White Paper

Diagnostics for Automobiles – A Snapshot

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ABSTRACT

A challenge with vehicles utilizing complicated computer systems is how to extract diagnostic data, evaluate it to expose possible problems and determine how to fix any problems. It is vital to know the general condition of a vehicle before it goes on a critical or dangerous mission. Electronic modules in vehicles provide information regarding the state of the vehicles. These modules contain diagnostic features such as OBDII required by government agencies for civilian vehicles, usually for emissions.

Most electronic modules (ECM = Electronic Control Module) found in modern vehicles contain a microcontroller with its attendant software program. These systems are designed to provide diagnostic data to external test equipment called a scan tool.

The Euro -3 emission norms are getting enforced by 2005 in 10 metro cities through out India. All the Automotive OEMs are using Euro-3 engines that are controlled by Electronic Control Unit (ECU) to achieve this. The ECUs provide a diagnostic network interface through a in-vehicle network protocol (such as ISO 9141, KWP2000 and CAN to read and adjust the engine parameters and also monitor the Diagnostic Trouble Codes (DTC's). The DTC's provide valuable information on the faults and also the sub system where the faults have occurred.

This paper deals with the overview of - Diagnostics for automobiles, Passenger cars, trucks, buses and other heavy vehicles like Fork Lift, Earth equipment and tractors. It also describes the OBDII protocols and a diagnostics system that is suitable for configuring and monitoring the Euro – 3 vehicles in India.

INTRODUCTION

As systems got more complex the link between cause and symptom became less obvious. This meant that electronic systems had to have some level of self diagnosis – and to communicate to the outside world. Initially many systems used their own protocols which meant that garages had to have a large number of tools – even to diagnose a single vehicle. To overcome this, standards were agreed – starting at the physical level. This allowed vehicle manufactures to use common tools for end of line test - AND Garage equipment manufacturers to design tools to diagnose a number of vehicles. What really drove industry was the OBD regulations – first in California, then the US, and most recently in Europe

As Diagnostics systems were produced on diferring physical and datalink layers, it became obvious that the same information could be communicated across many links. For example OBD regulators allow J1850 (*2), ISO 9141-2, KWP2000 and CAN. Each link is described in separate standards. However all the above links have to allow the same information to be passed- and this is defined in a single standard – SAE J1979. SAE uses the term "Test Modes", ISO uses the term "Services". A service is an information exchange which provides specific functionality

There are many diagnostics services defined and many ways of achieving the same functionality using different services. We can see the data stored within a system – such as Trouble codes – or some form of identifications. We can capture live data – such as Engine or vehicle speed. We may want to transfer large amounts of data – for example reflashing a module. We may wish to take direct control of a modules I/O – for example disabling individual cylinders to identify a fault.

INTRODUCTION TO VEHICLE NETWORK BASICS

There are many electronic systems currently in wide spread use in vehicles. Vehicle electronic modules normally provide a diagnostics capability. Most electronic modules (ECM = Electronic Control Module) found in modern vehicles contain a micro controller with its attendant software program. These systems are designed to provide diagnostic data to external test equipment called a scan tool. Figure 1 is a simplified example of a contemporary bus system. Figure 1 is only one of many possible network configurations.

