
Volvo SuperTruck 2018

Heavy Vehicle Networking using SAE J1939

PREPARED BY DR. JEREMY DAILY

NMFTA
National Motor Freight Traffic Association, Inc.

Agenda

- Truck Systems and Communications
- Networking and Wiring Diagrams
- Interpreting Data with J1939
- J1939 Transport Protocol
- J1939 Address Claims
- Diagnostics
  - SAE J1939-73
  - ISO14229 - UDS
  - Proprietary protocols
- Cybersecurity Challenges

Training Goals

Understand the need for in-vehicle communication using CAN and SAE J1939

Connecting to J1939 Networks

Interpret J1939 network traffic using the SAE Standard

Recognize SAE J1939 Transport Protocols for larger messages

Introduction to J1939 Address Claiming

Demonstration of RP1210 functionality for diagnostics

Realize J1939 is inherently an open (and potentially insecure) read-write bus

Truck Systems

Primary Functions

- Go – Convert fuel into mechanical energy to accelerate heavy loads
- Stop – Brake the tractor-trailer systems, often with anti-locking air brakes
- Steer – Give the driver the ability to guide the vehicle
- Haul – Support heavy loads and pull trailers

Additional Functions

- Protect – Restrain occupants in a crash. Assist drivers to avoid crashes.
- House – Provide places to sleep while on a long haul
- Entertain – Radio, CDs, Bluetooth, and Satellite options
- Monitor – Telematics and fleet management
- Diagnose – Provide information related to vehicle operation and potential faulty parts
- Comply – US DOT regulation, EPA and emissions regulations

Truck Engines

Primary function to efficiently produce motive power

Also:

- Comply with emission requirements
- Aid diagnostics and troubleshooting
- Record driving and diagnostic events
- Additional Power for
  - Compressed Air
  - Power take off (PTO) equipment
  - Electrical systems

Computer controls are paramount to realize these functions

Engine Control Module (ECM)

The driver's side of a Navistar A26 Engine in an International LT truck.

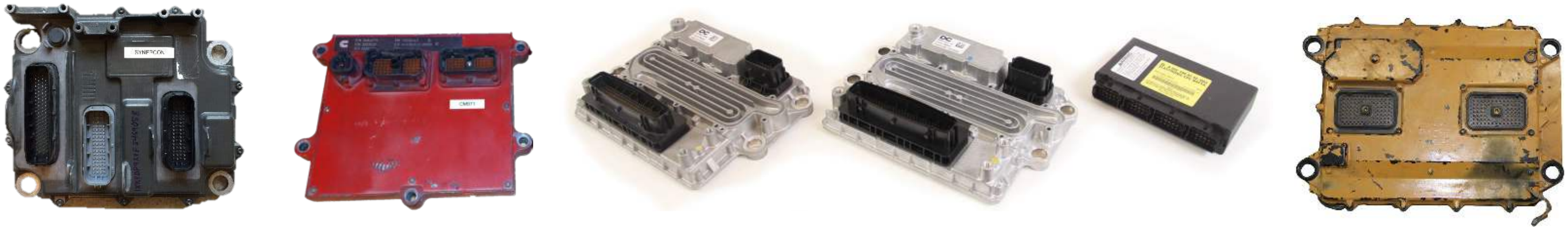
Engine Control Module (ECM)

The ECM is an electronic control unit (ECU) primarily responsible for the operation of the engine.

Single ECUs that are engine mounted (Cummins, PACCAR, Navistar)

Multiple ECUs communicating over a network (Detroit Diesel, Volvo)

Engine controllers are often the most advanced and expensive electronic units on a truck



Data from an ECM

Live Status Data

- Data broadcast to all ECUs regarding current status and operation
- Examples: Engine speed, accelerator pedal position, wheel-based vehicle speed and many others

Configuration Data

- Does not change with time
- Features, Parameters, Calibration Settings

Historical Data

- Data that changes with time
- Mileage, hours, histogram data for aftertreatment, et al.

Diagnostics Data

- Diagnostic Messages including Failure Mode Indicators and Suspect Parameters (or subsystems)
- Freeze Frame Data

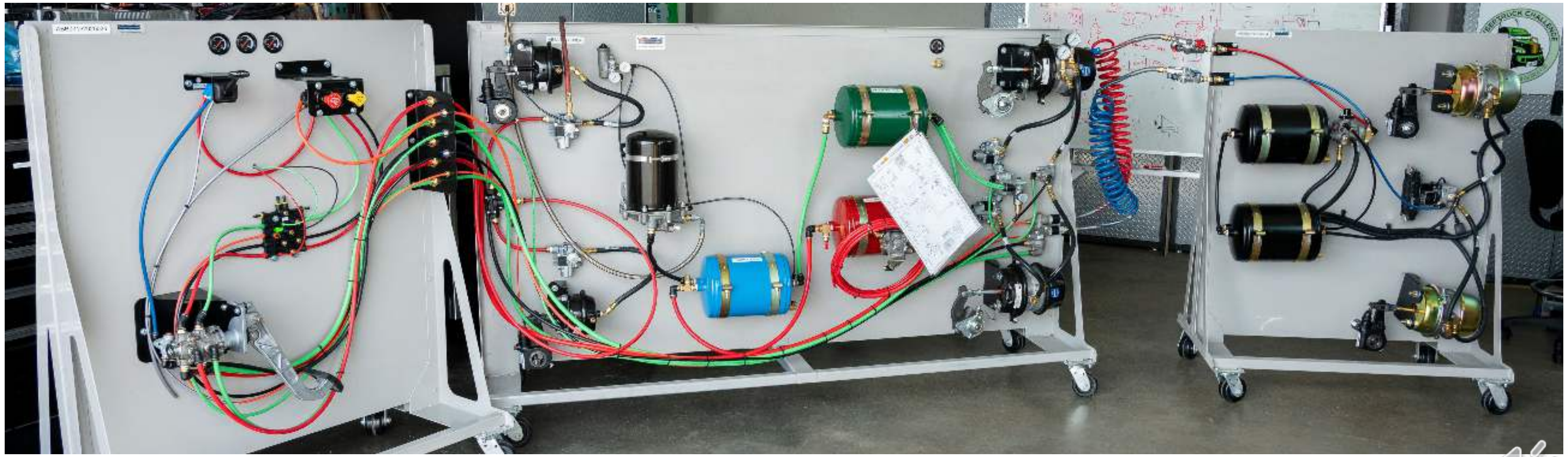
Event Data

- Recordings from Triggered Events like Last Stops, Hard Brake, External Triggers, or Fault Codes
- Useful for driver training and crash reconstruction

Electronic Brake Controllers

1. Sense wheel speeds
2. Determine if wheel lock-up is impending
3. Modulate the air pressure to the brake chambers
4. Tell the engine to stop producing torque

store.partshighway.com



In-Vehicle Networking

HOW DOES THE BRAKE CONTROLLER COMMUNICATE WITH THE ENGINE CONTROLLER?

Controller Area Network (CAN) in Trucks

National Motor Freight Traffic Association, Inc.

IN THE DIAGNOSTIC PORT

Pin C: CAN-High
Pin D: CAN-Low

IN THE WIRING HARNESS

Yellow: CAN-High
Green: CAN-Low

The CAN bus is typically a twisted-pair of copper wire connecting the ECUs.

Diagnostic Connector Pinouts – SAE J1939

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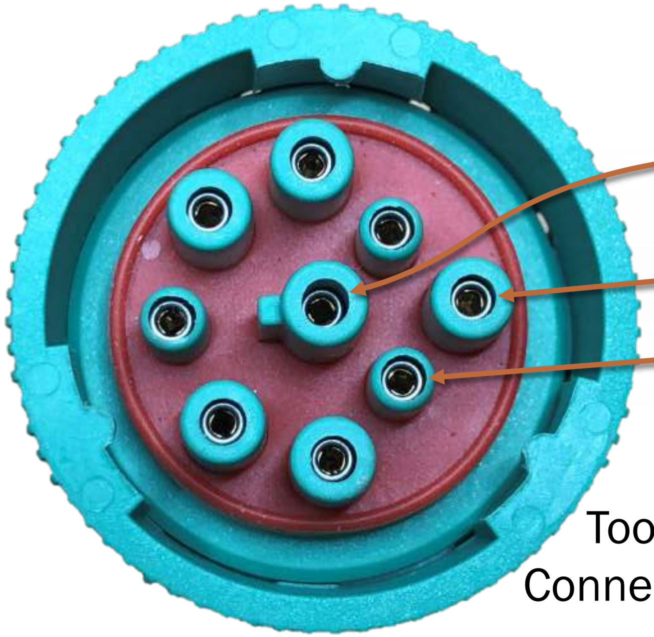
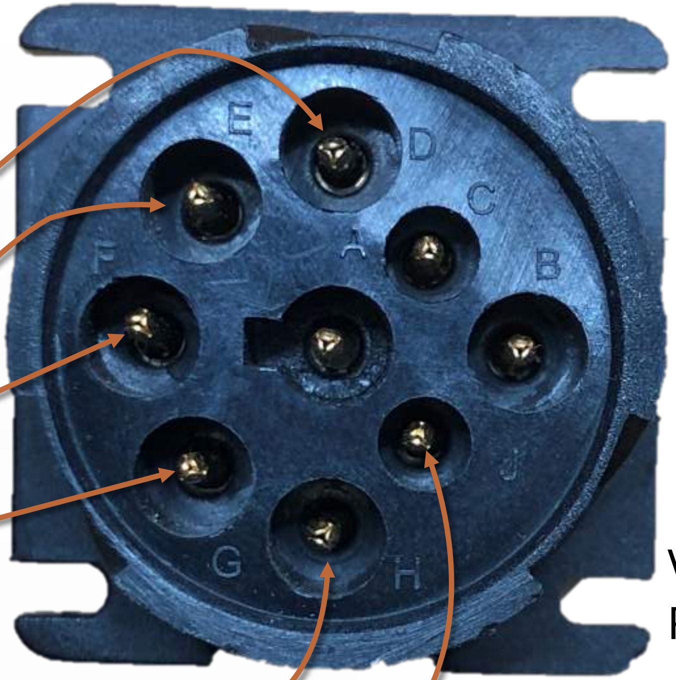


Tool Connector

Pin	Signal
A	Ground
B	Vbatt (+12V)
C	J1939 High
D	J1939 Low
E	Shield
F	J1708 A(+)
G	J1708 B(-)
H	CAN2 High
J	CAN2 Low



Vehicle Port

250k - Black Connector
500k - Green Connector
Green goes into Black
Black cannot plug into Green

Some History: J1708 and J1587

First mainstream heavy vehicle diagnostics communication protocol

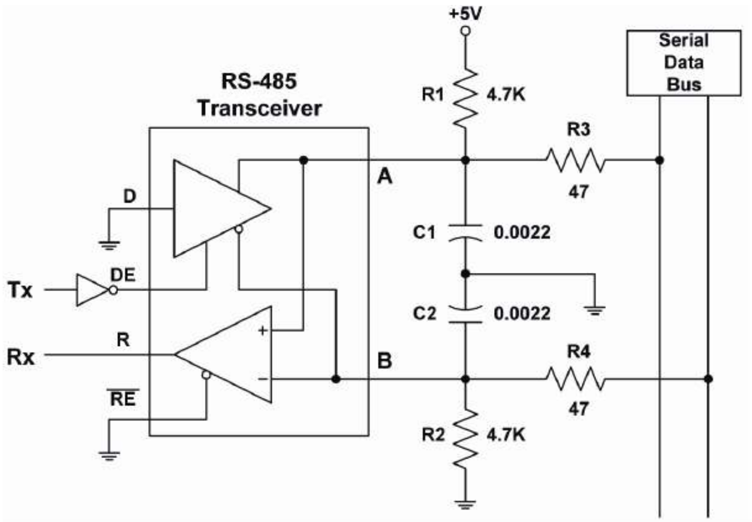
Based on RS-485 communications at 9600 baud

Message frames are determined by time spacing between bytes (this can be fragile)

8-bit check sum to verify message contents (not strong)

Physical wiring and signaling are defined in J1708

Meaning of the messages are defined in J1587



Message Composition:
MID = Message Identifier (like Source Address)
PID = Parameter Identifier (like SPN)
Data = encoded value of PID
Checksum = 1 byte to check message transmission errors

J1708 Message Example

J1708 DATA FRAMES

```
80 FF B7 00 00 CA
80 54 1B BE C0 11 28 CF 5B 7F 5C 58 FD
80 54 1C BE 08 12 5B 80 5C 59 2B C7 B6
88 31 00 97 3F FF 54 1C A8 18 01 D1 01 FF 70
8C 41 F3 46 00 A8 17 01 3A
80 55 40 79 00 B7 85 01 B8 70 02 F4 04 2E 9A 56 00 F5
80 54 1C BE 3C 12 28 CF 5B 80 5C 59 7D
80 54 1C BE 52 12 5B 83 5C 5B 59
80 55 40 79 00 B7 96 01 B8 53 02 F5 04 2E 9A 56 00 00
80 54 1D BE B0 12 28 CF 5B 85 5C 5C 00
80 54 1D BE EC 12 5B 86 5C 5D 2C F0 9D
80 54 1D BE 0B 13 28 CF 29 C0 5B 89 5C 5F B4
```

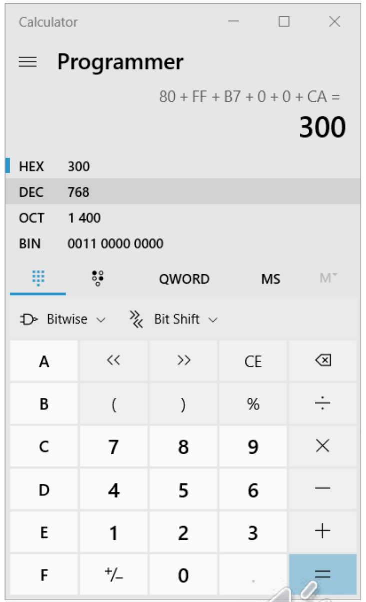
J1708 MEANING

Message Identifiers are at the beginning

The message is considered valid if the 8-bit sum is zero.

- 80+FF+B7+00+00+CA = 300

8-bit sums ignore carry



Popular MIDs

- Engine 1: 128 (0x80)
- Brakes, Power Unit: 136 (0x88)
- Brakes, Trailer #1: 137 (0x89)
- Instrument Cluster: 140 (0x8C)
- Cab Climate Control: 146 (0x92)
- Off-Board Diagnostics Tool: 172 (0xAC)

