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Diagnostics and Prognostics for Military and Heavy Vehicles

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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. These regulations will soon be mandated for commercial diesel engines.

While emissions might not be an important issue for military vehicles, the amount of emissions or rather their change over the short term can indicate problems in the entire powertrain.

Much information about the potential vehicle breakdowns can be derived from relevant data obtainable from modern electronic modules.

INTRODUCTION

The ability to provide electronic diagnostic information for vehicle systems in civilian vehicles is well known. Less known is the nature of the data available during normal vehicle operation. This data can be utilized using appropriate algorithms to provide prognostics to indicate future system problems.

Some of these systems can be readily transferred to the military sector with slight modifications to provide specific features. This paper will discuss the current state of diagnostics and examine future possibilities.

Using existing technology and experience transferred from the civilian sector will result in reduced development and implementation costs, shorter design time and greater reliability.

AUTOMOTIVE NETWORK SYSTEMS

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 microcontroller 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.

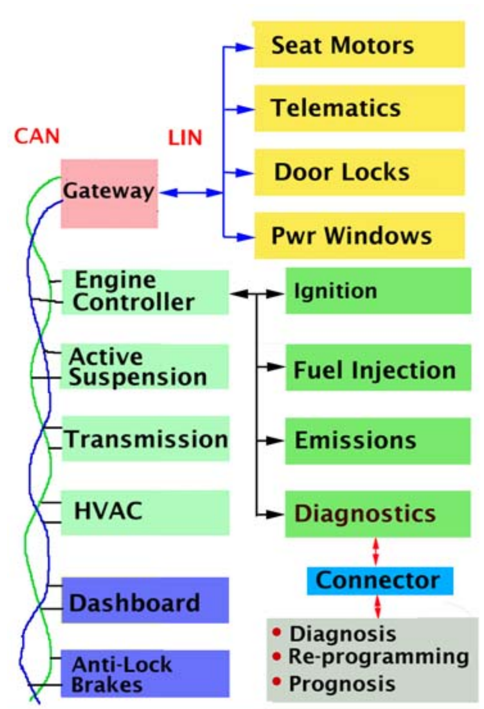

Figure 1: Example of an Automobile Network

AUTOMOTIVE NETWORK DESCRIPTION

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. Figure 3 shows the physical connection.

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.

Figure 2 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 a 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 Kbits/sec.

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

Example Diagnostic System

Figure 5 shows a typical diagnostic system for heavy trucks. This is a wireless connection but wired versions using RS232 and USB are common. A proprietary frequency-hopping protocol reduces interference and increases security.

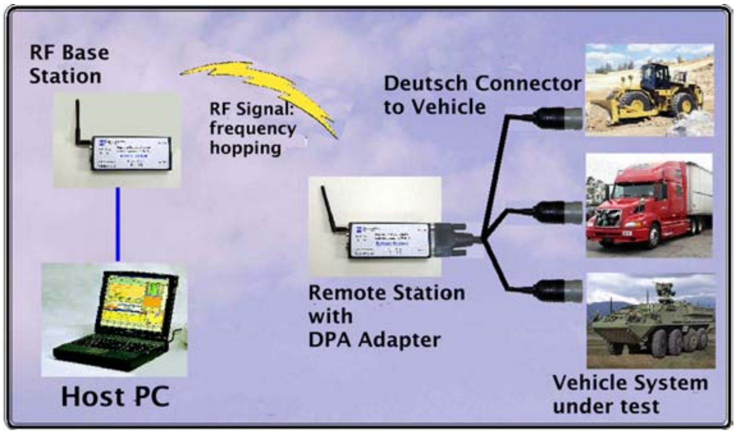

Figure 5: Heavy Vehicle Diagnostic System

Deutsch Connectors

Figure 6 displays the two standard connectors used to connect the Protocol Adapter to the heavy vehicle. These are called Deutsch connectors and are 9 or 6 pin.

Figure 6: 9 and 6 Pin Deutsch Connectors

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.