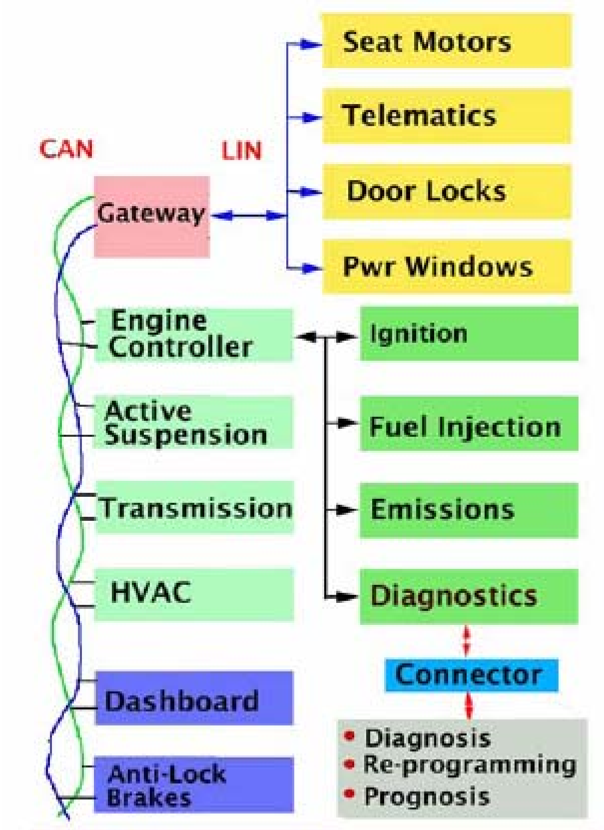


Figure 1: Example of an Automobile Network

AUTOMOTIVE NETWORK DESCRIPTIONS

Figure 1 has two buses connected together (CAN and LIN) by a gateway that will be in one of the ECMs, depending on the design. Often the gateway is in the ECU (Engine Controller Unit). The ECU contains important engine control functions and is often the clearinghouse for the vehicle diagnostics.

CAN Bus (Controller Area Network)

The CAN bus, signified by the twisted pair, is on the left side and connects the major system modules. It operates at a upper speed of 1 Mbit/second with 500 Kb/s and lower common. CAN is a two wire differential pair operating at 1.5 and 3.5 volts. CAN is very popular and there is much hardware and software support from many vendors. CAN is not a complete network system but rather consists of the physical layer (the differential pair), the priority scheme (highest priority message always gets through first) and some error detection and handling circuitry. Message creation and processing is handled by higher-level protocols.

LIN Bus (Local Interconnect Bus)

The LIN bus connects modules that have lower speed and complexity requirements. The LIN bus is simpler and less expensive than the CAN bus. It is useful for less demanding applications such as operating seat motors and door locks. The LIN bus is a 12-volt single wire UART serial design.

ECU (Engine Control Unit)

The Engine Control Module is often the most important module in a vehicle and is central to the system. Its possible components are shown in the four boxes on the right starting with "Ignition" at the top of Figure 1.

The general term for vehicle modules is ECM (Electronic Control Module). Each ECM can exchange information with any other module to accomplish certain tasks. For instance, the transmission module will supply the speedometer with current speed as well as optionally to the radio to modify the volume if appropriate, all transmitted over the CAN bus as general network traffic. Figure 2 is an airbag ECM.

Figure 2: ECM - Example Electronic Control Module

DIAGNOSIS AND DATA TRAFFIC SYSTEMS

Each module can provide diagnostic information to a clearinghouse module, usually the ECU, for dissemination to the outside world through a standard connector. Figure 1 shows this connector as connected to the ECU.

This connector is used not only for diagnostic purposes but also to field reprogram the FLASH memory in various modules and to collect data for prognostics using the normal data traffic flow.

CONTROLLER MODULE MODES

A module can be in two modes:

1. **Standard:** the modules and vehicle operate normally and network traffic consists of ordinary data needed for the operation of the vehicle. Data present on the various buses is useful for prognostics or determining future problems. This data is usually proprietary to the manufacturer.

2. **Diagnostic:** The module is put into the diagnostic mode by a scan tool that then can make queries of the ECM. The ECM will send information to the scan tool concerning problems with the vehicle.

DIAGNOSTICS - PUBLIC AND PROPRIETARY

Public Diagnostic Protocols

Diagnostics can use a government-mandated standard such as OBDII (On Board Diagnostics Version 2) as specified by CARB (California Air Resources Board) and the EPA (Environmental Protection Agency) for automobiles and light trucks. These are normally concerned with vehicle emissions and the method and information needed to access and decipher them is Public knowledge. OBDII requires trouble codes to be reported with a generic scan tool such as the one in Figure 3.

