CAN Communication Diagnostics

Overview

The vehicle's networks include:

- Controlled Area Network (CAN)
- Controlled Area Network with Flexible Data Right (CAN FD)
- Local Interconnect Network (LIN)
- Ethernet
- A^2B

Figure 1. Vehicle Networks

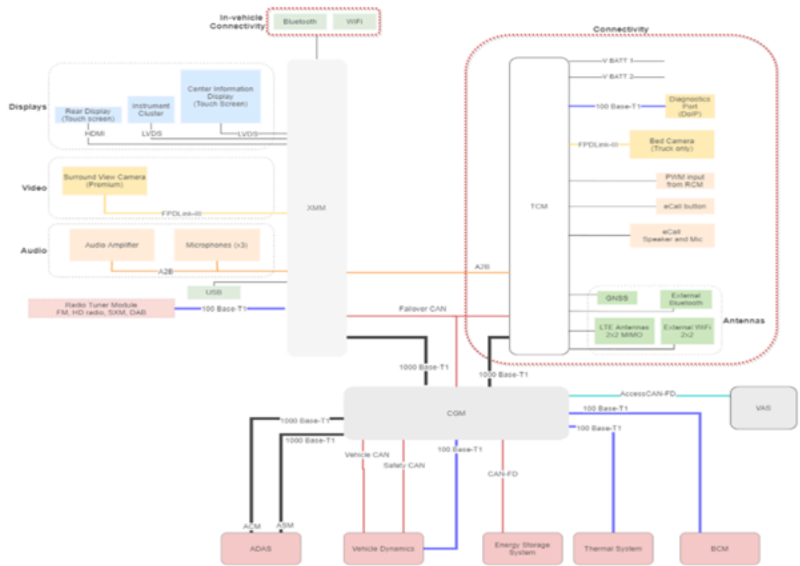
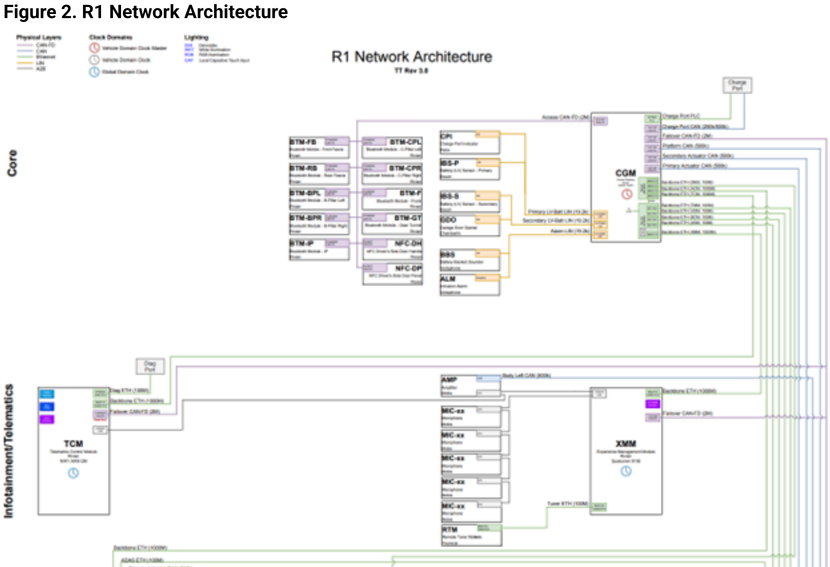


Figure 2. R1 Network Architecture

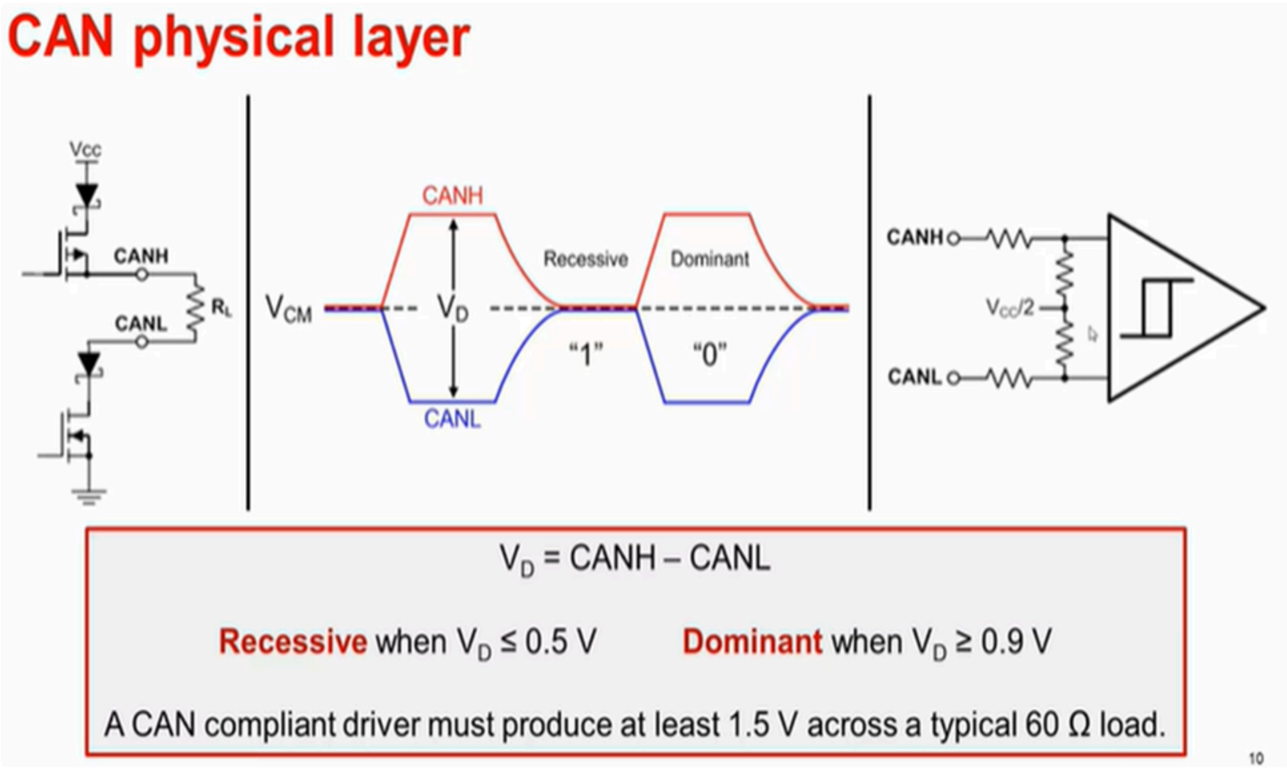


Controlled Area Network

The Controlled Area Network (CAN) bus allows for different modules such as power seats, door modules, and climate control units to talk to each other seamlessly in the vehicle. The communication rate is 500 kbps. This bus hierarchy was designed to reduce cost, weight, and wiring. The CAN is the main bus for communication in the vehicle.

The CAN physical layer has 2 wires: CAN Hi and CAN Low. The difference in the voltage between CAN Hi and CAN Low is called voltage delta (VD). A logic 1 is represented by the recessive state and is defined as VD less than or equal to 0.5V. A logic 0 is defined by the dominant state when VD is greater than or equal to 0.9V. A CAN compliant driver must produce at least 1.5V across a typical 60Ω load.

Figure 3. CAN Physical Layer



What is Termination

The CAN is designed to be used with twisted pair cabling with 120Ω characteristic impedance. The network should be wired in a bus topology (limiting stubs as much as possible) and properly terminated at both ends with resistors that match the impedance of the network. This helps to reduce signal integrity issues like reflections. If nodes are removed from the bus, care must be used with where to place the termination resistors.

Termination may be a single 120Ω resistor at each end of the bus or it may be “split termination”. Using split termination improves signal integrity and electromagnetic emissions and eliminates fluctuations in the bus common mode voltage levels (not differential). Since CAN networks may be shorted to voltage sources, the power rating of the termination resistors should consider the short circuit current protection of the CAN receivers in the network.