Immobilizer and Security Features

Many vehicles have an immobilization feature. Each ECM is programmed with the serial numbers of the other ECMs in the vehicle. This makes it harder for thieves to swap ECMs to disable anti-theft features and get stolen vehicles running. If a module is legitimately replaced as a service event, the new ECM(s) must be reprogrammed with the appropriate vehicle codes in order to operate.

The purpose is to provide access to reprogramming for the aftermarket repair shops that are not franchised new car dealers. CARB and EPA wanted to provide the updating of ECMs to reduce tailpipe emissions and help the repair of electronic systems that are emissions related. J2534 will soon include diagnostic capabilities.

Pass Thru Adapters for J2534

Figure 7 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 7: J2534 Pass Through Adapter

PASS-THRU AND PROTOCOL ADAPTERS

Figure 8 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.

Adapters supporting the RP1210 standard and others work similar but usually with different physical layers and with the Deutsch connectors shown in Figure 6. 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.

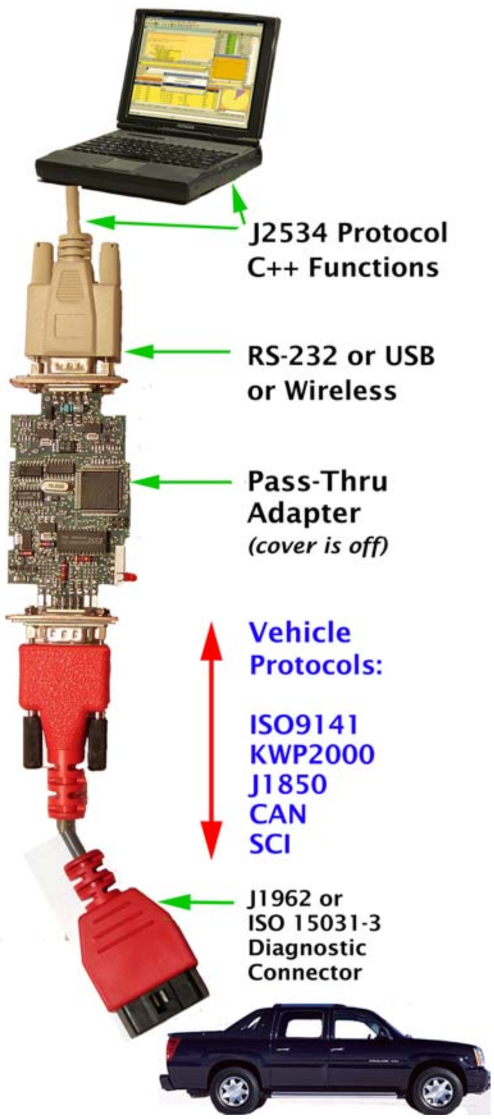

Figure 8: J2534 Pass Through Block Diagram

CAN PRIMER - CONTROLLER AREA NETWORK

CAN is becoming the predominate 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.

<u>CAN speeds:</u>

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).

<u>Identifier:</u>

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.

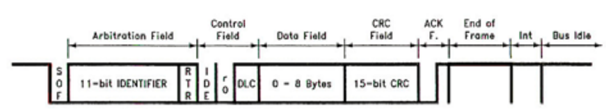

Figure 9: CAN Frame 11 Bit identifier

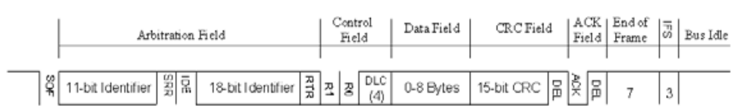

Figure 10: CAN Frame 29 Bit identifier

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 13 illustrating these voltage levels.

CAN Controllers:

There are many microcontrollers available with CAN modules. Stand-alone CAN controllers are available as well as physical layer chips. Nearly all CAN controllers require this interface chip to create the differential levels and connect to the physical wires. The controller and not the CPU does most of the work making the frames, performing arbitration and filtering.

Data Frame:

CAN has 4 types of frames: data, remote, error and overload. A CAN data frame consists of a start bit, identifier (11 or 29 bits), data bytes of zero to eight bytes and various small fields including the CRC check. The start of a frame (SOF) is a falling edge and the end is 7 bits high. A data frame has from 0 to 8 bytes of data.