CARB and EPA are starting to address heavy vehicle emissions (diesel engines) and public standards similar to OBDII are expected in the next few years. The EPA has issued guidelines concerning offroad diesel vehicles such as construction equipment and locomotives.

Proprietary Diagnostic Protocols

Diagnostics not prescribed by the government are usually proprietary to the vehicle or subsystems manufacturer. Each vehicle manufacturer or major supplier has its own proprietary diagnosis system and this information is usually kept confidential. It can be made available to qualified firms needing this information for product development.

OBDII: ON-BOARD DIAGNOSTICS VERSION 2

California Air Resource Board (CARB) specified that all automobiles sold in California after model year (MY) 1994 must provide a system for generic reading of emissions related trouble codes. The EPA (Environmental Protection Agency) is also involved federally with this program. The European Community has also implemented OBDII as part of its Euro Stage III Directive in 2000. India has adapted this as Bharat Stage -3 (BS-3) from mid of 2005.

Figure 3 shows the special connector found under the steering column on all MY1996 and later cars and a commercial scan tool. This connector is specified by SAE J1962 and is equivalent to ISO 15031-3. Normal network messages are also available on this connector. OBDII specifies a vehicle warning light called MIL (Malfunction Indicator Lamp). This light displays a message similar to "Service Engine Soon" to the vehicle operator. Pending errors will not illuminate the MIL but are available to the scan tool. If a pending error code exists for predetermined time duration, it will be turned into a Diagnostic Trouble Codes (DTC) and the MIL will be turned on.

The scan tool receives these error codes and displays them. The user then must look in a book to decipher the code given or display the meaning of the codes depending on the scan tool design. The meaning of these codes is publicly available on the Internet.
In this case, the DTC P0742 means "Torque Converter Clutch Circuit Stuck On". The "P" specifies the problem is in the powertrain and other prefixes are body (B), chassis (C) and network (U).

Figure 3: OBDII Scan Tool

CARB and EPA allow a newer CAN based protocol specified by J2284-3 to be used as an alternative to OBDII in MY 2003. This CAN bus runs at 500 kb/s

RP1210 FOR HEAVY TRUCKS

Heavy trucks and equipment usually have several different module systems. Different vendors will supply major system such as the engine, transmission, brakes and HVAC (Heating Ventilation and Air Conditioning) and each will have their own network protocols and diagnostics. An industry consortium, TMC (Truck Maintenance Council) was formed to develop the RP1210 protocol to provide a common interface for diagnostic purposes.

These manufacturers provide their proprietary software that conforms to RP1210 to provide diagnostic information to mechanics. This software runs on a standard laptop. This software conforms to the RP1210 protocol to access the ECMs of the vehicle through a Protocol Adapter device. The physical network on the vehicle is usually a UART based protocol called J1857 and is being replaced by the faster and more advanced CAN based J1939.

An example of this is the RP1210 standard used to facilitate diagnostics in heavy trucks and similar vehicles. Figure 4 illustrates such a system. The soldier is holding a ruggedized laptop. The arrow points to the

Protocol Adapter that can provide to various different physical protocols such as CAN, J1850 (BDLC) and J1708 (UART) depending on the vehicle's ECMs. The interface between the adapter and the laptop conforms to the RP1210 specification. The sub-system manufacturer provides the laptop software.

Figure 4: Heavy Vehicle Scan Tool System

SAE J2534 – REPROGRAMMING

CARB and the EPA specified that all automobiles sold in the USA must provide a method of reprogramming the ECMs in automobiles and light trucks beginning in model year 2004. The same J1962 connector in Figure 3 is used.

