Quarto Technical Services

TECHNICAL REPORT

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Technical Report on the Application of Auto Saver Systems to Operate on Vehicles Equipped With Vehicle Electrification Systems

Introduction

This report was commissioned by Auto Saver Systems, Inc. to determine if their Electronic Corrosion Protection (ECP) devices will impact the operation of the Isolation Detection Systems that are required on Vehicle Electrification (VE) products. The VE product categories include Hybrid, Plug-In, Electric, and Fuel Cell vehicle products.

Research Statement

Do either the Auto Saver battery-connected ECP or On-Board Diagnostic (OBD) Diagnostic Link Connector (DLC) ECP devices impact the operation of a Hybrid or Electric Vehicle Loss of Isolation (LOI) Detection System?

Research Questions

The research questions posed by Auto Saver Systems, Inc. to be addressed by this report are:

1. Could the Auto Saver battery-connected or OBD DLC ECP Module units interfere with a hybrid or electric vehicle's isolation barrier or create an LOI between the high voltage system of the vehicle and the chassis?

2. Could the Auto Saver battery-connected or OBD DLC ECP Module units impair a hybrid or electric vehicle's LOI monitoring?

3. Are there any other similar risks associated with using the Auto Saver battery-connected or OBD DLC ECP Module units on a hybrid or electric vehicle?

Discussion

The Isolation Fault Detection system is designed to determine if there has been a loss or reduction of insulation resistance barrier between the High Voltage (HV) bus. The HV bus is defined as the positive and negative power bus that connects and electrically powers all high voltage components. All components connected to the HV bus are electrically isolated from the vehicle chassis and body. However, these HV components are mounted to the body. An isolation barrier is defined as the resistance or impedance barrier that isolates the HV bus from the vehicle chassis or body. This barrier is necessary to ensure that any leakage of HV to the vehicle body or chassis remains at a safe level for any person operating, diagnosing or, servicing a HV system. The discussion in this paper focuses on whether the battery-connected or OBD DLC connected ECP Modules will effect the resistance/impedance barrier between the HV system and the vehicle body.

The energy of the HV bus must remain isolated from the body and maintain the minimum insulation resistances outlined in the Federal Motor Vehicle Safety Standard (FMVSS) 305 [1] [2] and the Society of Automotive Engineers (SAE) Standard J1766 [3]. Depending on applying the standards if, the Isolation Detection System does not use a monitor (visual indicator) the required minimum resistance barrier is 500Ω/Volt when monitoring the high voltage component resistance (or impedance) to the chassis. If a monitor is used then, the minimum requirement for LOI detection is 100Ω/Volt. There are also specific electronic control units (ECU) that are powered by the low voltage (12 volt) system but, monitor or control the HV system that, can effect the resistance value of the isolation barrier. Therefore, these electronic modules are considered to be part of the HV control system and would (electrically be considered a) HV component by the LOI Detection System. The power inverter and battery pack controllers are examples of 12 volt controllers that directly interface with HV components and the HV bus. Although these components may isolate the 12V chassis from the HV system using opto-isolators or a dc-dc converter integrated circuit, a failure of an opto-isolator or converter device can lead to an isolation fault condition.

When the HV components are mounted on the chassis, they are electrically in parallel with the chassis. Therefore, the total resistance of the HV bus is a reciprocal sum of all resistances. For the vehicle to remain at a safe operating (resistance/impedance) level, this total parallel resistance sum must be greater than the FMVSS-305 and/or the SAE J1766 requirements. A total parallel resistance that is less than the requirement specification violates the requirement and the isolation fault system would report an Isolation Fault in the system (i.e., HV energy is "leaking" to the vehicle chassis).

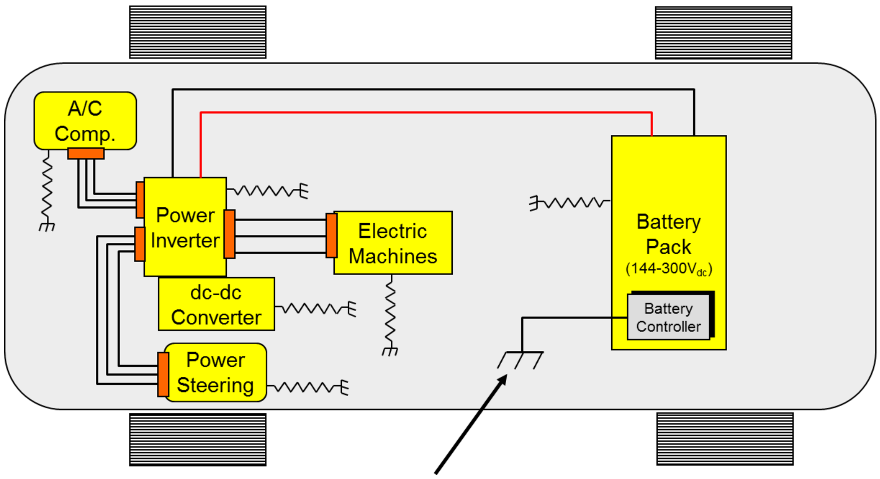


Figure 1: HV Component Resistances vs. Vehicle Chassis

There are numerous HV component failures that can cause an Isolation Fault condition. Some of these failures would be battery pack cell electrolyte leakage, electric machine insulation aging, or any number of other electronic component failures – any of which will permit HV energy to contact the vehicle chassis.

