
TECHNICIAN
TRAINING
BY DORMAN PRODUCTS
DORMAN
Training Seminar Series
Presents
HD Vehicle Multiplexing
Part 1

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DORMAN
Aftermarket Innovators

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Your Instructor For This Class

Sulev "Swede" Oun

- **Owner, O&K Truck and Auto Repairs Ltd.**
- **ATTP Master Instructor, New York State**
- **Author, "Medium/Heavy Duty Truck Electricity and Electronics"**
- **Training provider for various Associations, industry and various NY State agencies**
- **Developed trainings that range from four hours to multiple days, specializing in brakes, electrical, regulations and many other subjects relating to our industry.**
- **Member of various organizations such as SAE, CVSA, TANY**

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What will be covered

- **Introduction to "Multiplexing"**
- **Controller Basics (PCM, ECM)**
- **Controller Area Networking (CAN)**

I will utilize J1939. Part 2 will continue also utilizing J1587/J1708.
Many systems share information on both J1587/J1708 and J1939.

Part 1 is the beginning of another journey.
Part 2 will continue the journey.

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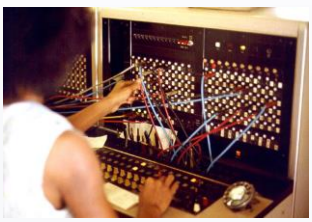
Multiplexing (*From Wikipedia, the free encyclopedia)*

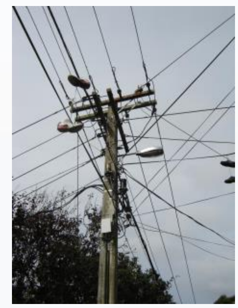
"In telecommunications and computer networks, multiplexing (also known as muxing) is a process where multiple analog message signals or digital data streams are combined into one signal over a shared medium. The aim is to share expansive resource.

For example, in telecommunications, several phone calls maybe transferred using one wire. It originated in telegraphy and is now widely applied in communications."



We are going to build off this concept.

We've come a long way in such a short time.



Heavy Duty Truck Multiplexing (Networking)

In a typical truck, there's a lot of signals and data trying to "talk" at the same time and a lot of controllers trying to "listen".

Just like human conversations. You might be talking, and I might not care about what you are saying (going in one ear and out the other). However, another person talking might have a subject that I might care about and I will definitely "tune them in and ignore you". Unfortunately, I might be stuck listening to all the conversation regardless. This is where "selective hearing" comes in.

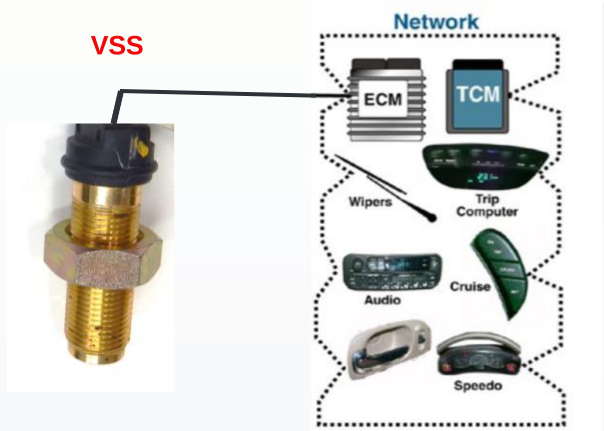
Let's substitute us to the controllers (computers) utilized in trucks.

Overview

Today's trucks have numerous electronic control units (ECU's) to control various subsystems such as the:

- Engine
- Transmission
- Brakes
- Lights
- Infotainment
- Instrument cluster etc.

These controllers are networked together to share information.



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Why Multiplexing?

In the day when life was simple trucks were also simple.
Most functions were directly managed by the driver using mechanical, hydraulic, pneumatic and of course electrical signals.
Example: The accelerator pedal connected to the engine control unit by a "Mechanical Linkage". Really? Yes, the good old days.
Electrical functions were typically hard wired to switches on the dash through relays to actuators.
Just like cars, trucks throughout the years became more complex, requiring more "miles" of wire to enable the electrical and mechanical systems to manage the vehicle.
This ultimately required the use of "Data Bus Communication".

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Benefits (dependent on how you look at it)

- Reduced wiring
- In many cases replacing relays and circuit breakers with electronic devices (see previous lunch and learn on lighting devices).
- Electronic devices (controllers) communicate over the vehicles Data buses.
- Monitoring inputs (sensors and switches).
- Supplying power to outputs.

Simplified: A multiplexed system continuously monitors inputs and sends messages over a shared-wire data bus to control outputs.

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- "Data Bus Communication" makes use of "Multiplexing" since the first use of "Electronic Control Module" (ECM) introduced on trucks in the 1980's.
- The first use of multiplexing were a simple module to module systems that didn't require an understanding of these systems to diagnose issues.
- Typical system might be an engine manufacturer allowing a chassis module to communicate with the fuel injection control module.
- Today's technicians must access the trucks data bus connecting several various modules (controllers) to read, diagnose and repair any issues.
- Simply put: The multiplexed system can interpret "different messages" transmitted on the same wire.
  - Messages traveling along the "data bus".
  - The data bus handles multiple messages at the same time.