J2534 specifies the C++ functions used to communicate with the Pass-Thru adapter, the J1962 connector, programming voltages and various error conditions. Updating FLASH Memory Contents

Modern ECMs usually have their software programmed into FLASH non-volatile memory that can easily be programmed to repair software bugs and various upgrades. These are normally emissions related and especially so if the result of a CARB or EPA recall.

PASS THRU ADAPTERS FOR J2534

Figure 5 is a typical J2534 Pass-Thru adapter. It must provide for various physical protocols such as CAN and several UART specifications as well as specific programming voltages. Figure 8 is the block diagram.
The vehicle manufacturer provides the laptop software to send the encrypted data through the pass-through device to the addressed ECM. The ECM decrypts the data and programs it into its own FLASH memory.

J2534 supports vehicle protocols ISO 9141, KWP2000, J1850 PWM & VPW, CAN, and Chrysler SCI. These are the network protocols that the Pass-Thru Adapter must use to communicate with various vehicles. Most vehicle makers are switching to the CAN bus.

Figure 5: J2534 Pass Through Adapter

PASS-THRU ADAPTERS AND TESTER SOFTWARE

Figure 6 is a block diagram of a J2534 Pass-Thru Adapter system. This device provides the interface between the physical layer of the vehicle and to a computer such as a laptop or custom smart terminal. In both cases, the program running on the personal computer is provided by the vehicle or subsystem OEM. The firmware inside the Pass-Thru Adapter translates and passes the J2534 messages to and from the vehicle over the particular physical layer used.

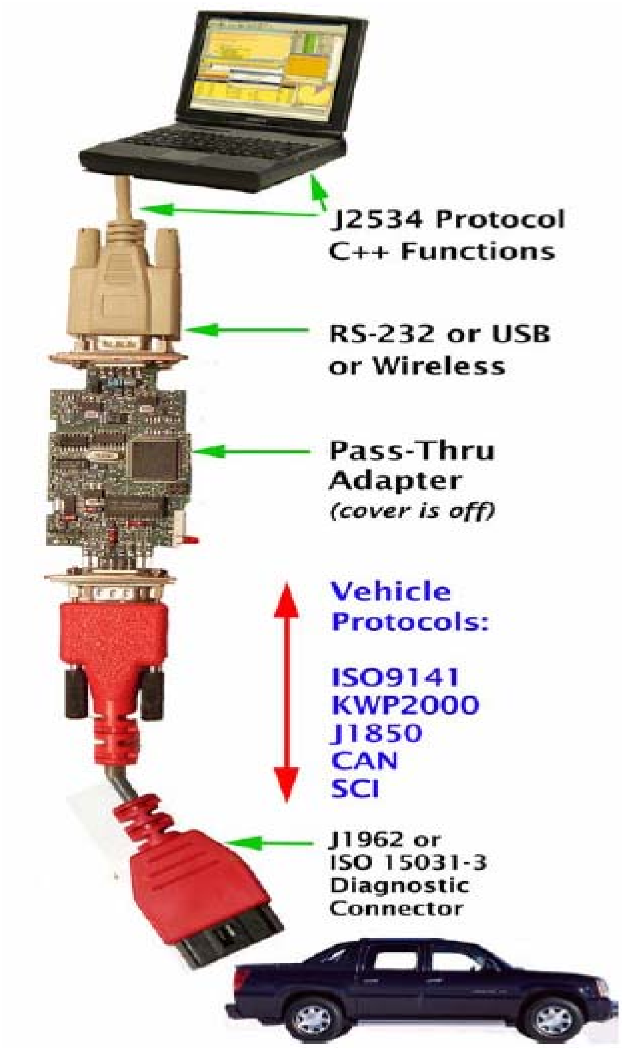
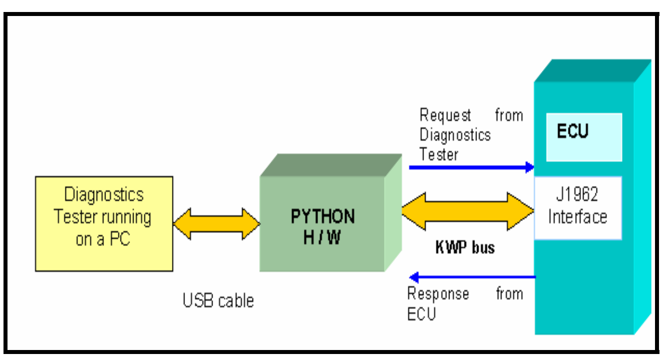