Isolation Fault System Operation

The vehicle HV Isolation Fault Detection circuit uses two methods to monitor the chassis for a HV fault: 1) Direct Current (DC) Passive System, and 2) Alternating Current (AC) Active System [4] [5]. The DC system operates only when the vehicle HV system has been powered ON and is operating. The AC system operates only when the vehicle has been powered OFF and the HV system is no longer in operation.

DC Isolation Detection Circuit Operation

The DC Isolation Fault Detection System consists of a Resistor Network, typically two (2) series connected resistors of approximately one megohm resistance (1MΩ). From a summation point of view, the DC system provides a simple gross insulation resistance measurement that continually measures the resistance between the HV system and the vehicle chassis anytime the HV system is operating.

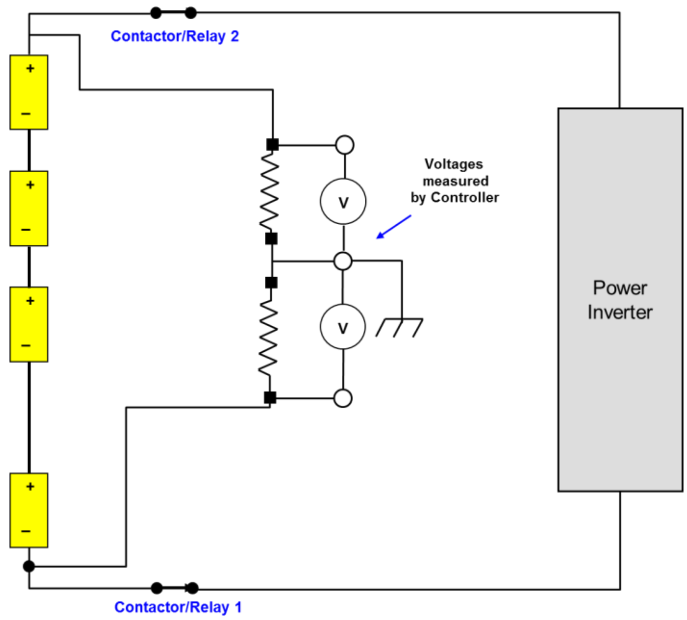


Figure 2. DC Passive Isolation Fault Detection System

The DC Passive Isolation Fault Detection System is a "hard wired" (typically via a HV component) connection across the DC HV bus. When the system is operating within parameters there will be an equal voltage drop across the two (2) series connected resistors. For example, if the battery pack voltage is $300V_{dc}$ the voltage drop will be balanced (equal) across both resistors (i.e., $150V_{dc}$ drop across each resistor). When there is a lowering of resistance (whether on the Negative or Positive rail) due to an Isolation Fault, the faulty component or area of the system will cause an imbalance by altering the total resistance of the circuit, and cause a resistance imbalance between the two series resistors.

To determine if there is an imbalance in the system, the Battery Controller would acquire this voltage drop data by measuring the voltage drop across the series connected resistors, and use the center point between the resistors as the ground reference point for the measurement.

The calculation for determining loss of isolation in a DC circuit is a simple calculation based on the entire battery pack voltage (V_{pack}) and the battery pack mid voltage point ($V_{mid\text{-}p}$). If the battery pack voltage = 300V then, the mid-point is 150V. If the Battery Controller senses voltage that is ≤ the FMVSS-305/SAE J1766 level or, ≤ the voltage threshold calibration level set in the diagnostic software (e.g., a conservative calibration = 185kΩ) for the $300V_{dc}$ example then, the system would log a diagnostic fault.

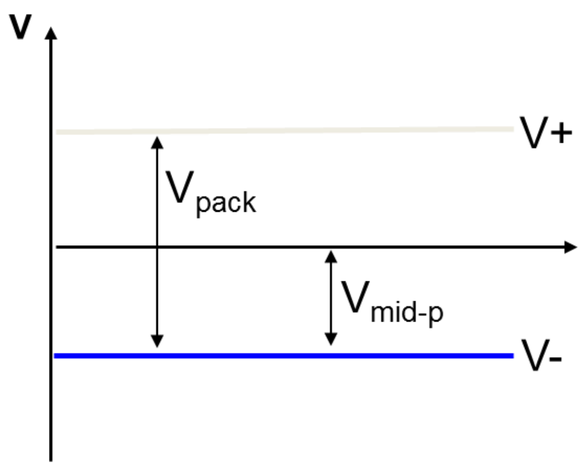


Figure 2a. DC Passive Isolation Fault Basic Diagnostic Threshold

$$\frac{2 * V_{mid\text{-}p}}{V_{pack}} \begin{cases} > 1.8 = \text{LOI Fault} \\ \text{Normal Operation} \\ < 0.2 = \text{LOI Fault} \end{cases}$$