Example: Electronically controlled transmission connected to the engine to control engine speed and torque output during shifting.

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Let's not put the cart before the horse!

Computer System Basics

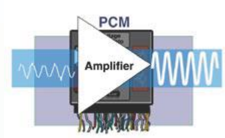
- **After all, it's the controllers (computers/nodes) that must talk with each other.**
- **What is a computer?**
  - **It's an electronic switch (controller).**
  - **It processes information very fast.**
  - **It contains Instructions.**
  - **Most computers can process millions of instructions every minute.**
  - **The speed of processing information makes the computer ideal for controlling a vehicles operation.**
- **The basic function of a vehicle's computer is to:**
  - **Receive data.**
  - **Process the data and/or store data.**
  - **Output signals.**

"Keep it Simple"

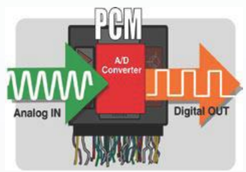
Computer Controlling a Basic System

- **Sensor sends a value to the computer/controller (INPUT).**
- **The input value is used by the computer to determine the condition of the monitored system.**
- **The input value is compared to a preprogrammed value in the computers memory and decides on an action to take.**
- **The decision is converted into an "Output" signal to control an output device "OR" reports information to a diagnostic system or something as simple as a warning light or dashboard gauge.**

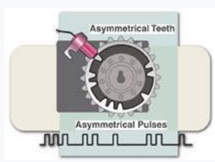
Computer Signals



Analog Sensors



A/D Converters



Digital Signal Generators

Real world application controlling a fuel injection system (No fuel-No start) utilizing a typical "Common Rail Fuel Injection" system.

- **This fuel injection system utilizes a crankshaft driven fuel pump to provide pressurized fuel to a rail. Distribution lines transmit fuel from the rail to individual injectors serving each cylinder.**
  - **The ECM turns on fuel flow from each nozzle as part of the injection process.**

NOTE: The pressure in the rail is very high supplying fuel to all cylinders that varies with operating conditions and the pump providing this high-pressure fuel is not electronically controlled.

- **However:**
  - **The ECM does monitor data from the rail pressure sensor to determine when rail pressure drops below or above a target value.**
  - **If pressure exceeds the limit, the ECM adjusts a metering valve to increase the flow of fuel from the rail into a drain line until the pressure data indicates rail pressure has fallen into an acceptable measurable range.**
  - **If pressure in the rail is too low, the ECM adjusts the metering valve to allow less fuel to flow from the rail into the drain (return) line.**

- This described a closed loop system because the ECM (controller) adjusted the controlled device (meter valve) based on the input (sensor..) that's monitoring the effect of the adjustment.

Stop! With this basic information, would you be able start a diagnostic process for a no start or rough running issue. What data would you monitor on a scan tool?

Note: Other examples are ABS and fuel/emissions control using O2 sensors.
How about Exhaust Gas Recirculation (EGR) systems and aftertreatment systems.

Data Received (Inputs)(Information)

Two types of data received are:

- Digital signals that vary between one of two states, either on or off (0 or a 1).

Note: Computers perform their operation on digital data.

- Analog signals vary within an acceptable range. Usually a voltage level between 0 and 5 volts.

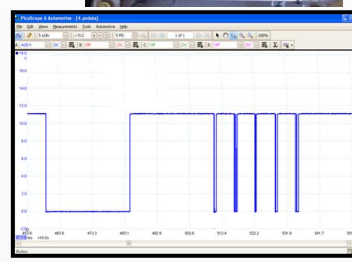
Using a temperature sensor as an example:

- 5-volt signal would indicate highest temperature.
- 0-volt would indicate lowest expected temperature.
- Each voltage level in between would correspond to a different temperature.

Do we have enough information up to this point to figure out any Issues?

How Computers "Think"

Computers speak in 1s & 0s. I don’t know that language and neither do you! If we want to talk directly to one computer or listen in on conversations between several interconnected computers in the same vehicle, we need an interpreter to convert all those 1s & 0s into words and messages we can understand.



To give you a visual idea of what the computer speak looks like, we have to the right a screen shot of a PICO labscope waveform capture.

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How Computers "Think"

The Scan Tool as Interpreter

Our dialog with the vehicle computer begins when we use the scan tool to enter a request for data. We may ask for information about fault codes, or about the current state of engine sensors. The computer responds to our request and sends back a string of coded voltage pulses representing data. The scan tool converts data from the vehicle computer into words and measurements and displays them on the scan tool display screen. The scan tool is the middleman—the interpreter—in our communication with the computer.

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Was this simple enough so far?

The microphone I am using is another example of using electronics to generate a signal.

