Tech Note: Troubleshooting Isolation Faults

Tech Notes are internal announcements that help to communicate and track new information about Tesla Service concerns.

As part of the Model S high voltage safety philosophy, the high voltage electrical system is isolated from the vehicle. This means that there is no electrical current carrying path between the vehicle and any high voltage conductor. To ensure that this isolation is always met, a monitor is installed in the battery, which periodically measures the resistance between the high voltage conductors and the chassis.

Three different conditions can introduce a conduction path to the chassis: a physical defect of the insulation material, contamination (of any size, e.g. dust, bolts, etc.), or moisture. When debugging isolation, look for signs of moisture or physical damage to HV cables, bus bars, and connectors.

This procedure aids in investigation of loss of isolation by separating the High Voltage system until the suspect component is found. The HV distribution network needs to be separated further and further apart until the isolation loss is found. To correct degradation or loss of isolation, the component with isolation breakdown needs to be localized and faulty component/components replaced.

This document contains quick reference flow charts for intermittent faults, and for when faults are present. It also includes detailed, step by step instructions to be used when faults are present. After repairing a fault, a final quality inspection always needs to be performed. A quick reference flow chart and detailed instructions are included for the final inspection procedure.

WARNING: Only technicians who have been trained in High Voltage Awareness are permitted to perform this procedure. Proper personal protective equipment (PPE) and insulating HV gloves with a minimum rating of class 00 (500V) must be worn any time a high voltage cable is handled. Refer to service bulletin SB–13-92-003, High Voltage Awareness Care Points for additional safety information.

General Electrical Definitions

- **Electrical isolation:** Separating two conductive materials from electrical contact. In our case, isolating the HV electrical system from the vehicle ground.
- **Electrical insulation:** A non-conducting material that provides electric isolation of two parts at different voltages. It prevents the flow of electric current through it. In Tesla vehicles in particular it isolates HV systems to chassis ground, HV systems to LV systems and between HV conductors. Different materials have different dielectric ratings.
- **Isolation resistance:** The electrical resistance between two conductors separated by an insulating material.
- **Electrical continuity:** The state of being a whole, unbroken circuit. A continuity test is done to determine whether a circuit is open or closed. An open circuit cannot conduct electricity. A closed circuit has continuity. A simpler way to understand continuity is if there is a conductive path between two test points.
- **Electrical shielding:** A conductor shielding that is at chassis potential (“ground”), whose purpose is to reduce or eliminate electro-magnetic interference, or radio frequency interference.
- **Electrical isolation test:** A direct current (DC) resistance test that is performed between subcircuit common and subsystem chassis ground to verify that a specified level of isolation resistance is met. The BMS performs this measurement.

Tesla-Specific Definitions

- **BMS:** The Battery Management System is a printed circuit board assembly, which communicates with the BMBs (each module) and with the powertrain/vehicle. The Battery Management System performs the isolation test.
- **HVIL:** High Voltage Interlock Loop.
- **PPE:** Personal Protective Equipment, for example, high voltage gloves.
- **Pack voltage:** The total voltage of the string of modules in series inside contactors (Figure 1). Since the cells are hard connected, the pack voltage is always live.
- **DC link voltage:** A high voltage DC bus outside the HV battery contactors (Figure 1). This bus is only live when the contactors are closed.

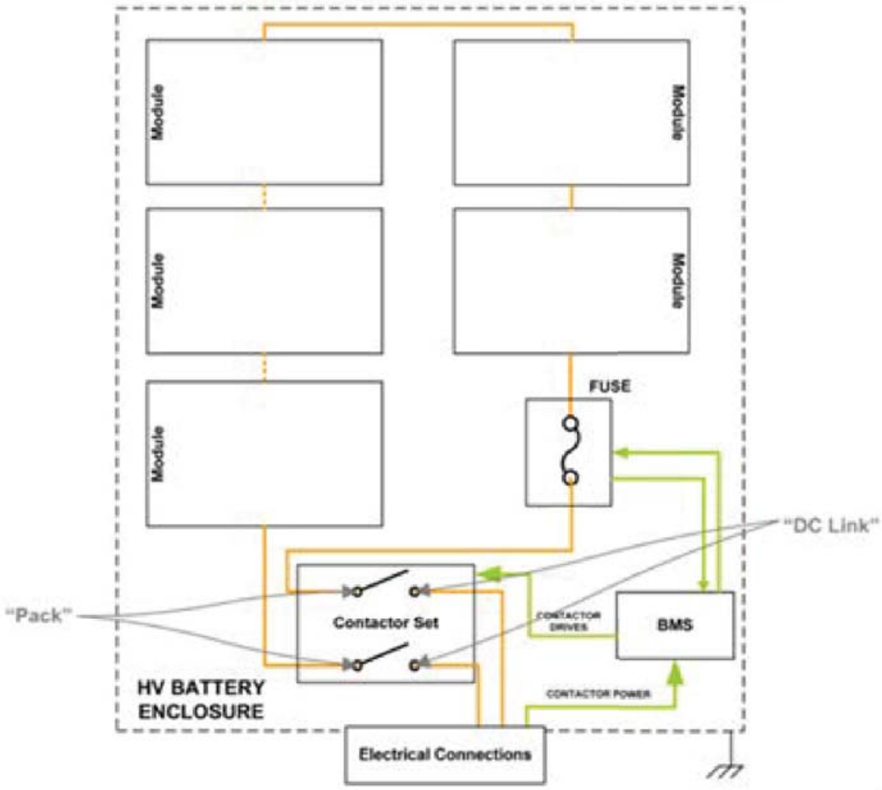


Figure 1

Model S HV Network and Isolation Measurement

The orange lines indicate the high voltage distribution network found in the Model S (Figure 2). The green symbols show the chassis ground potential. The housing of every powertrain component is connected to ground.

An isolation fault is triggered any time there is continuity between an orange line and chassis ground.

The BMS takes this measurement inside the battery contactors, which is why the values observed on the TDS will be different depending on the contactor state. This can be used to determine whether the fault is internal or external to the high voltage battery.

Several parts of the high voltage loop are only connected to high voltage in certain situations using a variety of switches. If there is an intermittent isolation fault, it is possible that the breakdown is located in one of these switched circuits.