Figure 2b. DC Passive Isolation Fault Threshold Calculation Example

Vehicle specific software algorithms and filtering would typically be set to a more conservative (higher resistance calibration) that determines when the threshold has been breached. The upper and lower threshold boundaries are set as variables in the diagnostic software and can be calibrated. Timing in how the diagnostic is set, and the diagnostic sampling rate, is also a variable that can be set in the software. As an example, the DC Isolation Fault Detection diagnostic software system may use a 30 – 60 second loop time, coupled with a sample rate of 5 samples/min. This type of software loop and algorithm timing could be used to ensure that the diagnostic is not over-sensitive (e.g., under sampled), causing a diagnostic trouble code (DTC) log in the controller if, an intermittent/anomaly condition is encountered by the diagnostic software.

AC Isolation Detection Circuit Operation

The AC Isolation Fault Detection System (not used in all vehicle models) is primarily designed to determine if there is an Isolation Fault in the HV Battery Pack by using an impedance measurement. Fundamentally, the controller will be measuring the impedance difference between the body, and a calibrated reference value. Note (in Figure 3) that when the vehicle is powered OFF the HV Contactors (Relays) are open and the AC sine wave signal will be injected (through the RC network) into the HV Battery pack module or cell string.

The AC Active Isolation Fault Detection System consists of a complex system residing in the Battery Controller consisting of a sine wave generator, amplifier system, and a series resistor-capacitor (RC) circuit. The AC detection circuit only operates after all vehicle systems have been powered OFF. The AC detection circuit can operate for up to 20 minutes after the vehicle has been powered OFF. The long operation of the circuit is necessary to ensure that enough quality samples are acquired in an electrically quiet vehicle system to determine the Impedance (Z) of the Battery Pack system. The impedance measurement (measured in Ω) is accomplished by using a complex impedance measurement equation:

$$Z = \sqrt{R^2 + (X_C + X_L)^2}$$

Figure 2c. Impedance Equation

The elements of the Impedance Equation that permit the solution for solving resistances in AC circuits is:

1. R = DC Resistance

2. X_C = Capacitive Reactance
3. X_L = Inductive Reactance
4. Z = Impedance

The AC Isolation Fault system circuit will measure the total Z of the circuit and the battery pack string. One of the major reasons that an AC system is used to detect a HV Battery Isolation Fault condition is that, it is difficult for a DC system to sense impedance changes between the Battery Pack and the vehicle chassis, due to the battery pack capacitances. Moreover, it would be nearly impossible for the DC Isolation Detection circuit to sense if there were an Isolation fault in a component (Battery Pack) that is highly capacitive, as the DC signal would not be effective in a capacitive circuit (i.e., DC signals block electrical current after the circuit is charged). The structure of a battery cell can be seen in the electrical representation. The Warburg and Randles Models [6] (adapted for Nickel Metal Hydride and Lithium Ion battery technologies) provide an equivalent electrical model that illustrates how the double-layer capacitance of a battery cell impacts the battery cell circuit. These models weigh heavily in how a diagnostic circuit would need to be designed for determining whether or not there was a reduction of impedance between the battery pack module/cell string and chassis ground.