- Crystal microphones (and there are other types also) use a phenomenon called "piezoelectricity."
  - The ability of some materials to produce a voltage when subjected to pressure to convert vibrations into an electrical signal.

Where else do you see this "piezoelectric" concept used?

How about the automotive market.

Today's vehicles are incorporating more sophisticating sensing technology utilizing piezoelectric ceramic products. It is said that automotive technology is the second largest market for piezoelectric ceramic products.

Some common usages of piezoelectric materials are injectors, actuators and sensors to sense, control and adjust a variety of different systems.

An actuator converts an electrical signals into a very precise physical movement (stroke).

Some examples are:

Piezo Fuel Injectors

- More accurate
- Open and close the pintle more rapidly
- More precisely controlled fuel spray

Piezoelectric Pressure Sensors

- These sensors respond to pressure, acceleration or other inputs by producing an electrical signal.
- The signal is relayed to a vehicle's computer(s).

Examples:

- Piezo tire pressure sensors
- Dynamic pressure sensors

Note: Many sensors are being used and developed for so many safety features of today's vehicles. These safety devices include faster control of braking, air bags, crash avoidance etc.

Piezoelectric simplified

- Piezoelectricity is the charge created across certain materials when a mechanical stress is applied, thus
- Piezoelectric pressure sensors use this effect by measuring the voltage across a piezoelectric element generated by the applied pressure.

  "Voltage proportional to the pressure."

Note: Typical materials for sensors are quarts and tourmaline.

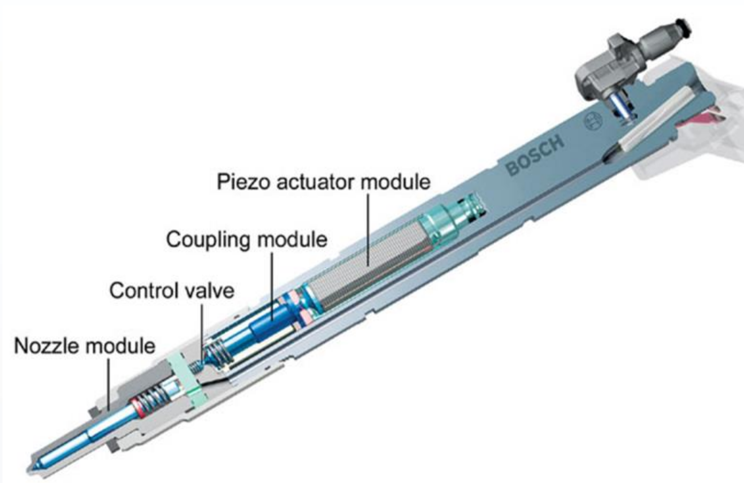
Inverse Piezoelectric Effect:

- **"Applying"** voltage to the material, causing it to change shape.

Application:

Piezo Fuel Injector Incorporate:

- Hundreds of little piezo material slices stacked on top of each other to increase the motion of the pintle due to the combined expansions.



How it works

- The stack produces 0.004 inch of movement to move the pintle far enough to inject fuel.
- The expansion of the piezo stack causes the pintle to be lifted (via two internal levers to achieve the right direction).
- Fuel spray begins.
- When the injection is complete, voltage cuts off and the piezo stack shrinks, and a spring closes the pintle.

Now for the communication part.

- Piezo injectors provide feedback by producing fluctuations in the electricity used to activate them.
- **If the engine control module (computer) calls for a certain injector opening time, say 0.5 seconds and the injector response shows it opened for only 0.490 seconds, the computer can add a very small bit of time to the next injection cycle to compensate.**

Also:

- By applying a little less electricity, the piezo crystals expand less, allowing the injector to open only part way. **(Longer injection time).**
- The **"speed"** of piezo injectors can also allow multiple injections during a single combustion cycle.

To accomplish this takes speed of communication to sense, decide and control.

"Very fast Data exchange speed"