Figure 4. CAN Bus Termination

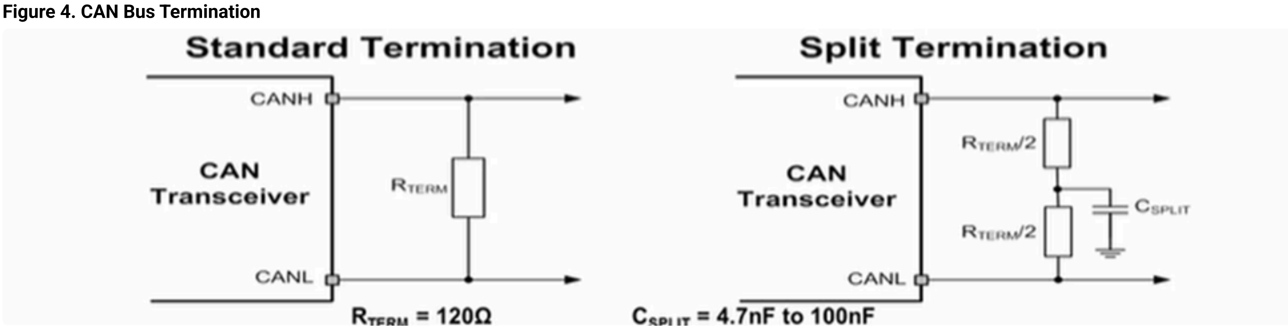
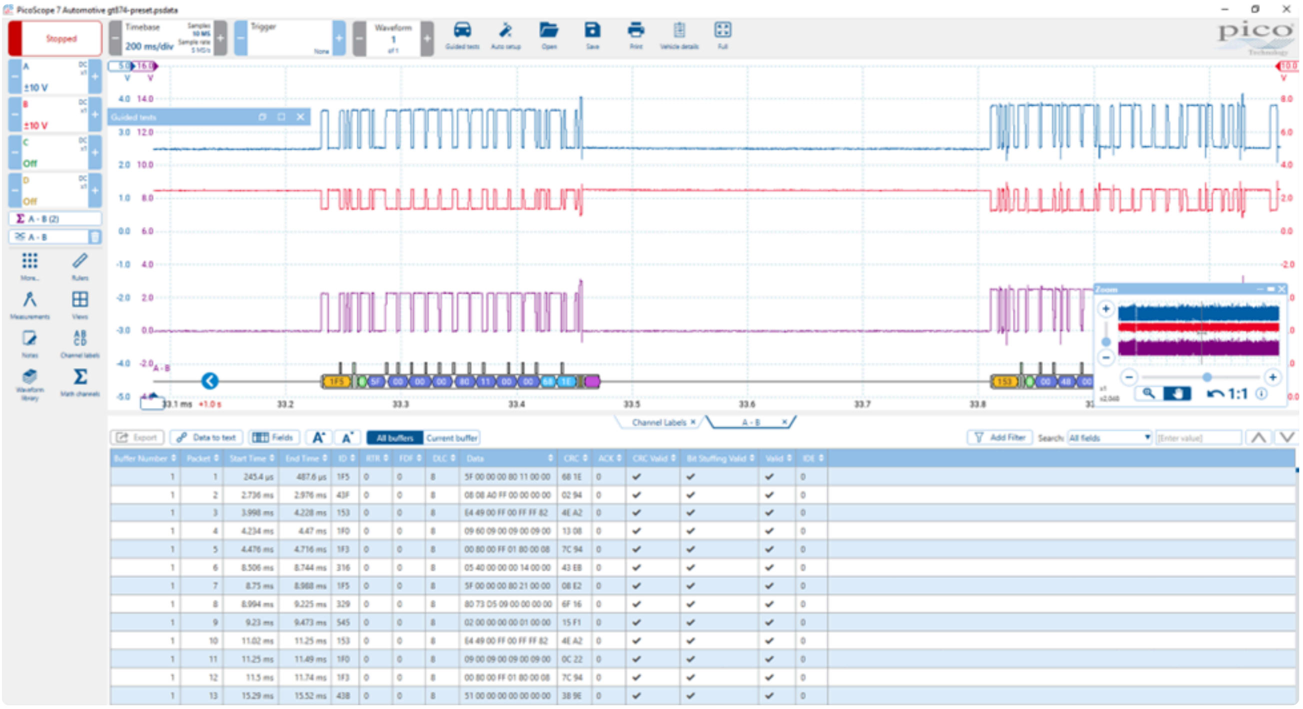


Figure 5. CAN Bus Termination Wiring Diagram

Figure 6. PicoScope Measurement



What's in a Frame?

Figure 7. Complete CAN Frame

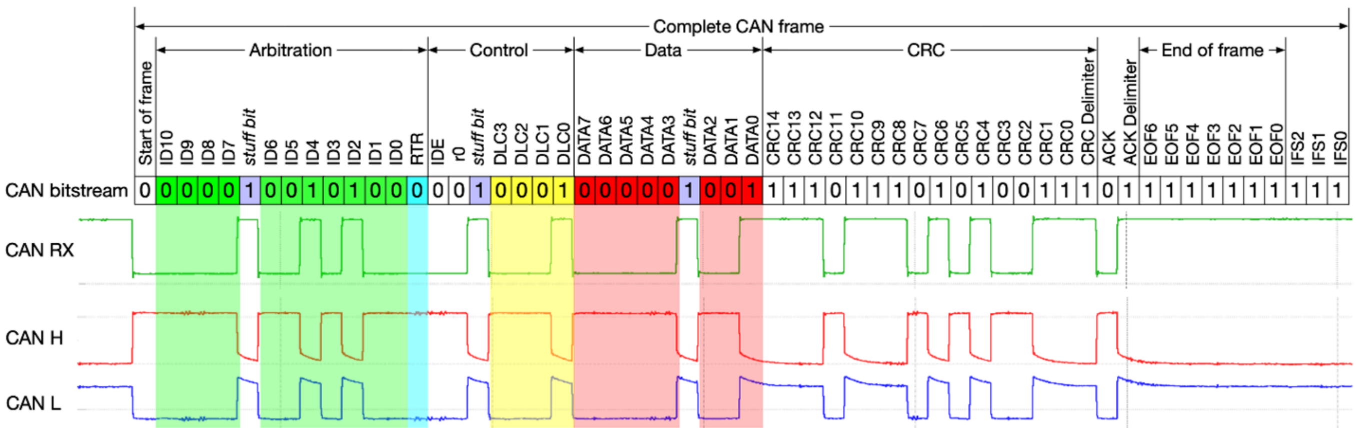


Figure 8. Complete CAN Frame Key

Field name	Length (bits)	Purpose
Start-of-frame	1	Denotes the start of frame transmission
Identifier (green)	11	A (unique) identifier which also represents the message priority
Stuff bit	1	A bit of the opposite polarity to maintain synchronisation; see Bit stuffing, below
Remote transmission request (RTR) (blue)	1	Must be dominant (0) for data frames and recessive (1) for remote request frames (see Remote Frame, below)
Identifier extension bit (IDE)	1	Must be dominant (0) for base frame format with 11-bit identifiers
Reserved bit (r0)	1	Reserved bit. Must be dominant (0), but accepted as either dominant or recessive.
Data length code (DLC) (yellow)	4	Number of bytes of data (0–8 bytes)[a]
Data field (red)	0–64 (0-8 bytes)	Data to be transmitted (length in bytes dictated by DLC field)
CRC	15	Cyclic redundancy check
CRC delimiter	1	Must be recessive (1)
ACK slot	1	Transmitter sends recessive (1) and any receiver can assert a dominant (0)
ACK delimiter	1	Must be recessive (1)
End-of-frame (EOF)	7	Must be recessive (1)
Inter-frame spacing (IFS)	3	Must be recessive (1)

What is CAN FD

Rivian has roughly 60 devices on the R1T that use the CAN and the CAN with Flexible Data Right (CAN FD). The CAN FD is an enhancement to the CAN protocol, and increased bandwidth is one of the major advantages. The 8-byte limitation of the CAN data rate is constraining for some applications and requires multiple messages to send the requisite data. The CAN FD can send the same data in half the time as the standard CAN, or 2 times the data in the same amount of time.

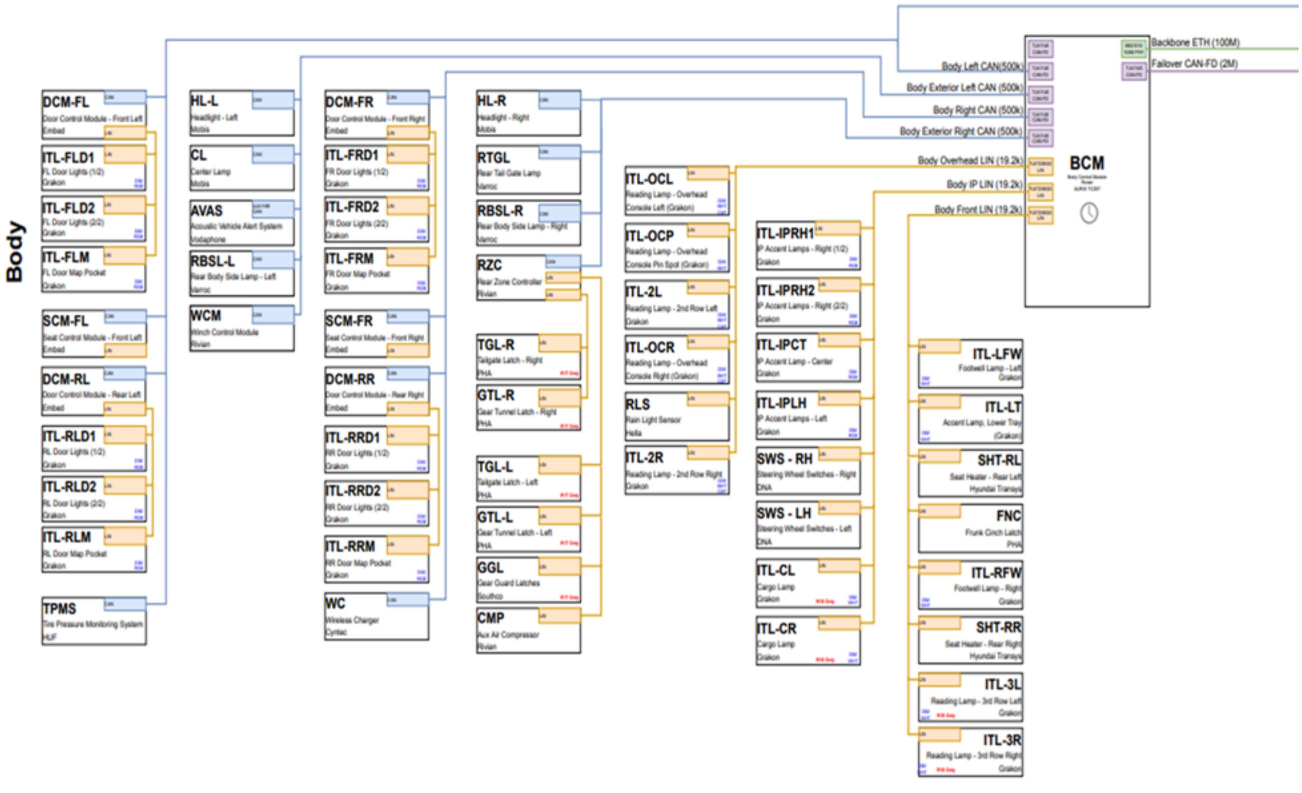
The CAN FD increases usable bandwidth by up to 2+ Mbps. There are 2 key differences between the CAN and the CAN FD protocols:

- Data rate: The CAN FD frames have the option to have separate data rates for arbitration portions and data portions. Arbitration portions adhere to the CAN, while data may be transmitted at a higher data rate.
- Data field length: The CAN FD frames allow for data fields up to 64 bytes, which is 8 times more than the standard CAN.