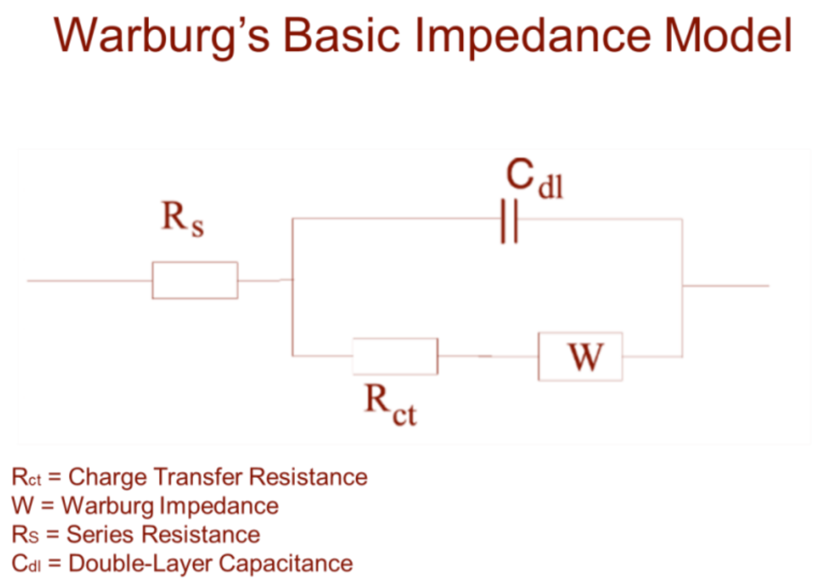


Figure 3. Warburg's Basic Battery Cell Impedance Model

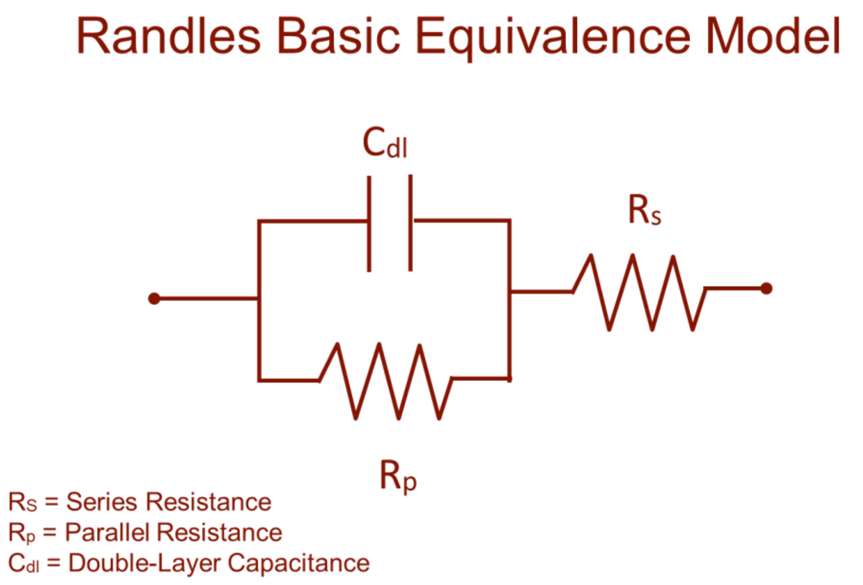


Figure 4. Randles' Basic Battery Cell Equivalence Model

The representative circuit provided (reference Figure 3) indicates that a sine wave of less than $5V_{ac}$ at a low Hertz (Hz) frequency (i.e., 2.5 Hz) is injected into a Unity Gain amplifier.

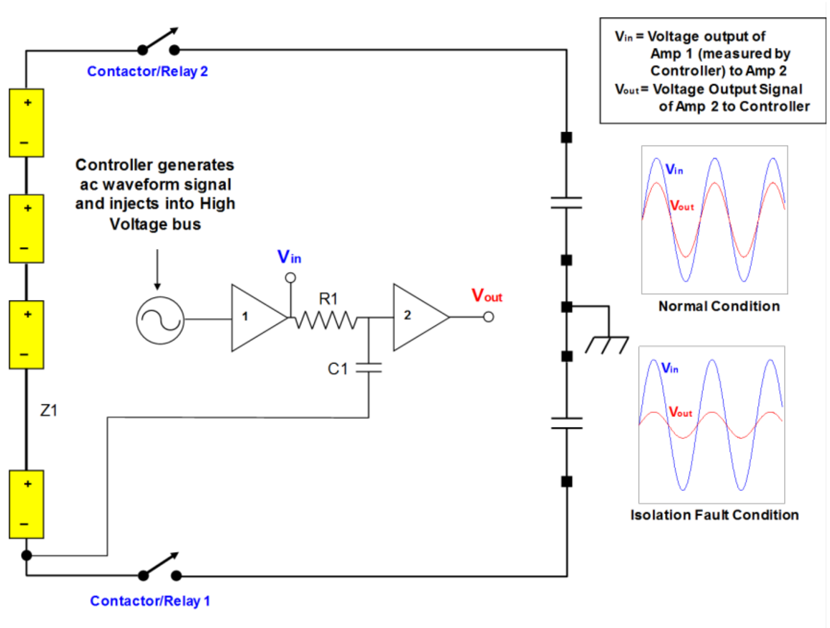


Figure 5. AC Active Isolation Fault Detection System

The low Hz is used to minimize the effects of X_C, any X_L of the Battery Pack, and ensure high frequency noise is rejected by the electronic filtering in the sensing system. Thus, a $5V_{ac}$ results at the output (V_{in}) of the amplifier. This output of the first Unity Gain amplifier (indicated by the Blue AC waveform) will be used as a reference waveform by the controller. The output of the first Unity Gain amplifier will be transferred into the second Unity Gain amplifier with a parallel branch to the RC network and Battery Pack. As the $5V_{ac}$ signal is transferred to the RC circuit and Battery Pack, the Z of the Battery Pack will determine the amplitude of the signal that is transferred into the second Unity Gain amplifier. Example: A Battery Pack with an Isolation Fault will have low Z (with respect to the vehicle chassis) that will result in low amplitude signal to the second Unity Gain amplifier. A Battery Pack with no Isolation Fault would result in a very high Z and have less effect on the sine wave output of the second Unity Gain amplifier. The output of the second Unity Gain amplifier is represented by the Red sine wave in representative circuit. At the output of the second Unity Gain amplifier is V_{out} that is transferred to the Battery Controller. The Battery Controller will compare the Blue (reference) waveform from the first Unity Gain amplifier to the varying Red output waveforms from second Unity Gain amplifier and determine if a diagnostic voltage threshold has been breached to log a DTC.