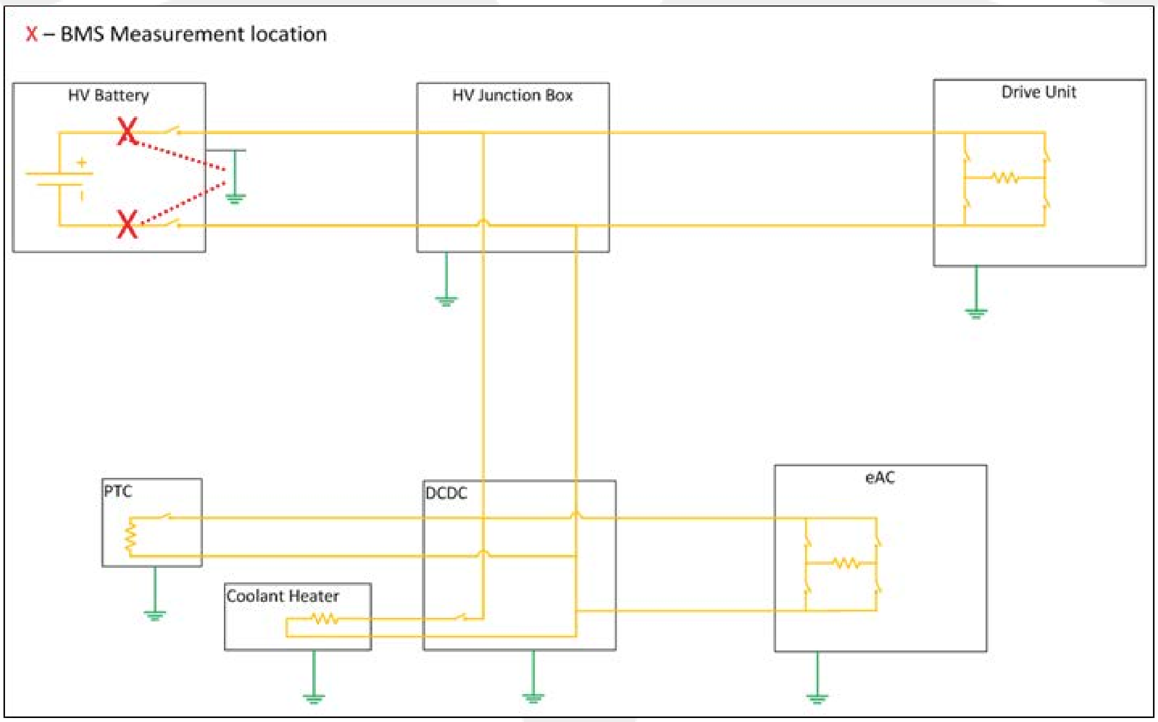


Figure 2

Required Equipment

WARNING: Always use high voltage gloves and personal protective equipment (PPE) when handling any high voltage component.

WARNING: High voltage gloves must be replaced every 6 months. Verify the certification expiration date on your gloves has not expired before each use. Refer to SB-12-92-005, High Voltage Gloves Inspection and Maintenance, for additional verification and replacement procedure information.

Required Equipment:

- Fluke 1507, 1587, or equivalent, set to Insulation and 500 VDC (Figures 3 and 4)

Figure 3 (Fluke 1507, set to 500V, positive lead connected to insulation jack)

Figure 4 (Fluke 1587, set to 500V, positive lead connected to insulation jack)

- CLASS III (1000 V / 10 A) rated probing leads (Figure 5)

Figure 5

- Properly rated HV Gloves
- A laptop with the latest version of Tesla Diagnostic System (TDS) loaded
- Diagnostics Cable (Tesla P/N 1013230-00-A)
- ~~DCDC plug~~ (not available yet)
- KET Dummy Plugs for DCDC HV Connectors (Tesla P/N 1025041-00-A) (Figure 6)