Stuffed Bits:

CAN controllers use phase lock loop regeneration techniques to maintain each node's clock frequency and synchronization. To provide maximum stability, the CAN controller will insert an extra inverted bit if there are five consecutive bits with the same polarity.

This inserts transitions where needed into the bit stream to help nodes synchronize node clocks. CAN uses NRZ encoding. The CAN controller automatically adds and removes these stuffed bits without any interaction from the programmer. An oscilloscope will reveal their presence on the bus. They are invisible to the CPU.

Error Frame:

CAN has a robust error mechanism and a CAN controller will take itself off the bus if it detects too many errors. This is called the Bus-Off condition and only a CPU reset can bring it back online. This allows a bus to continue operation if a node goes defective.

Priority Levels:

The CAN message with the highest priority always gets control of the bus and overrides any other messages. The message identifier determines the priority with the lowest value (0) being the highest priority. This arbitration is automatically calculated by the CAN controller hardware. Any messages losing the arbitration stops transmitting and retries after the winning message concludes.

Recessive and Dominant Levels:

Voltages levels of 0 and 5 volts can be also expressed as low & high, 0 or 1, False or True... or in the case of CAN, Dominant or Recessive. The terms Dominant and Recessive refer to not only the voltage/logic levels, but also gives a sense of the priority scheme of CAN. Dominant is 0 and recessive 1. Dominant overrides recessive on a bit by bit basis.

Arbitration:

Any node on the bus can only make the signal go from a “1” to a “0”. It cannot force a “0” into a “1” (Wired OR). At rest, the bus is at a “1”. A node therefore makes a “0” by pulling the bus low and a “1” by not doing anything. It makes sense then, that a node making a “0” will override another making a “1”. This is the essence of CAN arbitration.

Each node can detect if its output matches what is on the bus. If a node is putting out a “1” (by doing nothing), and it sees a “1” on the bus, it continues with the next bit and so on until the frame is completed.

If it puts out a “1”, and sees a “0” (from another node), it immediately takes itself off the bus and this allows node with the dominant bit to continue its frame. The priority message (i.e. the lowest identifier = 0) continues transmitting and is not destroyed as in an Ethernet system.

It is possible a node will detect a dominant bit even when it is transmitting a recessive bit on the last bit of the identifier field and stop transmitting. This explanation is simplified by using a single ended bus and not the usual differential pair.

Figure 11 is a simplified representation of the output circuitry of a CAN controller. The circuitry to create the differential voltages is not shown for simplicity.

It is clear to see that any node can pull the bus down to a "0" or a dominant level, but is unable to pull the voltage up to a "1" or the recessive level. See Figure 14 illustrating these voltage levels.

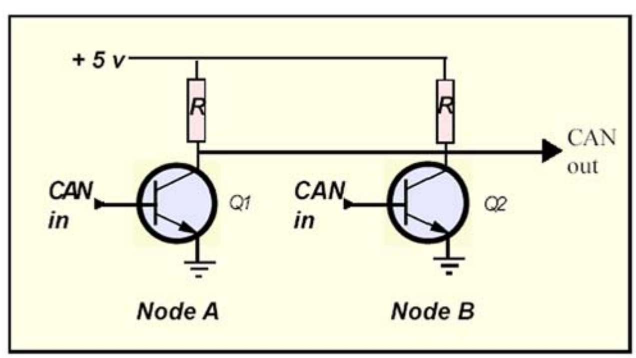

Figure 11: CAN Output Circuit for Arbitration

HEAVY VEHICLE NETWORKS

J1708

J1708 is one of the original communications link systems used on trucks and buses and is still widely used. It is a standard serial protocol (UART) with a speed of 9600 baud on a differential bus. A maximum of 4 nodes is possible limiting its use on modern vehicles. It uses a random destructive arbitration scheme. J1708 is the physical layer for J1857.