J1587 Message Decoding Example

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```
80 FF B7 00 00 CA
80 54 1B BE C0 11 28 CF 5B 7F 5C 58 FD
80 54 1C BE 08 12 5B 80 5C 59 2B C7 B6
88 31 00 97 3F FF 54 1C A8 18 01 D1 01 FF 70
8C 41 F3 46 00 A8 17 01 3A
80 55 40 79 00 B7 85 01 B8 70 02 F4 04 2E 9A 56 00 F5
80 54 1C BE 3C 12 28 CF 5B 80 5C 59 7D
80 54 1C BE 52 12 5B 83 5C 5B 59
80 55 40 79 00 B7 96 01 B8 53 02 F5 04 2E 9A 56 00 00
80 54 1D BE B0 12 28 CF 5B 85 5C 5C 00
80 54 1D BE EC 12 5B 86 5C 5D 2C F0 9D
80 54 1D BE 0B 13 28 CF 29 C0 5B 89 5C 5F B4
```

Packed PIDs into 1 message

80 54 1B BE C0 11 28 CF 5B 7F 5C 58 FD

- 80 - MID for Engine #1
- 54 – PID 84, Road Speed
- 1B – Value of Road Speed (27 * 0.5 = 13.5 mph)
- BE – PID 190, Engine Speed
- C0 11 – Value of Engine Speed (3089 * 0.25 = 772.25 rpm)
- 28 – PID 40, Engine Retarder Switches Status
- CF – (11001111) Engine Retarder switch Off
- 5B – PID 91, Percent Accelerator Pedal Position (APP)
- 7F – Value of Percent APP (127*0.4 = 50.8%)
- 5C – PID 9C, Percent Engine Load
- 58 – Value of Engine Load (88 * 0.5 = 44%)
- FD – Checksum (80+54+1B+BE+C0+11+28+CF+5B+7F+5C+58+FD = 0x600)

These interpretations are from the SAE J1587 Document: https://www.sae.org/standards/content/j1587_201301/

Power Line Carrier SAE J2497

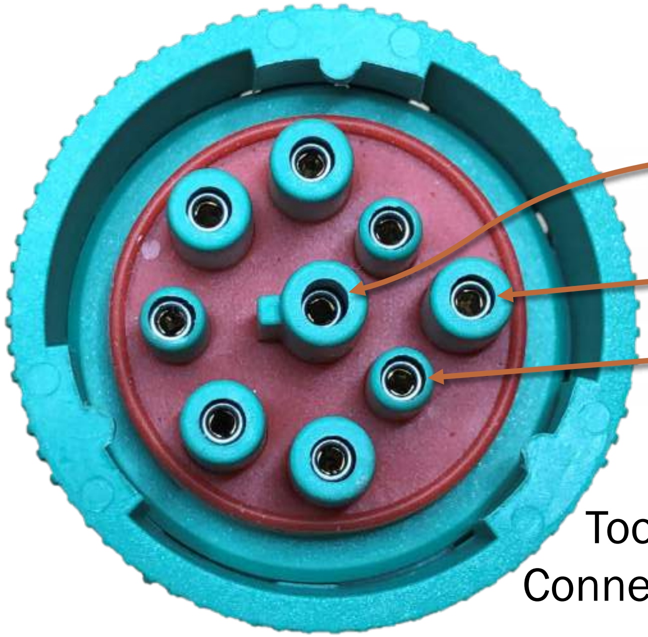
When trailers are connected, similar J1708/J1587 data is transmitted over the trailer power (+12V) line using frequency spectrum modulation.

Trailer Diagnostic Tools

Electronic Brake Controller

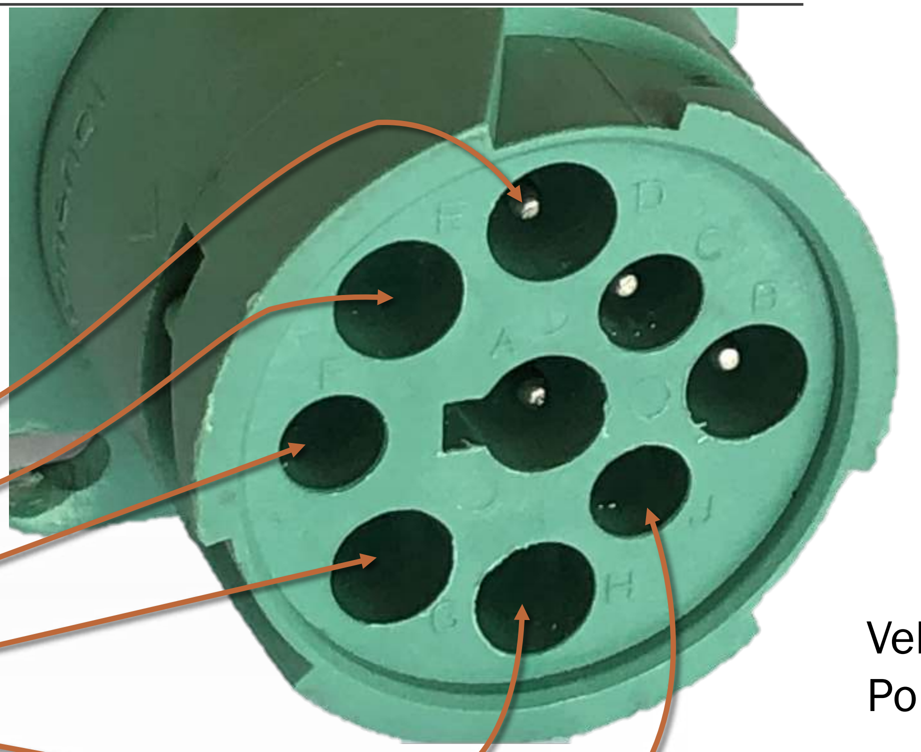
J560 Connectors

Diagnostic Connector Pinouts – PACCAR



Tool Connector

Pin	Signal
A	Ground
B	Vbatt (+12V)
C	J1939 High
D	J1939 Low
E	Shield
F	Diag CAN H
G	Diag CAN L
H	CAN3 High
J	CAN3 Low

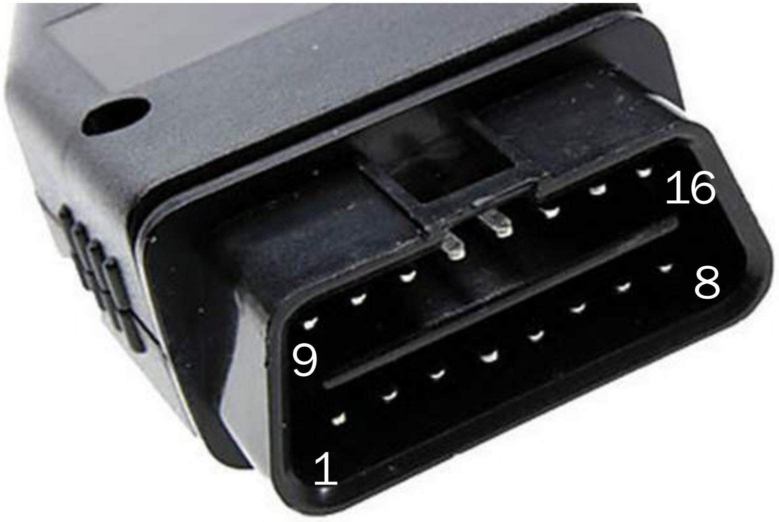


Vehicle Port

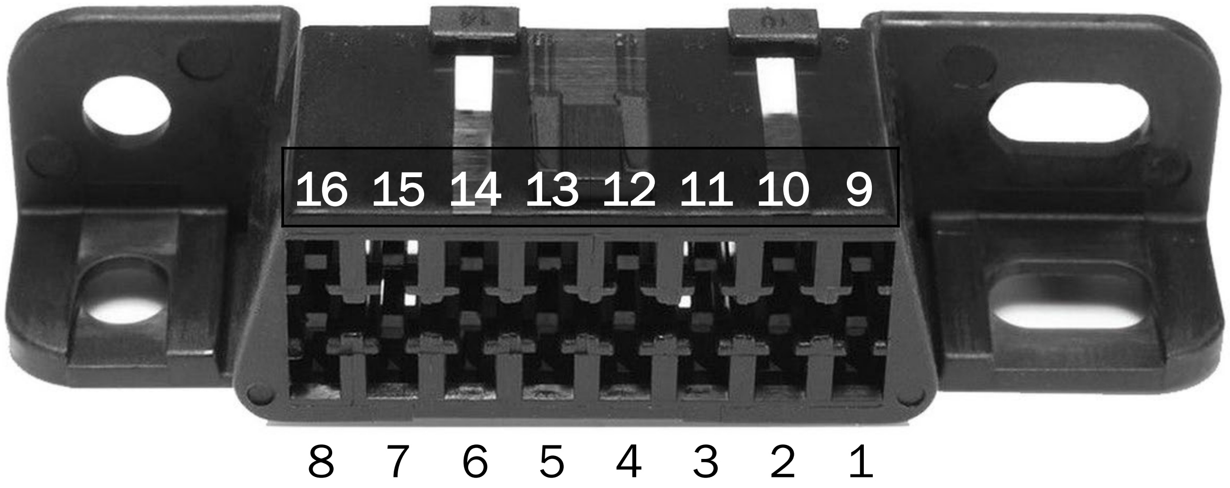
Diagnostics CAN is at 250k.

PACCAR Sells a crossover cable for diagnostics.

Diagnostic Connector Pinouts – Mack/Volvo



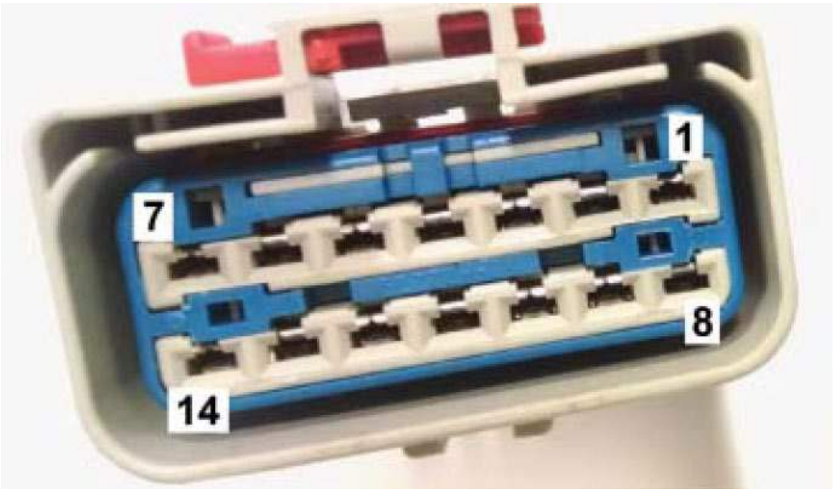
Pin	Signal
3	J1939 High
5	Ground
6	ISO 15765 L
11	J1939 Low
12	J1708 A(+)
13	J1708 B(-)
14	ISO 15765 L
16	VBatt



Source: DG Technologies Product Pinouts and Industry Connectors Reference Guide
https://dgtech.com/wp-content/uploads/2016/04/Pinouts_ICR.pdf

RP1226 Accessory Connector Pinouts

Pin	Signal	Pin	Signal
1	Switched Battery	8	Ground
2	CAN 1 High	9	CAN 1 Low
3	Reserved (not used)	10	Reserved (not used)
4	CAN 2 High	11	CAN 2 Low
5	OEM Reserved	12	OEM Reserved
6	J1708 A(+)	13	J1708 B(-)
7	Ignition (PLC)	14	Battery (always on)



Source: ATA TMC RP1226
https://www.atabusinesssolutions.com/Shopping/Product/viewproduct/2675472/undefined

Diagnostic Connector Pinouts – Key Point

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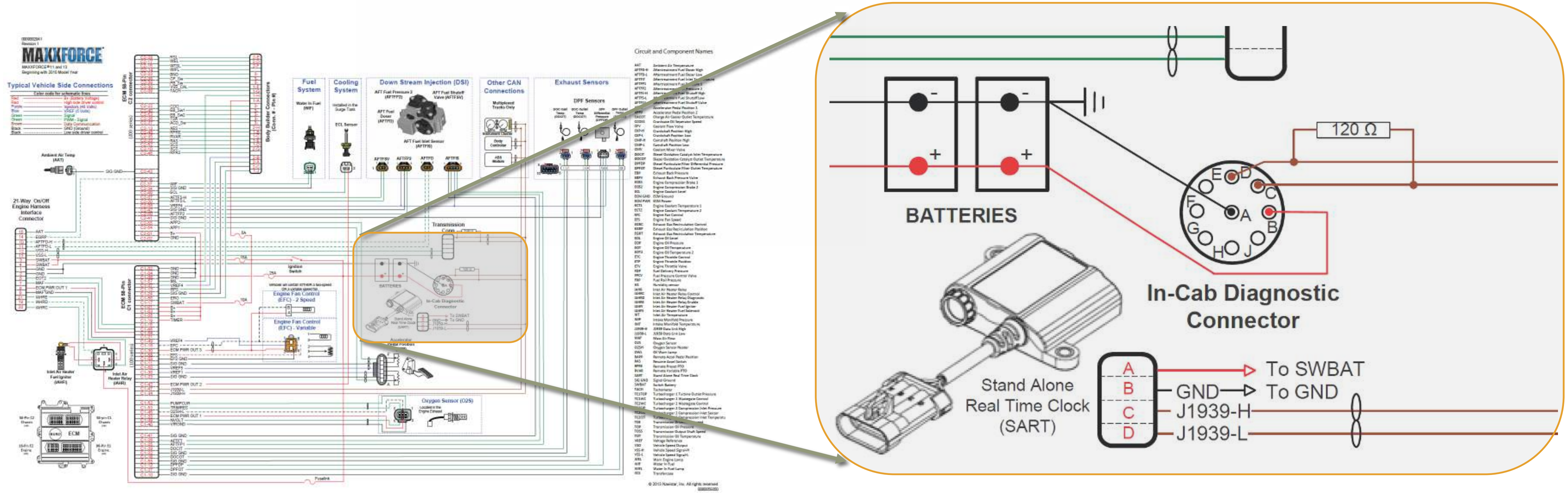
Use the wiring diagrams to verify the actual pinouts of the diagnostic connector.



Bill of Materials to Build a J1939 Diagnostic Connector

National Motor Freight Traffic Association, Inc.

Qty.	Manufacturer	Part Number	Supplier	Supplier Part Num	Description
1	Amphenol Sine Systems	AHD16-9-1939S8R	Digi-Key	889-2245-ND	Green Plug Housing
4	Amphenol Sine Systems	AT62-201-16141	Digi-Key	889-1469-ND	Nickle Socket Contact
	Allied Wire and Cable			GXL-18 YELLOW	J1939 H Wire
				GXL-18 GREEN	J1939 L Wire
				GXL-18 RED	VBatt Wire
				GXL-18 BLACK	Ground Wire

Detailed Deutsch Connector Systems are described in the LADD catalog:
https://laddinc.com/literature/product-catalog/

After Class Exercise

Design a J1939 breakout box with the following features:

1. Split the signals coming in to two signals going out
2. Connect test points to each signal

If you don't have time to build one yourself, they are commercially available. For example: https://www.dgtech.com/product/j1939-breakout-box/

Connecting to the CAN Bus

Controller Area Network

Introduced by Bosch in the 1980s

Multi-master priority-based bus access with non-destructive message arbitration

Utilizes a 15-bit cyclic redundancy check (CRC) to reliably detect transmission errors

Reliable delivery is built in with an acknowledgement bit at the end of the frame

Low latency with up to 8 bytes of data per frame (Classic CAN)

Bit rates up to 1mbit/second

Required on all passenger cars for emission compliance starting in 2008 (Standard 11-bit CAN ID)

Utilized by SAE J1939 as the foundational networking protocol in the 1990s ()

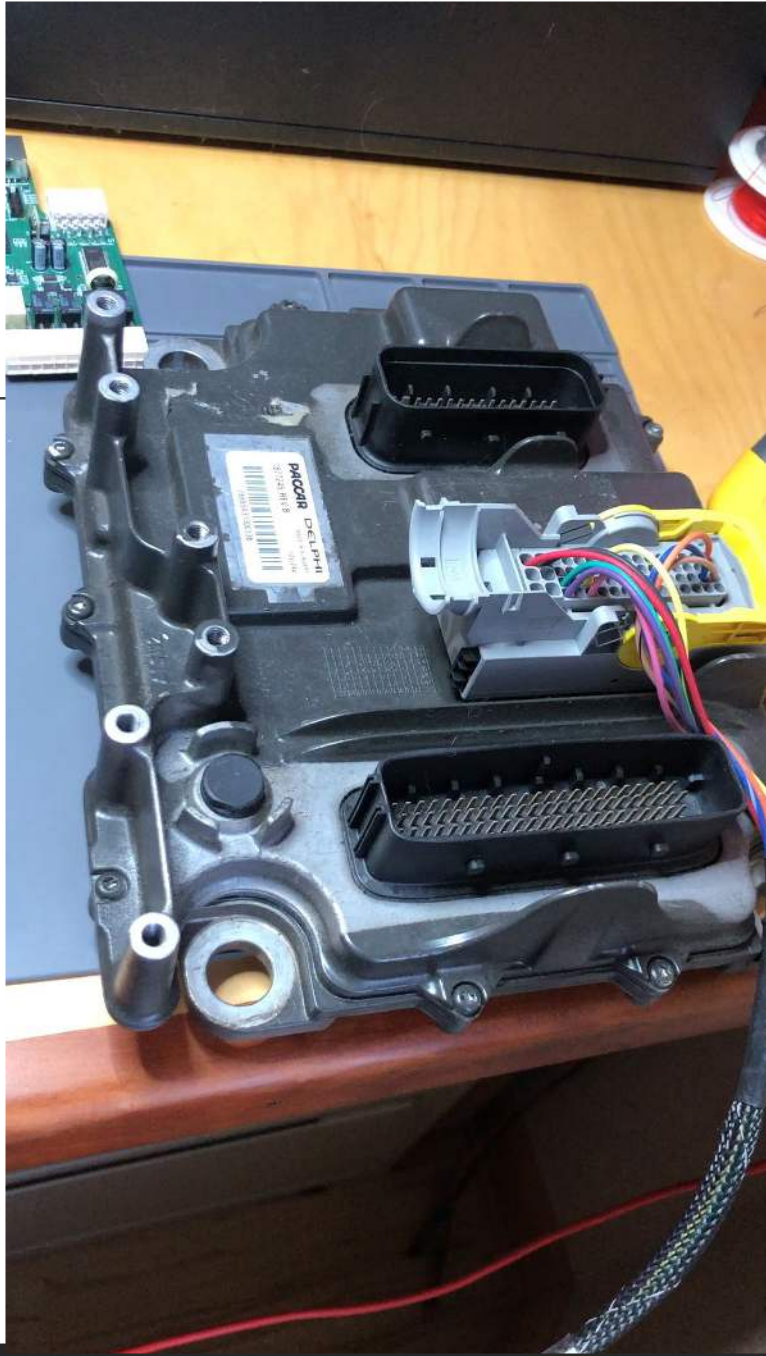
Extended 29-bit CAN Frame

SOF	11-bit CAN ID	SRR	IDE	18-bit CAN ID	RTR	Control Field	Data Bytes	CRC	ACK	EOF

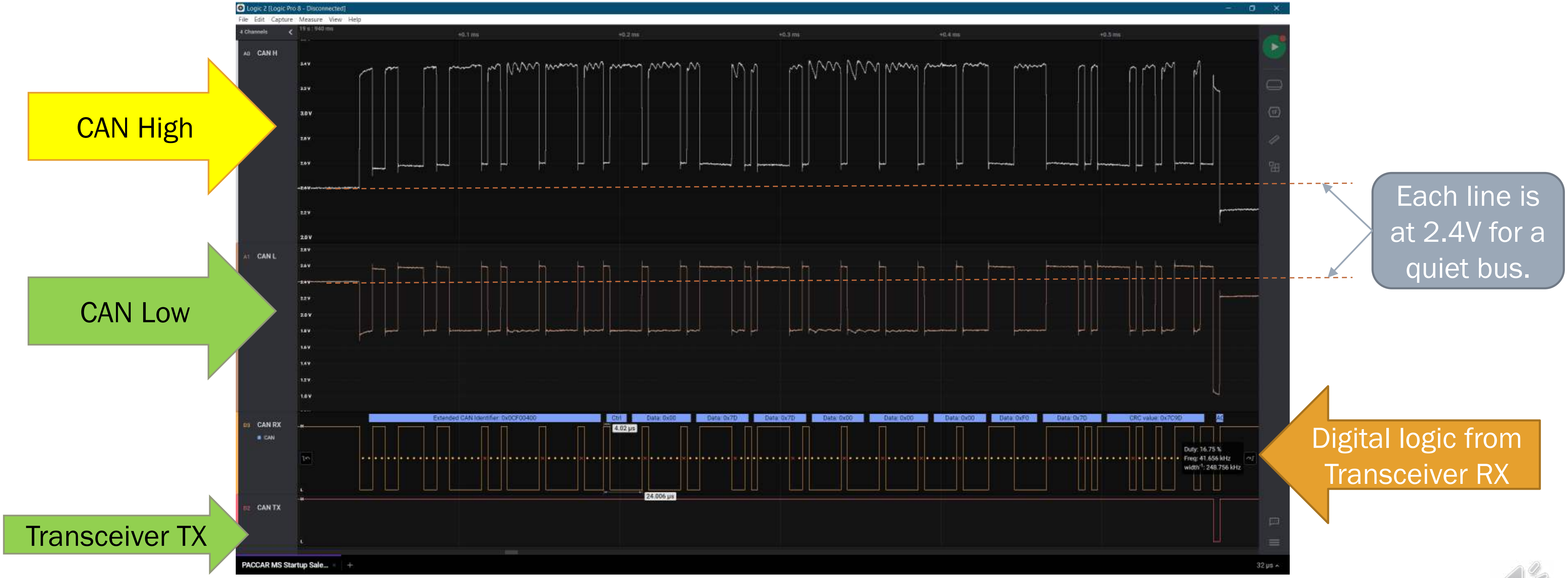
CAN Signaling: Measurement Example

- PACCAR MX Engine Control Module (ECM)
- Synercon Technologies Smart Sensor Simulator
  - Completes the CAN network circuit
  - Provides connectivity for the ECM
- DG Technologies J1939 Breakout Box
- Raspberry Pi with a CAN-FD Hat
  - Runs embedded Linux with SocketCAN
  - Records CAN traffic using can-utils `candump` command
- Fluke Scope Meter as an Oscilloscope
  - Measures voltage traces between CAN High and CAN Low
- Saleae Logic Probe
  - Analog Voltage measurements (duplicating the oscilloscope)
  - Digital measurements from the CAN Transceiver
  - CAN signal decoding features
  - PC application interface

What is on the wire? Let’s monitor the yellow CAN-H and green CAN-L lines.



CAN Signaling: Single Frame



CAN Measurements Observations

A bit time is about 4 microseconds. This is 1/250000.

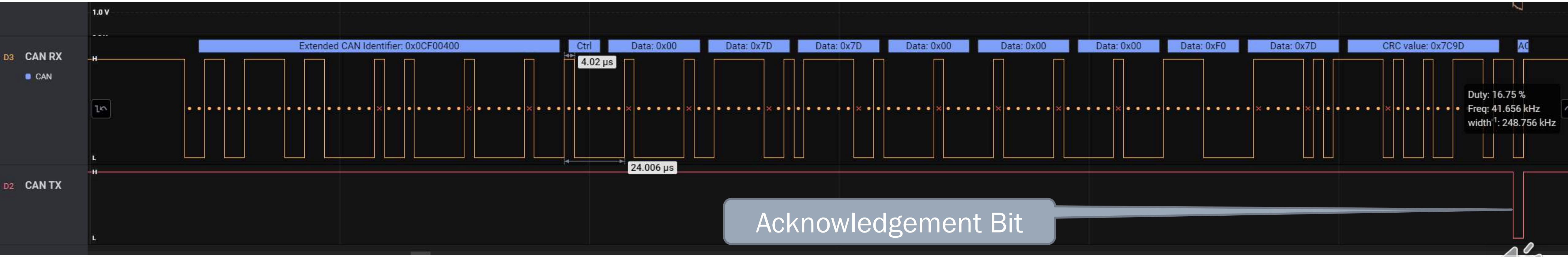
Data that has all zeros still has extra bits in the field. These are called stuff bits.

Stuff bits are inserted after 5 sequential bits of the same value.

At the end of the message, A bit is seen on the TX line, which indicates an acknowledgement the message was received.

The total message length is about 500us.

Signaling is non-return-to-zero (NRZ).



SAE J1939 is Built on CAN

National Motor Freight Traffic Association, Inc.

The main features that define J1939 are:

A standardized meaning for 29-bit arbitration identifiers.

A mechanism for sending messages larger than 8 bytes (up to 1785 bytes) using the transport protocol.

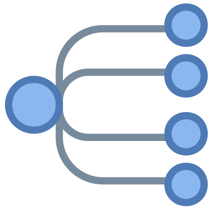
The ability for a controller application to negotiate a unique source address.

SAE International®	SURFACE VEHICLE RECOMMENDED PRACTICE	SAE J1939 JUN2012 Issued 2000-04 Revised 2012-06 Superseding J1939 APR2011
Serial Control and Communications Heavy Duty Vehicle Network - Top Level Document		

Types of J1939 Messages

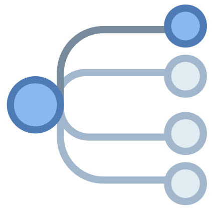
Broadcast

- Messages sent for any controller application (CA) to use
- CAN Arbitration ID specifies a source address (SA) in the last 8 bits of the ID
- Implicitly defined the destination address as 255 (Global)



Point-to-Point

- One controller application sends a message to another
- CAN Arbitration ID specifies a source address (SA) in the last 8 bits of the ID
- A destination address (DA) is in bits 9-16 of the CAN ID.

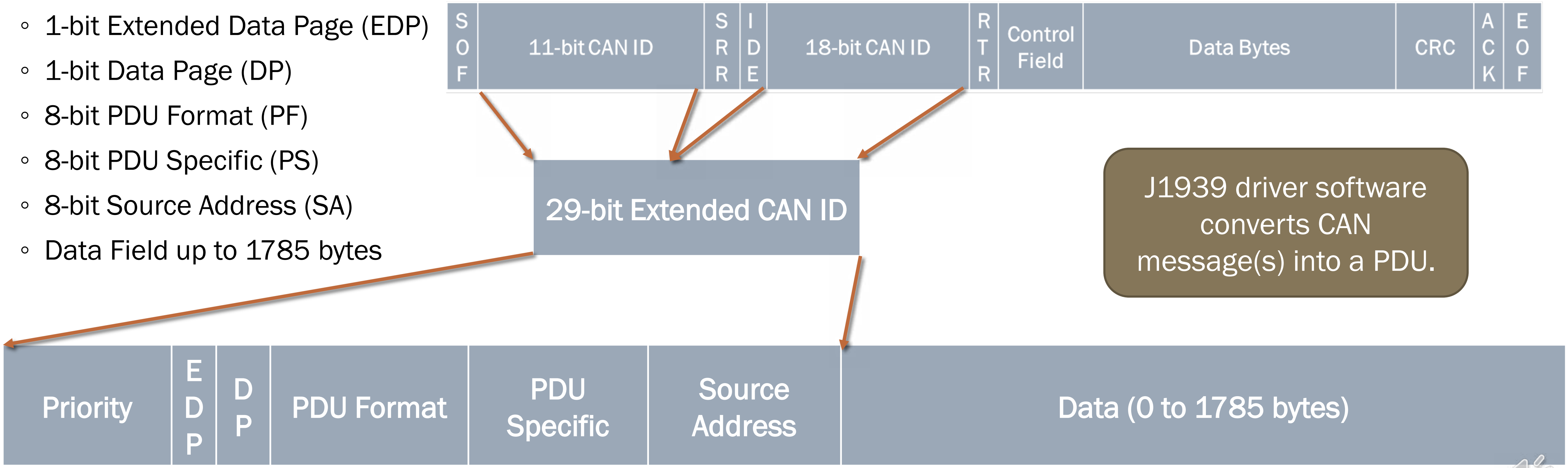


How do some messages implicitly set the destination address to 255?

J1939 Protocol Data Unit

A J1939 message has all the elements in the protocol data unit (PDU)

- 3-bit Priority
- 1-bit Extended Data Page (EDP)
- 1-bit Data Page (DP)
- 8-bit PDU Format (PF)
- 8-bit PDU Specific (PS)
- 8-bit Source Address (SA)
- Data Field up to 1785 bytes

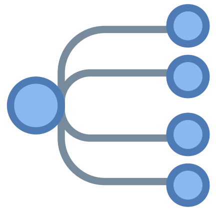


J1939 driver software converts CAN message(s) into a PDU.

PDU 2 Format Messages

The PDU format #2 is for broadcast messages

- EDP, DP, PF and PS create the Parameter Group Number (PGN)
- PS becomes the group extension (GE)
- PF value must be greater than or equal to 240 (0xF0)
- Destination address is implied to be 255 (0xFF)

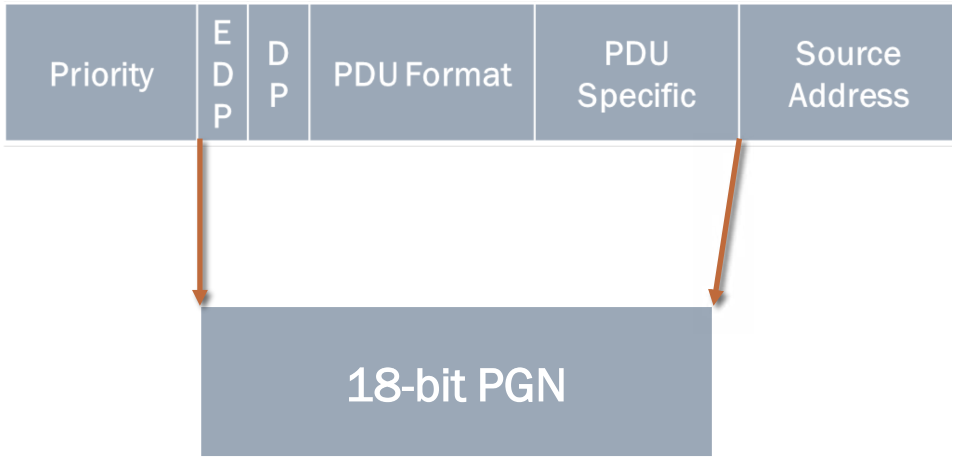


Parameter Groups Numbers are 18 bits.

- Most applications on a truck set the EDP and DP to zero
- Parameter Groups collect similar data for the PDU data field
- PDU 2 messages have a hex values where the leading nibble is F

Examples:

- PGN 65265 (0xFEF1) is for Cruise Control and Vehicle Speed
- PGN 61444 (0xF004) for the Electronic Engine Controller 1 group



PDU 1 Format Messages

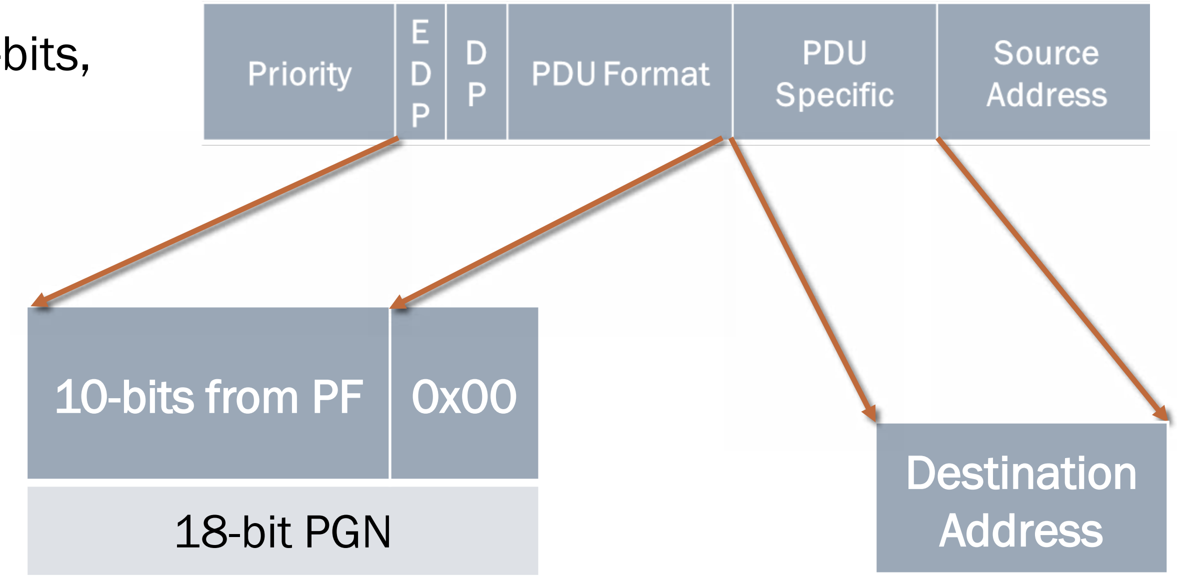
The PDU format #1 is for point-to-point messages

- EDP, DP, PF and 00 create the Parameter Group Number (PGN)
- PS becomes the destination address (DA)

Parameter Group Numbers (PGNs) are still 18-bits, but the last 8 bits are set to zero.

Source and Destination are explicit

PGN values in hex do not have 0xF as the first nibble.



Processing CAN IDs

1. Read the CAN ID as a 32-bit integer
2. Separate the ID into the PDU elements using bit masking and bit shifting
3. Determine if it is a PDU1 or PDU2 message based on the value of PF
   1. If PDU1, PS is the Destination Address
   2. If PDU2, PS is the Group Extension, set Destination Address to 0xFF