Local Interconnect Network

The Local Interconnect Network (LIN) is a single-wire communication up to 19.2 kbit/s. The core of the LIN is a serial network protocol controller and a physical layer transceiver.

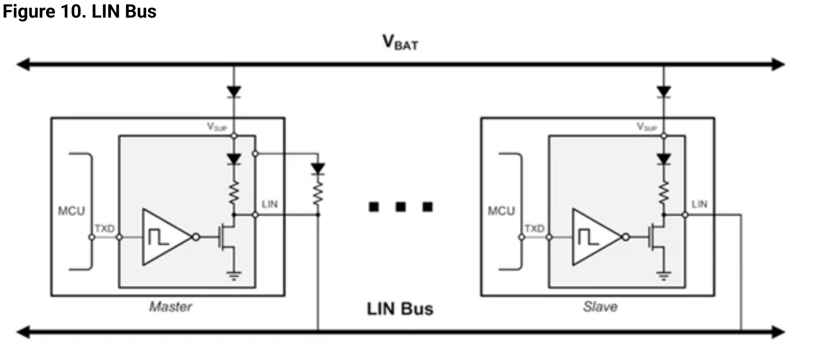
Figure 9. LIN Diagram



The LIN relies on a single master communicating with up to 16 slave devices. Rivian has roughly 70 devices on the R1T that use LIN.

The LIN is a broadcast, serial, one-wire interface and is typically implemented as a sub-bus of a CAN network. It allows automotive manufacturers to reduce cost by offloading low-speed, non-safety critical functions from a 2-wire CAN bus to a 1-wire bus.

Figure 10. LIN Bus



The LIN physical layer signals either recessive or dominant. To indicate dominant, the LIN pin voltage must be less than or equal to 0.4 of the system's supply voltage. It is recessive when the LIN pin voltage is greater than or equal to 0.6 of the system's supply voltage.

Figure 11. LIN Physical Layer

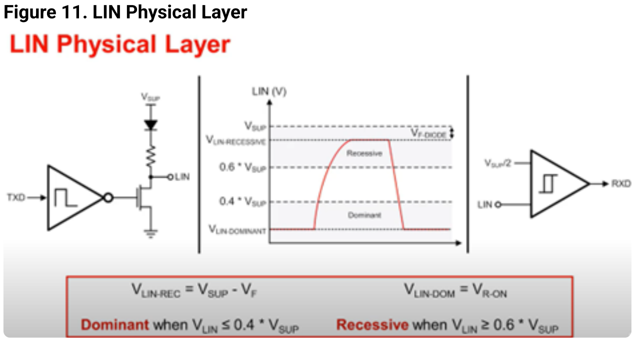
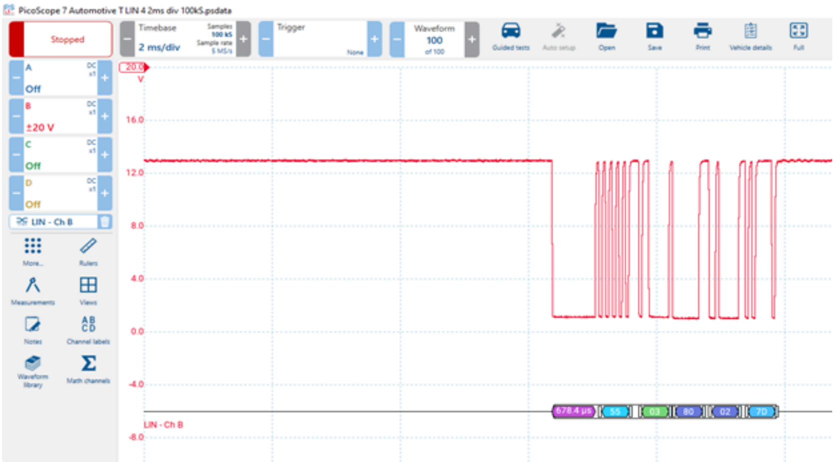


Figure 12. PicoScope Measurement



Ethernet Network

Ethernet network 100BASE-T1 is a physical full-duplex interface enabling transmission of 100 Mbps. Rivian has roughly 10 devices on the R1T that use Ethernet. With more sensors, controls, and interfaces all using higher bandwidth, faster data throughput and more reliable networks are required. Automotive Ethernet is a physical layer standard designed for use in automotive connectivity applications.

Figure 13. Ethernet Network

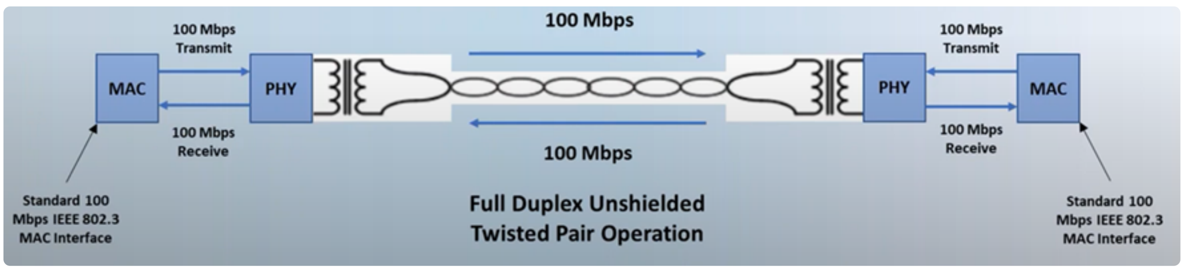


Figure 14. Ethernet Network Diagram

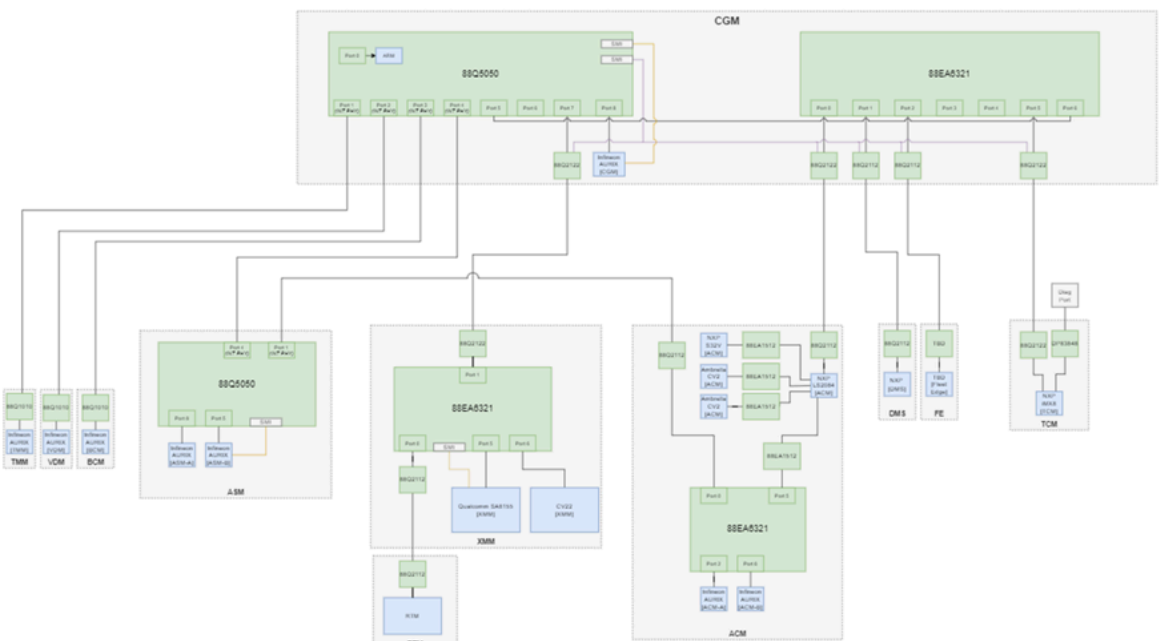
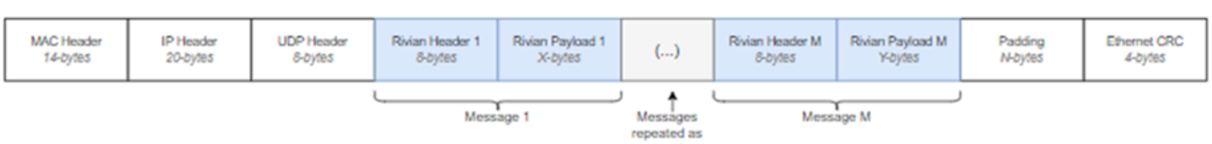