J1587

J1587 is currently the most popular heavy vehicle network and specifies the message formats and messages for general information on the vehicle bus and diagnostics. The diagnostics are manufacturer specific. The J1708 physical layer is used with J1857.

Standard Operating Messages

J1587 specifies the message formats to provide a method for obtaining many types of information from the vehicle. These messages are standardized and listed in the J1587 specification which is available from the SAE.

A request for a particular piece of data is sent to the vehicle using a message format called a MID (Message Identification Character) which specifies major areas of the vehicle such as the engine, transmission, tires and the trip recorder. There are up to 255 MIDs.

This request will also include a PID (Parameter Identification Character) which specifies a system within those specified by the MID. Examples are Crankcase Blowby Pressure, Throttle Position and Road Speed. There are about 500 potential PIDs. Not all are used in a given vehicle.

Data can be 1, 2 or more bytes and is specified by which range the PID is selected from. The general message format is:

MID…PID(s)…Checksum

Figure 12 illustrates a typical heavy vehicle J1587 network interface system. The laptop utilizes custom software to query the J1587 systems on-board the vehicle and to receive and display the replies. A manufacturer of a system such as engines or HVAC will make this software RP1210 compliant.

FIGURE 12: J1587/J1708 VEHICLE NETWORK

J1939

J1939 is becoming the industry standard for heavy vehicles but the J1587/J1708 system will continue to coexist with J1939 on heavy trucks. J1939 specifies the entire network from the physical layer to the application software as shown in Figure 13.

J1939 Documentation

The J1939 specification exists in many different documents concerning various areas and they have the designation of J1939/xx as in J1939/71. Figure 13 shows some of the J1939 documents and how they relate to the OSI model. Additional documents are J1939 (base doc), /01 (defining truck & Bus applications), /81 (Network management), /82 (Compliance) and /83 (a tutorial). The OSI Presentation, Session and Transport layers are not used as such in the J1939 context.

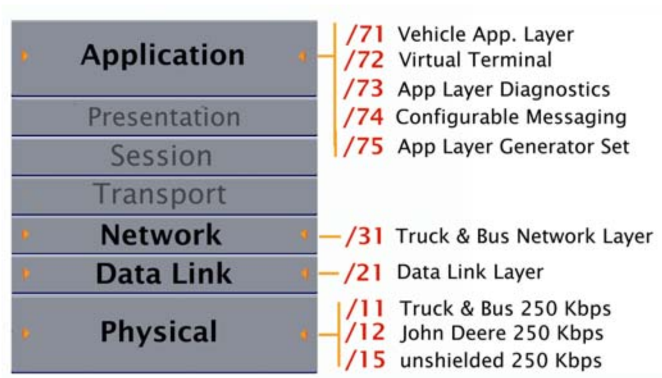

Figure 13: J1939 and the OSI Model

J1939 Physical Layer (J1939/1*x*)

J1939/11 uses a 250 kb/s differential shielded CAN bus, extended 29 bit identifiers and a capacity for up to 30 nodes using shielded cables. J1939/15 specifies a maximum of 10 nodes using unshielded wires. The CAN protocol as prescribed in ISO 11898 is followed. 11 bit identifiers are specified under J1939 to be used for proprietary OEM messages.

The J1939/13 document specifies the 9-pin Deutsch connector shown in Figure 6.

The CAN physical layer has a differential drive with active voltages at 3.5V and 1.5V and passive voltages, both at 2.5 volts. Figure 14 shows the voltage levels for the dominant (0) and recessive (1) logic states.

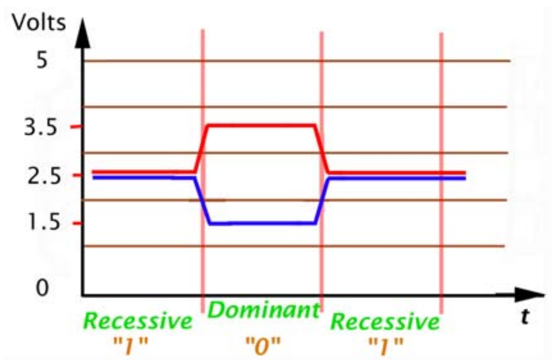

Figure 14: CAN Differential Voltage Levels

J1939 Data Link Layer (J1939/21)

The Data Link Layer specifies the message frames used and uses the extended CAN 2.0B frame for this purpose. 29 bit identifiers are used while the 11 bit identifiers are reserved for proprietary messages.