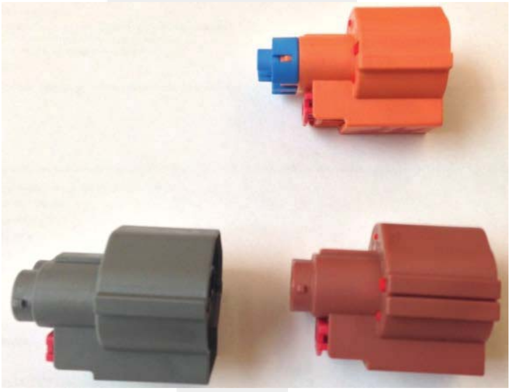


Figure 3

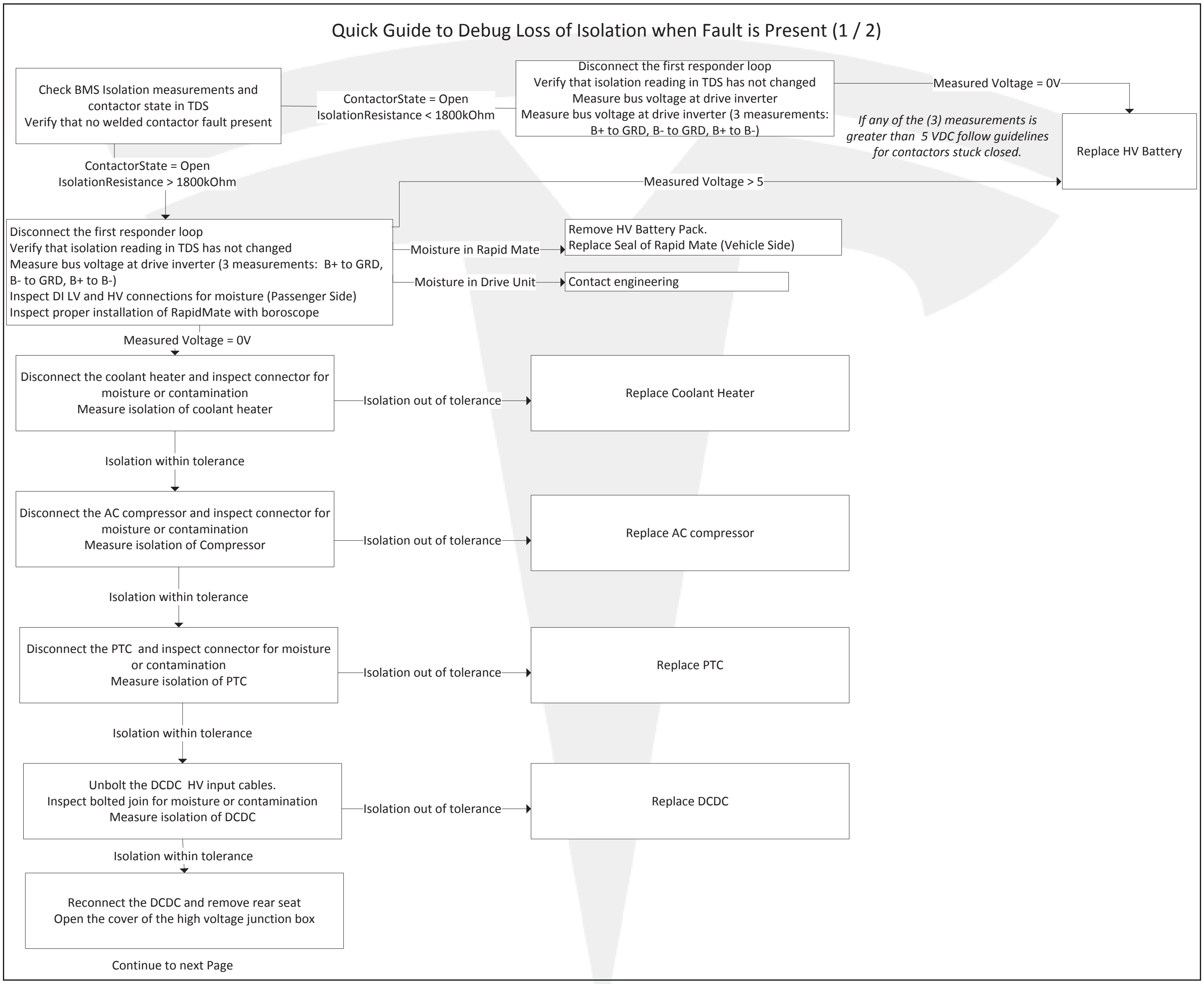
Check your high voltage gloves for damages, scuffs, and air retention prior to starting any work with high voltage. If your HV gloves no longer retain air, do not use them. For more information, refer to Service Bulletin SB-12-95-005.

Confirm that both the meter and the probing leads are rated for high voltage. Do not use leads that are damaged, show signs of wear, or are not CAT III (1000V) rated (Figure 5).

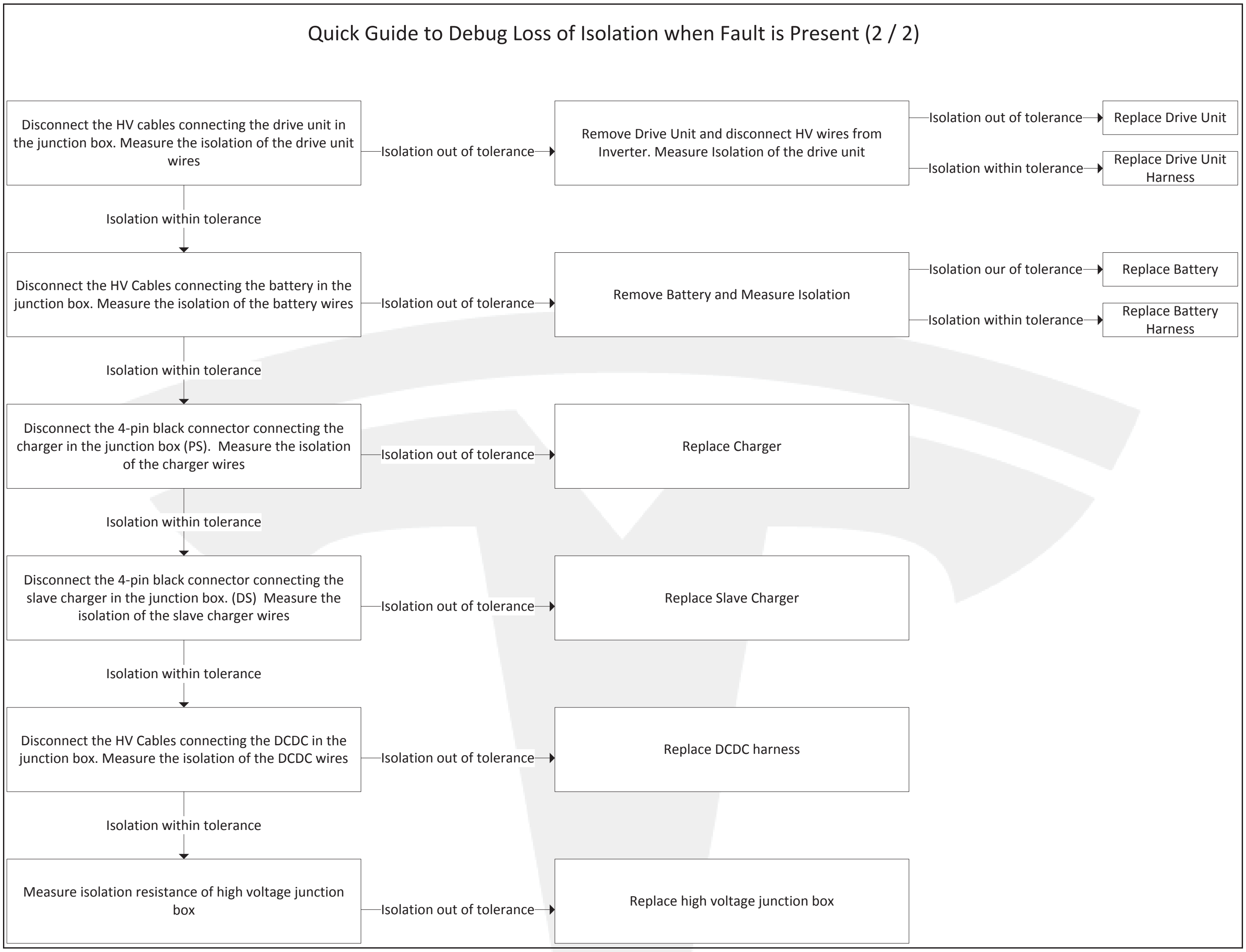
Quick Guide (When Fault is Present)

WARNING: Only technicians who have been trained in High Voltage Awareness are permitted to perform this procedure. Proper personal protective equipment (PPE) and insulating HV gloves with a minimum rating of class 00 (500V) must be worn any time a high voltage cable is handled. Refer to Service Bulletin SB-13-92-003, High Voltage Awareness Care Points, for additional safety information.