```
PRIORITY_MASK = 0x1C000000
EDP_MASK      = 0x02000000
DP_MASK       = 0x01000000
PF_MASK       = 0x00FF0000
PS_MASK       = 0x0000FF00
SA_MASK       = 0x000000FF
PDU1_PGN_MASK = 0x03FF0000
PDU2_PGN_MASK = 0x03FFFF00
```

Bit Masking and Shifting

Example: Determine the PGN from the CAN Frame Capture

ID Hex Nibbles	0	C				F				0				0				4				0				0			
ID Binary	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
PGN Mask Hex	0	3				F				F				F				F				0				0			
Mask Binary	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
AND Result	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Shift right 8 bits									0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0
Hex after shift									0	0				F				0				0				4			

0x00F004 = 61444 dec

Python Based Parsing

```
def get_j1939_from_id(can_id):
    priority = (PRIORITY_MASK & can_id) >> 26
    edp = (EDP_MASK & can_id) >> 25
    dp = (DP_MASK & can_id) >> 24
    PF = (can_id & PF_MASK) >> 16
    PS = (can_id & PS_MASK) >> 8
    SA = (can_id & SA_MASK)
    if PF >= 0xF0: #240
        DA = 255
        PGN = (can_id & PDU2_PGN_MASK) >> 8
    else:
        DA = PS
        PGN = (can_id & PDU1_PGN_MASK) >> 8
    return priority,PGN,DA,SA
```