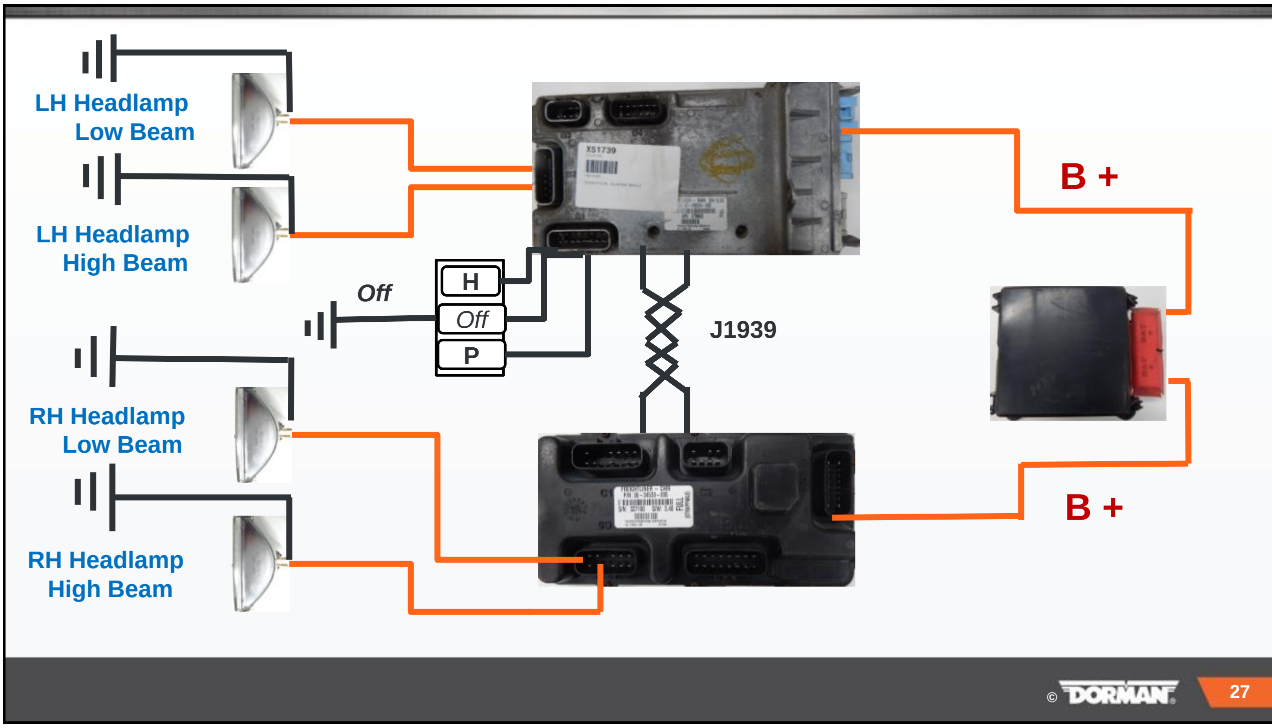
As a side note: If you ever used a grill igniter or electric cigarette lighter, you used piezoelectricity. Pressing the button causes a spring-loaded hammer to hit a piezo crystal producing a voltage/electrical current that flows across a small spark gap, igniting the gas.

Now that we have a little more information and knowledge, it shouldn't be too complicated if you build a foundation and knowledge base to put it all together.

What we learned so far:

- Trucks have many controllers
- Controllers are decision makers, but more importantly they "CONTROL".
- Computers need "input" so they can properly "output".
- Today's sensors and actuaters need to be very precise and very fast.
- Today's trucks network the various controllers and devices in a chassis to simplify the hardware, eliminate miles of wires, thus reducing the number of pins on modules by sharing.

Note: Instrument panels are a perfect example of reducing wires (see lighting lunch and and learn). By using smart switches etc. and sharing various electronic signals, there is only a minimal need for hard wires.



LH Headlamp
Low Beam
LH Headlamp
High Beam
Off
H
Off
P
J1939
B +
RH Headlamp
Low Beam
RH Headlamp
High Beam
B +
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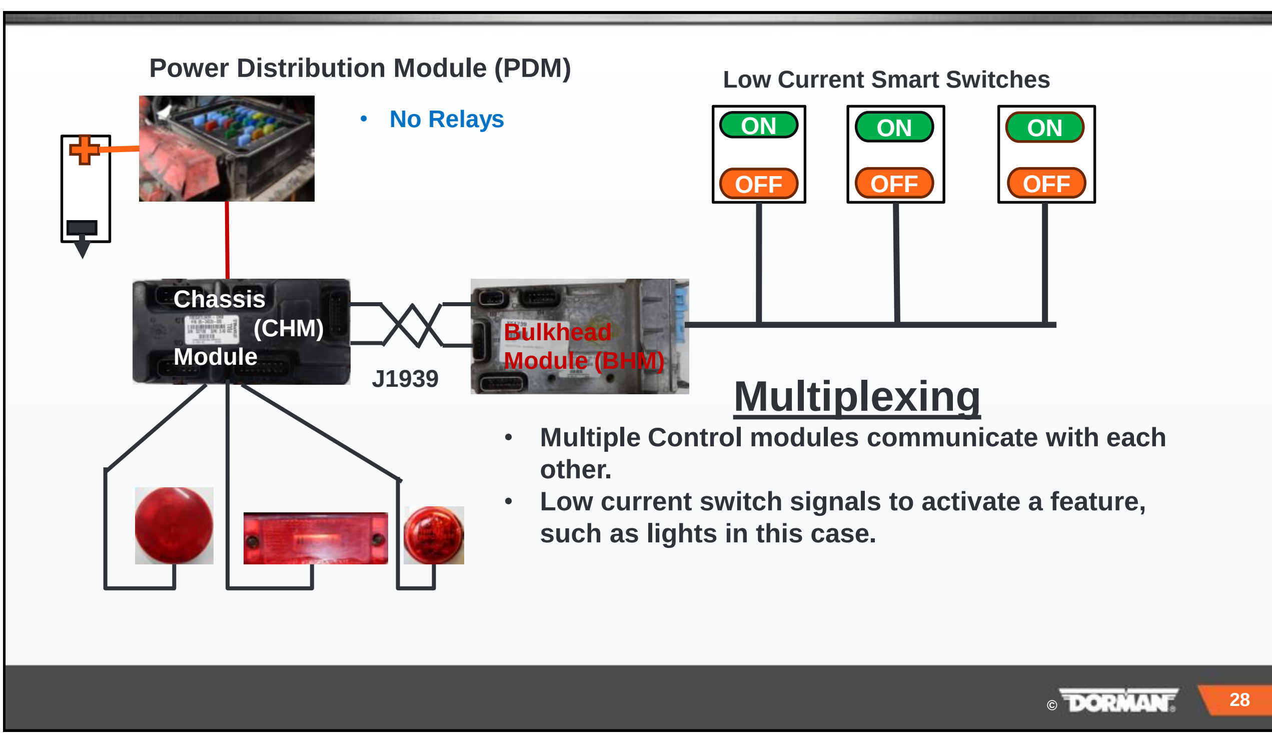