From a summation point of view, the AC system has significantly more measurement granularity, when compared to the DC system. The AC Active Isolation Fault system will only operate after the HV and Low voltage (LV) system have been powered OFF which, will permit a more refined (electrically quiet) measurement system. The AC Isolation Fault System can also be used to determine if there is an Isolation Fault in other systems (i.e., Power Inverter, Electric Transmission, Electric Air Conditioning Power Inverter/Compressor, etc.). This is accomplished by closing one of the HV Contactors and injecting the sine wave signal onto the positive (or negative) HV bus to measure the Z of other electronic components. The use of the AC Active Isolation Fault circuit is applied by closing the Positive or Negative contactor (i.e., K2 or K1) and inject the AC sine wave onto the Positive or Negative HV bus (or both) to test individual HV components.

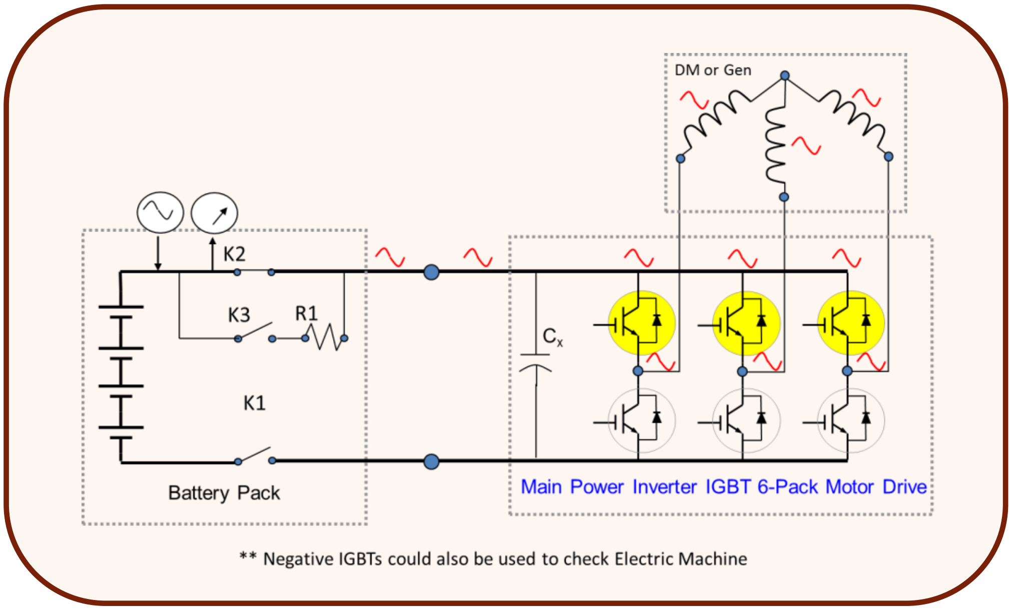


Figure 6. AC Active Isolation Test for Electric Machines

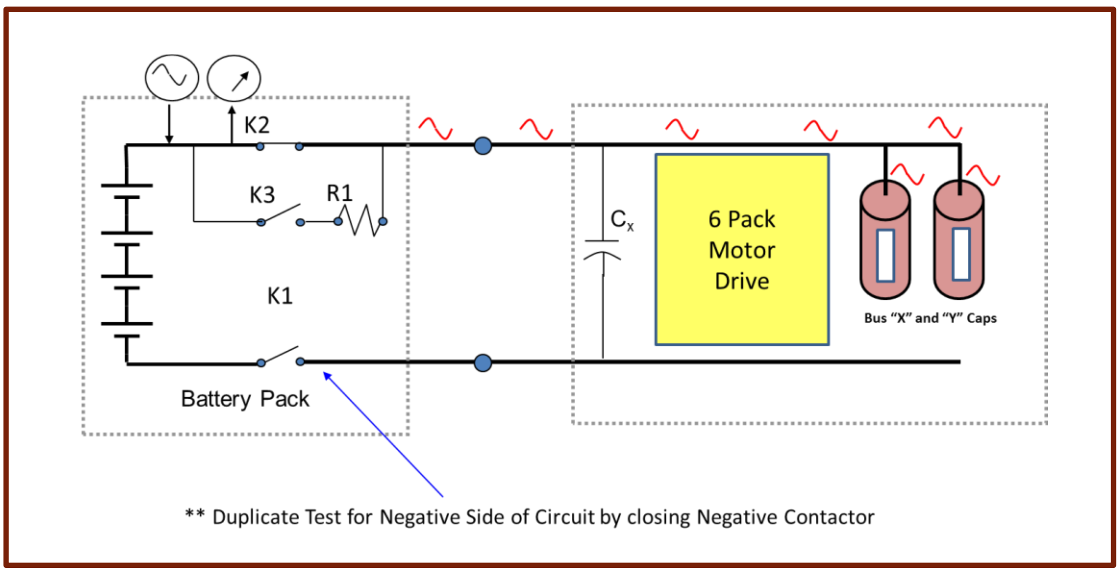


Figure 7. AC Active Isolation Test for Power Inverter System

The individual HV components can be tested with the responsible controller commanding the power electronics or power transistors ON (i.e., IGBT), whether by the high or low side power switching that, will permit the sine wave to be transmitted into the component. The AC Detection circuit will measure the impedance of each circuit for its resistance barrier between the HV bus and vehicle chassis. Whether the component is an electric machine in a transmission, power inverter, DC-DC converter, air conditioning compressor, etc., this method can be utilized. Although