NOTE: A detailed step by step version of this procedure is included later in this document.



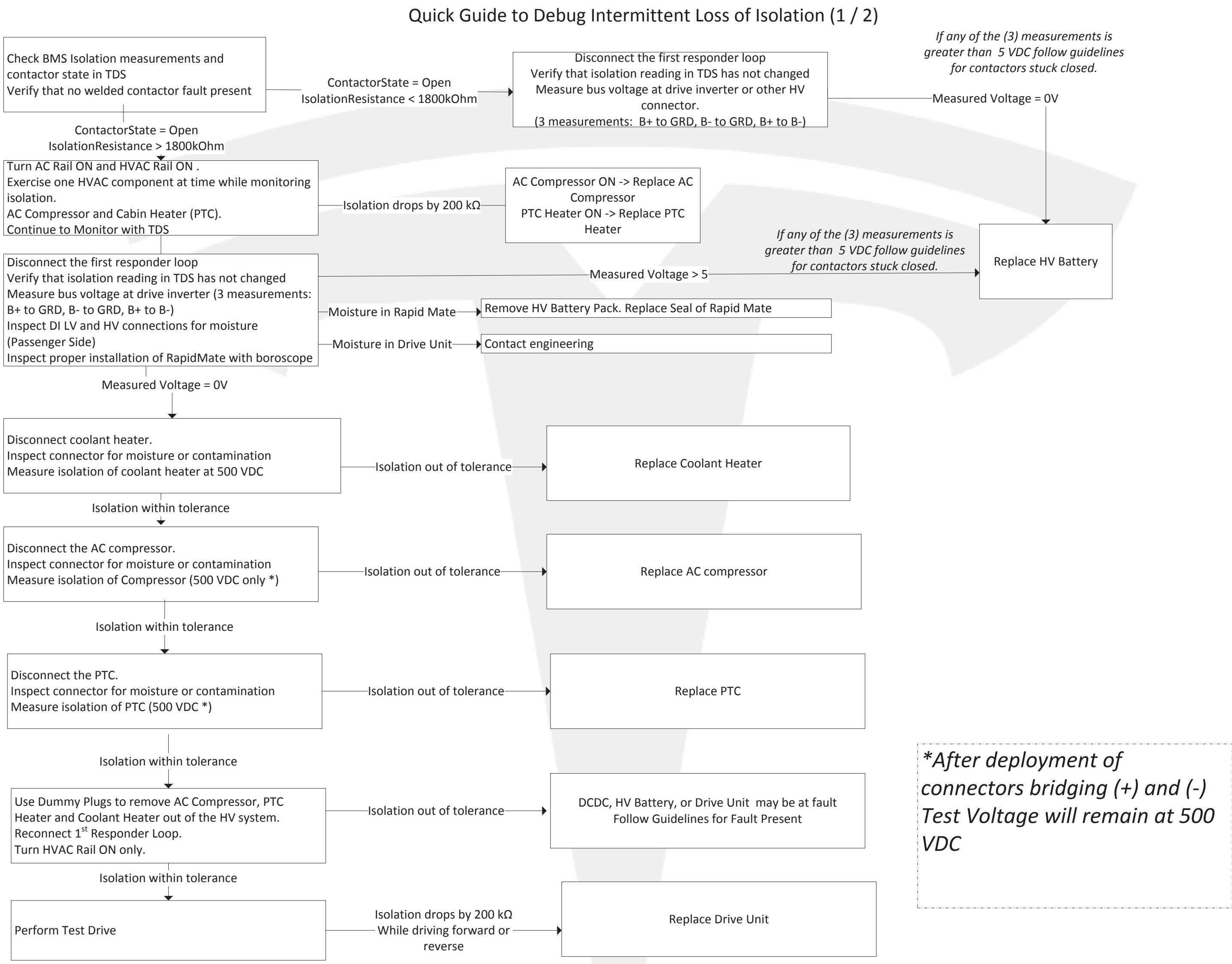
Flow Chart 1 (Quick Guide—Fault is Present, part 1 of 2)



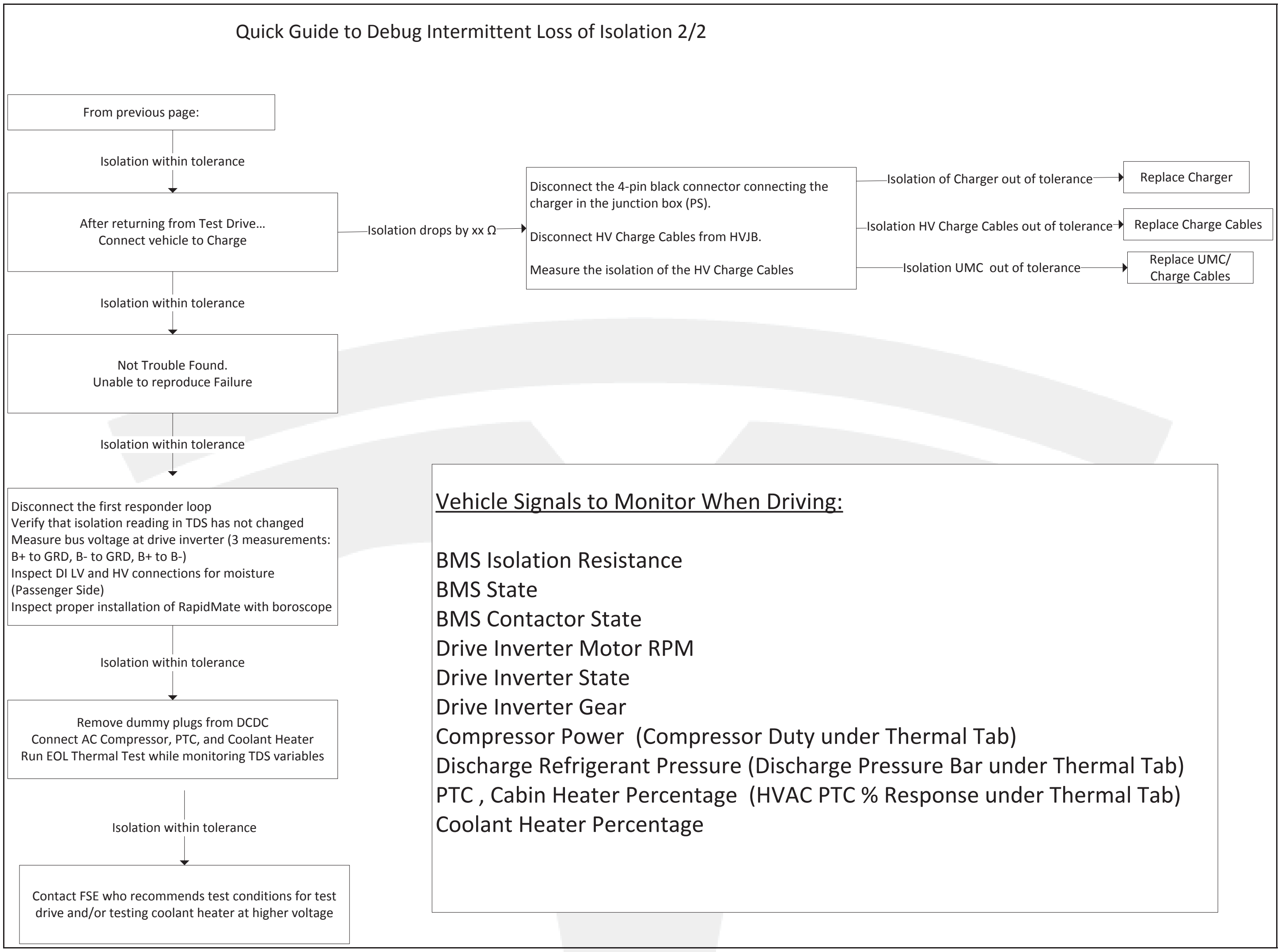
Flow Chart 2 (Quick Guide—Fault is Present, part 2 of 2)