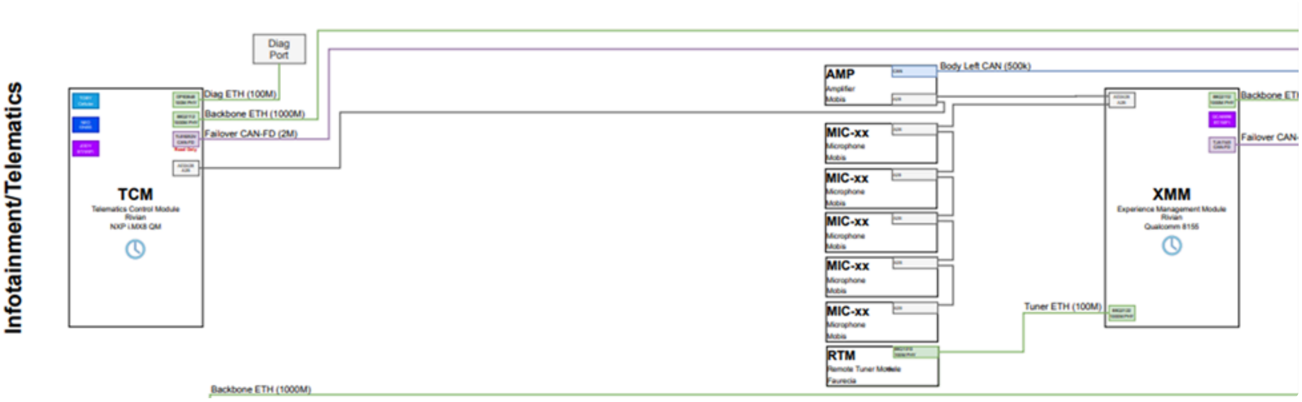
Figure 15. Ethernet Network Messages



A^{2}B Audio

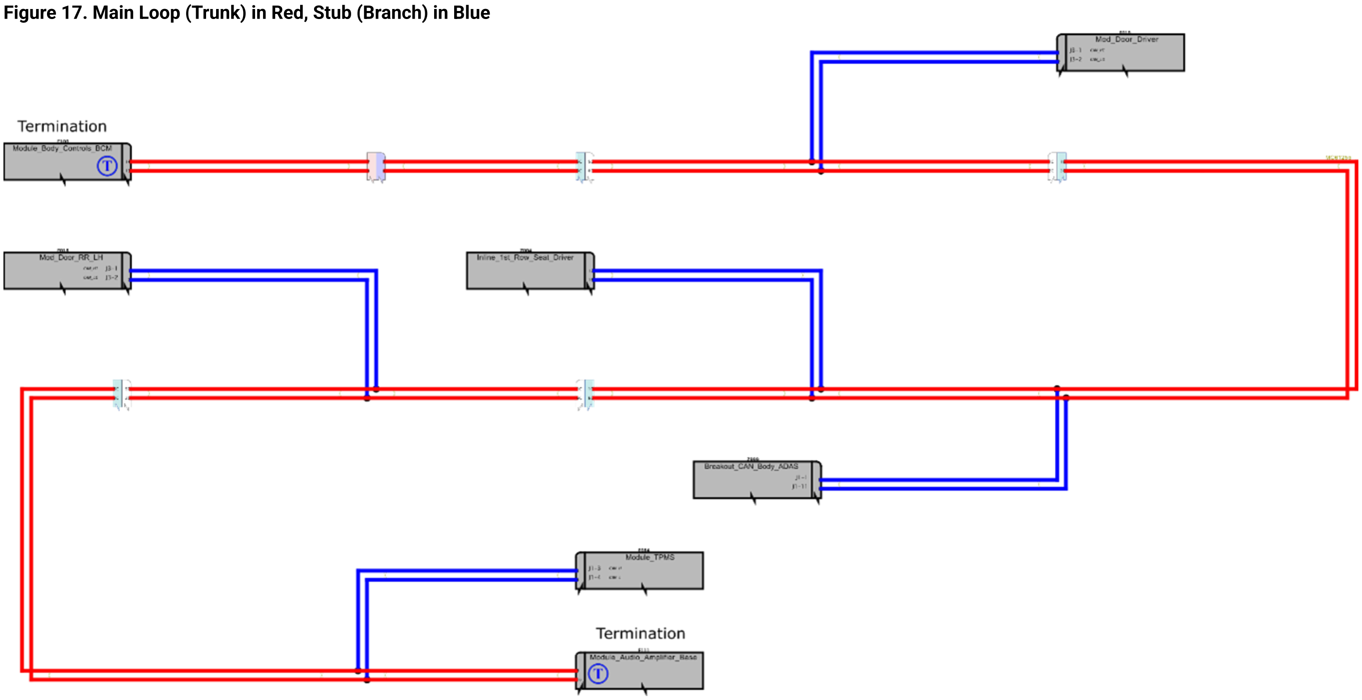
A^{2}B is a high bandwidth, bidirectional, 2-wire digital audio bus. Rivian uses it to send and receive audio and data between the telematics control module (TCM), autonomy eXperience module (AXM), microphones, and amplifier.

Figure 16. A^{2}B Audio



Troubleshooting the CAN

Figure 17. Main Loop (Trunk) in Red, Stub (Branch) in Blue



A CAN bus has two types of circuits:

- Main Loop or Trunk: The part of the bus that is directly between the terminating resistors.
- Stub or Branch: Parts of the circuit that branch off to other control modules that do not contain terminating resistors.

> **Important:**
> These measurements should only be taken with the vehicle powered off.

Verifying Network Termination Resistance

- Backprobe any device on the network and measure resistance between the CAN Hi and CAN Low.
- Resistance should be 60Ω if both termination resistors are present.
- If measurement is 120Ω, only one terminating resistor is present, and two resistors are required.
- There is an open in one or both wires between the terminating resistors.

Figure 18. Body Left CAN

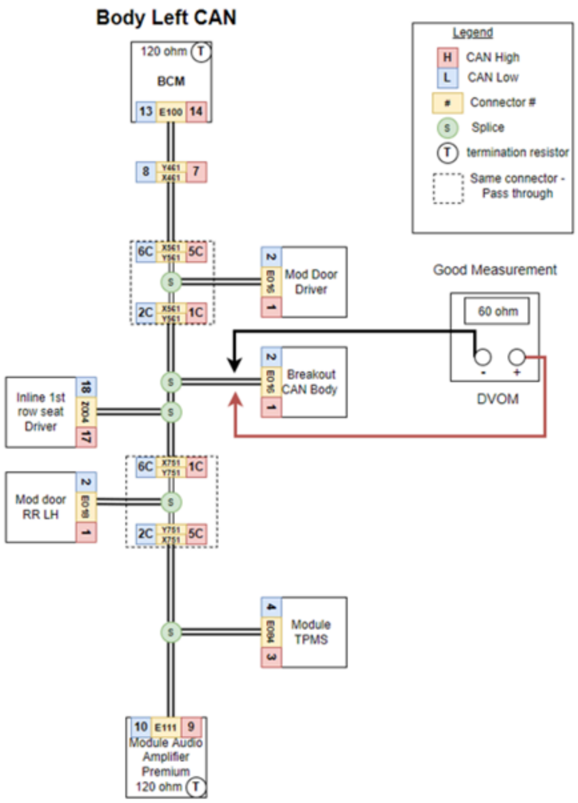
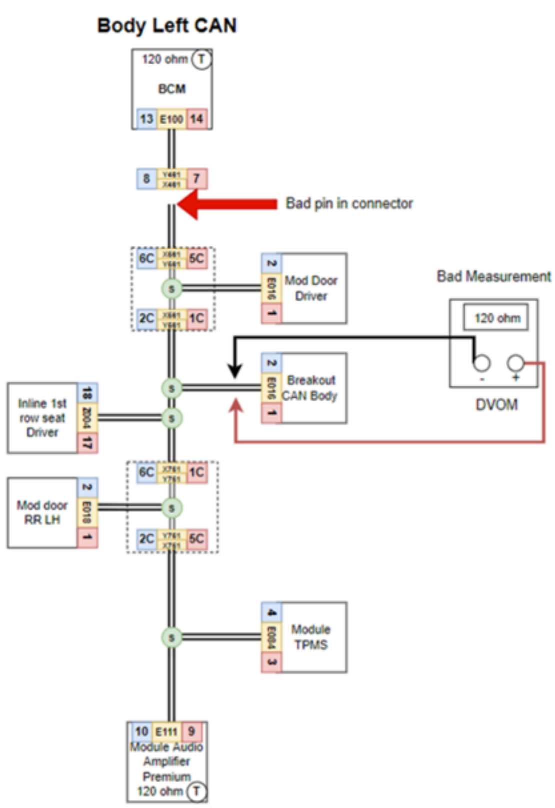


Figure 19. Body Left CAN with Bad Pin in Connector



Missing Terminating Resistor

- Your terminating resistance is 120Ω.
- If there is an open circuit anywhere in the main bus, you will see 120Ω because you will always be measuring 1 terminating resistor.