using the AC Isolation Fault Detection method for components external of the Battery Pack is utilized (in some form) by the majority of vehicle electrification models currently in service, it is a diagnostic utilized by OEMs and must be comprehended when considering how the ECP Modules may effect it.

AC Isolation Detection Electronic Circuit

The AC Isolation Detection electronic circuit is a mix of active and passive components, coupled with subsequent software algorithms to “scrubb” (analyze) the analog data transmitted from the electronic circuit.

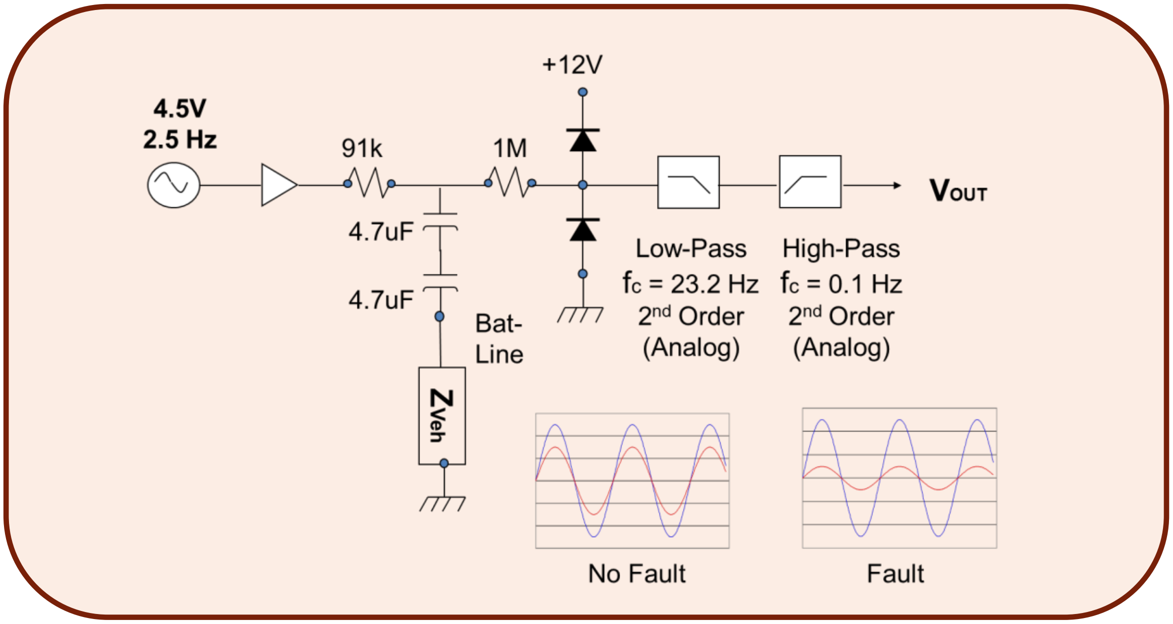


Figure 7. Representative AC Active Isolation Fault Electronic Circuit

The (representative) electronic hardware circuit contains the following elements:

1. $4.5V_{ac}$ @ 2.5Hz sine wave generator
2. Unity Gain Amplifier
3. Series connected 91kΩ and 1MΩ resistors
4. Two (2) Capacitors rated @ 4.7µF connected to the 91kΩ resistor represents an RC circuit that is connected to the HV Battery (i.e., Bat-Line)
5. Z_{Veh} represents the Impedance of the HV Battery Pack and Vehicle

6. Two (2) Rectifier Diodes are connected in parallel with the input section of the circuit, and in series represent transient protection for the circuit.

7. The resulting sine wave from the RC network and Z_{Veh} Impedance is transferred into a Second Order Low Pass Analog Filter with a Corner/Cutoff (f_C) Hz = 23.2 Hz. After the signal is transmitted through the Low Pass Filter, it is transmitted into a Second Order High Pass Analog Filter with a Corner/Cutoff (f_C) Hz = 0.1Hz. Using the Low and High Pass Filters ensures only the sine wave signal (without extraneous noise or signaling) is passed to the software for processing.