A J1939 frame contains the priority level of the message, which module sent the message (up to 254 modules) and the appropriate data. The data can be from 0 to 8 bytes as in the CAN protocol and if the messages sent need to be longer than this, then additional CAN frames will be sent.

The first three identifier bits are used as the priority level with the rest of the identifier bits used to define and select the information in the data field(s).

J1939 Network Layer (J1939/31)

J1939 describes the exchanging of information on different networks. A Router is used where the protocol is the same but data rates, address space and media may be different. This can be used to connect a J1939 network to other J1939 networks but with different speeds or media types. A Gateway is used to connect to connect different protocols such as a J1939 to a J1708 network.

J1939 Application Layer (J1939/71 thru 75)

The Application Layer obtains information about the vehicle either by sending a request or by getting a periodic message. A user program will either put a J1939 message on the CAN bus and subsequently receive a reply or monitor the bus for messages that are periodically sent by vehicle modules. A module will also send proprietary messages using 11 bit identifiers.

Parameters and Parameter Group Numbers (PGN)

Parameters are items such as engine RPM, oil pressure, water temperature, transmission status and vehicle speed. Associated with these parameters are data such as PSI, mph, state and number. This data in turn is defined with elements including range, error, offset, data length and resolution.

Parameters are grouped according to some similar characteristics into Parameter Groups and are expressed by its Parameter Group Number (PGN). This is the number used in J1939 to access the data about a particular parameter or a set of parameters. PGNs are described in the document J1939/71.

Parameter Groups can have parameters grouped according to a common function (i.e. engine pressures), update rate (i.e. those messages updated every minute) and by subsystem (i.e. all those from the ABS brakes).

Examples of PGNs are:

65128	VF	Vehicle Fluids
65147	CT1	Combustion Time #1
65168	ETH	Engine Torque History
65193	EO1	Exhaust Oxygen #1
65210	TDI	Trip Distance Information
65215	EBC2	Wheel Speed Information
65255	VH	Vehicle Hours
65269	AMB	Ambient Conditions
65273	AI	Axle Information

For example, the PGN **65269 Ambient Conditions** contains the following parameters:

- Barometric Pressure
- Cab interior temperature
- Ambient air temperature
- Air inlet temperature
- Road surface temperature

J1939 specifies this PGN is transmitted once a second, is 8 bytes long and has a priority of 6. Other information included is its PDU format is 254, is in Data Page 0 and the PDU specific is 245. These attributes are not dealt with in this paper. They are part of the Data Link Layer and are documented in J1939/21.

The parameter **Air inlet temp** (#4) has two bytes, a resolution of 0.03125 C/bit with a -273 C offset. Its range is -273 C to +1735 C. If a problem developed with this parameter such as being stuck or out of range, this would be reported to the diagnostic system. In this case the Suspect Parameter Number reported will be 170. The other four parameters have similar attributes.

Diagnostic Trouble Codes (DTC)

Diagnostics are standard messages sent to the Deutsch connector in Figure 6 when an affected module declares a fault. These messages will be requested by a special scan tool with the appropriate software to send and receive J1939 messages. Diagnostics are separated into emissions and non-emissions related faults.

A DTC consists of:

1. Suspect Parameter Number (SPN)
2. Failure Mode Identifier (FMI)
3. Occurrence Count (OC)
4. Conversion Method of SPN (CM)

SPN: This is the number of the fault. Examples are Brake Switch (597), Injector Cylinder #1 (651) and Fuel Feed Rate Sensor (831). J1939 lists over 2,000 SPNs.

FMI: Indicates the nature of the fault. This includes Data Valid (but with an above or below range), Data erratic, Voltage high/low/shorted and Circuit open.