Figure 20. Soft Set Connector Example 1

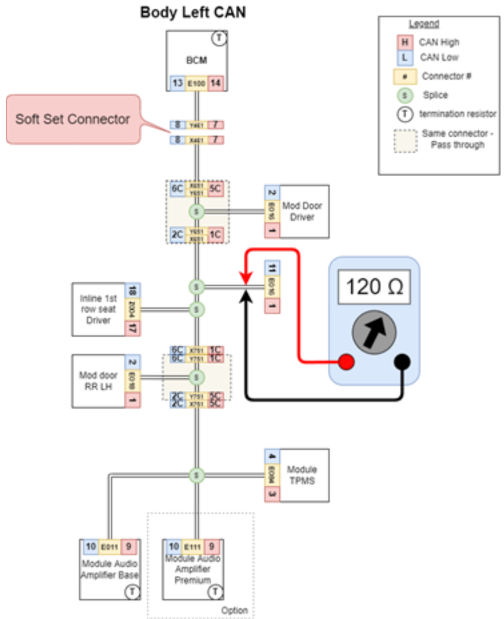
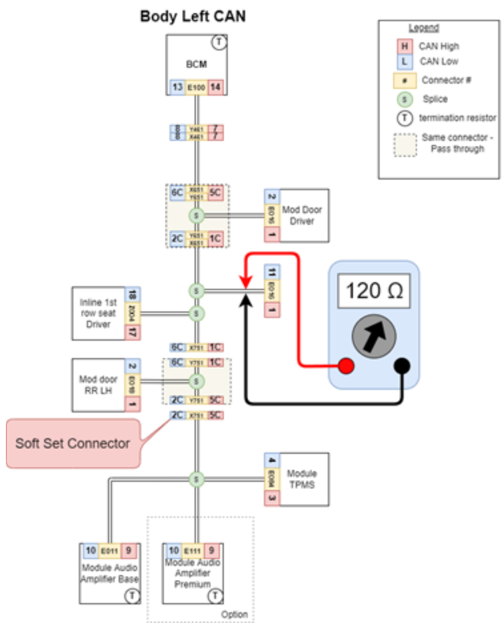


Figure 21. Soft Set Connector Example 2



- Narrow down the location of the open circuit by unplugging each module that contains a terminating resistor one at a time while monitoring resistance.
- If you see the resistance jump significantly higher than 120Ω when you unplug the control module, then you will know the circuit from that module to the test point is ok.
- In **Unplugged Amplifier**, the amplifier is unplugged, removing 120Ω from the circuit that is connected to the test meter. The resistance jumps very high, likely in the kΩ range (probably not OL).
- In **Unplugged BCM**, the other terminating module, the body control module (BCM), is unplugged. Since the BCM is no longer connected to the same circuit as the test meter, the resistance the meter is reading does not change.

Figure 22. Unplugged Amplifier

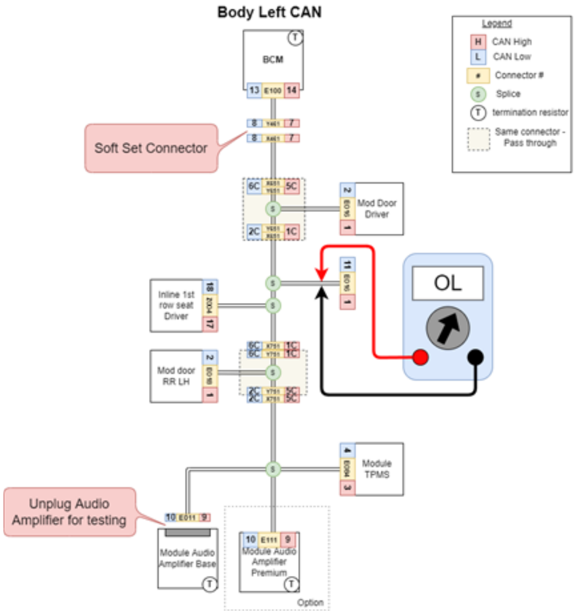
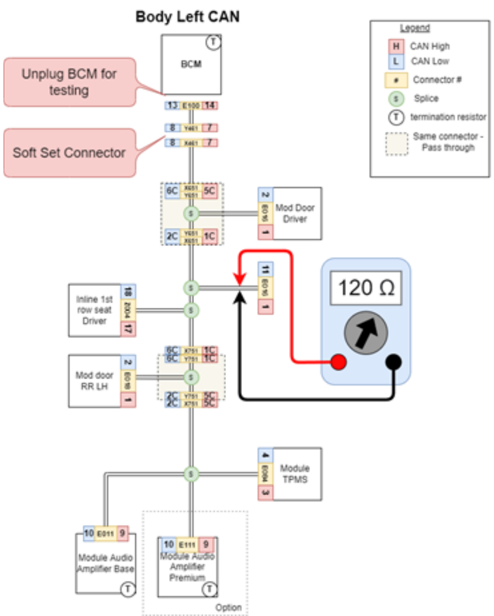
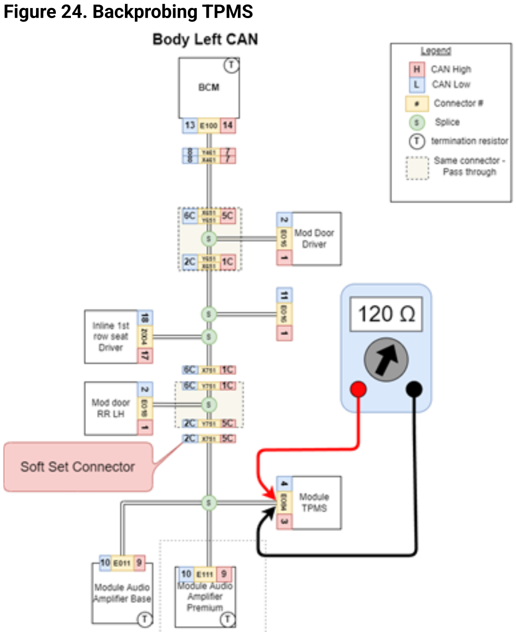


Figure 23. Unplugged BCM



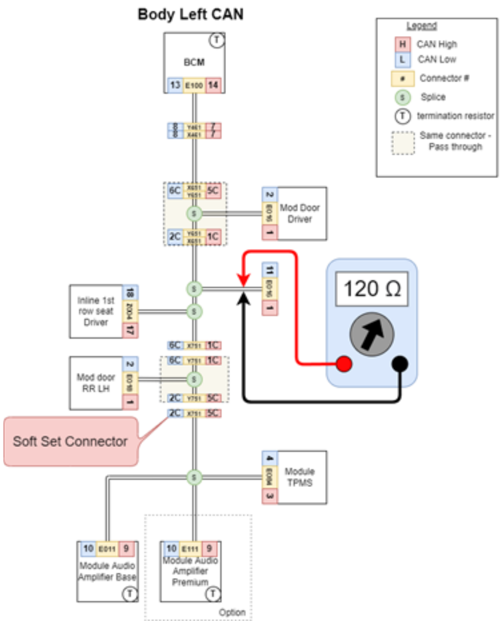
Since both terminating resistors are still connected to part of the bus, you will measure 120Ω at any point you measure on the bus **if** the open circuit is on the main loop. In **Backprobing TPMS**, we are backprobing the tire pressure monitoring system (TPMS) module and measuring the terminating resistor in the amplifier.

Figure 24. Backprobing TPMS



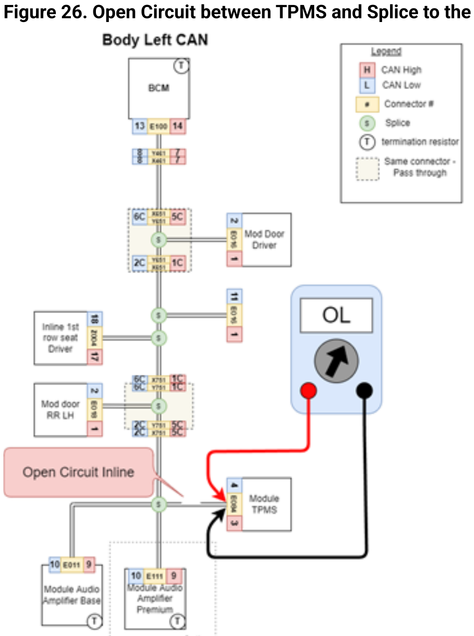
In **Breakout Connector**, we are measuring from the breakout connector. There is an open circuit between the breakout and the audio amplifier's terminating resistor, but the circuit is complete to the BCM's terminating resistor.

Figure 25. Breakout Connector



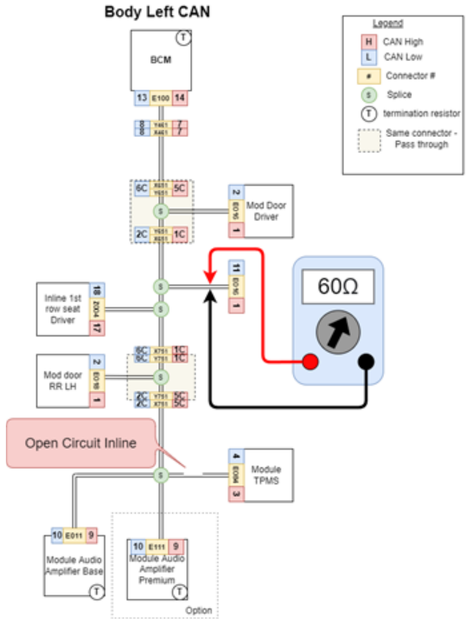
In **Open Circuit between TPMS and Splice to the Main Loop**, there is an open circuit in a wire between the TPMS and the splice to the main loop. If there are no terminating resistors connected to the part of the circuit that is being tested, we will see an open circuit.