Quick Guide (When Fault is Not Present)

WARNING: Only technicians who have been trained in High Voltage Awareness are permitted to perform this procedure. Proper personal protective equipment (PPE) and insulating HV gloves with a minimum rating of class 00 (500V) must be worn any time a high voltage cable is handled. Refer to service bulletin SB–13-92-003, High Voltage Awareness Care Points for additional safety information.



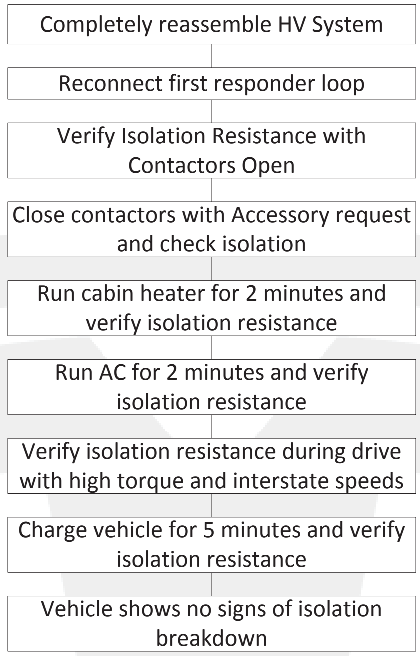
Flow Chart 3 (Quick Guide—Fault is Intermittent or No Longer Present, part 1 of 2)



Flow Chart 4 (Quick Guide—Fault is Intermittent or No Longer Present, part 2 of 2)

Quick Guide for Post Repair Final Inspection

NOTE: A detailed step by step version of this procedure is included later in this document.



Flow Chart 5 (Post Repair Isolation Inspection)

Typical Isolation Values

Values measured by TDS:

Contactor State	BMS State	Healthy Isolation Resistance
Open	Standby	> 3000 kΩ
Closed	Support	> 2000 kΩ
Closed	Charge	> 2000 kΩ
Closed	Drive	> 2000 kΩ

Values measured when individual high voltage components are probed with 500 VDC via a Fluke 1507/1587:

CAUTION: To prevent damage, set the Fluke 1507 or 1587 to 250 VDC when measuring isolation of the AC compressor and PTC cabin heater (until connectors bridging + and – are available).

Points to Measure	Expected Isolation
Cabin Heater (PTC) HV + reference to Ground (a)	> 18 MOhm
Cabin Heater (PTC) HV – reference to Ground (a)	> 18 MOhm
AC Compressor HV + reference to Ground (a)	> 10 MOhm
AC Compressor HV – reference to Ground (a)	> 10 MOhm
Battery Coolant Heater HV + reference to Ground (e)	> 18 MOhm
Battery Coolant Heater HV – reference to Ground (e)	> 18 MOhm
DCDC – reference to Ground (c)	> 10 MOhm
DCDC + reference to Ground (c)	> 10 MOhm
HVJB Cable – to Drive Inverter reference to Ground (b)	> 4.0 MOhm
HVJB Cable + to Drive Inverter reference to Ground (b)	> 4.0 MOhm
HVJB Cable – to HV Battery Rapid Mate reference to Ground (b)	> 4.0 MOhm
HVJB Cable + to HV Battery Rapid Mate reference to Ground (b)	> 4.0 MOhm
HVJB Cable – DCDC (b)	> 4.0 MOhm
HVJB Cable + DCDC(b)	> 4.0 MOhm
HVJC Cable – to Charger reference to Ground (b)	> 4.0 MOhm
HVJC Cable + to Charger reference to Ground (b)	> 4.0 MOhm
HVJB Bus Bar - to Ground	> 4.0 MOhm
HVJB Bus Bar + to Ground	> 4.0 MOhm
DC Link – reference to Ground (d)	> 3.2 MOhm
DC Link + reference to Ground (d)	> 3.2 MOhm

(a) With the component removed from DCDC and probed with 250 VDC (until connectors bridging + and – are available).
(b) With each cable removed from HVJB.
(c) With all cables removed from DCDC.
(d) With the AC Compressor, Cabin Heater, and Coolant Heater disconnected from DCDC.
(e) With the component disconnected from the DCDC.