Figure 6: J2534 Pass Through Block Diagram

This system is being followed in India to read the information from and also to write information to the ECU on BS-3 compliant Engines.

DIAGNOSTIC TESTER SOFTWARE

The Diagnostics Tester software performs diagnostics on K - Line with Dearborn Group's Python Pass-Thru hardware as the interface between the PC and the ECU.



The Diagnostics Tester software performs the diagnostics by requesting diagnostic information as per ISO / DIS 14230.3.

The Diagnostic Tester software automatically sends out requests to the ECU for the parameters to monitor. These requests will be in the form of KWP2000 diagnostic services. The ECU will respond to this request with the parameter values.

The Diagnostic Tester software applies appropriate conversion factors (like scaling factor and offset) to the response data and displays the resulting engineering values in the application window. The adjustment values will be logged into a file, which is of text format.

DIAGNOSTIC VEHICLE NETWORKS

The popular diagnostics protocols are KWP2000 (ISO 14230) and ISO 15765.

KWP2000 (ISO 14230)

This International Standard specifies common requirements of diagnostic services which allow a client (tester) to control diagnostic functions in an on-vehicle Electronic Control Unit (e.g. Electronic Fuel Injection, Automatic Gear Box, Anti-lock Braking System, ...) connected to a serial data link embedded in a road vehicle.

The information transfer happens via a physical link – either via K -line or a L -line. Normally K-line is used for communication. The communication connection could be for diagnosis test or maintenance/ calibration. Line K is a bi-directional line. It is used during initialization to convey address and other information relevant for establishing, maintaining the communication and for data transfer. Line L is a unidirectional line and is only used during initialization to convey address information.

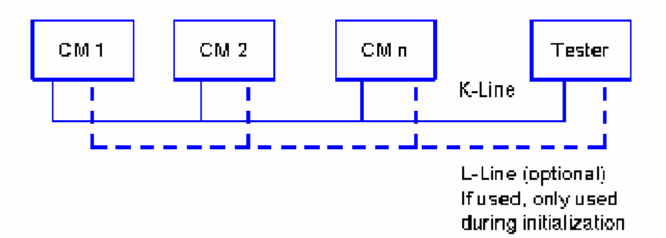


Figure 7: Network Bus Topology

Protocol Layers

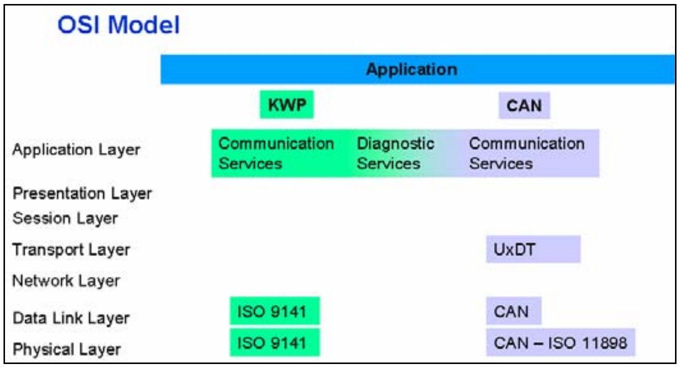


Figure 8: KWP2000 & ISO 15765 Protocol Layers

This is based on ISO 9141 –2, but allows 24V as well as 12V. *At logic " 1 "* equivalent voltage source greater than 90 % VB and a*t logic " 0 "* equivalent voltage of less than 10 % of VB.