(OC): This value is the number of times the fault has occurred. A fault will normally occur a certain number of times before it turns into a DTC and reported as such. This is called a Pending Code. The ECUs test using algorithms on the data received from devices such as oxygen sensors to determine if they are defective.

These error algorithms will check a number of times to ensure the device or system is indeed defective and not the result of an aberration. False errors can result from insufficient operating temperatures, too few driving cycles, normal device variance or spurious signals. In cases of false errors, the pending code will be erased or the occurrence count lowered and the testing process restarted. A DTC is created when the defect will result in emissions greater than 150% of the allowed levels.

CM: Indicates which version of the J1939 spec is used to interpret the SPN. This is one bit and is usually "0".

An example of a DTC is this one with a problem with the vehicle's accelerator pedal:

SPN =	91	Accelerator pedal position.
FMI =	3	the pedal voltage is above normal.
OC =	5	Trouble has occurred 5 times.
CM =	0	Use Version 4 of SPN conversion.

Diagnostic Messages (DMx)

DMs are messages sent to the vehicle system to request certain information and use PGNs. Examples are:

DM1: Sends all active DTCs and MIL status.
DM2: Sends previously active DTCs.
DM5: Reports diagnostic readiness.
DM11: Clear/reset all active DTCs.
DM14: Access ECU module memory.

Normal Proprietary Message Traffic

Proprietary OEM traffic is not part of the J1939 specification. This information can be seen and read on the bus in the form of raw 11 bit identifier CAN messages but their meaning is difficult to decipher.

Any proprietary traffic will largely consist of non-diagnostic information related to the ongoing operation of the vehicle. Diagnostics are handled separately.

People often attempt to reverse engineer this data to determine what they represent. This can be an inefficient method due to the complexity of the entire vehicle system and the protocols used. However, it is remarkable what message codes people are able to determine in this manner.

For instance, if you have a CAN analyzer connected to a bus and you press the trunk release button, you will detect a CAN message if the trunk is controlled via the vehicle network. This message can be noted and now the "pop-the-trunk" frame is known. By impressing this message on the CAN network with the analyzer, the trunk will open again.

For more information regarding the J1939 specification, refer to the appropriate documentation available from the SAE. www.sae.org

SUMMARY OF DIAGNOSTIC CAPABILITIES

The range of information and the features of the various diagnostic protocols are extensive. These protocols provide documented access to vehicles and their ECUs allowing relatively easy and complete data to make decisions.

Data from diagnostics systems are useful but the data available from the proprietary systems can also be used. It may be difficult to determine or obtain the translation tables from the OEM because of confidentiality issues. OEMs will be willing to divulge the necessary information only to strategic partners with non-disclosure and formal intellectual property sharing agreements.

The preceding overviews are just the beginning of vehicle networks. These networks have many more features that are useful for diagnostics and prognostics.

DIAGNOSTICS AND PROGNOSTICS

PURPOSE:

Most of the current vehicle network systems normally generate driver information only after an error or defect has occurred. Not many provide prognostic or predictive information concerning probable defects or notice of maintenance service actions. An exception is the lamp in some cars that notify it is oil change time.

Diagnostics

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.

Prognostics

An additional feature is to provide some prognostic information such as brake wear or tire pressure to alert the operator to potential or future problems. This is a field that is expanding.

While this information has become very useful, much more real-time information can be provided to operators, maintenance personnel and those directing the actions of the operator such as field commanders.

Transferring Technology

Network and diagnostic systems such as J1939 are widespread in the light vehicles, the truck and bus industry. These systems contain a great deal of engineering expertise and are well developed and robust. Much is known about the behaviour of these systems. They have spread to agriculture, construction, marine and stationary motors. With modifications they can easily be transferred to military vehicles in order to increase the reliability and provide more safety to passengers.

ERROR REPORTING

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 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)

The ubiquitous "Service Engine Soon" lamp has been discussed. However, J1939 specifies three more indicators. These lamps can be useful in some vehicles to provide additional information. In each of these conditions, a DTC will also be issued.