TDS Variables to Monitor

Variable (found in Battery Isolation panel of TDS)	Where found in Touchscreen Diagnostic Mode	CAN Signal	Values / Range	Comments
BMS Isolation Resistance [kΩ]	Basic > Isolation Resistance	PT_BMS_ISOLATIONRESISTANCE	~3500 kΩ when contactors are open ~2200 kΩ when contactors are closed	This value can take 10-15 seconds to update as BMS completes this measurement
BMS State	Basic > BMS State	PT_BMS_STATE	Standby, Drive, Support, Charge, Fast Charge, Clear Fault, Fault, Charger Voltage	
BMS Contactor State	Basic > Contactor State	PT_BMS_CONTACTORSTATE	Open / Close	
Compressor Power [W]	Thermal > Compressor Duty %	THC_COMPCONSUMPTIONPWR_W	0 = Off	
Cabin Heater PTC [%]	Thermal > HVAC PTC %	PT_THC_PTCDUTYFB_PERC	0 = Off	
Battery Coolant Heater [%]	N/A	PT_THC_BATTERYHEATERPCT	0 = Off	
Drive Motor RPM [RPM]	N/A	PT_DI_MOTORRPM		
Drive Inverter State	Basic > DI State	PT_DI_STATE	PreAuth, Standby, Fault, Enable, Clear Fault	
Drive Inverter Gear	Basic > Gear	PT_DI_GEAR	P, R, N, D, Invalid	Cycle through all gears while testing.
Drive Inverter Torque [Nm]	Basic > Torque	PT_DI_TORQUEMOTOR		
Refrigerant Discharge Pressure [bar]	Thermal > Discharge Pressure Bar	PT_THC_REFRIGERANTPRESSURE		
Battery Coolant Heater Shutting Off	N/A	PT_THC_BATTERYHEATERGOINGDOWN		
Battery Coolant Heater Temp [^{0}C]	N/A	PT_THC_BATTERYHEATERTEMP		
Battery Coolant Heater State	N/A	PT_THC_BATTERYHEATERSTATE		
12V Battery Voltage [V]	12 V Battery Voltage	ETH_IBS_VOLTAGE		

Checking for High Voltage

WARNING: Only technicians who have been trained in High Voltage Awareness are permitted to perform this procedure. Proper personal protective equipment (PPE) and insulating HV gloves with a minimum rating of class 00 (500V) must be worn any time a high voltage cable is handled. Refer to service bulletin SB–13-92-003, High Voltage Awareness Care Points for additional safety information.

Depending on the failure mode, the contactors might not open as expected. Therefore, it is imperative to confirm that contactors are truly open. Without 12V contactor power, high voltage outside the HV Battery (DC Link Voltage) should be 0V. To confirm that the contactors are open, follow these steps:

1. Position the vehicle in preparation for raising it, but keep the vehicle at ground level at this time.

2. Close all doors.

3. Touch CONTROLS > DRIVING > JACK on the touchscreen to enable jack mode.

4. On the touchscreen, touch CONTROLS > E-BRAKE & POWER OFF > POWER OFF.

5. Connect a laptop running Tesla Diagnostic System (TDS) to the vehicle. Select Views > Battery > Battery Isolation. Monitor the following values:

Signal	Expected Value
BMS Isolation Resistance	> 3000 kΩ
BMS Contactor State	Open
Compressor Power	0 W
Cabin Heater PTC	0%
HVAC Rail	Off
ACC Rail	Off
Drive Rail	Off

NOTE: If TDS shows an isolation resistance reading below 3000 kOhm when contactors are shown open, the high voltage battery is faulty and needs to be replaced.

WARNING: Unless the first responder loop has been disconnected, the vehicle can go into support mode after being idle for a period of time. This can re-enable high voltage. Always disconnect the first responder loop after touching POWER OFF on the touchscreen. Failure to follow this instruction could result in serious injury or death due to exposure to high voltage.

6. Disconnect the First Responder Loop. This ensures that contactors stay open regardless of requests for 12V battery support.

NOTE: Do not remove the 12V battery negative cable.

7. Use a voltmeter to check that pin # 4 is 0 VDC with respect to chassis ground (Figure 7).

Figure 7

8. Wait at least 30 seconds to allow HV Bus Voltage to decay.

9. Raise and support the vehicle.

10. Remove the rear undershield panel (refer to Service Manual procedure 12030501).

WARNING: Proper personal protective equipment (PPE) and insulating HV gloves with a minimum rating of class 00 (500V) must be worn while performing this procedure.

11. Remove the orange drive inverter cover (Figure 8).

Figure 8

CAUTION: To prevent future water ingress, check the drive inverter cover O-rings for distortion or damage and replace as necessary. When reinstalling the drive inverter cover, insert the cover at an angle to prevent damage to the O-rings (Figure 9). Once the left (B+) O-ring is seated, rotate the cover into position.

Figure 9

12. Use the drive inverter case as a chassis ground. Measure the following voltages (Figure 10):
    - B+ to ground
    - B– to ground
    - B+ to B–

Figure 10

13. If any of the voltages are more than 10 V, the contactors are not fully opened. Refer to the stuck contactor guide to discharge the battery.

NOTE: Replace the high voltage battery if all voltages are zero and the vehicle has BMS internal isolation warnings or faults. There are failure modes (such as compromised isolation, blown fuse and damaged contactors) that could still result in 0 VDC readings in DC Link Voltages.

NOTE: If possible, discharge the HV battery before removing it from the vehicle. Use the TDS Battery Shipping pane to check if the “Ok to ship by land” or “Ok to ship by air” indicators have turned green. If necessary, reduce the battery’s state of charge (SOC) by operating the cabin heater or driving the vehicle.

Troubleshooting When the Fault is Present

NOTE: If the isolation value is currently within specifications, do not perform this procedure. Refer to the Quick Guide (When the Fault is Not Present) section at the beginning of this document.

1. Set the meter to Insulation mode and 500 VDC. (Figures 3 and 4). To test the AC Compressor and PTC Heater (Cabin Heater), set the meter to 250 VDC.

⚠ **CAUTION:** To prevent damage, set the Fluke 1507 or 1587 to 250 VDC when measuring isolation of the AC compressor and PTC cabin heater (until connectors bridging + and – are available).

⚠ **WARNING:** Do not unplug or unbolt any HV component when contactors are closed or energized.

2. Disconnect the HV battery coolant heater from the DCDC converter. Inspect the connector and DCDC for any signs of contamination or moisture.
3. Probe the B+ to ground in the connector (Figure 11) and the B– to ground. If either reading is below 18 MOhm, replace the battery coolant heater.