Figure 26. Open Circuit between TPMS and Splice to the Main Loop



In **Open Circuit in Branch from Main Loop**, there is an open circuit in a branch coming off the main loop going to the TPMS module. There is no terminating resistor in the TPMS module, so it won't have any effect on the circuit resistance. The bus resistance will read normal at 60Ω.

Figure 27. Open Circuit in Branch from Main Loop



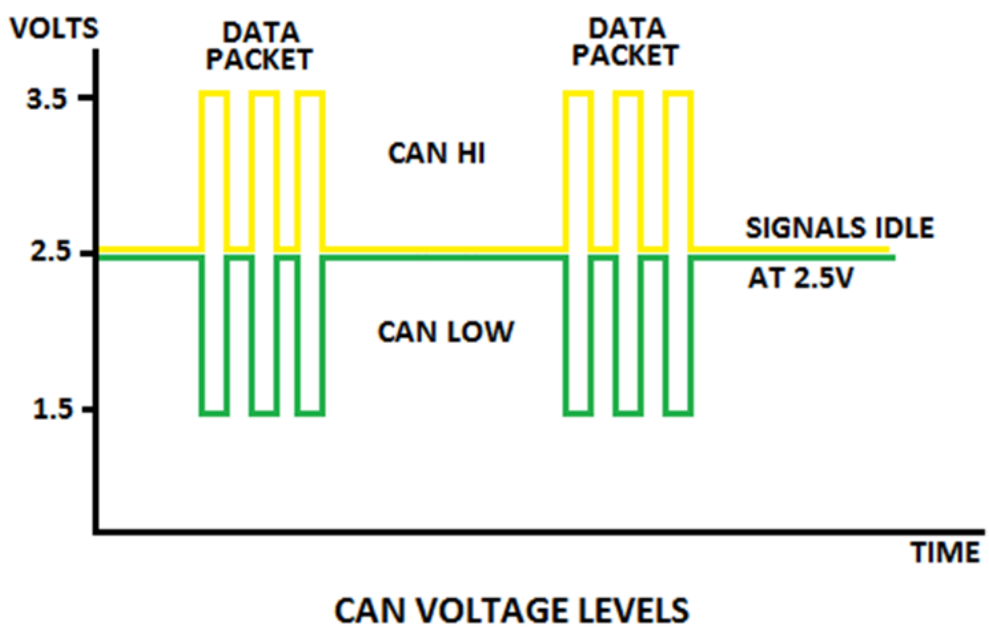
Breakout Harness

There are 2 locations to connect the CAN with this harness: passenger side A-pillar under the dash and under the passenger seat rail next to the center console.

Figure 28. Breakout Harness

When CAN voltages are measured with a multimeter, only the average voltage is displayed. Refer to **CAN Bus Signal Measurements**, **CAN Hi to Ground**, and **CAN Low to Ground** for common signal measurements.

Figure 29. CAN Voltage Levels



CAN Bus Voltage Levels

> **Important:**
> These measurements should only be taken with 1 device powered on the network.

Figure 30. CAN Bus Signal Measurements

CAN Bus Signal Measurements			
	Idle*	**Active Data**	**Typical**
CAN HI (≥ 2.5 VDC)	2.5 VDC	2.5 to 3.5 VDC	2.6 to 3.0 VDC
CAN LOW (≤ 2.5 VDC)	2.5 VDC	2.5 to 1.5 VDC	2.4 to 2.0 VDC

Figure 31. CAN Hi to Ground

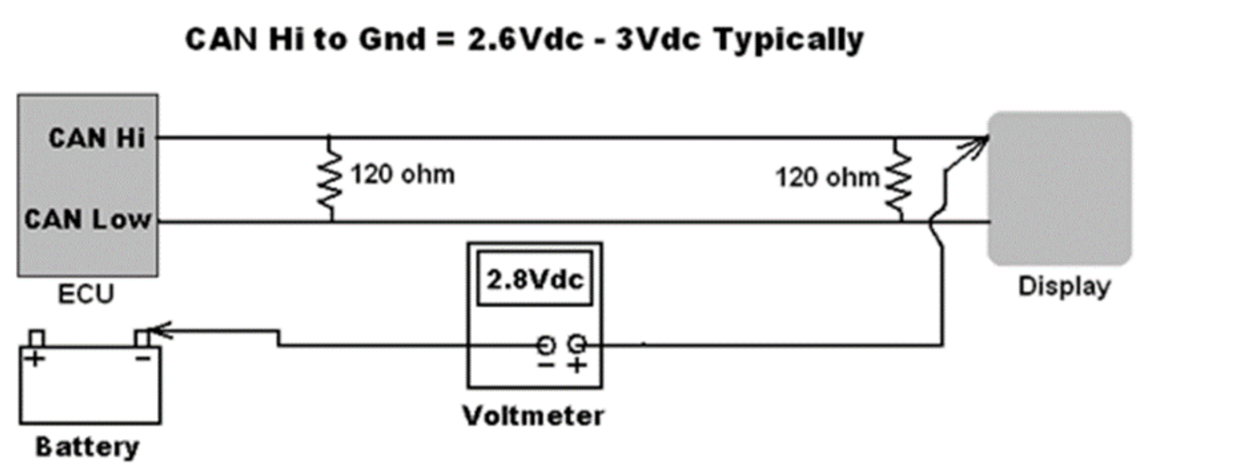
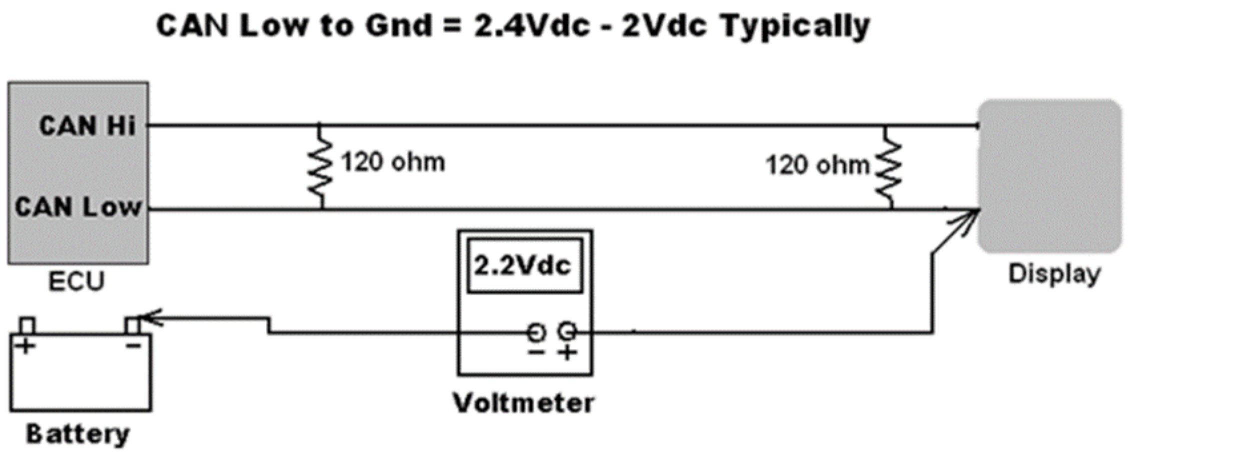


Figure 32. CAN Low to Ground



Note:
This procedure is a general guideline. Consult wiring information to determine CAN connections and pinouts for your specific equipment.

Common CAN Failures

- Device configuration settings
- Missing termination resistors
- CAN Hi and CAN Low wired backwards
- Damaged CAN port due to lightning or welding

Checking CAN Voltage

1. Disconnect all devices except for the device being tested, then power the device on.
2. Measure the voltage on any of the disconnected plugs between CAN Hi and GROUND. The resulting voltage should be between 2.5 and 3.0 VDC.
3. At the same location, measure voltage between CAN Low and GROUND. The resulting voltage should be between 2.5 and 2.0 VDC.

A low voltage of 1.4 VDC or less on either of these indicates a potential failure on the CAN port of the device.

If voltages are exactly 2.50 VDC and do not change after several seconds, this indicates the device connected is powered but not broadcasting data.

Checking for Reversed Wiring

- Perform the CAN voltage test detailed above and verify CAN Hi voltage is greater than CAN Low voltage. If not, the wires are reversed.

Using the PicoScope for the CAN

Picoscope

An oscilloscope is a tool used to give a visual representation of an electrical signal. It is voltage graphed over time. Rivian uses a PC based automotive oscilloscope made by Pico Technologies called a PicoScope and the PicoScope 7 Automotive software.

Picoscope Training

- Picoscope 7 intro - part 1
- Picoscope 7 intro - part 2
- CAN bus physical layer testing
  - Video - testing physical layer
  - Video - CAN bus diagnostics and serial decoding
- CAN bus serial decoding
- LIN bus decoding
- Wheel speed sensor testing
- Parking sensor testing
- Electric vehicle supply equipment (EVSE) charging communications testing
- EVSE proximity line resistance testing

Downloads

- PicoScope app for phone
- PicoScope download page (get Version 7)

Normal CAN Bus Signal

On a normally functioning CAN bus, you will see CAN Low and CAN Hi mirroring each other.