Malfunction Indicator Lamp MIL:

Used to indicate emissions related problems.

Red Stop Lamp:

A DTC has been issued that is catastrophic or a hard failure and so severe the vehicle should be stopped immediately. No engine oil is a good example.

Amber Warning Lamp:

A DTC has been issued that is not severe and stopping the vehicle is not required.

Protect Lamp:

This lamp is used to alert the operator to a problem that is not electronic in nature. These are usually of a mechanical nature such as high engine temperature.

THE DIAGNOSTIC, PROGNOSTIC SYSTEM

This system is designed to collect, process, store and disseminate the information from the vehicle's bus.

COLLECTING DATA

Data can be collected from three sources as follows:

1) Proprietary Network Traffic

Figure 15 is the data collected from a truck using the setup shown in Figure 12. This is normal data found on the truck 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 or by reverse engineering to build them.

80	50	00 55 01 5B 00 5C 00 BE 00 00
80	28	C0 79 00
80	B7	00 00 B8 00 00
8E	FE	BE 02 23 40
80	54	00 55 01 5B 00 5C 00 BE 00 00
80	54	00 55 01 5B 00 5C 00 BE 00 00
80	28	C0 79 00
80	B7	00 00 B8 00 00
88	31	00 97 3F FF 54 00 A8 F0 00 D1 01 FF
80	54	00 55 01 5B 00 5C 00 BE 00 00
80	54	00 55 01 5B 00 5C 00 BE 00 00

Figure 15: J1708 Proprietary Network Traffic

2) 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. It would seem that emissions related data and trouble codes would not be useful in military vehicles since vehicle emissions are not a large concern.

However, poor, abnormal or changing emissions can be rather useful in providing important diagnostic as well as prognostic information. Effects from small mechanical malfunctions can significantly affect the vehicle's overall emissions. Exhaust gases, engine torque and fuel mileage are especially affected.

3) 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.

PROCESSING THE DATA

The data collected will be processed according to the information including prescribed priority, compiled repair databases and vehicle mission.

The priority and action desired will be different if a vehicle is being test driven after a repair, in normal transport, in a dangerous area or in a combat situation.

Some statistical analysis and perhaps Fuzzy logic will be employed as well as other proprietary techniques to compute the results.

Limp-Home

Manufacturers often use limp-home processes to enable the vehicle to be driven to seek service rather than being towed. For example, a defective transmission might be put in second gear only if the first gear is not operating. The vehicle can be driven out of the area and to the service yard for repair.

Sometimes this is called punitive limp-home as it is onerous enough that the driver is forced to have the vehicle serviced. The ECM designer will make vehicle performance so bad it will not be pleasant to drive.

In some cases this might not be desirable for military vehicles. Even as the engine is being burned out from a lack of oil, it is imperative it be driven off the road so as to not block the rest of the convoy. Saving the engine in this case has a very low priority. A means to disable or otherwise handle such limp-home processes is in order taking into consideration the situation the vehicle is in.

DISTRIBUTING THE INFORMATION

Once the vehicle information is collected and results are calculated it becomes important to distribute this to those who can use this information. It is important to make sure the operators do not have an information overload. Information must be properly prioritized.

Virtual Terminals

J1939/72 specifies a virtual terminal used to provide and receive information from the operator. This terminal will normally be a LCD screen. More information can be provided than just the indicator lamps which have also been known in the past as "idiot lights".

Wireless Networks

Wireless networks offer an easy method to send information from a vehicle to distant interested parties. These present special problems in security and stealth. A military vehicle on a mission continually outputting a signal looking for a WiFi access point, trying to phone home or by collecting vehicle information from a roadside position is an unacceptable risk in detection.

Currently WiFi (IEEE 802.11b) is much in demand in the heavy truck business to collect diagnostic information. WiFi has 12 overlapping channels in the 2.4 GHz band and provides a raw data rate of 11 Mbits/s. Only three of these channels can be used in any physical environment and this might present problems as WiFi access points proliferate.