Figure 11

4. Disconnect the AC compressor from the DCDC converter. Inspect the connector and DCDC for any signs of contamination or moisture.

5. Probe the B+ to ground in the connector (Figure 12) and the B– to ground. If either reading is below 10 MOhm, replace the AC compressor.

Figure 12

6. Disconnect the PTC cabin heater from the DCDC converter. Inspect the connector and DCDC for any signs of contamination or moisture.

7. Probe the B+ to ground in the connector (Figure 13) and the B– to ground. If either reading is below 18 MOhm, replace the PTC heater.

Figure 13

8. Mark the positive and negative HV wires that enter the DCDC converter.

9. Disconnect the HV wires at the DCDC converter. Inspect the connectors and DCDC for any signs of contamination or moisture.

10. Measure the B+ connector side to chassis ground (Figure 14) and the B– to ground. If either reading is below 10 MOhm, replace the DCDC converter.

Figure 14

11. Reconnect the HV cables to the DCDC converter (torque - 5 Nm).

WARNING: The DCDC cables must be properly reconnected to the DCDC converter to prevent an electrical short in the next steps.

12. Remove the rear seat cushion frame from the vehicle (refer to Service Manual procedure 13023002).

13. Open the high voltage junction box lid. Inspect the inside of the junction box for any signs of contamination or moisture.

14. Mark the positive and negative HV wires that lead to the drive inverter (Figure 15).

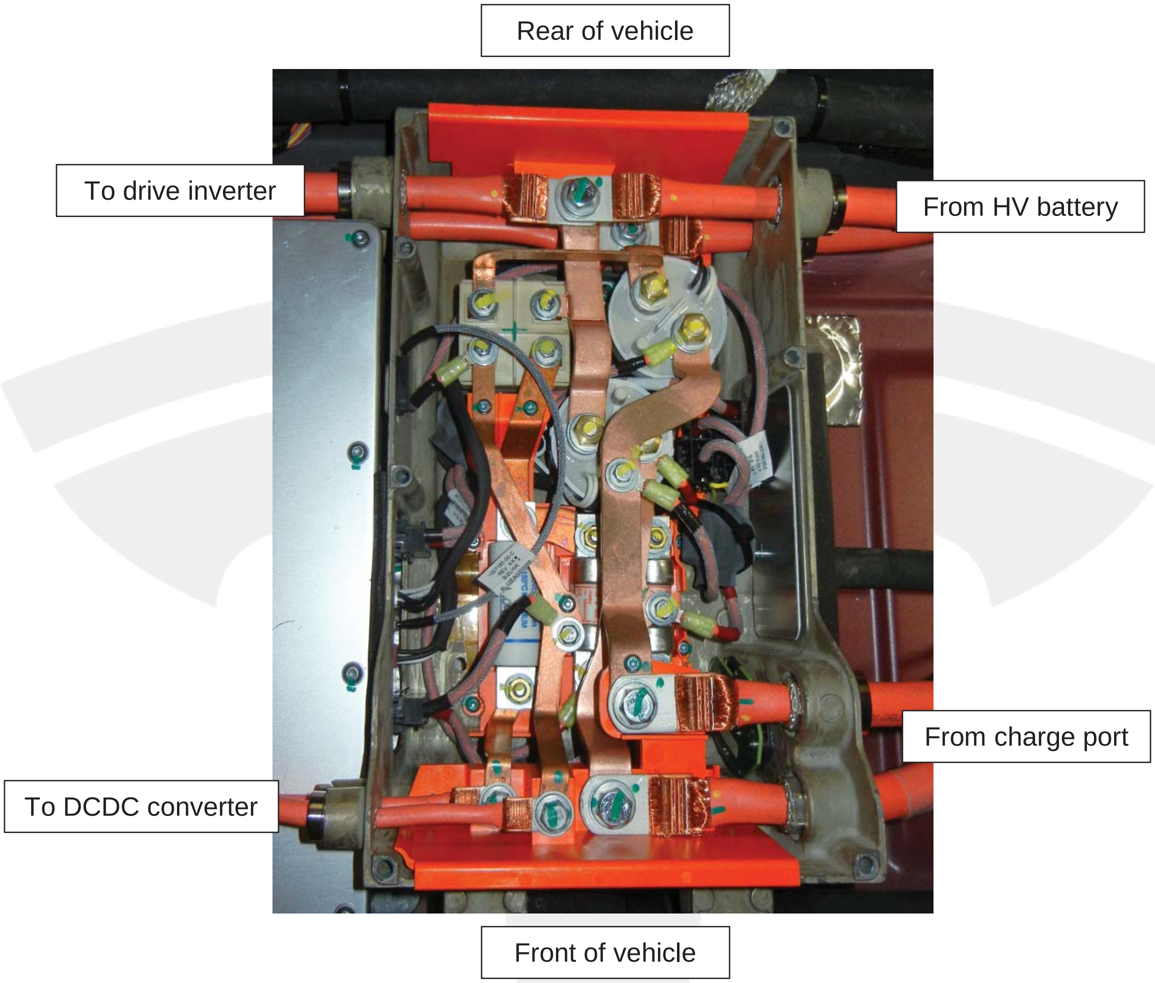


Figure 15

15. Unbolt the two wires that lead to the drive inverter. Measure the B+ wire to ground and the B– wire to ground. If both measurements are above 3.5 MOhm, skip to the next step.

    - If one or both of the measurements are below 3.5 MOhm, remove the drive unit from the vehicle and disconnect the high voltage wires from it. Measure the B+ post to the drive unit case, and the B– post to the drive unit case.
    - If the measurements are both above 3.5 MOhm, replace the high voltage harness that connects the junction box to the drive unit.
    - If either measurement is below 3.5 MOhm, replace the drive unit.

16. Mark the positive and negative HV wires that lead from the HV battery (Figure 15).

17. Unbolt the two wires that lead from the HV battery. Measure the B+ wire to ground and the B– wire to ground. If both measurements are above 3.5 MOhm, skip to the next step.