Message Structure

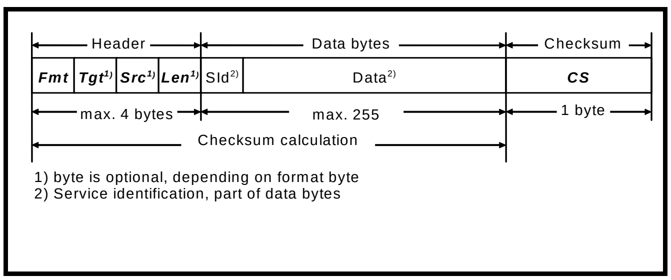
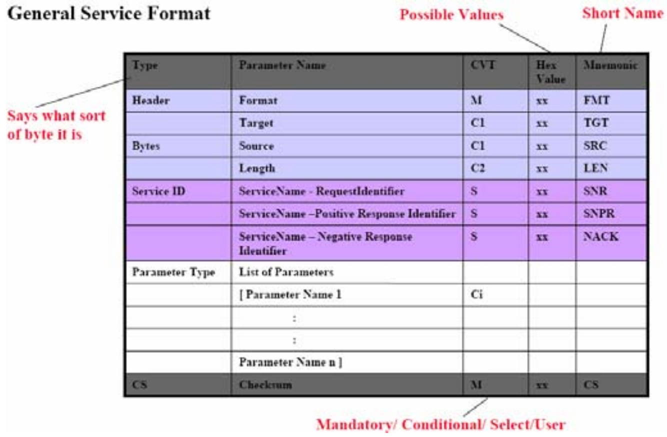


Figure 9: KWP2000 Message structure

The header consists of maximum of 4 bytes. A format byte includes information about the form of the message. The target and source address byte are optional for use with multi node or single node connections. The optional separate length byte allows message lengths up to 255 bytes. The checksum is calculated by simple 8-bit addition of all the bytes in the message excluding the checksum byte. Any carry or overflow is ignored and only the last byte is considered.

To initialize the ECU, the protocol provides 5 baud and Fast Initializations. The protocol also provides set of Diagnostic services. A service is an information exchange which provides specific functionality. The Diagnostic service format is as shown in figure below:



Type	Parameter Name	CVT	Hex Value	Mnemonic
Header	Format	M	xx	FMT
	Target	C1	xx	TGT
Bytes	Source	C1	xx	SRC
	Length	C2	xx	LEN
Service ID	ServiceName - RequestIdentifier	S	xx	SNR
	ServiceName –Positive Response Identifier	S	xx	SNPR
	ServiceName – Negative Response Identifier	S	xx	NACK
Parameter Type	List of Parameters			
	[Parameter Name 1	Ci		
	:			
	:			
	Parameter Name n]			
CS	Checksum	M	xx	CS

Figure 10: General Diagnostic Service format

KWP2000 for OBDII

- Allows testers not to meet 24V requirements
- 3 byte header, no length byte
- Maximum of seven data bytes
- Functional target address =33H for tester request messages
- Physical addresses for response
- Standard message timing
- 5 baud OR fast initialisation for vehicle
- 5 baud AND fast initialisation for tester
- Vehicle must support StopCommunication service
- SAE J1979 defined emission related diagnostic services have been supported.
- Vehicle must support TesterPresent service
- Other services are optional

ISO15765

"Diagnostics on CAN" is the title of the standard designed to implement the diagnostic services implemented in KWP2000 on CAN physical and data link layers. This provides the capability of long message transfer by using the transportation mechanism described in OSEK comms. It made CAN as the media for accessing emission related diagnostics. In practice Diagnostics must co-exist with Normal CAN communications

ISO 15765 follows the Physical and data link layers are ISO 11898 and CAN respectively. The Application layer supports ISO15765-3 for Manufacture specific Enhanced diagnostics and ISO 15031-5 (SAE J1979) for OBD Diagnostics.