8. After the Filtering has been completed, the signal is then transmitted **OUT** to the software for algorithmic processing to determine if the Battery Pack Z is within the calibration thresholds designed for the vehicle HV system. The algorithm will compare the Reference (Blue) sine wave amplitude to the signal OUT from the signal filtering to determine if the Battery Pack Z has a Fault or No Fault.

Auto Saver Electronic Corrosion Protection Device

The Auto Saver Electronic Corrosion Protection (ECP) Device is an auxiliary electronic unit that is designed to retard the natural corrosion of a motor vehicle body by using electrical currents at a specified frequency as outlined in the ECP Module patents [7] [8]. The ECP Modules connection to the vehicle uses one of two methods: 1) via a direct connection to the vehicle 12 volt battery (battery-connected ECP Module unit) and connections to the vehicle body or 2) connect to power, ground, and vehicle body via the OBD2 Diagnostic Link Connector (DLC). The battery-connected ECP Module acquires both positive and negative electrical power via a direct 12 volt battery ring terminal connection and operates continually unless it is disconnected or the 12 volt battery is removed. The ECP Module DLC connected unit uses Pin 4 (Signal Ground), Pin 5 (Chassis Ground), and Pin 16 (Battery Positive) for connections to electrical power, and also uses the DLC for connection to the vehicle body. Connections to the vehicle body are necessary for the ECP Module to inject currents that will electrically mitigate corrosion migration.

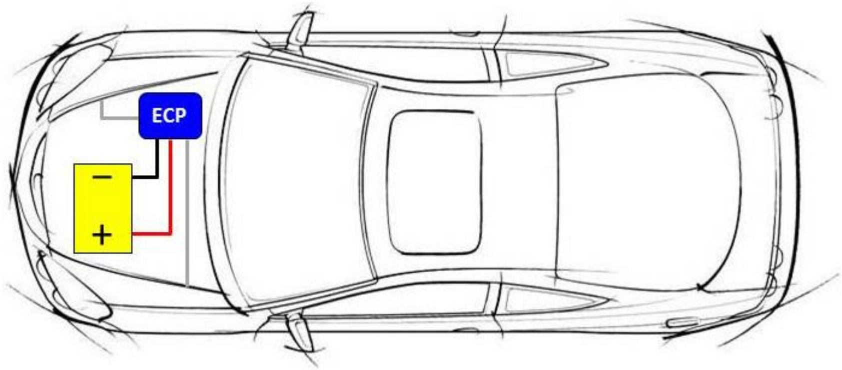
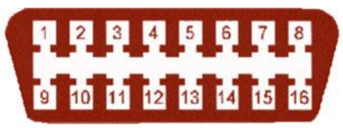


Figure 8a. Auto Saver, Inc. battery-connected ECP Module electrical connections

OBD2 CONNECTION TERMINALS



1. Blank
2. J1850 Bus +
3. Blank
4. Chassis Ground
5. Signal Ground
6. CAN (J-2234) High
7. ISO 9141-2 K-Line
8. Blank
9. Blank
10. J1850 BUS
11. Blank
12. Blank
13. Signal Ground
14. CAN (J-2234)Low
15. ISO 9141-2 Low
16. Battery Power

Figure 8b. OBD2 DLC

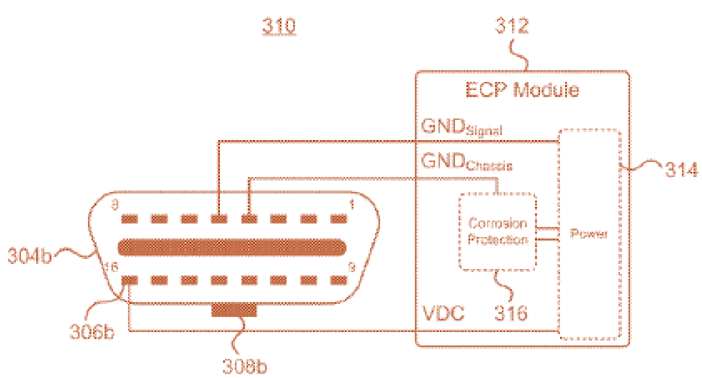


Figure 9. Auto Saver Inc. ECP OBD2 DLC Electrical Connections

The technical specifications utilized in this technical paper for purposes of how the battery-connected and DLC connected ECP devices [9] [10] units interface with the Active and Passive LOI Detection System are as follows:

Traditional Impressed current application:

1. Nominal Electrical Power Requirement: 12.00V
2. Constant Output Current: 24mA

Pulsed current application:

1. Nominal Electrical Power Requirement: 12.00V
2. Peak Output current: 50 mA
3. Pulse Frequency: 20 Hz
4. Average current Output: 0.6 mA
5. Example Pulse Waveform output injected onto a 1Ω (one ohm) vehicle body resistance is an alternating positive and negative going DC pulse.