```
PRIORITY_MASK = 0x1C000000
EDP_MASK      = 0x02000000
DP_MASK       = 0x01000000
PF_MASK       = 0x00FF0000
PS_MASK       = 0x0000FF00
SA_MASK       = 0x000000FF
PDU1_PGN_MASK = 0x03FF0000
PDU2_PGN_MASK = 0x03FFFF00
```

After Class Exercise

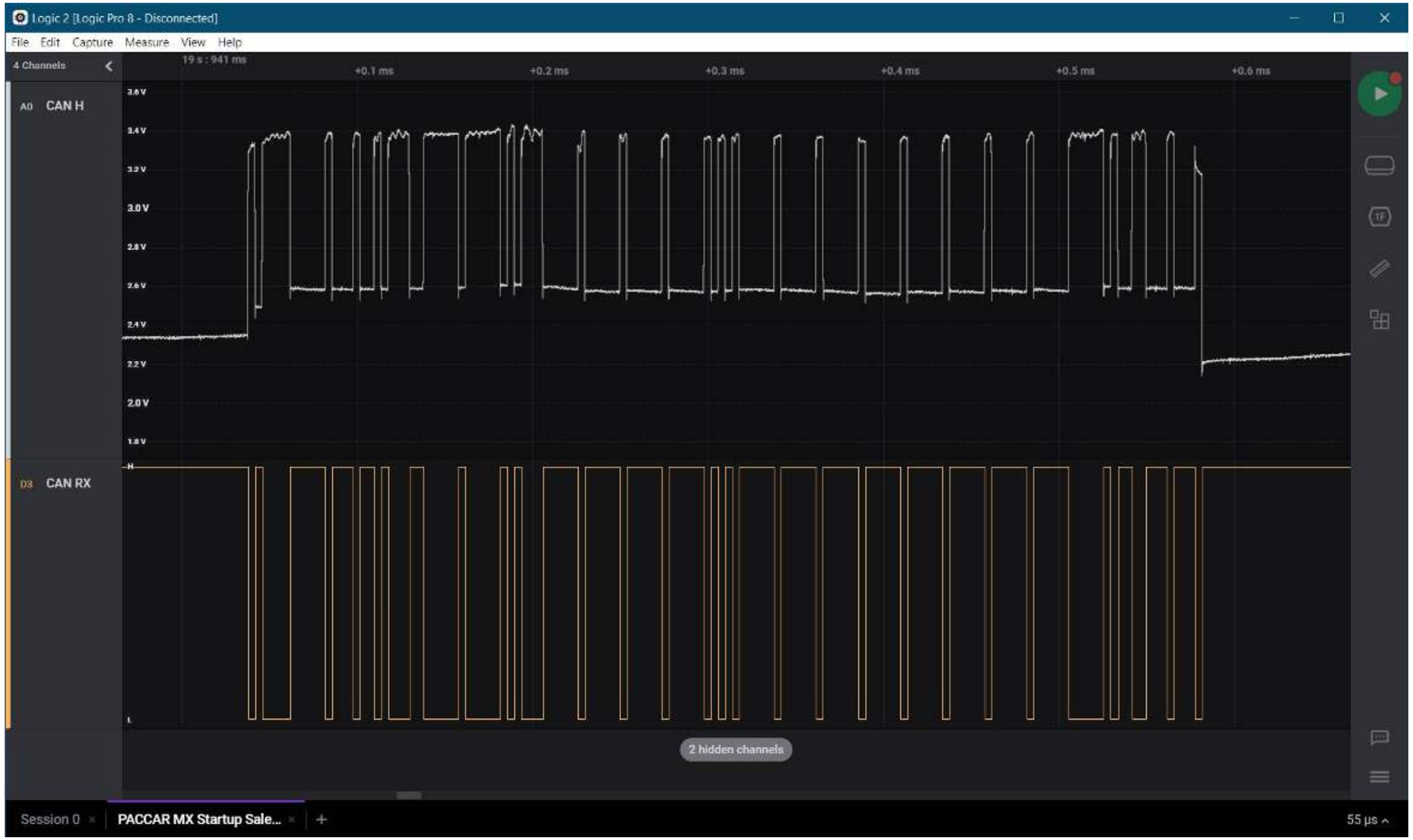
Determine the J1939 priority, parameter group number, destination address, and source address based on the trace of a CAN message.

There are 2 signals available:

1. Analog with 50MHz sampling
2. Digital with a time history of transitions.

Hints:

- There are stuff bits that need to be removed
- The CAN bus speed is 250k bits/second

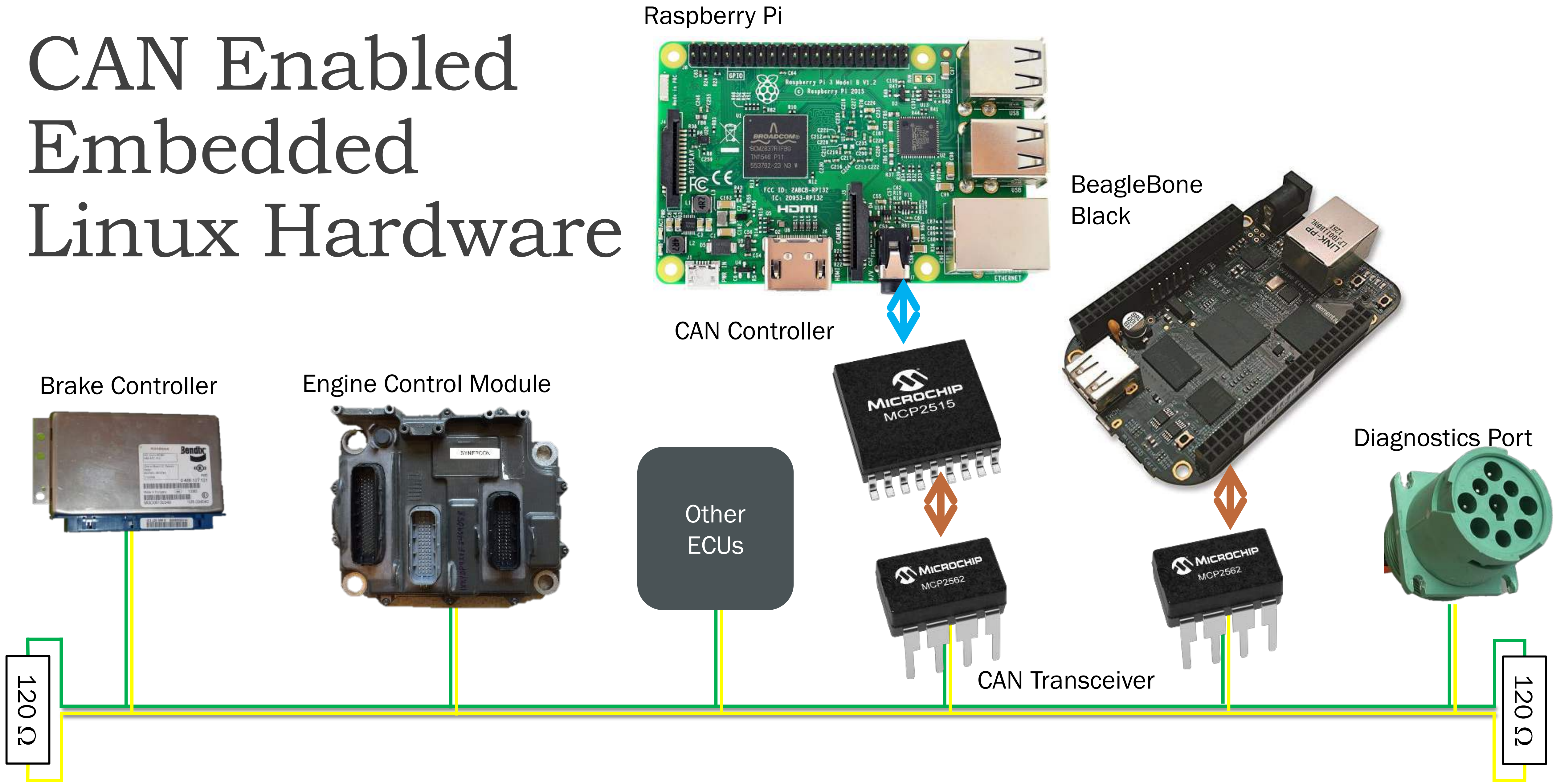


Download the traces from
https://www.engr.colostate.edu/~jdaily/cyber/challenge_data.html

Collecting Truck Data

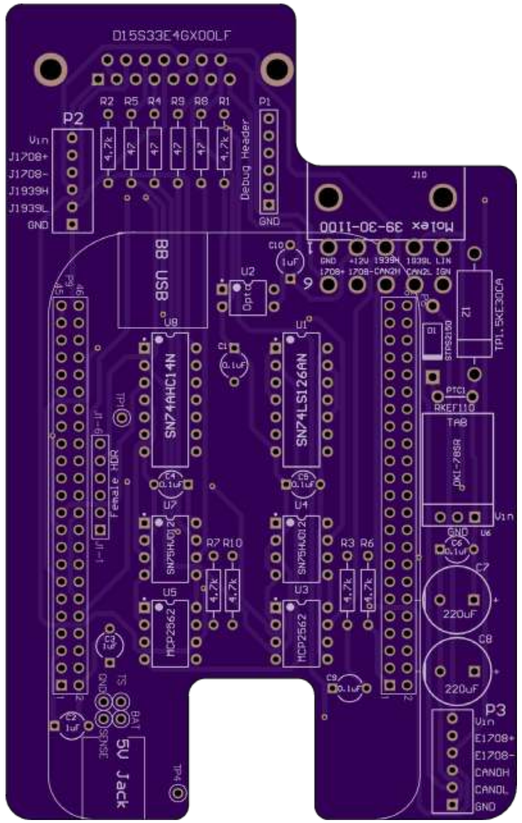
LET’S GET SOME DATA FROM A REAL TRUCK

CAN Enabled Embedded Linux Hardware



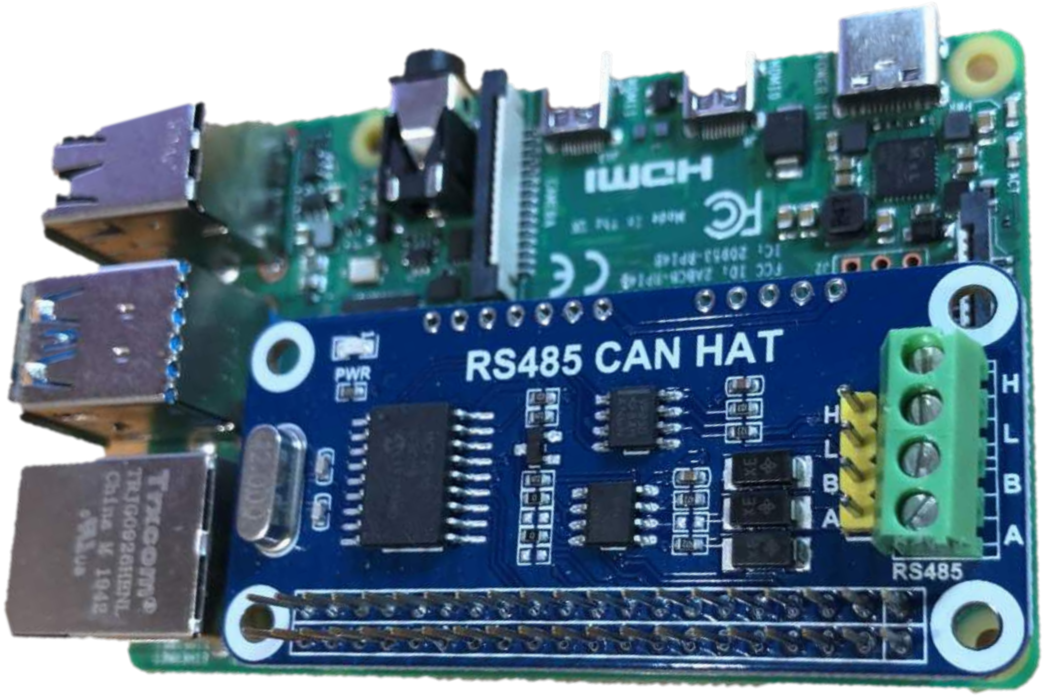
BeagleBone Black with Heavy Truck Cape

https://github.com/SystemsCyber/TruckCapeProjects/tree/master/hardware



https://oshpark.com/shared_projects/FXh7K628

Raspberry Pi with CAN Hat



https://www.amazon.com/RS485-CAN-HAT-Long-Distance-Communication/dp/B07VMB1ZKH/

https://www.amazon.com/Raspberry-Pi-MS-004-00000024-Model-Board/dp/B01LPLPBS8/

Software and Firmware Requirements

Linux with SocketCAN

- https://www.kernel.org/doc/html/v4.17/networking/can.html

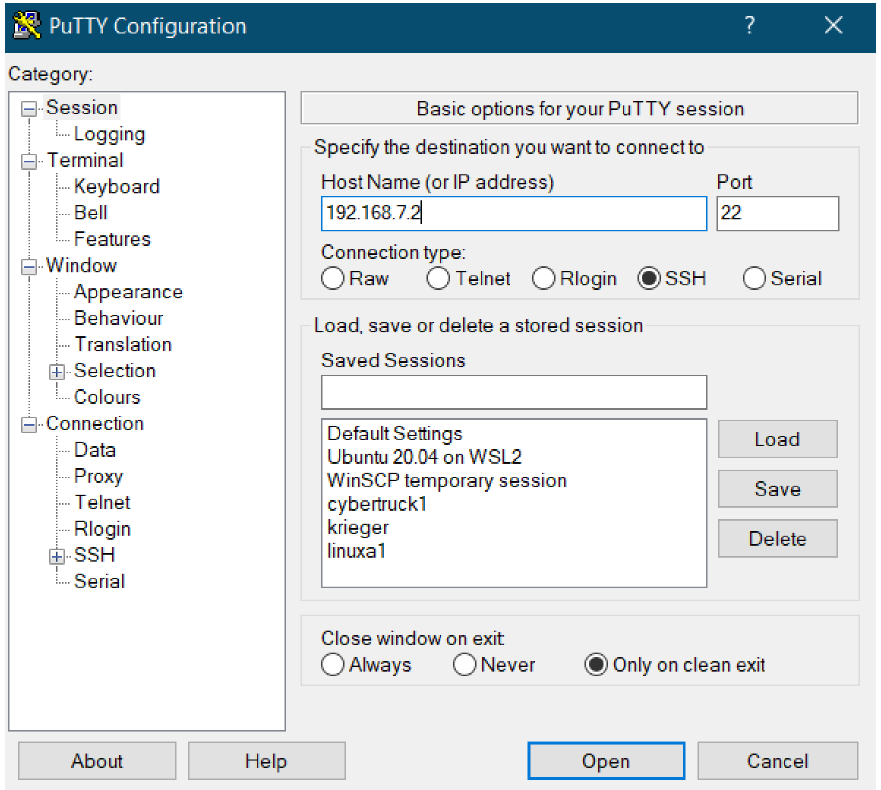
can-utils

- https://github.com/linux-can/can-utils

Additional configuration for the BBB can be found at https://github.com/SystemsCyber/TruckCapeProjects /blob/master/OSBuildInstructions.md

On Windows:

- PuTTy for a terminal access (SSH)
- WinSCP for secure file transfer



Connect to the BBB with USB

Check Network Interfaces

Once logged in, check for network interfaces:

`ifconfig | more`

This should produce a list of interfaces that show

- can0
- can1
- eth0 (among others)

can1 maps to pins C and D for J1939 on the diagnostic port

```
debian@beaglebone: ~
can0: flags=193<UP,RUNNING,NOARP>  mtu 16
        unspec 00-00-00-00-00-00-00-00-00-00-00-00-00-00-00-00  txqueuelen 10  (UNSPEC)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
        device interrupt 50

can1: flags=193<UP,RUNNING,NOARP>  mtu 16
        unspec 00-00-00-00-00-00-00-00-00-00-00-00-00-00-00-00  txqueuelen 10  (UNSPEC)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
        device interrupt 51

eth0: flags=-28605<UP,BROADCAST,RUNNING,MULTICAST,DYNAMIC>  mtu 1500
        inet 192.168.1.174  netmask 255.255.255.0  broadcast 192.168.1.255
        inet6 fe80::235:ffff:fe9b:7e9a  prefixlen 64  scopeid 0x20<link>
        ether 00:35:ff:9b:7e:9a  txqueuelen 1000  (Ethernet)
        RX packets 4639  bytes 408420 (398.8 KiB)
        RX errors 0  dropped 2502  overruns 0  frame 0
        TX packets 1874  bytes 175571 (171.4 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
        device interrupt 63

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 81  bytes 6556 (6.4 KiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 81  bytes 6556 (6.4 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

usb0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 192.168.7.2  netmask 255.255.255.0  broadcast 192.168.7.255
        inet6 fe80::235:ffff:fe9b:7e9c  prefixlen 64  scopeid 0x20<link>
        ether 00:35:ff:9b:7e:9c  txqueuelen 1000  (Ethernet)
        RX packets 407  bytes 32266 (31.5 KiB)
        RX errors 0  dropped 5  overruns 0  frame 0
        TX packets 125  bytes 25516 (24.9 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

usb1: flags=4099<UP,BROADCAST,MULTICAST>  mtu 1500
        inet 192.168.6.2  netmask 255.255.255.0  broadcast 192.168.6.255
        ether 00:35:ff:9b:7e:a0  txqueuelen 1000  (Ethernet)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

--More--
```

Connecting to a Truck and Reading Data

Check the bitrate of the physical channel:

- `ip -details -statistics link show can1`

Change bitrate to match system:

- `sudo ip link set can1 down`
- `sudo ip link set can1 type can bitrate 500000`
- `sudo ip link set can1 up`

Log the can data to a file:

- `candump -l –e any`

Logging and Interpreting Data

Finding things of interest:

- e.g. Look for Address Claim messages:
  `candump any | grep 18EE`