See RTC Magazine Wireless Meltdown, January 2004.
www.rtcmagazine.com/pdfs/2004/01/rtc01_wirelessconn2.pdf

Proprietary networks that frequency-hop are usually better choices. They are less likely to be compromised. These proprietary protocols are not usually published and therefore more secure. Standard WiFi might be more vulnerable and may prove irresistible to hackers.

Most truck tracking systems use a GPS receiver to determine position and some sort of cell or satellite phone to call this and selected diagnostic/prognostic information to a central location.

Military vehicles could use their secure communications channels to send such information to headquarters, the maintenance yard or even nearby convoy vehicles.

REAL LIFE EXAMPLE:

Clutch Analysis Software

Purpose of this Project:

A Tier 1 supplier of heavy-duty truck transmissions needed a non-obtrusive method of determining clutch wear. It was not easy to make a measurement of the clutch pedal as is often done with brake arm movement to measure remaining brake lining.

It was decided to develop algorithms that calculated clutch wear dynamically. This enabled the engineers to compare clutch wear against a variety of other events that are available on the J1939 network bus.

The Algorithms

The algorithms developed calculated clutch wear using data obtained from the clutch controller and sent on the J1939 network. The amount of energy absorbed by the clutch during its operation during starts and gear shifts was used dynamically to estimate the clutch life. All the information needed by the algorithm was retrieved from the J1939 bus and diagnostic system.

The Entire System

Figure 16 shows the clutch wear system. A Dearborn Group Gryphon analyzer equipped with Linux and a '486 CPU was used to capture the J1939 messages from the transmission. The algorithms run under the Linux OS in the Gryphon and they integrate and interpolate the data with the proprietary mathematical analysis program and the results were stored in the Gryphon's FLASH memory.

A laptop connected to the Gryphon was used to program the Gryphon with the clutch characteristics and wear patterns and to retrieve the clutch wear results.

The Results

The system was accurately able to estimate clutch wear and allowed the designers to work on the design of the clutch and transmission to optimize a variety of criteria such as wear, noise and vibration. As well, this information can be used to provide information for maintenance technicians.

This example confirms that appropriate analysis of network messages is able to provide useful prognostic information.

Figure 16: Clutch Wear System

CONCLUSION

It has been shown that the current electronic systems on vehicles is complex and its sophistication is very useful to provide diagnostic and prognostic information to the operator.

Much technology exists in the heavy vehicle industry and is adaptable to the special needs of military purposes. Not reinventing the wheel will save money and speed up design processes. New features are possible such as detecting vehicle rollovers and missile hits to vehicles and sending this information to interested parties will greatly enhance the operability of these vehicles as well as safety of the passenegers.

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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. Usually displays "Service Engine Soon" to the vehicle operator.

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.

APPENDIX

INDUSTRY STANDARDS ORGANIZATIONS

SAE: Society Of Automotive Engineers

The SAE is very active in developing specifications for many automotive fields. SAE specs begin with "J" as in J1939 and are available for sale on the SAE website www.sae.org. Committees that write and vote on various specifications consist of volunteers from member companies. The SAE historically has the most influence in the USA.

SAE
400 Commonwealth Drive
Warrendale, PA 15096-0001

ISO: Organization of International Standards

ISO is a worldwide standards organization based in Switzerland. Asian and European manufacturers use OSI standards but there is some influence in the USA.

ISO and SAE standards have some similar equivalents due to the financial and practical pressure to have vehicles compliant all over the world. For example, SAE J1962 which specifies the OBDII connector shown in Figure 2, has the equivalent OSI 15031-3 document. Another example of an automotive ISO spec is ISO9141 which is a vehicle network specification. www.osi.org

ISO documents are available in the USA from ANSI 11 West 42nd Street, New York, NY 10036.

MilCAN: Military CAN

The CAN bus priority arbitrator is not deterministic. That is, there are no guarantees when a particular message will get through. MilCAN is a solution when guaranteed response (latency) times are necessary.

www.milcan.org

TMC: Truck Maintenance Council

TMC is part of the American Trucking Association and are responsible for the RP1210 truck diagnostic protocol. www.truckline.com/cc/councils/tmc