Power Distribution Module (PDM)
No Relays
Low Current Smart Switches
ON
OFF
ON
OFF
ON
OFF
Chassis (CHM) Module
J1939
Bulkhead Module (BHM)
Multiplexing
Multiple Control modules communicate with each other.
Low current switch signals to activate a feature, such as lights in this case.
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Example of Bulkhead Module, Chassis Module and Headlight Switch working together:

- When the headlamp switch is turned on, the BHM senses the input.
- The BHM is programmed to know which outputs to activate and where the outputs are located (i.e., BHM,CHM or any other controller.
- In this case, the output for the left headlamp low beam are located on the BHM and the outputs for the right headlamp low beam are located on the CHM.
- The BHM directly activates the left headlamp low beam.
- Because the right headlamp low beam outputs are on the CHM, the BHM sends a message over the J1939 to the CHM to tell it to activate those outputs.
- Once the CHM receives the message, it activates the correct outputs and sends a message back to the BHM reporting the new status of the outputs.

Note: This design allows at least one headlight to work even if one of the modules fails.

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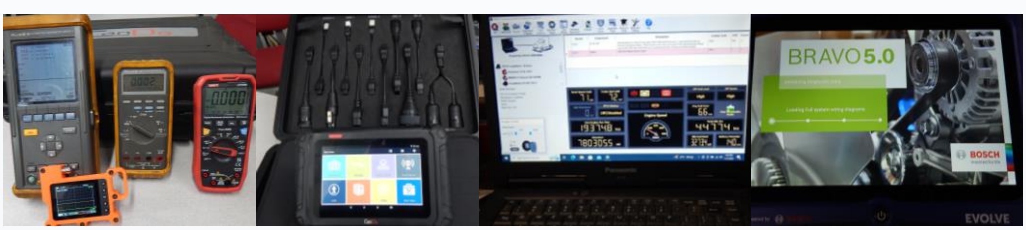
Multiplexing uses "protocols" (rules) to modulate electrons (messages) from subsystems to subsystems.

Reminder: Analog inputs are converted to digital signals by the receiving processor (controller) on the bus. These converted signals can then be broadcast digitally to other controllers on the network. They can also change back to analog format to effect actions.

IMPORTANT! This is why you must be knowledgeable, so you are comfortable looking at data and taking all sorts of electrical readings with your tools/testers.



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➢ A typical data bus consists of a **"twisted"** pair of wires to carry messages.
Example using chassis information to share with other computer-controlled systems.

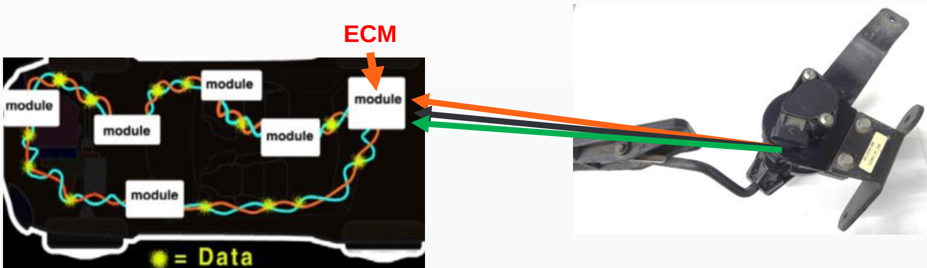
- The throttle position sensor (TPS) is the most often used as an example.

Why?

The TPS input is required for the engine management. However, the transmission, ABS, traction control, collision mitigation etc. also need this input.

How it works

The TPS signal communicates directly to one module (usually the Engine Controller). From there it is broadcast over the data bus (paired twisted wires) so that any other controller on the "network" can pick this signal up.



The following are common multiplexed controllers.