Normal CAN Bus Signal

0:00 / 0:03

Voltage (Vertical) Range

Voltage is displayed on the vertical Y axis. The PicoScope has a Y axis range of ±50mV to ±50V. There is an auto range function that will automatic set the voltage range based on the measured signal. Avoid using this option for signal measurements. In **Inconsistent CAN Hi**, CAN Hi, shown in blue, is not consistent. This is because the software is adjusting the range for CAN Hi between 5 and 10V.

Inconsistent CAN Hi

0:00 / 0:03

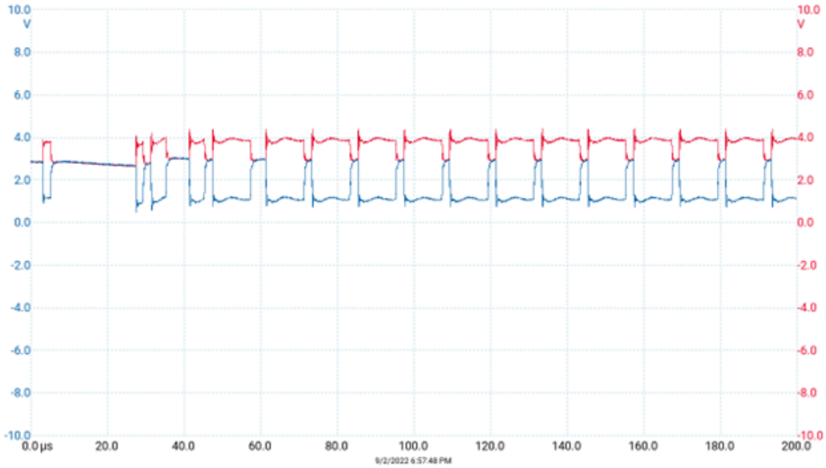
Identifying Faults

When diagnosing a CAN fault using a PicoScope, use the shape of the signal to narrow down where to look for the fault.

In **CAN Hi Is Open**, CAN Hi is open.

- Notice that the voltage on CAN Hi is increasing by about 1V.
- Voltage on CAN Low is dropping about 2V.
- Recessive voltage is also about 3V when a message is being transmitted.

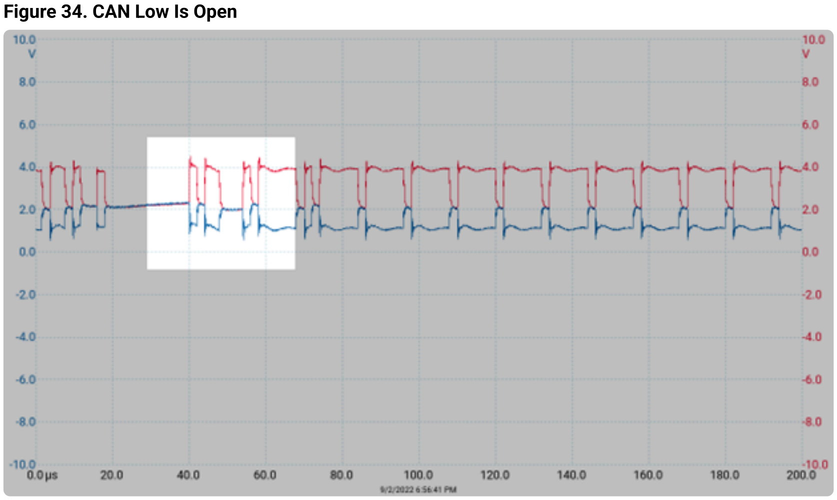
Figure 33. CAN Hi Is Open



In **CAN Low Is Open**, CAN Low is open.

- Notice that the voltage on CAN Hi is increasing by about 2V.
- Voltage on CAN Low is dropping about 1V.
- Recessive voltage is also only about 2V when a message is being transmitted.

Figure 34. CAN Low Is Open



Setting Up the PicoScope

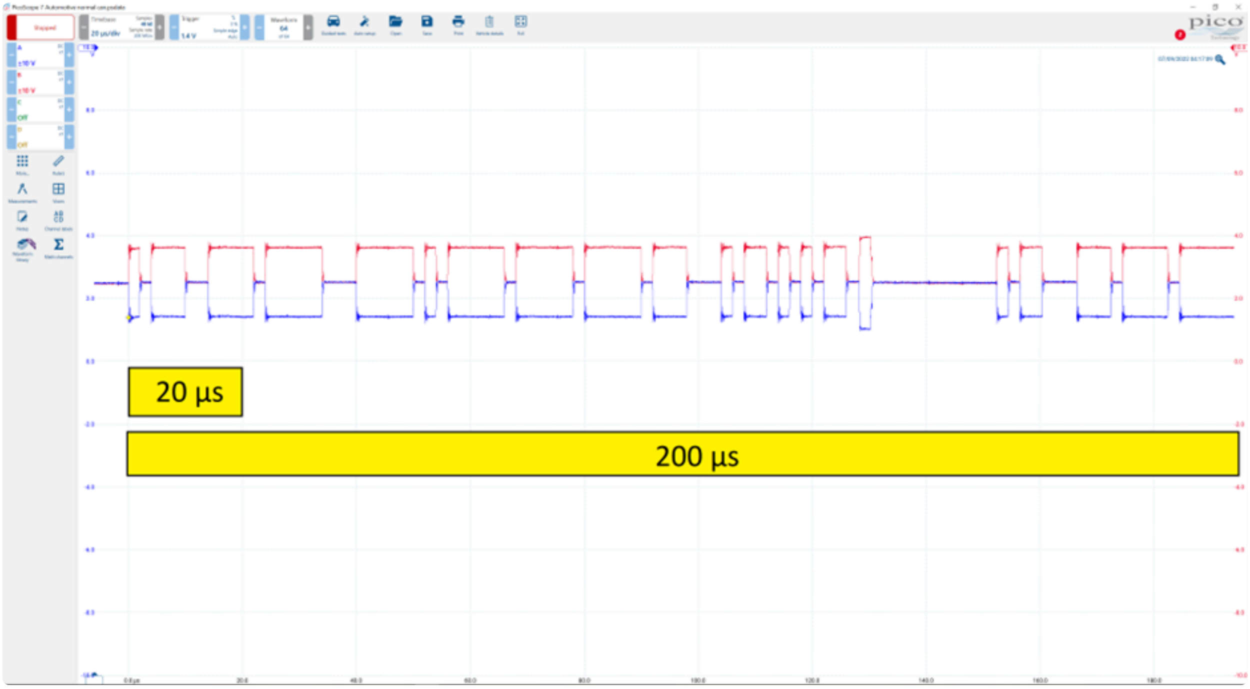
Proper setup is critical when using an oscilloscope. There are 4 main settings you will need to change depending on your measurements.

- Voltage (vertical) range, which sets the maximum voltage of the scope will display.
- Time base, or the amount of time between each division on the screen.
- Sample rate, or the number of samples taken per second.
- Trigger, which catches a signal at a specific level and makes viewing digital signals easier.

Time Base

The oscilloscope screen is typically split into 10 horizontal segments or divisions, and the time base is the amount of time each of those segments will display. In **Time Base Set to 20 µs/div** the time base is set to 20 µs/div so the total display will show 200 µs.

Figure 35. Time Base Set to 20 µs/div



Sample Rate

An oscilloscope at a basic level shows many consecutive signal values in time. The number of signals measured per second is called the sample rate. Increasing the sample rate will improve the resolution, but it will also limit the number of frames that can be saved and increase the file size. In **1 Million Samples Per Second (1 MS/s)** and **25 Million Samples Per Second (25 MS/s)**, notice the difference between 1 MS/s and 25 MS/s. To adjust sample rate, click the time base window and then click the sampling tab.