```
debian@beaglebone: ~
  can1  18FEF100   [8]  FF 00 00 50 CC 00 1F FF
  can1  0CF00300   [8]  DF 00 00 FF FF FF FF FF
  can1  0CF00400   [8]  F8 7D 7D 00 00 00 FF 7D
  can1  18FEF200   [8]  00 00 00 00 6E 06 FF FF
  can1  0CF00400   [8]  F8 7D 7D 00 00 00 FF 7D
  can1  18FDC100   [8]  FF FE FF FF FF FF FF FF
  can1  0CFF1100   [8]  00 00 00 00 00 00 00 00
  can1  18FD9F00   [8]  FF FF FF FF FF FF 00 CF
  can1  18FDAF00   [8]  1E 22 1E 22 FF FF FF FF
  can1  18FDB000   [8]  1E 22 FF FF FF FF FF FF
  can1  18FDB100   [8]  1E 22 FF FF FF FF FF FF
  can1  18FDB200   [8]  1E 22 1E 22 FF FE FF FF
  can1  18FDB300   [8]  20 22 FF FE FF FF FF FF
  can1  18FDB400   [8]  20 22 FF FE FF FF FF FF
  can1  18FEEF00   [8]  FF FF FF FE FF FF FF 00
  can1  0CF00400   [8]  F8 7D 7D 00 00 00 FF 7D
  can1  18FEF600   [8]  FF FE 41 FF FF 20 22 FF
  can1  18EBFF00   [8]  05 03 01 04 F0 E3 71 05
debian@beaglebone:~$ candump any |grep 18EE
  can1  18EEFF00   [8]  D0 6B 01 01 00 00 00 80
  can1  18EEFF0F   [8]  01 02 03 01 00 0C 00 90
  can1  18EEFF00   [8]  D0 6B 01 01 00 00 00 80
  can1  18EEFF0F   [8]  01 02 03 01 00 0C 00 90
```

Creating Meaning from Messages

HOW DO WE GET ENGINEERING VALUES FROM J1939 PROTOCOL DATA UNITS?

J1939 Network Layers

Layer	Name	Standard	Description and Purpose
7	Application	SAE J1939-71 (Applications) SAE J1939-73 (Diagnostics)	Defines how to interpret and compose J1939 messages with engineering values
6	Presentation	Not Used These services are built into the Data Link Layer.	
5	Session		
4	Transport		
3	Network	J1939-31	Clarifies the concept of a gateway between two separate networks.
2	Data Link	J1939-21	Describes how to make a J1939 PDU. Includes details on sending messages up to 1785 bytes long.
1	Physical	J1939-1X	Defined connectors, transceivers, wiring, pinouts, and signaling.

SAE J1939 Standards Organization

Follows the OSI 7-layer model for naming, e.g.:
- J1939-7X are for application layers
- J1939-1X are for physical layers

The standard collection adds much more definition to the CAN communications

Includes additional “Layers”
- J1939-8X Network Management
- J1939-9X Network Security

J1939 is large and not free

J1939 Accommodates Extensions
- PGN 0xEF00 is Proprietary A
- PGN 0xFFXX is Proprietary B
- PGN 0xDA00 is ISO-15765 (UDS)

A Digital Annex (J1939DA) has the applications defined in an Excel spreadsheet

https://www.sae.org/publications/collections/content/j1939_dl/

Recommendation:
- Acquire the Digital Annex first.
- Read J1939-21 for details on the PDU

Data Decoding and Encoding: Meaning for Bits and Bytes

Common data sizes

- Bit Mapped, like Switch States, (2-bits)
- Single Byte Data (8-bits)
- 2-byte Data (16 bits)
- 4-byte Data (32 bits)
- ASCII data (variable)

Exceptions:

- Field data, engine maps
- Suspect Parameter Numbers (19 bits)
- Failure Mode Indicators (5 bits)
- Others…

Scale, Limits, Offsets, Transfer (SLOTs)

Identifier	SLOT Name	SLOT Type	Scaling	Range	Offset	Length
1	SAEpr11	Pressure	5 kPa/bit	0 to 1,250 kPa	0	1 byte
2	SAEpr13	Pressure	8 kPa/bit	0 to 2,000 kPa	0	1 byte
3	SAEtm11	Time	1 h/bit	0 to 250 h	0	1 byte
4	SAEtm10	Time	1 h/bit	-125 to 125 h	-125 h	1 byte
5	SAEtm12	Time	1 h/bit	-32,127 to 32,128 h	-32,127 h	2 bytes
6	SAEtm06	Time	1 s/bit	0 to 4,211,081,215 s	0	4 bytes
7	SAEad01	Angle/Direction	0.0000001 deg/bit	-210 to 211.1081215 deg	-210 deg	4 bytes
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Bit Transmission Order

Transmission Order: The order in which bits are transmitted over the J1939 Link.

- Data is transmitted in increasing byte order (Byte 1 first, Byte 8 last)
- Bits within the byte are transmitted in decreasing order (Bit 8 first, Bit 1 last)

MSB – Most Significant Byte
MSb – Most Significant Bit

Bit Placement: The location within the byte of the start point of the data

- J1939 uses a convention of Byte.Bit.
- Example from PGN 65265 Cruise Control/Vehicle Speed

SPN	Location	Length	Suspect Parameter
967	8.1	2 bits	Engine Idle Increment Switch
968	8.3	2 bits	Engine Idle Decrement Switch
966	8.5	2 bits	Engine Test Mode Switch
1237	8.7	2 bits	Engine Shutdown Override Switch

MSb			Byte 8				LSb
8	7	6	5	4	3	2	1
1237		966		968		967	

Decoding Example:
Accelerator Pedal Low Idle Switch

Given the following CAN message (hex):

`0CF00300    [8]  D0 5A 25 FF FF 0F A0 81`

1. Break the CAN ID into J1939 values
   a) 0x0C is priority 3
   b) F004 is PDU2 format
      i. PGN is 0xF003 = 61443, Electronic Engine Control 2
      ii. Destination Address is 0xFF (implied)
   c) Source address is 0x00 = 0, Engine #1

2. Determine some Suspect Parameters in the data
   a) 558: Accelerator Pedal 1 Low Idle Switch
   b) 559: Accelerator Pedal 1 Kickdown Switch
   c) 1437: Road Speed Limit Status
   d) 2970: Accelerator Pedal 2 Low Idle Switch
   e) 91: Accelerator Pedal Position 1
   f) 92: Engine Percent Load At Current Speed
   g) 974: Remote Accelerator Pedal Position
   h)
   i)

Bit Encoding for SPN 558
00 - Accelerator pedal 1 not in low idle condition
01 - Accelerator pedal 1 in low idle condition
10 - Error
11 - Not available

Bit 8

Bit 1

Byte Position	Byte 1				Byte 2	Byte 3					
Hex Values	0xD0				0x5A	0x25					
Binary	0b 1101 0000										
SPNs	2970	1437	559	558	91	92	974	29	2979		
Engineering	N/A	On	Off	Off			N/A	N/A			

Decoding Example: Accelerator Pedal Position

Given the following CAN message (hex):

0CF00300 [8] D0 5A 25 FF FF 0F A0 81

1. Break the CAN ID into J1939 values
   a) 0x0C is priority 3
   b) F004 is PDU2 format
      i. PGN is 0xF003 = 61443, Electronic Engine Control 2
      ii. Destination Address is 0xFF (implied)
   c) Source address is 0x00 = 0, Engine #1

2. Determine <u>some</u> Suspect Parameters in the data
   a) 558: Accelerator Pedal 1 Low Idle Switch
   b) 559: Accelerator Pedal 1 Kickdown Switch
   c) 91: Accelerator Pedal Position 1
   d) 92: Engine Percent Load At Current Speed
   e) 974: Remote Accelerator Pedal Position
   f) 29: Accelerator Pedal Position 2
   g) 2979: Vehicle Acceleration Rate Limit Status
   h) 3357: Actual Maximum Available Engine % Torque
   i) 5398: Estimated Pumping – Percent Torque

Byte Position	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8
Hex Values	0xD0	0x5A	0x25	0xFF	0xFF	0x0F	0xA0	0x81
SPNs	558, 559…	91	92	974	29	2979…	3357	5398
Engineering		90*0.4 = 36%		N/A	N/A		160*0.4= 64%	129-125=32%

Byte order for Integers (Endianness)

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Post office boxes have mail loaded from the inside and taken out through the front.

This Photo by Unknown Author is licensed under CC BY-NC

Mailboxes have mail loaded and removed from the front.

Byte order for Integers (Endianness)

NMFTA
National Motor Freight Traffic Association, Inc.

Let's pretend our mailboxes are containers to hold bytes representing integers.

Example: the integer 100,293,486 is 0x05FA5B6E in hex, which is 4 bytes:

Most Significant Byte

0x05 0xFA 0x5B 0x5E

Least Significant Byte

Pretend each byte is a small package. In what order should the postmaster insert the bytes into the mailbox so they are in order when the customer extracts them?

MSB first

0x05 0xFA 0x5B 0x5E

Big Endian

LSB first

0x05 0xFA 0x5B 0x5E

Little Endian

Byte order for Integers (Endianness)

SAE J1939 encodes multi-byte integers in the Little Endian format.

This give the appearance the bytes are reversed and need to be swapped to interpret

Intel format = Little Endian = Least Significant Byte first

Motorola format = Big Endian = Most Significant Byte first (as we typically read and write)

Endianness doesn't affect single byte integers.

Byte Length	Decimal	Hex	Big Endian	Little Endian (J1939)
1	241	F1	0xF1	0xF1
2	743	2E7	0x02 0xE7	0xE7 0x02
2	25	19	0x00 0x19	0x19 0x00
4	1,890,056,399	70A7F8CF	0x70 0xA7 0xF8 0xCF	0xCF 0xF8 0xA7 0x70

Decoding Example: Engine Speed (RPM)

National Motor Freight Traffic Association, Inc.

Given the following CAN message (hex):
0CF00400 [8] 31 9D 9D A2 38 00 0F 9D

1. Break the CAN ID into J1939 values
   a) 0x0C is priority 3
   b) F004 is PDU2 format
      i. PGN is 0xF004 = 61444, Electronic Engine Control 1
      ii. Destination Address is 0xFF (implied)
   c) Source address is 0x00 = 0, Engine #1

2. Determine Suspect Parameters in the data
   a) 889: Engine Torque Mode
   b) 4154: Actual Percent Torque
   c) 512: Driver's Demand Engine - Percent Torque
   d) 513: Actual Engine Percent Torque
   e) 190: Engine Speed
   f) 1483: SA of Controlling device
   g) 1675: Engine Starter Mode
   h) 2432: Engine Demand- Percent Torque

Byte Position	Byte 1		Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7		Byte 8
Hex Values	0x31		0x9D	0x9D	0xA2	0x38	0x00	0x0F		0x9D
SPNs	899	4154	512	513	190		1483	1675	Res	2432
Engineering			32%	32%	14,498/8 = 1812.25				N/A	157-125=32%

J1939DA_202001.xls - Compatibility Mode

J1939™DA - DIGITAL ANNEX OF SERIAL CONTROL AND COMMUNICATION HEAVY DUTY VEHICLE NETWORK DATA - JAN2020

1. *RATIONALE*

This revision of the J1939 Digital Annex includes changes approved at the November 2019 (4Q2019) meeting.

1.1 *SCOPE*

This document is intended to supplement the J1939 documents by offering the J1939 information in a form that can be sorted and searched for easier use.

1.2 List of J1939 Data Worksheets in Workbook

- SPNs and PGNs
- SLOTs
- Industry Groups (Table B1)
- Preferred Addresses - Industry Group 0 - Global (Table B2)
- Preferred Addresses - Industry Group 1 - On-Highway Equipment (Table B3)
- Preferred Addresses - Industry Group 2 - Agricultural and Forestry Equipment (Table B4)
- Preferred Addresses - Industry Group 3 - Construction Equipment (Table B5)
- Preferred Addresses - Industry Group 4 - Marine Equipment (Table B6)
- Preferred Addresses - Industry Group 5 - Industrial, Process Control, Stationary Equipment (Table B7)
- Manufacturer Codes (Table B10)
- NAME Functions - All Industry Inclusive (Table B11)
- NAME Functions - Industry Group And Vehicle System Dependent (Table B12)
- SPN and PGN Supporting Information (Appendix D)

2. *REFERENCES*

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Documentation | Revision Column Definition | SPNs & PGNs | SLOTs | Manufacturer IDs (B10) | Global Source Addresses (B2) | Global NAME Functions (B11) | IG ...

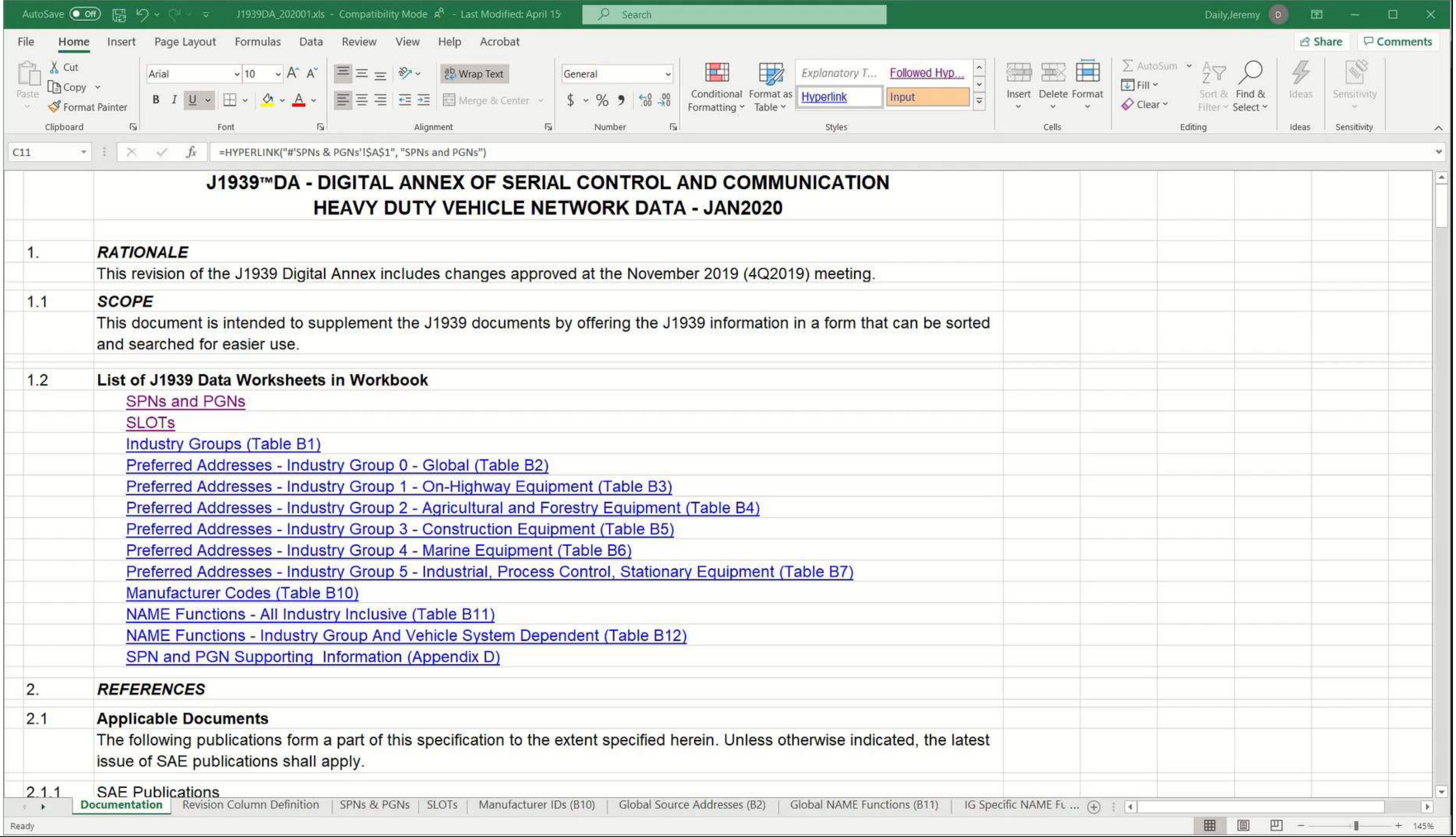
Decoding Example: Vehicle Miles

Determine the Odometer reading from the J1939 data.

Not all data defined in J1939 is present on the network.

Strategy:

1. Look up the SPN for distance
2. Search the J1939 Standard for the entry
3. Find the message in a log
4. Decode the logged message



J1939™DA - DIGITAL ANNEX OF SERIAL CONTROL AND COMMUNICATION
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2.1.1 SAE Publications

AutoSave Off J1939DA_202001.xls - Compatibility Mode - Last Modified: April 15 Search Daily,Jeremy

File Home Insert Page Layout Formulas Data Review View Help Acrobat Share Comments

A1 SPNs and PGNs

	P	Q	R	S	T	U
1						
2						
3						
4	Default Priority	PG Reference	SP Position in PG	SPN	SP Label	SP Description
5	3		1.1	695	Engine Override Control M	The override control mode defines which sort of command is used:
6	3		1.3	696	Engine Requested Speed	This mode tells the engine control system the governor
7	3		1.5	897	Override Control Mode Pric	This field is used as an input to the engine or retarder to determine
8	3		2-3	898	Engine Requested Speed/	Parameter provided to the engine from external sources in the
9	3		4	518	Engine Requested Torque	Parameter provided to the engine or retarder in the torque/speed
10	3		5.1	3349	TSC1 Transmission Rate	This parameter indicates the transmission rate at which the sending
11	3		5.4	3350	TSC1 Control Purpose	State signal which indicates which control mode the sending device is
12	3		6.1	4191	Engine Requested Torque	This parameter displays an additional torque in percent of the
13	3		8.1	4206	Message Counter	The message counter is used to detect situations where the
14	3		8.5	4207	Message Checksum	The message checksum is used to verify the signal path from the
15	3		1.1	681	Transmission Gear Shift In	Command signal to inhibit gear shifts.
16	3		1.3	682	Transmission Torque Conv	Command signal to override normal transmission control of the torque
17	3		1.5	683	Disengage Driveline Reque	Command signal used to simply disengage the driveline, e.g., to
18	3		1.7	4242	Transmission Reverse Gea	Allows devices external to the normal transmission shift selector
19	3		2	684	Requested Percent Clutch	Parameter which represents the percent clutch slip requested by a
20	3		3	525	Transmission Requested G	Gear requested by the operator, ABS, or engine.
21	3		4.1	685	Disengage Differential Loc	Command signal used to disengage the various differential locks,
22	3		4.3	686	Disengage Differential Loc	Command signal used to disengage the various differential locks,

- Sort A to Z
- Sort Z to A
- Sort by Color
- Sheet View
- Clear Filter From "SP Label"
- Filter by Color
- Text Filters
- (Select All)
- 2 Wheel Steer Actuator State
- 4 Wheel Steer Actuator State
- A/C High Pressure Fan Switch
- Above Nominal Level Front Axle
- Above Nominal Level Rear Axle
- ABS Fully Operational
- ABS Off-road Switch
- ABS/EBS Amber Warning Signal (F
- Absolute Engine Load - Percent Ai
- Absolute Laser Strike Position
- ACC Distance Alert Signal
- ACC System Shutoff Warning

Not all items showing

OK Cancel

Documentation | Revision Column Definition | SPNs & PGNs | SLOTs | Manufacturer IDs (B10) | Global Source A | IG Specific NAME Fu ...

Ready 145%

After Class Exercise

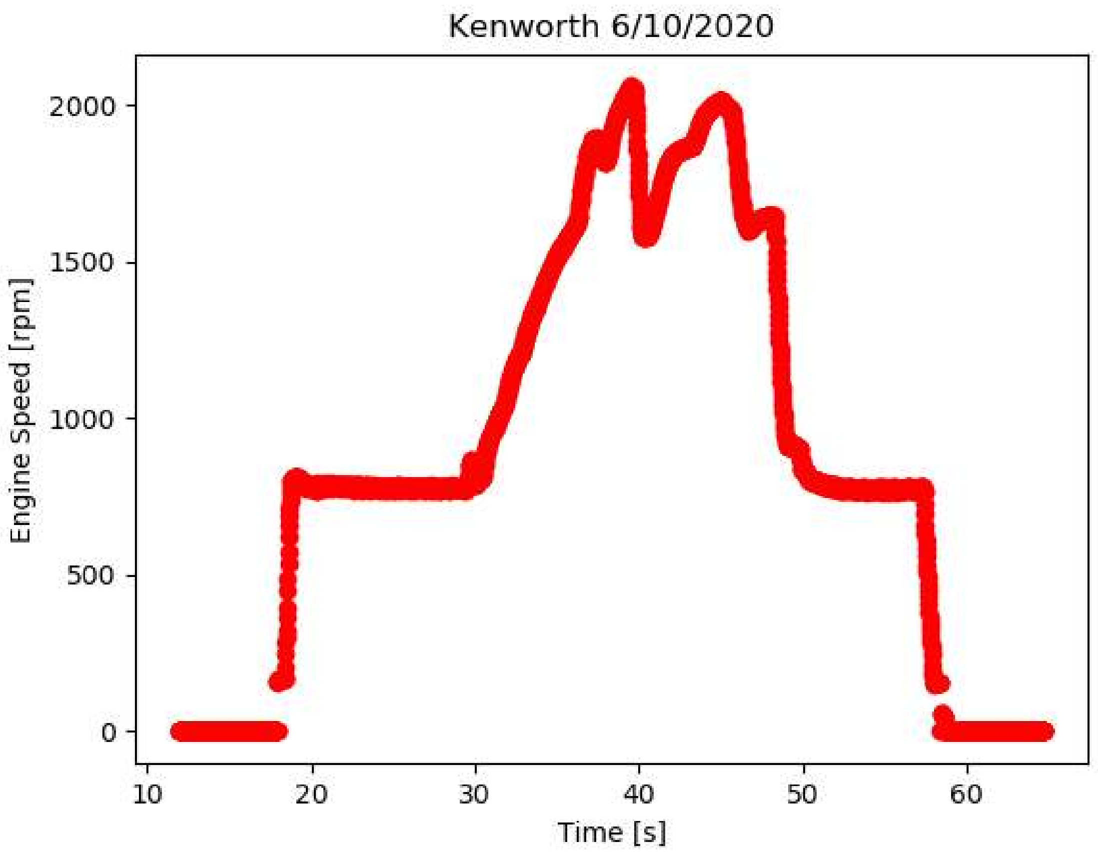
Signal Interpretation

A candump data log was capture during a startup seqence for a truck using Linux SocketCAN. The data comes from 2014 Class 6 truck with a box van where the operator started the engine, pressed the accelerator pedal and turned the engine off. The challenge is to determine the highest engine speed in RPM base on the log file.

1. Some other questions for consideration: How many ECUs are on the network?

2. What is the vehicle mileage?

3. Did the vehicle's wheels rotate?



https://www.engr.colostate.edu/~jdaily/cyber/KWTruck.txt

J1939 Transport Protocol

HOW CAN WE SEND MESSAGES LARGER THAN 8 BYTES IN A CAN FRAME?

J1939 Transport Protocol

Data more than 8 bytes in length requires multiple CAN frames to send the data.

Two Approaches that follow PDU formats

- Request to Send/Clear to Send (RTS/CTS) – point-to-point messaging
- Broadcast Announce Message (BAM) – global address
- Approach is determined with the first byte of the Connection Management Message
  - If 32 (0x20), then BAM
  - If 16 (0x10), then RTS
  - If 17 (0x11), then CTS

Three Parameter Groups to track

- Transport Protocol – Connection Management (TP.CM), PGN 60416 (0xEC00)
- Transport Protocol – Data Transfer (TP.DT), PGN 60160 (0xEB00)
- PGN of the data being transported

Details are in SAE J1939-21

J1939 Transport Protocol VIN Example

The following data were on J1939:

```
CAN ID: CAN Data (in hex)
1CECFF00: 20 12 00 03 FF EC FE 00
1CEBFF00: 01 31 58 4B 59 44 50 39
1CEBFF00: 02 58 37 46 4A 34 36 39
1CEBFF00: 03 30 35 38 2A FF FF FF
```

Parse the CAN ID into J1939 parameters:

- 0x1C000000 -> Priority = 7 (lowest)
- 0x00EC0000 -> PGN = 60416 (TP.CM)
- 0x00EB0000 -> PGN = 60160 (TP.DT)
- 0x0000FF00 -> Destination = 255 (Global)
- 0x00000000 -> Source Address = 0 (Engine 1)

J1939 Transport Protocol VIN Example (cont.)

Transport Protocol – Connection Management

```
1CECFF00: 20 12 00 03 FF EC FE 00
```

- `20 – Control Byte = BAM`
- `12 00 – Message size (18 bytes)`
- `03 – Number of packets (3)`
- `EC FE 00 – PGN of message (0x00FEEC = 65260 Vehicle Identification)`

Connection Mode: BAM

- Byte 1: Control byte = 32 (0x20), Broadcast Announce Message (BAM)
- Bytes 2,3: Total message size, number of bytes (Big Endian or reverse byte order)
- Byte 4: Total number of packets
- Byte 5: Reserved (0xFF)
- Bytes 6,7,8: Parameter Group Number of the packeted message (Big Endian)

Note: The destination on a BAM is often 255 for all the nodes.

1XKYDP9X7FJ469058*

J1939 Transport Protocol VIN Example (cont.)

National Motor Freight Traffic Association, Inc.

Transport Protocol – Data Transfer

```
1CEBFF00: 01 31 58 4B 59 44 50 39
1CEBFF00: 02 58 37 46 4A 34 36 39
1CEBFF00: 03 30 35 38 2A FF FF FF
```

- NN – Sequence Number (01 to FF)
- Data totaling the number of bytes in TC.CM
- FF FF FF – Filler for an 8-byte message

A maximum of 255 messages with 7 bytes each means a total of 255*7 = 1785 bytes maximum for each J1939 transport protocol message.

Decoded value from ASCII:

```
31 58 4B 59 44 50 39 58 37
 46 4A 34 36 39 30 35 38 2A

1  X  K  Y  D  P  9  X  7
 F  J  4  6  9  0  5  8  *

Or 1XKYDP9X7FJ469058
```

(VIN is usually 17 characters, so the * is dropped)

J1939 Request Messages

Many data available from and ECU are by request only. Examples include:

- Engine hours
- VIN
- Component Information

PGN 59904 (0xEA00) is for a Request

- Only 3 bytes long
- Data is the PGN being requested
- Should only be used 2-3 times per second

Example:

```
 CAN ID    CAN DATA
18EA0FF9   EC FE 00
```

- 18 – Priority (6 default)
- EA00 – Request PGN (59904)
- 0F – Destination Address (Retarder)
- F9 – Source Address (249: Off-Board Diagnostic Tool)
- EC FE 00 – PGN 65260: VIN (Reverse byte order)

Note: this is a point-to-point request to the retarder from the service tool.

The response may be BAM or RTS/CTS

J1939 Diagnostic Messages

UNDERSTANDING MESSAGES RELATED TO FAULT CODES

J1939-73 Application Layer - Diagnostics

Defines close to 60 Diagnostic Messages related to troubleshooting and monitoring components on a truck.

Defines lamp status
- Check Engine Lamp
- Malfunction Indicator Lamp MIL

Defines Failure Mode Indicators (FMI)

All trucks use some parts of J1939-73
- Diagnostic Message 1

Many parts of J1939-73 are not used
- Components use UDS or proprietary messaging
- Most concepts are implemented in ECUs in some fashion

Diagnostic Message 1 Example (No Fault Codes)

Broadcast once per second

Diagnostic trouble codes (DTCs) have four fields that use 32-bits:

- Suspect Parameter Number (SPN): 19 bits
- Failure Mode Identifier (FMI): 5 bits
- Occurrence Count (OC): 7 bits
- SPN Conversion Method (CM): 1 bit

PGN for DM1 is 65226 (0xFECA)

- Broadcast message with global destination
- Source Address tell which controller application is broadcasting

Unused bytes should be set to 0xFF

```
18FECA03 03 FF 00 00 00 00 FF FF

18 – Priority (6 default)
FECA – DM1 PGN (65226)
03 – Source Address (Transmission)

03 – Lamp Status (0000 0011)
FF – Lamp Flash Status (1111 1111)
00 00 0 – Suspect Parameter Number
0 – Failure Mode Indicator (FMI)
00 – Conversion and Occurrence Count
```

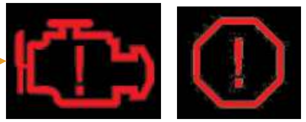
Diagnostic Trouble Code																															
Least Significant Byte of SPN								Second Byte of SPN								3 most significant bits for SPN, 5 bits for FMI								Conversion Method and Occurance Count							
Suspect Parameter Number (19 bits)																			FMI					CM	OC						
8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1

Lamp Status Bytes in DM1

DM1 Byte 1:

- Bits 8-7: Malfunction indicator lamp
- Bits 6-5: Red stop lamp
- Bits 4-3: Amber warning lamp
- Bits 2-1: Protect lamp

Emissions Related



DM1 Byte 2:

- Bits 8-7: Flash malfunction indicator lamp
- Bits 6-5: Flash red stop lamp
- Bits 4-3: Flash amber warning lamp
- Bits 2-1: Flash protect lamp

Lamp status bytes exist only at the beginning of the DM1 message

Multiple DTCs can be concatenated and broadcast

Lamp Status Bits:
00 = Off
01 = On
10 = Error
11 = Not Available (unused)

Flash Status Bits:
00 = Slow Flash (1/sec)
01 = Fast Flash (2/sec)
10 = Reserved
11 = Unavailable (don't flash)

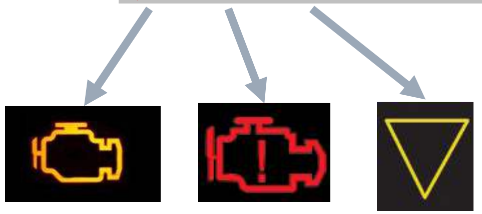
Diagnostic Message 1
Ex: Multiple Fault Codes

TRANSPORT PROTOCOL MESSAGES

```
1CECFF00 20 CA 00 1D FF CA FE 00
1CEBFF00 01 57 FF 9D 00 03 01 FB
1CEBFF00 02 06 0B 32 4A 00 0E 31
 …(182 more bytes in 26 frames)…
1CEBFF00 1D 09 01 84 06 09 01 FF
```

Last Frame

```
57 FF – Lamp Status
(0101 0111 1111 1111)
```



- All 3 lamps are on
- Protect is not used
- No lamps are flashing

J1939 PROTOCOL DATA UNIT

```
PGN: 0x00FECA = 65226 (DM1)
Dest. Address: 0xFF (Global)
Source Address: 0x00 (Engine #1)
```

```
Data: (0x00CA = 202 bytes)
```

```
57 FF 9D 00 03 01 FB 06 0B 32 4A
00 0E 31 … 09 01 84 06 09 01
```

Diagnostic Message 1
Ex: Multiple Fault Codes

`57 FF 9D 00 03 01 FB 06 0B 32 4A 00 0E 31 … 09 01 84 06 09 01`

Use SAE J1939-73 Appendix A for FMIs

DTC 1: `9D 00 03 01`

Diagnostic Trouble Code																															
Least Significant Byte of SPN								Second Byte of SPN								3 most significant bits for SPN, 5 bits for FMI								Conversion Method and Occurrence Count							
9D								00								03								01							
Suspect Parameter Number (19 bits)																			FMI					CM	OC						
8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1
1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1
Reverse Byte order: 0x0009D = 157																			3					0	1						

- SPN = 157 (Engine Fuel 1 Injector Metering Rail 1 Pressure)
- FMI = 3 (Voltage Above Normal, or Shorted to High Source)
- Count = 1

DTC 2: `FB 06 0B 32`

Diagnostic Trouble Code																															
Least Significant Byte of SPN								Second Byte of SPN								3 most significant bits for SPN, 5 bits for FMI								Conversion Method and Occurrence Count							
FB								06								0B								32							
Suspect Parameter Number (19 bits)																			FMI					CM	OC						
8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1
1	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	1	0	0	1	1	0	0	1	0
Reverse Byte order: 0x006FB = 1787																			11					0	50						

- SPN = 1787 (Engine Torque Limit Request - Maximum Continuos)
- FMI = 11 (Root Cause Not Known)
- Count = 50

Most diagnostic service tools interpret these codes.

J1939 Diagnostics Summary

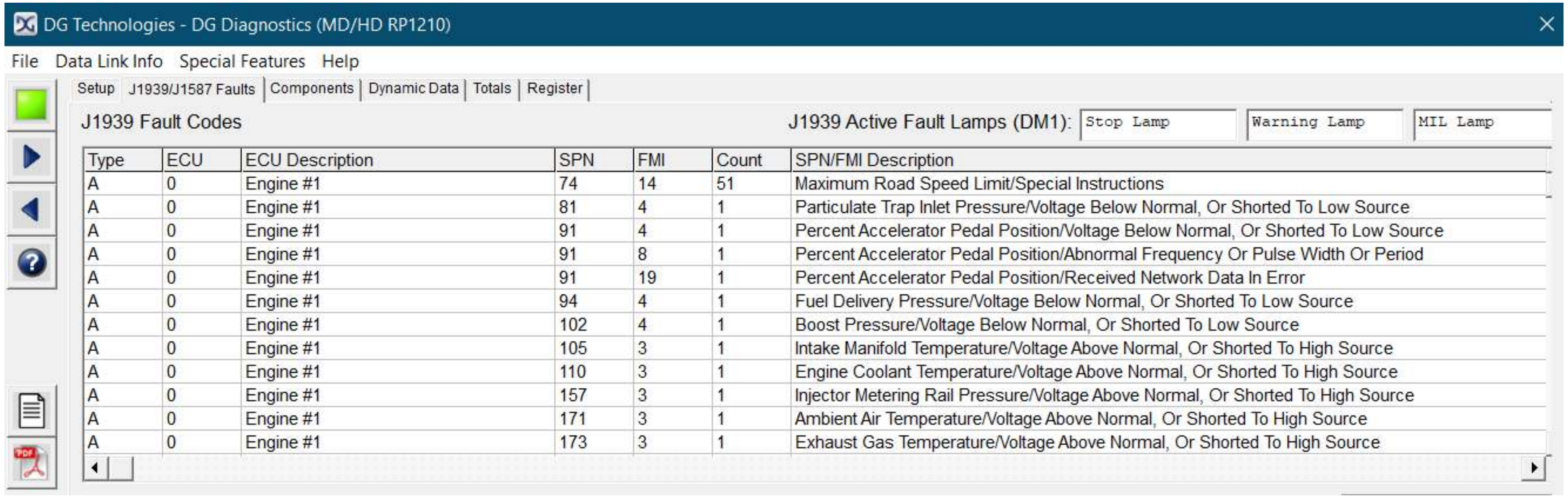
Diagnostic Trouble Codes are define with

- Suspect Parameter Number (i.e. the potential part that may be broken)
- Failure Mode Indicator (i.e. the symptom of the broken part)
- Occurrence Count (how many times the system sees the indication)

J1939-73 also discusses

- Firmware updates
- Memory access
- Emissions Compliance
- Freeze Frame Data
- Data Security

Many vehicles implement only a small portion of J1939-73



Type	ECU	ECU Description	SPN	FMI	Count	SPN/FMI Description
A	0	Engine #1	74	14	51	Maximum Road Speed Limit/Special Instructions
A	0	Engine #1	81	4	1	Particulate Trap Inlet Pressure/Voltage Below Normal, Or Shorted To Low Source
A	0	Engine #1	91	4	1	Percent Accelerator Pedal Position/Voltage Below Normal, Or Shorted To Low Source
A	0	Engine #1	91	8	1	Percent Accelerator Pedal Position/Abnormal Frequency Or Pulse Width Or Period
A	0	Engine #1	91	19	1	Percent Accelerator Pedal Position/Received Network Data In Error
A	0	Engine #1	94	4	1	Fuel Delivery Pressure/Voltage Below Normal, Or Shorted To Low Source
A	0	Engine #1	102	4	1	Boost Pressure/Voltage Below Normal, Or Shorted To Low Source
A	0	Engine #1	105	3	1	Intake Manifold Temperature/Voltage Above Normal, Or Shorted To High Source
A	0	Engine #1	110	3	1	Engine Coolant Temperature/Voltage Above Normal, Or Shorted To High Source
A	0	Engine #1	157	3	1	Injector Metering Rail Pressure/Voltage Above Normal, Or Shorted To High Source
A	0	Engine #1	171	3	1	Ambient Air Temperature/Voltage Above Normal, Or Shorted To High Source
A	0	Engine #1	173	3	1	Exhaust Gas Temperature/Voltage Above Normal, Or Shorted To High Source

J1939 Address Claim

HOW DOES A NETWORK KEEP TRACK OF THE SOURCE AND DESTINATION ADDRESSES IF IT CHANGES?

J1939 Address Claim

Each controller application (node) on the network should have its own source address.

Some ECUs have multiple controller applications.

- SA 0x00: Engine #1
- SA 0x0F: Engine Retarder

Address Claims happen

- On Boot
- When requested
- In response to other claims for the same address

Address Claim Parameter Group Number

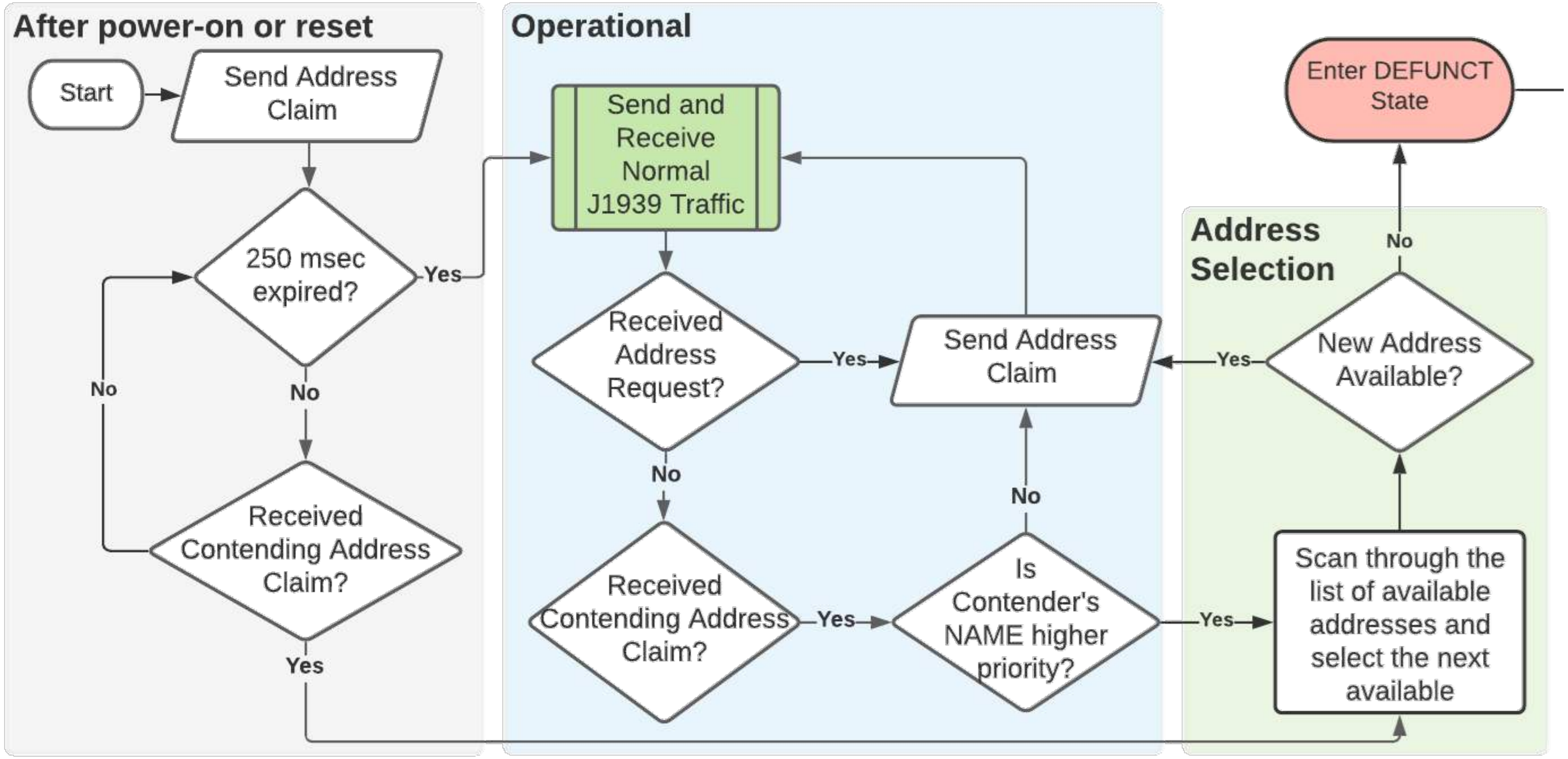
- 60928 (0xEE00)
- Mostly uses the Global destination address (0xFF)
- Source address is the address being claimed

Transmission Address Claim example:

`18EEFF03: 64 00 40 00 00 03 03 10`

- `18 – Priority 6 (default)`
- `EE – PGN 60928 = Address Claimed`
- `FF – Global Destination Address`
- `03 – Source address for Transmission #1`
- `64 00 40 00 00 03 03 10 - NAME Field`

How Address Claiming Works



See SAE J1939-81 Network Management

Address NAME Field

Arbitrary Address Capable	Industry Group	Vehicle System Instance	Vehicle System	Reserved	Function	Function Instance	ECU Instance	Manufacturer Code	Identity Number
	SAE		SAE	SAE	SAE			SAE	
1 bit	3 bits	4 bits	7 bits	1 bit	8 bits	5 bits	3 bits	11 bits	21 bits

- From SAE J1939-81, the following NAME field is 64 Bits (8 bytes) long.
- Value is translated with little endian format (Intel), so the least significant byte is first.
- Example 1: Caterpillar C15 with ADEM4 ECU