- Engine control module (ECM)
- **Fuel Injector control module (FICM)**
- Transmission control module (TCM)
- **Body control module (BCM)**
- Dash Display module (DDM)
- **Instrument cluster module (ICM)**
- Antilock Braking System (ABS)
- **Signal detect/actuation module (SAM)**
- Collision Warning System (CWS)
- **Collision Mitigation System (CMS)**
- Supplemental Restraint System (SRS)

Ask yourself: Is acceleration information important to all the above?
Not only for speed but also anticipation of something is changing.
And that information needs to get there fast.

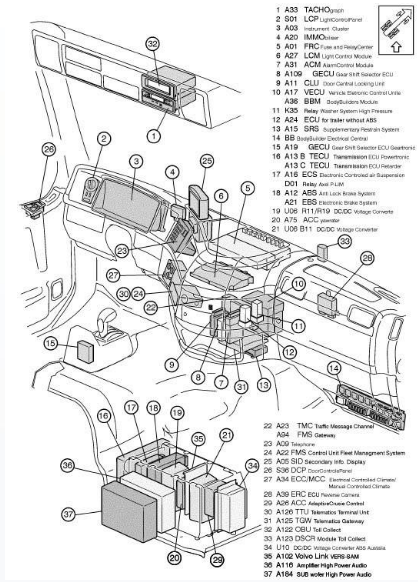
Volvo Truck Electric/Electronic Component locater/Identifier.

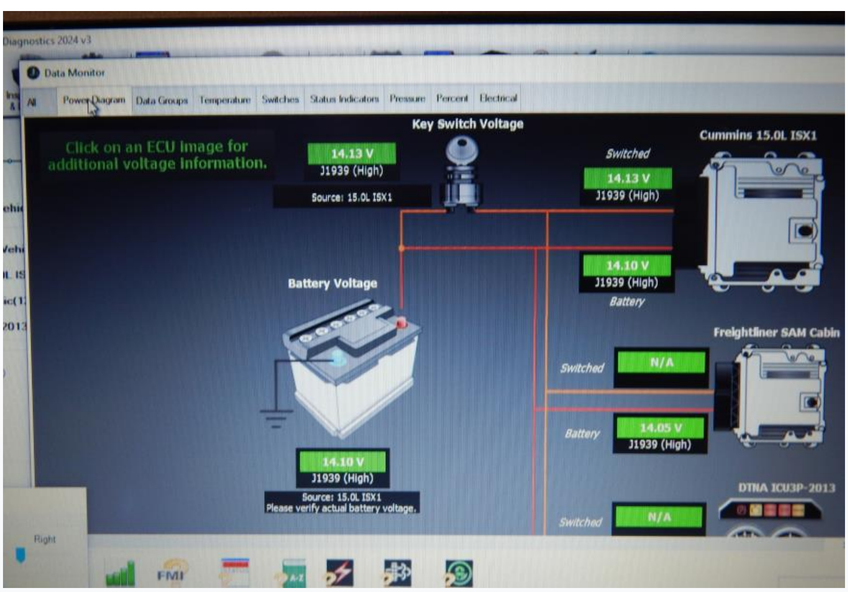
At first glance would you be able to figure out what these are and how they function.

How many of those components interact with each other?

That's just one manufacturer.

However, I do know how electrons work and fundamental electrical/electronics.





- Most recent systems use a serial data bus system to keep wiring/harness complexity to a minimum.
- Serial data transmission uses a single communication channel to deliver instructions rather than electrical signals to the controllers (modules).
- Most vehicles adopted the **"Controller Area Network"** (CAN) as the preferred data bus system.
- **CAN is a serial data transmission network used for:**
  - ECM networking
  - Comfort and convenience electronics and
  - Mobil on-board and external communications

Major advantage is that should one of the modules fail, the remaining modules will still be able to communicate (network).

CAN 2.0

CAN 2 is the basis for SAE J1939. This is the high-speed network standard used by trucks and buses in North America. (See OBD lunch and learns).
The J1939 bus is designed to function from 125 k bits per second (kb/s) up to a 1Mb/s. However, it also allows for speeds as low as 10Kb/s.
500Kb/s is the typical maximum, making it a class C bus.
Note: this is equivalent to the automobile CAN- C bus.

Multiplexing "Clock Speeds"

Microprocessor clock speed translates to an ability to make binary decisions per second.

- **Millions of binary decisions are required to process a simple output command.**
- Clock speeds of at least 16 MHz are required for J1939 transactions.
- Most current truck engine and transmission processors have clock speed of 32 MHz.

Note: It's something many people consider when purchasing personal computers.

Let's put it together.

➢ Serial in-vehicle networks need a procedure to control the bus access.

Master-Slave System. (There's also a multi-master bus system)

In a master–slave system:

- One controller acts as a "Master" to control the bus access and communication.
- The "Master" grants access to the "Slave" in a defined and predictable manner.

Example:

- Before a controller starts the transmission of a message, it will check to see "is the bus available". (Idle state). *Listening before transmitting.*
- If more than one controller starts sending a message, there could be a "Collision".
- The procedure to solve the collision is known as "arbitration".