Figure 36. 1 Million Samples Per Second (1 MS/s)

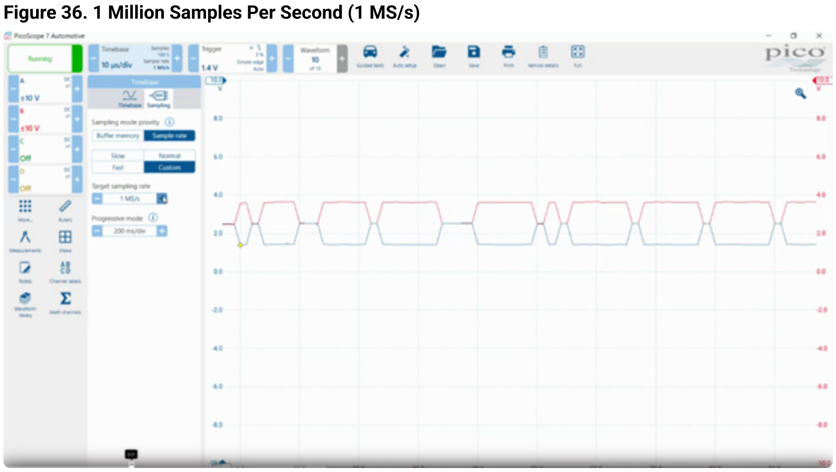
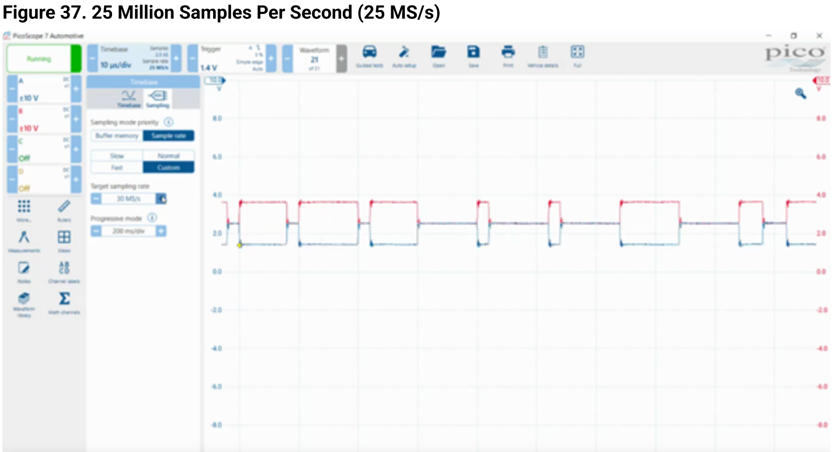
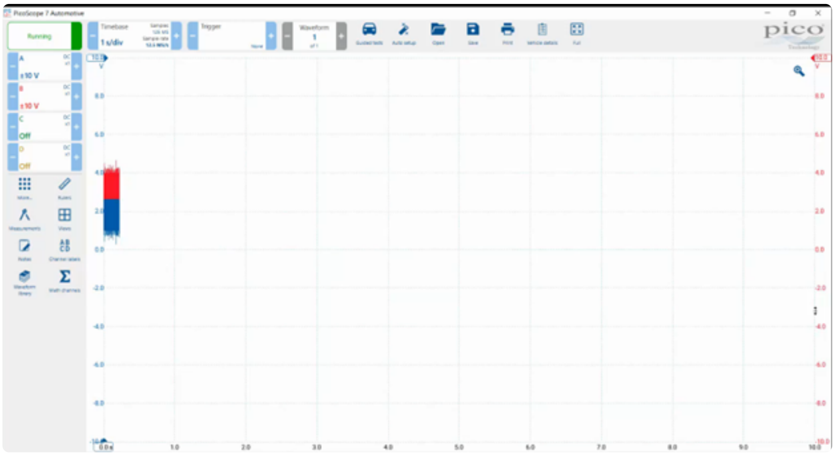


Figure 37. 25 Million Samples Per Second (25 MS/s)



High sample rates can also be leveraged in another way. The PicoScope software only shows about 10 frames per second. If you're watching the CAN for an intermittent issue with a normal time base of 20 µs/div, you will only see 200 µs of the signal displayed, or 0.2 milliseconds. At 10 frames per second, you will only see 2 milliseconds of signal per second. That's just 0.2%. The sample rate will be set according to the collection time and the maximum number of samples that the device can collect (based on the number of samples requested).

Figure 38. High Sample Rate



Motors and Hall Sensors

Most drive motors Rivian uses incorporate hall effect sensors to monitor speed and direction. The electronic control unit (ECU) can use the feedback from the hall sensors to drive a motor to move an actuator to a specific location. This is helpful for devices that are not driven to their end stop, such as a seat motor or steering column motor. For a control module to be able to detect direction it requires 2 hall sensors positioned at 90 degrees from each other. Depending on the direction of the rising edge, one of the hall sensors will count before the other hall sensor is activated, so they are activated back-to-back.

Hall Sensor Example 1 and **Hall Sensor Example 2** show both hall sensors of a hood strut while the hood is opening or closing. In **Hall Sensor Example 1**, notice how the raising edge of the red signal happens just before the blue line and in **Hall Sensor Example 2** the leading edge of the blue signal occurs first.

Figure 39. Hall Sensor Example 1

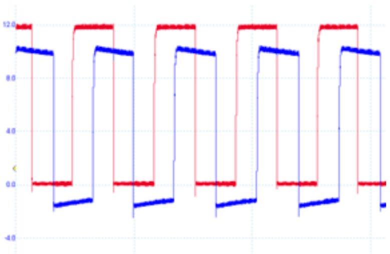


Figure 40. Hall Sensor Example 2

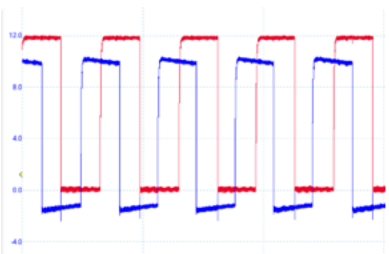


Figure 41. Hall Sensor Signals A and B

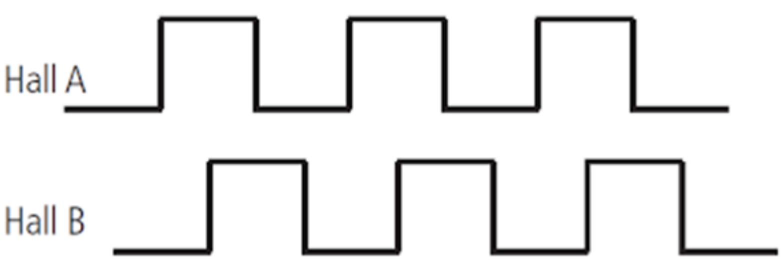


Figure 42. Hall Effect Sensor Diagrams

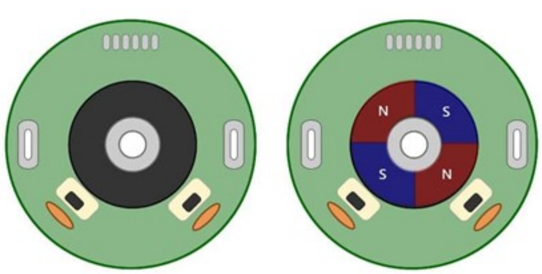
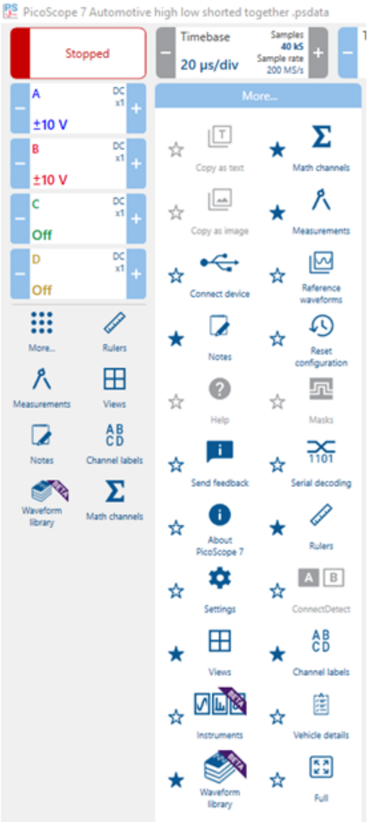


Figure 43. PicoScope Function Layout



Connecting the Picoscope

Depending on what you're measuring you will connect the PicoScope in different ways.

If you're measuring CAN, use 2 channels, 1 connected to CAN Hi and one to CAN Low. Connect both ground leads together and connect them to the vehicle ground. The best way to connect to CAN is via the CAN breakout harness using back probes. The CAN breakout uses the industry standard 9 pin D-Sub DB9 connector.

It is important to know that the CAN breakout harness only provides CAN Hi and CAN Low. It does not have power or ground. There is a tool in development that will make connecting much easier.

Figure 44. CAN Bus Breakout Connector (Female Connector)

Pin	Assignment
1	Not connected
2	CAN_Low
3	Not connected
4	Not connected
5	Not connected
6	Not connected
7	CAN_High
8	Not connected
9	Not connected

D-Sub plug

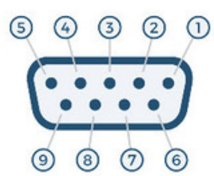


Figure 45. Breakout Harness

Figure 46. CAN Breakout Interface Box

Picoscope Tests

Measuring CAN Voltage

- Set Time Base to 20 μs/div.
- Connect blue wire to channel 1 and red wire to channel 2.
- Set channel A and B voltage to 10 volts.
- Connect CAN Hi to the red lead and CAN Low to the blue lead.
- Connect both grounds together and connect them to chassis ground.

Introduce Faults

Intentionally cause faults on the CAN bus and observe what happens. This helps to identify they type of fault and may also help start to track down the location.

- Open CAN Hi on the main branch while monitoring the voltage.
- Open CAN Low on the main branch while monitoring the voltage.
- Open CAN Hi on the side branch while monitoring the voltage.
- Open CAN Low on the side branch while monitoring the voltage.
- Short each CAN to ground.
- Short CAN Hi and CAN Low together.

Charge Port Door

- Connect probe A to Hall sensor 1.
- Connect probe B to Hall sensor 2.
- Connect probe C to Hall sensor VCC and Hall Ground.
- Connect probe D to Motor + and Motor –.

Charge Port

- Connect probe A to Pilot.
- Connect probe B to Proximity.
- Connect probe C to Motor Position sense.
- Connect probe D to Motor + and Motor –.
- Open the charge port and connect the cable.
- Press release and remove the cable.
- Plug into direct current (DC) charger if possible.