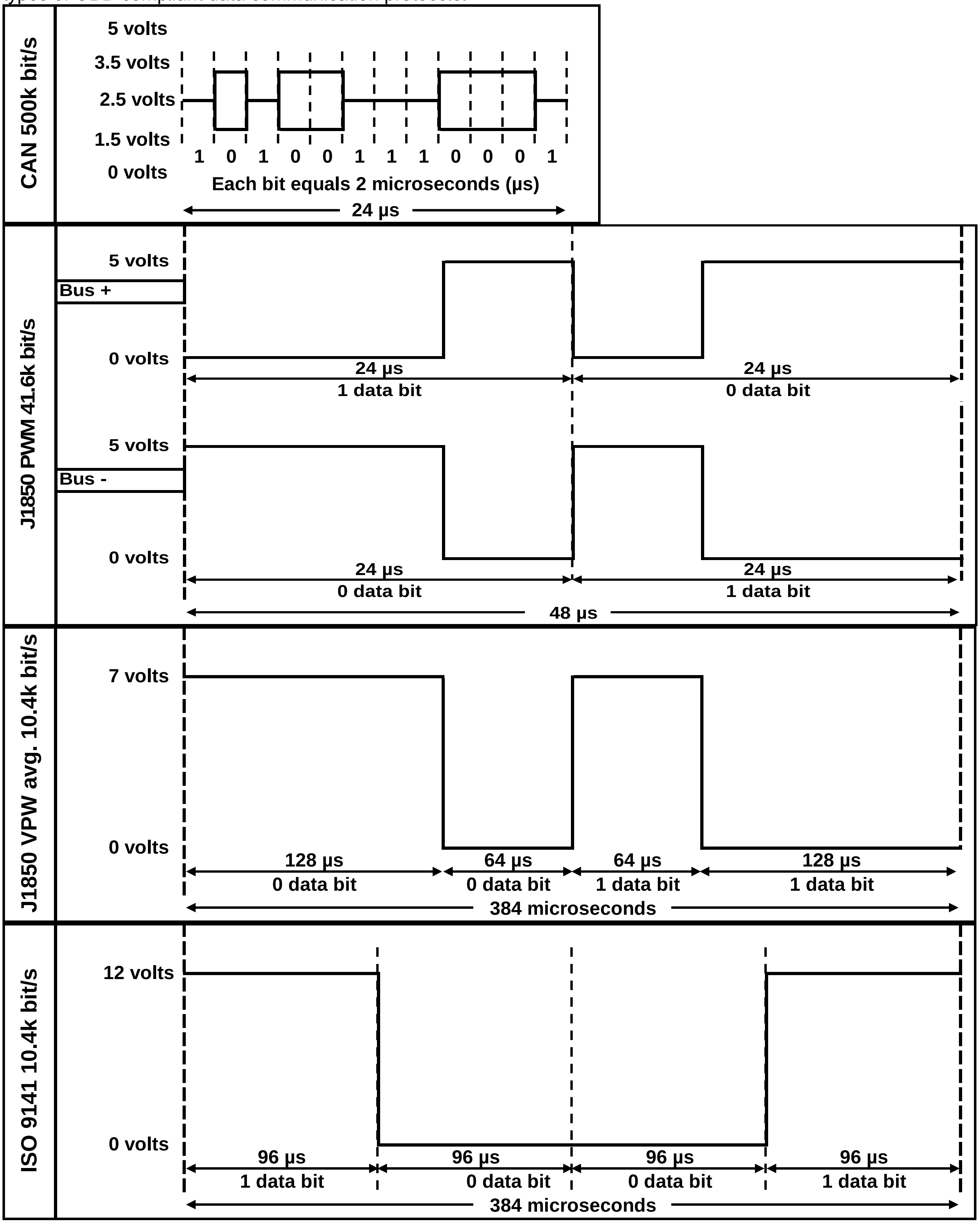
network. Also, be aware that there are CAN systems that cause the CAN_H circuit to go to a steady 5 volt state and the CAN_L circuit to go to a steady 0 volt state during idle conditions. Do not use communication system diagnostic procedures that are not approved by the specific vehicle manufacturer. Be sure to follow each diagnostic procedure correctly and under the proper operating conditions.

- With the ignition key off and the PCM connector disconnected, a circuit resistance test can be used to determine if an open circuit exists between the PCM and DLC in either of the CAN data circuits. Resistance measurements should be very low (typically less than 5 ohms), indicating circuit continuity is good. If excessive resistance is measured, ensure the resistance test is not inadvertently measuring a terminating resistor. Multiple circuit segments may need to be tested if other control modules are positioned between the PCM and DLC (refer to the previous DaimlerChrysler and GM diagrams).
- A short to ground can also be identified through a resistance measurement between the CAN data circuits and ground. Low resistance should not be measured between either CAN data circuit and ground. Multiple circuit segments may need to be tested if control modules are positioned in series with each other instead of connected in parallel to the network (refer to the previous GM diagram for a system with modules connected in series and refer to the DaimlerChrysler and Toyota diagrams for systems wired in parallel).
- A short to B+ can be identified by measuring voltage on the CAN data circuits with the ignition key on. If a short to voltage exists, the measured voltage will be relatively steady and outside typical ranges. Separate circuit segments may need to be tested individually to identify where the short to B+ actually exists.
- CAN circuits shorted together may also be identified by measuring resistance between the CAN_H and CAN_L circuits with all associated modules disconnected from the CAN network. Resistance measurements should not indicate circuit resistance values less than approximately 60 ohms. Always use appropriate service information specifications for the vehicle being tested.

CAN systems bring many new and exciting possibilities for module and sensor evolution into further advanced electronic systems which will play an important role in achieving continued efficiency improvements and reduced emissions. CAN implementation will also bring new challenges as malfunctions occur with resulting symptoms, some of which will be new and will require updated diagnostic procedures and thought processes. Already there are many variations in CAN systems with each system having unique features. Diagnosis of each system must be based on the proper use of correct and updated tools, service information and procedures.

Serial Data Voltage Waveform Comparison

Note: the information on this page is intended only as a general reference and comparison between the different types of OBD compliant data communication protocols.



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