Important! The J1939 "Bus Topology" implies that "NO" controller is in charge like the the previous example. There is no central network controller or hub. "No single controller acts as a "Master".

Benefit: If the data link gets cut in half, the devices on either side of the break should still be able to communicate with each other, but not with the controllers on the other side of the break.

This is important Knowledge when troubleshooting potential J1939 data link problems.

J1939 Data Connector

J1939 green 9-pin for EPA MY 2013

A. Battery negative
B. Battery positive
C. J1939 Can busline, dominant high (+)
D. J1939 Can busline, dominant low (–)
E. Can shield
F. J1587 busline, dominant high (+)
G. J1587 busline, dominant low (–)

Note: The post 2013 green colored 9-pin data connector is backwards compatible with pre-2013 receptacles. A smaller F-pin cavity on the green receptacle is designed to block access by a black pre-2013 plug.

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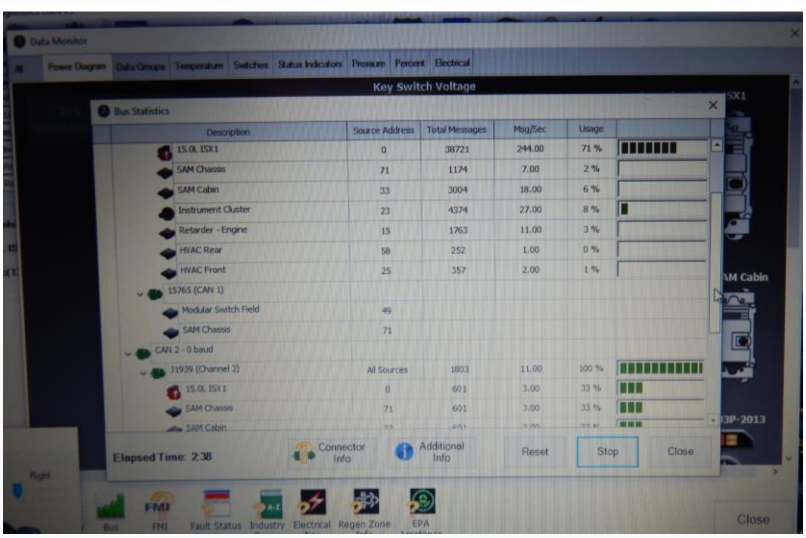

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Communication Signals

The following example is utilizing time-division multiplexing.

- Simply put, time-division multiplexing is communication devices time-sharing a common signal path such as a pair of copper wires (data link).
- Each communication device takes turns using the common data link to transmit its information.
  - This information is a form of digital-encoded data.
  - Digital has two states: "high and low" or "on and off".
  - Specific patterns of highs and lows have specific meaning.
  - Each device on the data link interprets the pattern of these highs and lows and knows what they represent.
  - Each controller takes turns using the common data link wire to transmit its digital-encoded information.

Note: The speed of transmitting these digital signals by the communication devices is so fast that it might appear as though the devices are communicating on a common data link at the same time.

"Everything comes back to speed"

- The high rate of speed over J1939 can be an issue.
- The high frequency effects the amount of "capacitance" between the two data link wires.
- This phenomenon distorts the shape of the digital waveform, and the CAN transceiver located in each controller might not be able to distinguish the difference between "Logic One" and "Logic Zero".

Why Twisted Wires?

Data Link conductors are twisted together to:

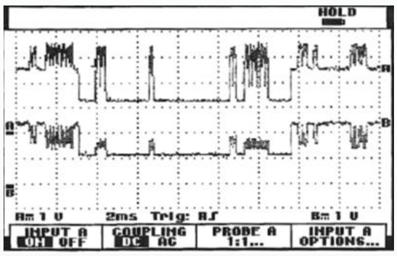
- Help provide immunity to magnetic fields.
- By twisting the wires together, any voltage induced into the wires by magnetic fields will be equal on both wires.

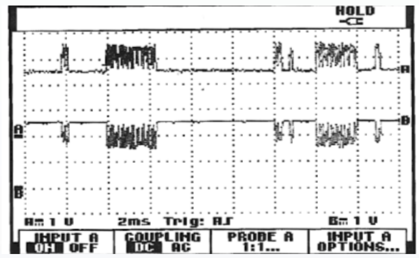
Note: The twisted wires are coded yellow and green. Also, SAE standard for J1939 data bus requires a twist through a full cycle once per centimeter (2½ times per inch). At either end of the data bus is a "terminating resistor" to:

- Prevent twisted pair from acting like an antenna to attract signal interference and;
- Suppress data signals at the end of line to prevent data collision. (More to come on this).