    - If one or both of the measurements are below 3.5 MOhm, use a boroscope to check for proper seating of the HV Rapid Mate (Figures 16, 17, and 18). Check for signs of wear or damage to outer skirt (Figure 19).
    - Take a picture of the HV Rapid Mate by placing your phone or camera near it. Figure 18 was taken by sliding a phone to the right-hand-side (passenger side) of the HV Rapid Mate.
    - Remove the battery from the vehicle. Inspect the vehicle side Rapid Mate connection for signs of moisture, and replace it if necessary.
    - Measure B+ to ground on the battery. Repeat the measurement for the B– side. If either of the measurements are below 2.6 MOhm, replace the HV battery. If both values are above 2.6 MOhm, replace the harness that connects the HV battery to the high voltage junction box.

Figure 16: Inner seal not fully engaged

Figure 17: Inner seal fully engaged

Figure 18: Inner Seal Not Fully Engaged

Figure 19: Example of Compromised Outer Skirt

18. Disconnect the 4 pin master charger DC link connector in the junction box. Measure B+ to ground and B– to ground. If either measurement is below 50 MOhm, replace the master charger.

19. Disconnect the 4 pin slave charger DC link connector in the junction box (if installed). Measure B+ to ground and B– to ground. If either measurement is below 50 MOhm, replace the slave charger.

20. Mark the wires that connect the DCDC converter to the junction box (Figure 15). Disconnect the wires and measure the B+ line to ground and B– line to ground. If either measurement is below 10 MOhm, replace the harness that connects the DCDC converter to the junction box.

21. Make sure that all HV cables are disconnected from the junction box.

22. Measure the B+ bus in the junction box to ground and B– bus to ground. If either measurement is below 3.5 MOhm, replace the high voltage junction box.

Final Inspection

1. After replacing the faulty component in the system, reassemble the high voltage system completely and remove the dummy plugs from the DCDC, if installed.

⚠ **WARNING:** Ensure that all high voltage joints are properly torqued before connecting the first responder loop. Refer to the Service Manual for proper torque specifications.

2. Reconnect the first responder loop.

NOTE: Do not sit in the driver's seat yet.

3. Verify on the TDS that with the contactor state open, the isolation resistance is above 3000 kOhm.

NOTE: Do not step on the brake pedal yet. The drive rail must be off for the next steps.

4. Sit in the driver's seat to turn on the accessory rail. Verify that the isolation resistance decreases, but remains above 2000 kOhm with the contactor state closed.

5. Set the driver and passenger HVAC controls to high to activate the PTC cabin heater.

6. Allow the PTC cabin heater to run for 10 minutes. Verify with the TDS that the isolation resistance remains above 2000 kOhm.

7. Set the driver and passenger HVAC controls to low to activate the air conditioner compressor.

8. Allow the A/C compressor to run for 10 minutes. Verify with the TDS that the isolation resistance stays above 2000 kOhm.

9. If available, connect a Memorator or equivalent data logging hardware and test drive the vehicle. Include multiple high torque accelerations and several minutes of interstate speed driving.

10. Review the traces from the Memorator or data logging hardware. Check that the isolation never dropped below 2000 kOhm.

11. Charge the vehicle for 10 minutes. Verify that the isolation resistance never drops below 2000 kOhm during charging.

Vehicle Side HV Rapid Mate/HV Battery Replacement Guidelines

Replace the vehicle side HV Rapid Mate if:

- The vehicle side HV Rapid Mate is deformed (thermal damage, kinks, plastic deformation, torn edges)
- There is water ingress, but there is evidence that vehicle side HV Rapid Mate was seated properly.
- There are signs of arcing, corrosion, or contaminants.
- The blade surface areas are pitted or abraded.
- There is evidence of heavy arcing.
- There is clear evidence that debris and moisture ingress resulted from a faulty vehicle side Rapid Mate and not improper installation.

Do not replace the Vehicle Side HV Rapid Mate if:

- The blades can be cleaned non-abrasively.
- There are mild arcing and carbon traces that can be cleaned with a soft cloth.
- The root of the terminal blade is pitted due to arcing.
- There are high spots on the root of terminal blade that can be filed to prevent excessive insertion force.
- Inspection confirms that vehicle side Rapid Mate was clearly not properly seated, and the perimeter is not damaged, and there are no signs of corrosion or contaminants.

Replace the HV Battery if:

- The troubleshooting guides show that loss of isolation is internal to the battery.
- The battery side Rapid Mate has sufficient deposits or corrosion.
- The battery side Rapid Mate is damaged (i.e. plastic deformation).
- The battery side Rapid Mate shows signs of discoloration.

Do not replace the HV Battery if:

- There is mild arc damage where carbon traces can be cleaned away. Wear high voltage gloves and eye protection while blowing away deposits and debris carefully with compressed air.

Figure 20 shows the perimeter seal that prevents debris from entering the HV connections and the inner seal that prevents water intrusion. The pen is pointing to the perimeter, which shows deformation and requires vehicle side Rapid Mate replacement.

Figure 21 shows signs of moisture in the battery side HV Rapid Mate that resulted in loss of isolation. The moisture was observed close to the seal. This condition can be repaired by drying out the moisture and cleaning any debris.

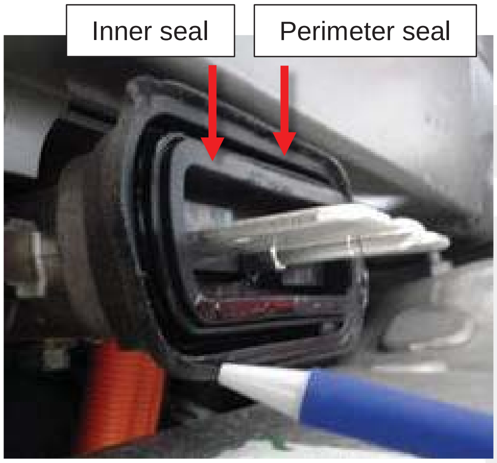


Figure 20 (Deformed vehicle side Rapid Mate perimeter seal)

Figure 21 (Water in battery side Rapid Mate)

In contrast, Figure 22 shows gross contamination in the HV Rapid Mate (Battery Side) that resulted in loss of isolation. In this case the HV Battery was replaced. The vehicle side Rapid Mate shows arcing and corrosion and was also replaced (Figure 23).

Figure 22 (Arcing and corrosion on vehicle side Rapid Mate)

Figure 23 (Significant amount of water in battery side Rapid Mate)