CAN Message format

CAN is becoming the predominant vehicle network and a short CAN primer is presented here. CAN is a two wire pair that is peer-to-peer and has no master or slaves. Each node is an equal and all nodes receive all messages since there are no physical addresses used. Each node decides whether to accept or ignore a particular message with a filtering system. Most CAN networks conform to the ISO 11898 specification. The "identifier" which is either 11 or 29 bits differentiates messages. The identifier number of a message is the message's priority. Zero is the highest priority. The arbitration is non-destructive and bit wise. This way, the message with the highest priority always gets through.

CAN Speeds:

Maximum speed is 1 Mbits/sec with 250K and 500K common. The higher the frequency, the shorter the permissible network cable lengths. Maximum CAN cable lengths are typically a 1 meter drop line from the bus and total bus length up to 40 meters (@ 1 Mbits/s).

Identifier:

A CAN message can be *Standard* with a 11 bit identifier or *Extended* with a 29 bit identifier. The identifier is used to provide unique frames and priority levels.

With 11 bits, 2,048 unique prioritized messages are possible and 29 bits provides 536 million. Frames are not addressed to a recipient.

The CAN specification CAN 2.0A has an 11 bit identifier and CAN 2.0B has both 11 and 29 bits. Figure 9 is the standard (11 bit) CAN frame. Figure 10 is the extended (29 bit) CAN frame. The actual frame length depends on whether the identifier is 11 or 29 bit, the number of data bytes (0 to 8) and the number of stuffing bits.

Figure 9: CAN Frame 11 Bit identifier

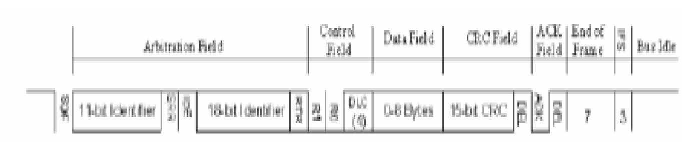


Figure 10: CAN Frame 29 Bit identifier

CAN Physical layer:

CAN is normally a differential twisted pair but there are single wire versions. The most popular physical layer has a differential drive with active voltages at 3.5V and 1.5V and passive voltages, both at 2.5 volts. See Figure 11, illustrating these voltage levels.

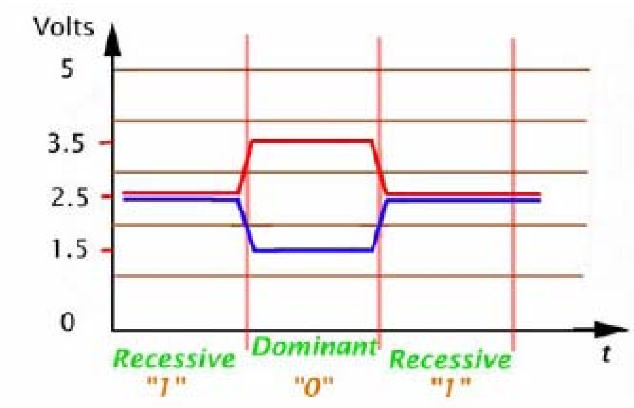


Figure 11: CAN Voltage Levels

ISO 15765 uses USDT (Unacknowledged Segmented Data Transfer) and UUDT (Unacknowledged Unsegmented Data Transfer) to transmit Message frames with more than 8 bytes of data.

DIAGNOSTICS SYSTEM - ERROR REPORTING

Most of the current vehicle network systems normally generate driver information only after an error or defect has occurred. The normal usage of diagnostic systems on vehicles is to alert the operator of a malfunction in the vehicle by activating the MIL and by subsequently providing some clue as to the nature of the defect or the failure to a repair mechanic using a standard scan tool.