- CAN transceivers are also designed to look at differences between CAN H and CAN L. NOT the voltage levels referenced to ground. (Referred to as differential voltage)

Example of differences between CAN H and CAN L





Bad Signal **Good Signal**

Channel A is CAN High and Channel B is CAN Low

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- ➢ **A changing magnetic field causes voltage (noise) to be induced into both conductors.**
  - **The noise can be interpreted as a logic high and change the meaning of the message.**

Very Important!!! **Maintain wire integrity. Even replacing with ordinary insulated wire could cause a communication issue between the modules (controllers). The insulation could change the capacitance between the conductors.**

Simple explanation of Capacitance:

By definition, a "capacitor" is a device, which opposes changes in voltage. However, capacitance, in and of itself, is the ability to oppose voltage changes or fluctuations.

For example: Two adjacent conductors can function as a capacitor. This capacitance is usually small unless the conductors are close to each other for a long distance. This can be an unwanted capacitance between isolated circuits. This stray capacitance can allow signals to leak between the circuits (Crosstalk). It can be an issue in circuits utilizing high frequency.

Hopefully, this gives you another reason to maintain wire Integrity.

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Impedance

Trying for a simple explanation towards the 120-ohm resistors that you might have heard about. Old TV antenna cables are often used for relating impedance to J1939 cable.
Those old "high-frequency" TV cables were often specified in ohms.
For example, a 300-ohm cable refers to the "characteristic Impedance" . Basically, it is a measurement of how the cable appears to a high frequency force.
Note: you cannot measure this with an ohmmeter.

- J1939 cable has the same "Characteristic Impedance". However, it is 120 ohms.
  - This 120 ohms also can't be read with an Ohmmeter.

Very Important! This "characteristic impedance is not the 120 Ohm terminating resistance.
Another reason to assure cable integrity.

- Another requirement of J1939 is cable length.
  - The "backbone" (network cable length) should be no longer than 40 meters (131 ft.).
  - The stubs connecting the controllers to the backbone should be no longer than 3 meters (9 feet 10.11 inches).

Everything relating to cables so far are meant to help maintain accurate data transmission.

Terminating Resistor

This is the "real" resistance that can be measured with the Ohmmeter.

- Terminating resistors are used to minimize "standing waves", quite often referred to as echoes or reflections.

Note: think about speakers being spaced far apart, and the closest speaker gets mixed with the delay of the farthest speaker and to you it now sounds garbled.

- On a data link the controllers can't tell what is a reflection and what is the next message.
  - The terminating resistors cause the signal energy to be absorbed, leaving no energy for reflections.
  - The terminating resistors also provide a relative low resistance path for current to flow between CAN H and CAN L.

Remember Capacitance and voltage differential? This permits capacitance in the system to rapidly discharge.
Diagnostics: If only one J1939 terminator resistor is missing, the vehicle will probably not show any symptoms. However, if both terminating resistors are missing, chances are pretty good there will be no communication.

Summary

- Multiplexed electrical system reduces wiring.
- Control modules transmit messages by controlling the voltage differences between the two wires of the data bus.
- The control modules check the data bus for messages.
- Any module on the bus may transmit a message if the data bus is free.
- A message protocol is programmed into all the modules on the data bus to instruct the modules on message priority.
- When a message is transmitted, the first portion of the message informs the other modules of the message priority.
- All the control modules connected to the data bus can hear all of the messages being transmitted.
- If a message being transmitted on the bus isn't required by a receiving module, that module will disregard the message without any further processing.

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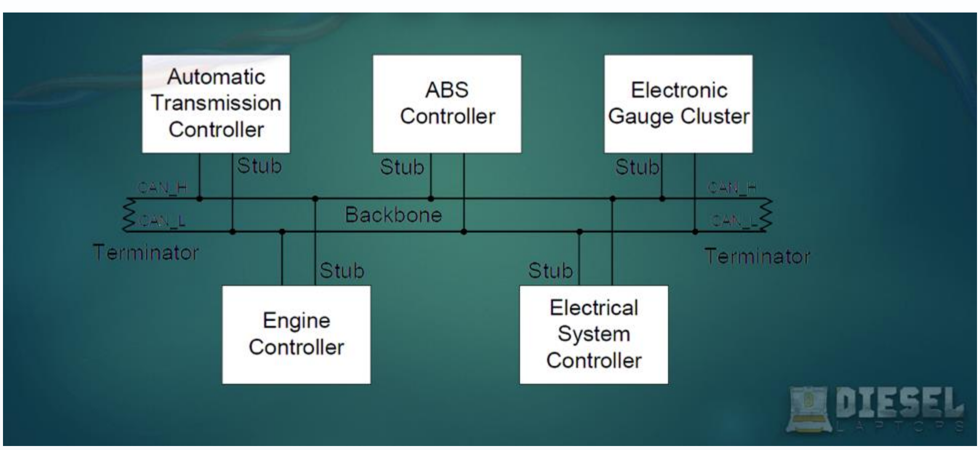

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- How do they know?
- Does that mean they don't need us anymore?

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We offer greater freedom to fix cars and trucks
by engineering exclusive, labor-saving
and cost-effective repair solutions.

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