```
can1  18EEFF00   [8]  D0 6B 01 01 00 00 00 80
```

- Example 2: Detroit Diesel CPC3Evo

```
can1  18EEFF00   [8]  00 00 C0 01 00 00 00 00
```

- Example 3: Allison Transmission

```
can1  18EEFF03   [8]  64 00 40 00 00 03 03 10
```

CAN ID has:

- Priority = 6,
- Parameter Group Number = 0xEE00,
- Destination Address = 0xFF (Global),
- Claimed Source Address = 0x00 (Engine #1)

Example 1: Caterpillar

National Motor Freight Traffic Association, Inc.

```
can1  18EEFF00   [8]  D0 6B 01 01 00 00 00 80
```

Byte 8 (0x80) = 0b1000 0000, which means:

- it is arbitrary address capable,
- the industry group is 0 (global), and
- the vehicle system instance is zero.

Byte 5 -7 (00 00 00), which means:

- the vehicle system, function, and function instance are all zero, which is consistent with an engine controller

Byte 4 (0x01), Bits 1-8 = MSB of Mfg Code
Byte 3 (0x01), Bits 8-6 = LSB of Mfg Code

- 0b0000 0001 000~~0 0001~~ = 0b1000 = 8 (dec)

Byte 3 (0x01), bits 1-5 = MSB of Identity Field
Byte 2 (0x6B) = 2nd byte of identity field
Byte 1 (0xD0) = LSB of identity field

- 0b0 0001 0110 1011 1101 0000 = 93,136 (dec)

Manufacturer ID Codes (Table B10)

The list of all Manufacturer Identifier code assignments.

Return To Documentation Tab

R	Mfr ID	Manufacturer
	0	Reserved
	1	Bendix Commercial Vehicle Systems LLC (formerly Allied Signal Inc.)
	2	Allison Transmission, Inc.
	3	Ametek, US Gauge Division
	4	Ametek-Dixson
	5	AMP Inc.
	6	Berifors Electronics AB
	7	Case Corp.
	8	Caterpillar Inc.
	9	Chrysler Corp.
	10	Cummins Inc (formerly Cummins Engine Co)
	11	Dearborn Group Inc.
	12	Deere & Company, Precision Farming
	13	Delco Electronics
	14	Detroit Diesel Corporation
	15	DICKEY-john Corporation
	16	Eaton Corp

Example 2: Detroit Diesel

```
can1  18EEFF00   [8] 00 00 C0 01 00 00 00 00
```

Byte 8 (0x00) = 0b0000 0000, which means:

- it is NOT arbitrary address capable,
- the industry group is 0 (global), and
- the vehicle system instance is zero.

Byte 5 -7 (00 00 00), which means:

- the vehicle system, function, and function instance are all zero, which is consistent with an engine controller

Byte 4 (0x01), Bits 1-8 = MSB of Mfg Code
Byte 3 (0xC0), Bits 8-6 = LSB of Mfg Code

- 0b0000 0001 110~~0 0000~~ = 0b1110 = 14 (dec)

Byte 3 (0x01), bits 1-5 = MSB of Identity Field
Byte 2 (0x00) = 2nd byte of identity field
Byte 1 (0x00) = LSB of identity field

- 0b0 0000 0000 0000 0000 0000 (likely not used)

Manufacturer ID Codes (Table B10)

The list of all Manufacturer Identifier code assignments.

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R	Mfr ID	Manufacturer
	0	Reserved
	1	Bendix Commercial Vehicle Systems LLC (formerly Allied Signal Inc.)
	2	Allison Transmission, Inc.
	3	Ametek, US Gauge Division
	4	Ametek-Dixson
	5	AMP Inc.
	6	Berifors Electronics AB
	7	Case Corp.
	8	Caterpillar Inc.
	9	Chrysler Corp.
	10	Cummins Inc (formerly Cummins Engine Co)
	11	Dearborn Group Inc.
	12	Deere & Company, Precision Farming
	13	Delco Electronics
	14	Detroit Diesel Corporation
	15	DICKEY-john Corporation
	16	Eaton Corp

Example 3: Allison Transmission

```
can1  18EEFF03 [8] 64 00 40 00 00 03 03 10
```

Byte 8 (0x10) = 0b0001 0000, which means:

- it is NOT arbitrary address capable,
- the industry group is 1 (on-highway), and
- the vehicle system instance is zero.

Byte 7 (0x03), the vehicle system is the transmission

Byte 6 (0x03), function is the transmission

Byte 5 (0x00), the function and ECU instance is zero, which means it's the first instance.

Byte 4 (0x00), Bits 1-8 = MSB of Mfg Code
Byte 3 (0x40), Bits 8-6 = LSB of Mfg Code

- 0b0000 0000 010~~0 0000~~ = 0b0010 = 2 (dec)

Bytes 3-1 (0x00064) comprise the identity field

All Industry Groups Inclusive NAME Functions (Table B11)

The NAME Functions assigned to the lower 128 Function values. These lower 128 NAME Function values are independent of the Vehicle System or Industry Group, which means they can be used all eight Industry Groups. These should not be confused with the upper 128 NAME Functions of Industry Group 0 which is an Industry Group itself but applicable to all industries. The NAME fields are described in SAE J1939-81.

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Revised	Function ID	Function Description	Notes
	0	Engine	While the function identifies what is typically the mechanical power source of the machine, the reference tends to be to the management system that controls the torque vs speed vs command (typically throttle) of said power source.
	1	Auxiliary Power Unit (APU)	Power source for operating systems without the use of the prime 'drive' engine.
	2	Electric Propulsion Control	Control system which operates the drive mechanism when it is electrically powered, such as battery-motor, or engine-generator-motor hybrids
	3	Transmission	A mechanical system for alter the speed vs torque output of the engine to a level usable by another system on the machine. Although again the network reference is actually to the system which controls the operation of said

Manufacturer ID Codes (Table B10)

The list of all Manufacturer Identifier code assignments.

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R	Mfr ID	Manufacturer
	0	Reserved
	1	Bendix Commercial Vehicle Systems LLC (formerly Allied Signal Inc.)
	2	Allison Transmission, Inc.
	3	Ametek, US Gauge Division
	4	Ametek-Dixson

RP1210 Programming

USING DIAGNOSTIC SERVICE TOOLS TO CONNECT TO THE NETWORK

RP1210 Vehicle Diagnostics Adapters

Truck owners want only one hardware device to work with all their ECUs and diagnostics software

American Trucking Association (ATA) and their Technology Maintenance Council (TMC) published Recommended Practice (RP) number 1210 to define a Windows API for vehicle diagnostic adapters (VDAs)

J1939

Nexiq USB Link 2

DG DPA 5 Pro

Noregon DLA +

USB
Bluetooth
Wifi

Service Computer

Function Prototypes

Function Name	Description
RP1210_ClientConnect (…)	Load the routines for a particular protocol on the correct channel
RP1210_SendCommand(…)	Send command to change the behavior or property of the VDA
RP1210_SendMessage (…)	Send a message through the VDA to the vehicle network
RP1210_ReadMessage (…)	Read a message from the vehicle network
RP1210_ClientDisconnect (…)	Disconnect the client and close the driver

The message structure depends on the type of client

- J1939
- CAN
- J1708

RP1210 Log files are helpful to understand diagnostic communication.

https://www.atabusinesssolutions.com/Shopping/Product/viewproduct/2675472/TMC%20Individual%20RPs

RP1210 Log File Example
DG Technologies DPA5

```
FT:0011,AT:0030  XX,CC,00,02,001,J1939:Baud=Auto,0,0,0
Exe Name: C:\PROGRAM FILES (X86)\CUMMINS\POWERSPEC5\POWERSPEC.EXE :Thu Jan 13 13:05:10 2022
FT:0000,AT:0000  02,SC,00,17,45,35,30,30,30,30,30,00,00,00,00,00,00,00,00,00,00,00
FT:0000,AT:0000  02,SC,00,1,18,00
FT:0001,AT:0001  02,SC,00,7,4,0d,00,ef,00,ff,00,fa
FT:0000,AT:0000  02,SC,00,1,18,01
FT:0252,AT:0252  02,SC,00,10,19,fa,d6,eb,56,01,00,81,00,00,00
FT:0000,AT:0000  02,SM,00,15,0,0,00,ef,00,06,fa,00,81,02,01,01,ff,01,ff,00,00,
FT:0265,AT:0013  02,RM,19,4104,1,00,01,9b,da,00,ef,00,00,00,fa,81,01,02,00,01,70,01,05,30,
FT:0000,AT:0000  02,SM,00,15,0,0,00,ef,00,06,fa,00,81,00,03,00,00,01,01,00,00,
FT:0027,AT:0027  02,RM,23,4104,1,00,01,9b,f3,00,ef,00,00,00,fa,81,00,03,01,01,01,02,01,00,7f,04,28,31,
```

CC – Client Connect
SC – Send Command

SM - Send Message
RM – Read Message

RP1210 Client Connect

FT:0011,AT:0030 XX,CC,00,02,001,J1939:Baud=Auto,0,0,0

Exe Name: C:\PROGRAM FILES (X86)\CUMMINS\POWERSPEC5\POWERSPEC.EXE :Thu Jan 13 13:05:10 2022

CC – Client Connect

00 – Legacy Window Handle (always 0x00)

02 – Returned Client ID (Used by all the other commands)

001 – Device ID (Selected from the RP1210 INI files for the device connected)

J1939:Baud=Auto – Protocol String

0 – TX Buffer Size (Set to zero to accept default of 8k)

0 – RX Buffer Size (Set to zero to accept default of 8k)

0 – IsAppPacketizingIncomingMsg (set to zero to have the VDA do J1939 transport protocol)

RP1210 Send Command

FT:0001,AT:0001 02,SC,00,7,4,0d,00,ef,00,ff,00,fa

02 – Connected Client (Result from Client Connect)
SC – Send Command
00 – Return value from Command (00 = Success for Command 4)
4 – Command Number (4 = Set Message Filtering for J1939)
7 – Message Size for Command
0d,00,ef,00,ff,00,fa – Command message for setting J1939 Filter

Filter Flag

PGN to Filter

Priority

Source Address

Destination Address

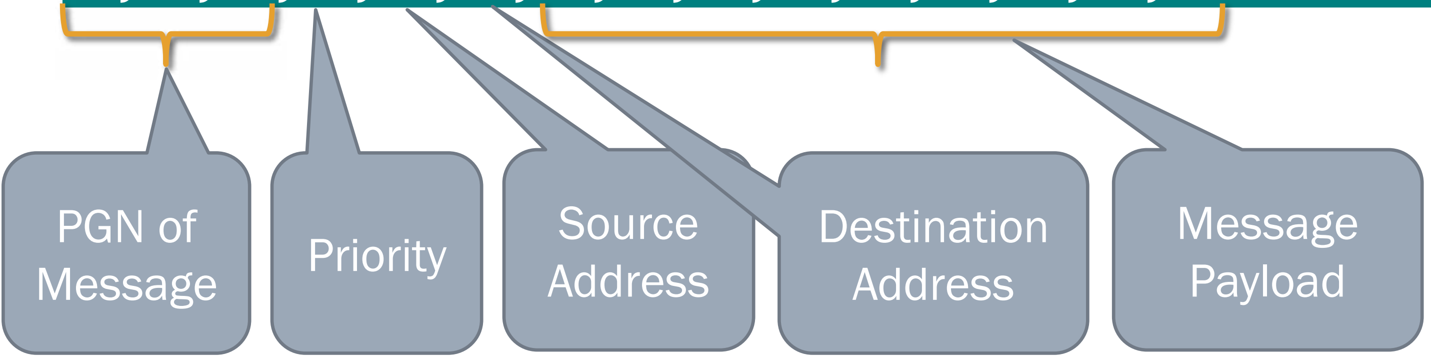
Each command has different meanings for the parameters.

See the RP1210 Document for details.

RP1210 Send Message

FT:0000,AT:0000 02,SM,00,15,0,0,00,ef,00,06,fa,00,81,02,01,01,ff,01,ff,00,00,

02 – Connected Client (Result from Client Connect)
SM - Send Message
00 – Return value (00 = Successfully sent message)
15 – Message Size including identifiers and messages
0 – Legacy Notify Status on Transmit (always set to zero)
0 – Legacy Block on Send (Flag ignored and aways set to zero)
00,ef,00,06,fa,00,81,02,01,01,ff,01,ff,00,00 – Message to be sent (in hex)



Note: In this case, the message is 9 bytes, so the VDA will encapsulate the message in the J1939 Transport Protocol.

RP1210 Read Message

National Motor Freight Traffic Association, Inc.

```
FT:0265,AT:0013   02,RM,19,4104,1,00,01,9b,da,00,ef,00,00,00,fa,81,01,02,00,01,70,01,05,30,
```

```
02 – Connected Client (Result from Client Connect)
RM – Read Message
19 – Message size in bytes
4104 – Buffer Size
1 – Block on Read (1 – BLOCKING IO)
00,01,9b,da,00,ef,00,00,00,fa,81,01,02,00,01,70,01,05,30 - Received Message
```

- 00,01,9b,da – Timestamp from VDA
- 00,ef,00 – PGN of Message
- 00 – How/ Priority (RTS/CTS)
- 00 – Source Address
- fa – Destination Address
- 81,01,02,00,01,70,01,05,30 – Message Payload

Note: In this case, the message is 9 bytes, so the CAN traffic will show the message in the J1939 Transport Protocol. The VDA provides the result.

RP1210 Summary

The RP1210 system has been around since the 1990s

Vendors provide their details using the INI files; Applications parse the INI files

Technicians select their drivers based on the parsed INI files

Multiple drivers and VDAs can co-exist on computers

Function prototypes are common across all VDAs; Logging capabilities are different

RP1210 makes J1939 transport protocols transparent; CAN logs may look different

There are many more details in the actual RP1210 document

Unified Diagnostic Services over J1939

UDS COMMUNICATIONS AS DEFINED IN ISO 15765

Unified Diagnostic Services (UDS) over CAN

UDS is used by many truck component makers for diagnostics and maintenance actions

- Bendix Brake Controllers
- Detroit Diesel Electronic Controllers
- Mack and Volvo Diagnostics
- Many others

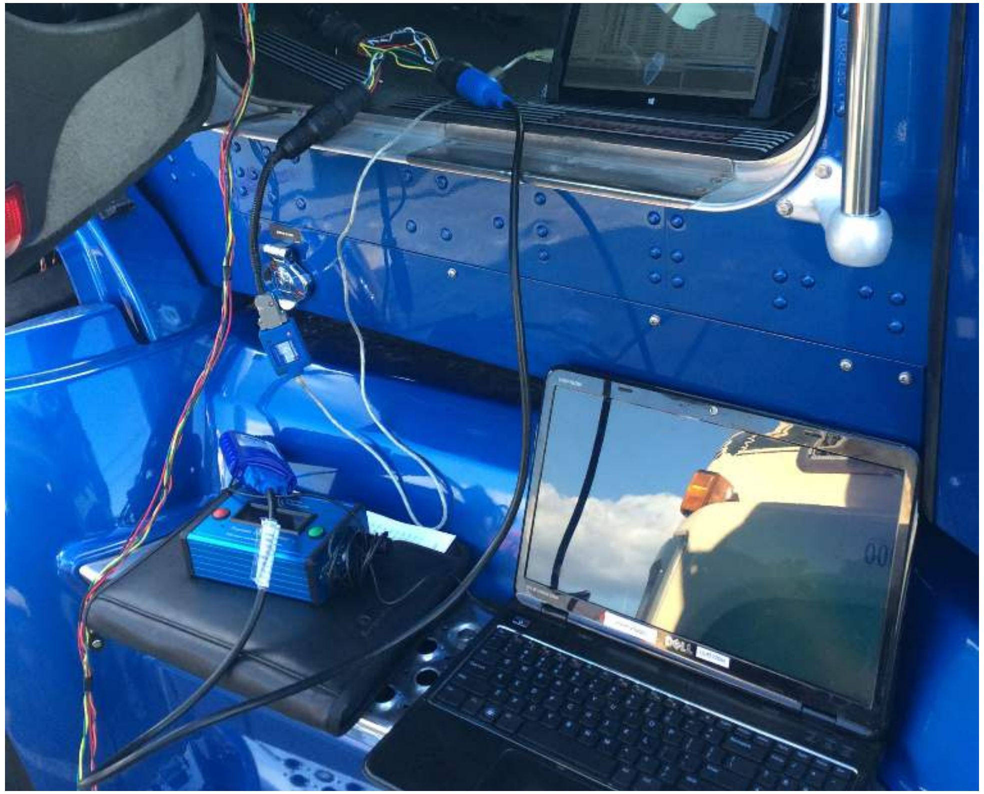
Message meaning is defined in ISO 14229

J1939 uses PGN 55808 (0xDA00) for UDS

- PDU1 format (Point-to-point) uses Destination Address

UDS has its own transport protocol (ISO-TP)

- 4096 bytes maximum per message.



UDS Example: Establish UDS Session

National Motor Freight Traffic Association, Inc.

MESSAGE FROM OFF-BOARD TOOL (SA: F1)

CAN ID → 18DA00F1 02 10 03 00 00 00 00 00

18 – Priority 6
DA – PF for ISO 15765 (PGN = 0xDA00)
00 – Dest. Address (0x00 = Engine #1)
F1 – Source Address (0xF1 = Service Tool)

0 – Single Frame Message
2 – Message Size (2 bytes)
10 – Service ID (0x10 Establish Session)
03 – Session Type (0x03 = Extended)

MESSAGE FROM ENGINE #1 (SA: 00)

18DAF100 06 50 03 00 14 00 C8 01 ← Unused

0 – Single Frame Message
6 – Message Size (6 bytes)
50 – Service ID Response for Session
03 – Session Type (0x03 = Extended)
00 14 00 C8 – Session Timing Parameters

Service Identifier (SID) Responses always add 0x40 to the Request SID.
Example: 0x10 - Request
0x50 - Response

UDS Example: Seed-Key Exchange

MESSAGE FROM OFF-BOARD TOOL (SA: F1)