DTCS AND PENDING CODES

Every time an ECM performs a test and this test fails; its occurrence is noted as a Pending Code (PC). When this defect event has happened for a preset number of times, the PC is turned into a DTC and the MIL is illuminated to alert the operator.

The reason for this process is that one test failure of a device does not necessarily mean it is defective. It could mean that conditions are not suitable for its proper operation. For example, many devices need the correct operating temperature to function properly and if this condition is not met, a false failure could be reported. Pending Codes are available to the scan tool but normally there is no lamp illuminated to show that a PC exists. These codes can be used to determine potential problems that with some probability are about to happen. An action can be taken to alert the operator if appropriate. It might also be useful to know if the impending defect is catastrophic or only abnormal operating performance and not serious.

The ECM manufacturer designs an algorithm to determine when a PC is turned into a DTC. It would be useful to collect the PCs and apply looser rules to them to provide additional prioritized information to the operator before a hard fault occurs

Malfunction Indicator Lamps (MIL) is used to indicate emissions related problems. In each of these conditions, a DTC will also be issued.

COLLECTING DATA

This system is designed to collect, process, store and disseminate the information from the vehicle's bus. Data can be collected in three sources as follows:

Proprietary Network Traffic

This is normal data read from the vehicle during ordinary operation and does not represent any requests made from the diagnostic system in J1587. In this case, it is not known what these messages translate to since they are proprietary to the OEM. In order to use this type of traffic, agreements will be needed with the ECM manufacturers for disclosure of the translation tables.

Diagnostic Network Traffic

Diagnostic information can be collected from the diagnostic systems as described in this document. Some diagnostic systems such as OBDII, J11587 and J1939 are published specifications. Others, notably those that feed the RP1210 standard, are proprietary. Diagnostic data can be emissions or non-emissions related.

Requested Network Traffic

The networks discussed provide much information on a by request or periodic basis. This can be emissions or non-emissions related. It can include items such as temperatures, speeds, pressures and fluid levels.

CONCLUSION

The Diagnostics interface for vehicles has become very important as there are norms like OBDII for Emission diagnostics and becoming the standard across the world. Many OEMS are supporting the Enhanced Diagnostic services to diagnose the vehicle problems. KWP2000 is the protocol currently used for this purpose and in future it is ISO 15765 which is based on CAN.

There many tools available in the market to perform the Diagnostics. Of the shelf OBD Scan tools are available in the market to perform the OBDII services. To perform Manufacturer specific diagnostic services, customized tools are necessary that work with SAE J2534 Pass Through devices / RP1210 devices or any proprietary devices that support the diagnostic protocols.

REFERENCES

1. “Diagnostics and Prognostics for Military and Heavy Vehicles”, by Mr. Robert Boys, Dearborn Group, Inc.

2. “KWP2000 and Diagnostics on CAN” by Mr. Richard Price, Dearborn Group, Inc

DEFINITIONS, ACRONYMS, ABBREVIATIONS

BDLC: Byte Data Link Communications. The J1850 physical and data link layers. J1850 is an car network.

CAN: Controller Area Network

CARB: California Air Resources Board

CPU: Central Processor Unit. On a microcontroller, the processing part of the chip which addresses various modules of which CAN could be one.

DTC: Diagnostic Trouble Code

ECM: Electronic Control Module

ECU: Engine Control Unit

EPA: Environmental Protection Agency

Ethernet: The network most familiar as used by personal computers. 10 or 100 Mbits/s and a destructive collision detect protocol.

HVAC: Heating, Ventilation and Air Conditioning

MIL: Malfunction Indicator Lamp

OBDII: On Board Diagnostics Version 2

OEM: Original Equipment Manufacturer

RS-232: a standard for serial data transmission.

UART: Universal Asynchronous Receiver Transmitter. A serial port on a computer. Usually uses RS232.

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