```
18DA00F1 02 27 09 00 00 00 00 00

18DA00F1 04 27 0A B1 27 00 00 00
```

0 – Single Frame Message
2 – Message size (2 bytes)
27 – SID for Security Exchange
09 – Request Seed

0 – Single Frame Message
4 – Message size (4 bytes)
27 – SID for Security Exchange
0A – Parameter for Key
B1 27 – Value of Key

MESSAGE FROM ENGINE #1 (SA: 00)

```
18DAF100 04 67 09 EC 65 21 05 03

18DAF100 02 67 0A EC 65 21 05 03
```

Repeated Buffer Contents Not Used

0 – Single Frame Message
4 – Message size (4 bytes)
67 – SID for Security Exchange Response
09 – Parameter for Seed
EC 65 – Value of Seed

0 – Single Frame Message
2 – Message size (2 bytes)
67 – SID for Security Exchange Response
0A – Key Acknowledge (Accepted)

UDS Example: Read Data By Identifier

National Motor Freight Traffic Association, Inc.

MESSAGE FROM OFF-BOARD TOOL (SA: F1)

18DA00F1 03 22 F1 51 00 00 00 00

18DA00F1 30 08 00 00 00 00 00 00

0 – Single Frame Message
3 – Message size (3 bytes)
22 – SID (0x22 = Read Data By Identifier)
F1 51 – Data Identifier (Proprietary)

30 – Flow Control Frame
08 – Send up to 8 more frames

MESSAGE FROM ENGINE #1 (SA: 00)

18DAF100 10 09 62 F1 51 11 29 00

18DAF100 21 11 2A 00 51 11 29 00

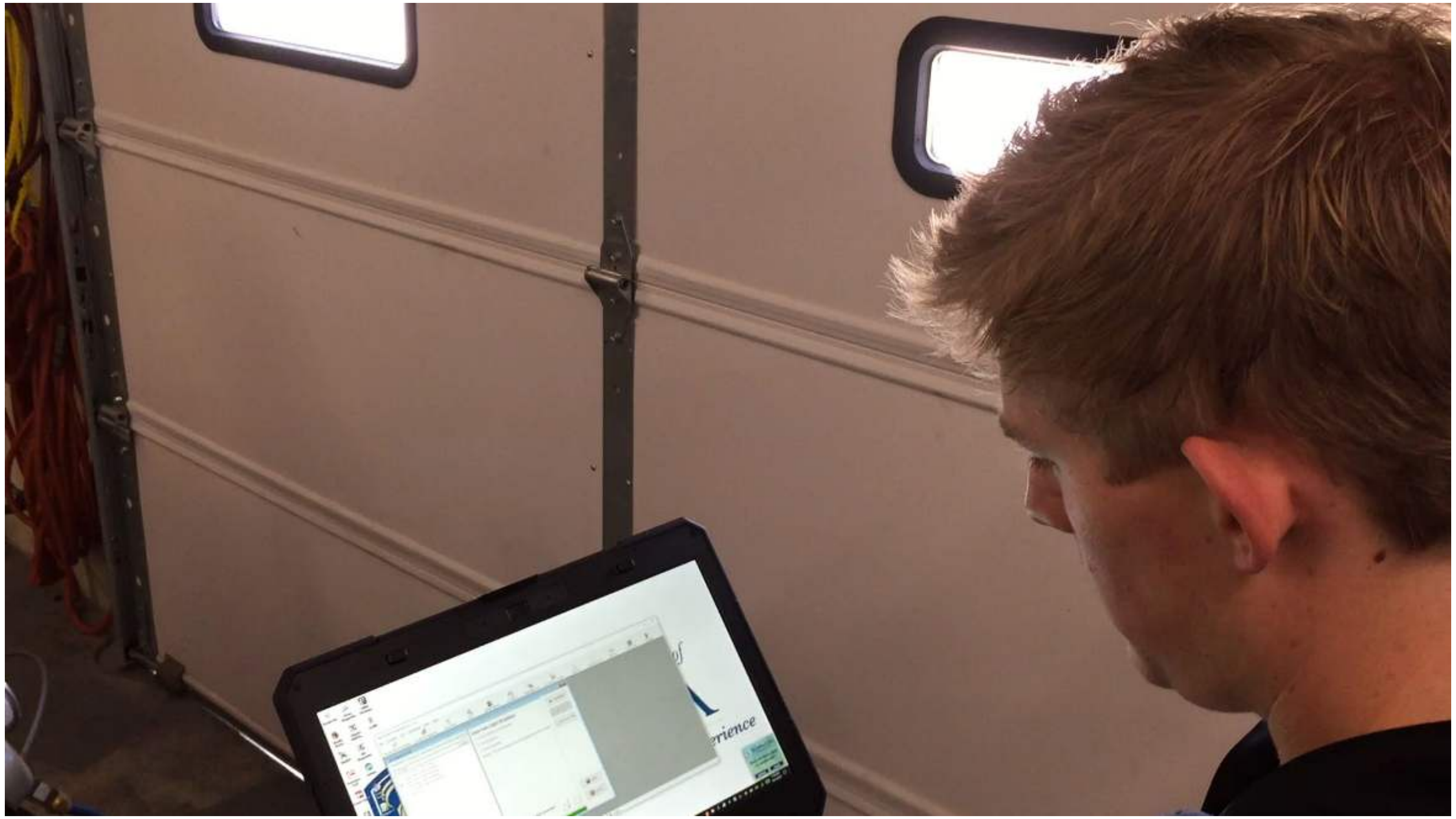
Same memory

1 – First Frame of Message
0 09 – Message Size (up to 4096)
62 – SID Response (0x22 + 0x40)
F1 51 – Data Identifier of Response
11 29 00 – First 3 bytes of data

2 – Consecutive Frame
1 – Frame Sequence Number
11 2A 00 – Last 3 Bytes of Data

Example UDS Session for Brake Controls

- A session is established for brake controller diagnostics
- Students commanded a brake chuff test
- All communications went over UDS
- The brake controller trusts the UDS commands



Resources for Unified Diagnostic Services

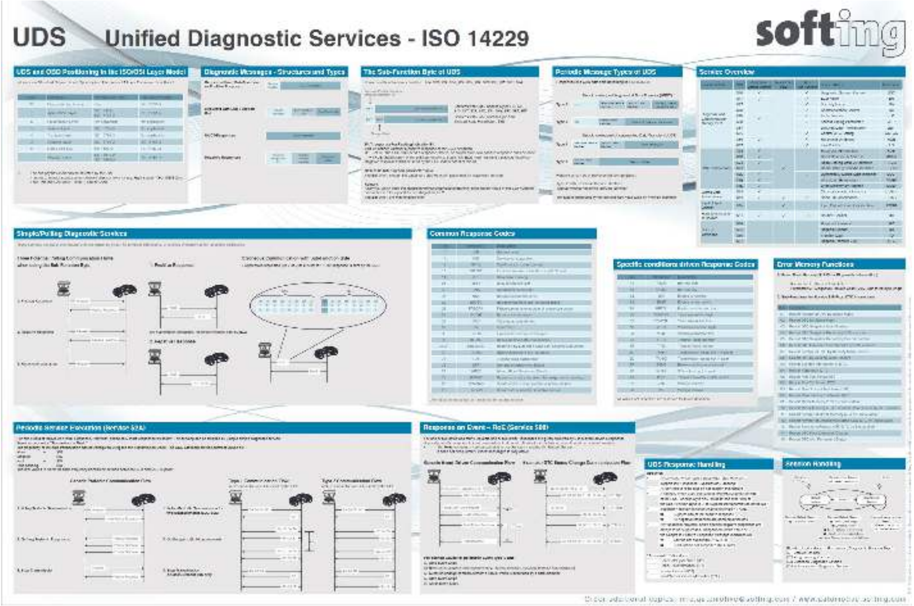
UDS, like J1939, is extensive and has many reference documents

Most UDS communications have proprietary meaning

UDS is also used in passenger cars (with different CAN IDs)

UDS uses a server and client model

- Server: on-board ECU
- Client: off-board diagnostic tool



Links for additional information:

- https://en.wikipedia.org/wiki/ISO_15765-2
- https://www.sae.org/publications/books/content/r-474/
- https://automotive.softing.com/fileadmin/sof-files/pdf/de/ae/poster/UDS_Faltposter_softing2016.pdf

Proprietary Diagnostic Protocols

Network traffic from Cummins Insite shows diagnostics over Proprietary A messages: PGN 61184 (0xEF00)

Some J1939 fields are duplicated in proprietary protocols

Data may be richer compared to J1939
- Commands for service routines
- Calibration modifications

Navistar protocols extensively use Proprietary B messages (PGN =0xFFXX)

Cybersecurity Considerations for J1939

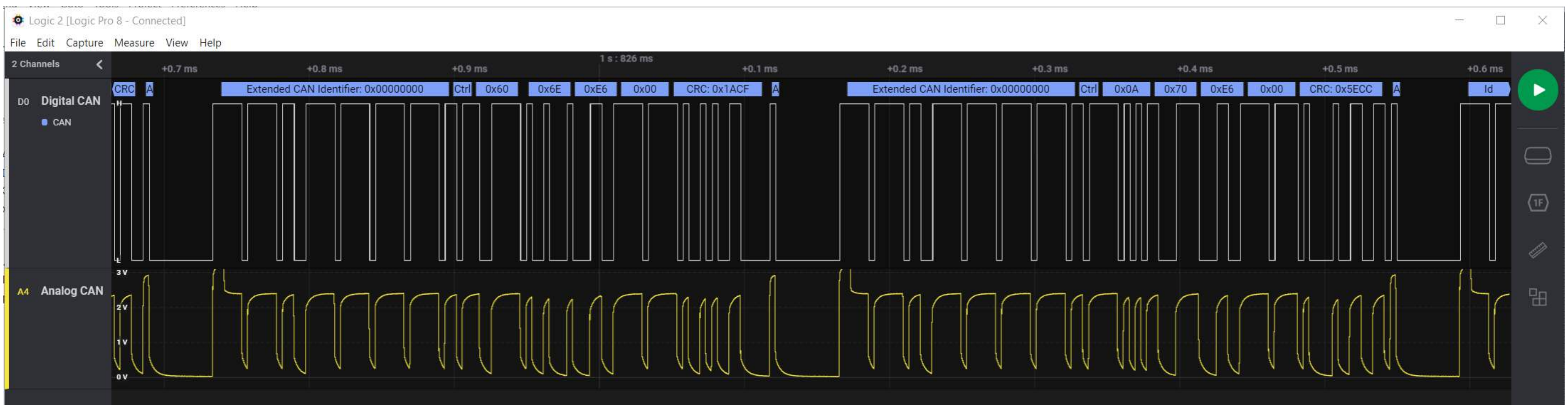
WHAT CAN DO WRONG IF A HACKER GETS ACCESS TO THE NETWORK?

Denial Of Service

Normal J1939

Flooded J1939

Denial of Service



By repeating high priority messages (ID = 0), no other legitimate message can get access to the network.

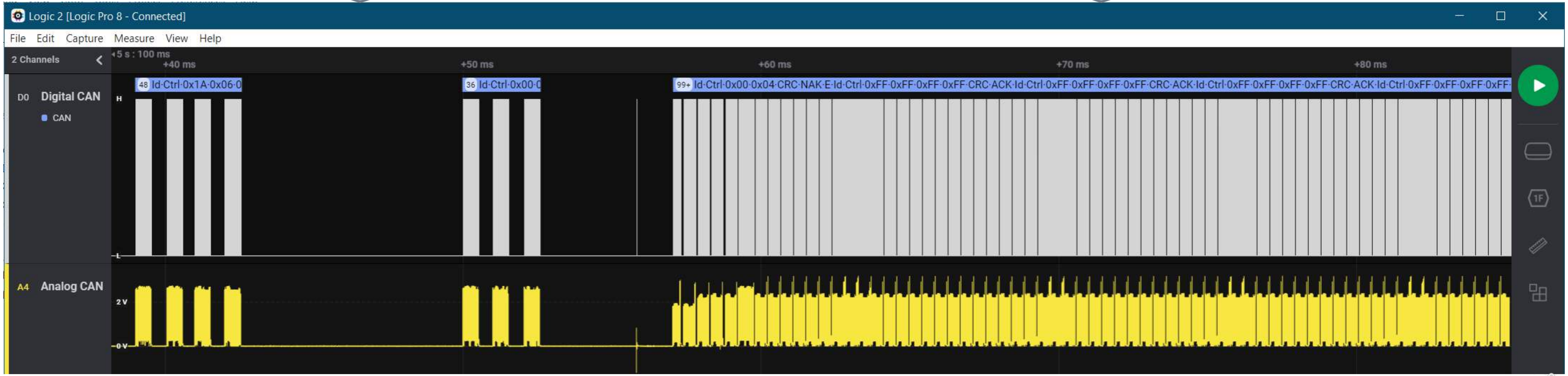
This will shut down communications and potentially stall a truck.

There are no native protections against this in J1939; avoid connecting unknown new devices to J1939.

Spoofing Messages and Commands

Normal J1939

Spoofed J1939

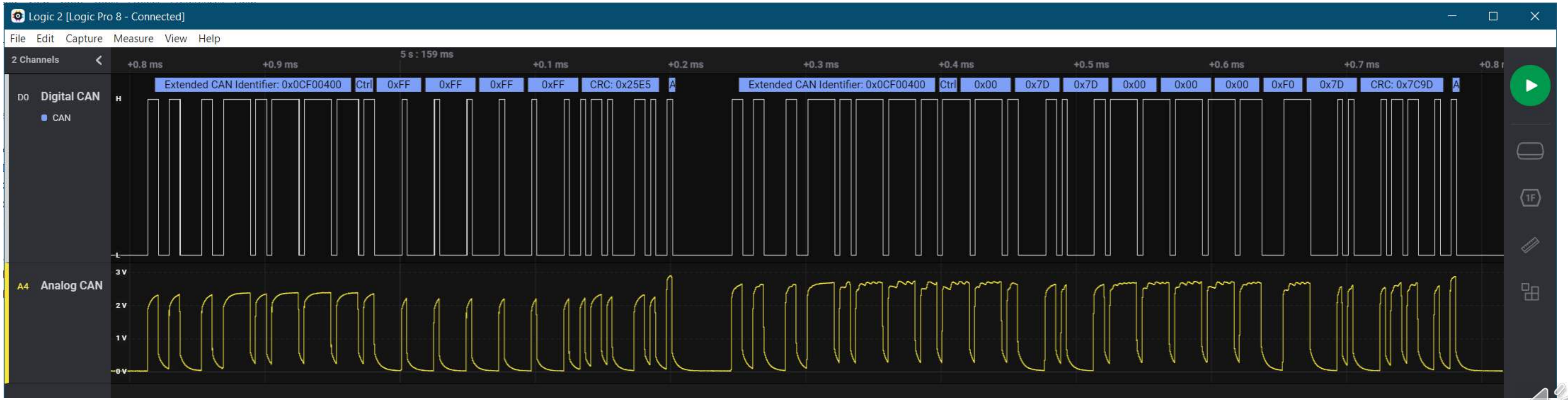


Spoofing Messages and Commands

Two messages with the same IDs will be interpreted the same way

- One message is legitimate (right)
- The other is spoofed (left)

The network doesn't know which message is legitimate



The operator reported that the vehicle suddenly stopped working when they were sitting in traffic. There was no sign of overheating or mechanical failure

Summary

The need for in-vehicle communication using CAN and SAE J1939

Connecting to J1939 Networks

Classify the different types of communication over J1939

Interpret J1939 network traffic using the SAE Standard

Recognize SAE J1939 Transport Protocols for larger messages

Understand J1939 Diagnostic Messages

Introduction to J1939 Address Claiming

Demonstration of RP1210 functionality for diagnostics

Showed examples of Unified Diagnostic Services (UDS) over J1939

Realize J1939 is inherently an open (and potentially insecure) read-write bus