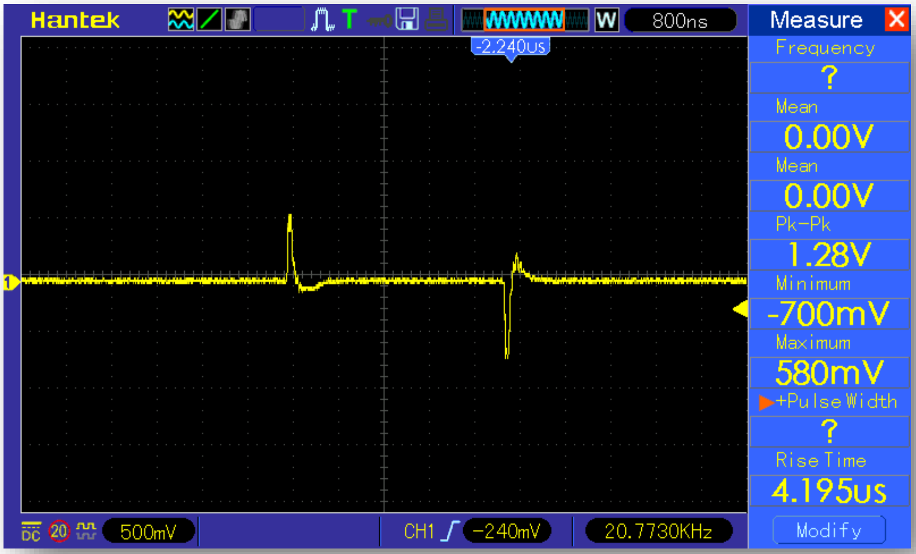


Figure 10. Auto Saver ECP output pulse waveform

From the perspective of the OBD DLC connected ECP Module, current is connected to Pin 4 of the DLC for routing to the vehicle body On a traditional or VE product the DLC (grounding pin) is typically routed (to a web of ground connections) by the main vehicle grounding harness. Therefore, there is no single grounding circuit for the DLC as its ground signals would be routed onto the entire ground plane of the vehicle electrical system. The same thought would be applied to Pin 16 (Battery +) connection. Pin 5 of the DLC is allocated for Signal Ground. An excerpt from SAE Standard J1962 [11] specifies Pin 5 as follows:

> *"6.3.4 Vehicle Connector Contact 5*
> *Vehicle connector contact 5 is designated signal ground and shall be implemented in the vehicle connector in such a way as to provide a ground reference for the communication transceivers in external test equipment and as a possible power ground for test equipment taking current as in SAE J1978."*

The SAE J1978 Standard [12] specifies OBD2 Scan Tool requirements and thereby, would govern (with SAE J1962) how Pin 5 of the DLC is utilized by off-board equipment. Since the ECP is not specified as original equipment for the vehicle, it would be considered auxiliary or off-board equipment connected to Pin 5. Therefore, the ECP Module uses a ground pin on the DLC that is specifically allocated to grounding signals for electronic module transceivers and is not considered a traditional "ground" termination point for electronic/electrical equipment [13].

6. The OBD DLC ECP module is powered and electrically connects only to 12 volt vehicle system via the DLC. Therefore, it has no connection to the HV power bus or any of the HV components that would effect the impedance/resistance barrier value between the HV system and the vehicle body. Its operating impedance (resistance) is 433Ω.

Interfacing the ECP Module with the Vehicle Isolation Fault Detection Circuits

The battery-connected and OBD DLC ECP are low power, mid-to-high Hz module (pulsed current application). From the perspective of ECP Module interface operation with the vehicle Isolation Fault Detection System, both the battery-connected and OBD DLC units will be discussed (treated) as one interchangeable interface from the electrical/electronic perspective. When a VE product has been powered ON, the ECP Module operation would be considered negligible in usage of electrical power resource, and/or the injection of electrical noise onto the vehicle body. The small ECP signal on the vehicle chassis would be negligible or inconsequential, due to the scores of other electrical signals utilizing the body as the ground for the circuits. Additionally, when the VE system is powered ON, only the DC Passive Isolation Fault Detection circuit is operational. The DC Passive circuit operates on a more rudimentary (passive) resistor network technology circuit (when compared to the AC Active circuit). The DC Passive circuit measures voltage on a more gross (DC) scale by measuring the total Battery Pack voltage drop across a high resistance (two resistor) network. Fundamentally, the DC Passive circuit contains no active electronic components that would be effected by inductive or capacitive changes. Higher fidelity (i.e., more sensitive) signal measurements are not within the design or operating purview of the DC Passive circuit. Since Passive component operation is not effected by frequencies, and do not effect phase angles, the DC system is very stable as a Battery Pack isolation fault detection circuit.

However, when the VE product has been powered OFF, there could be interactions between the ECP Module and the AC Active Isolation Fault Detection electronic circuit. Since the AC Active system utilizes active electronic components and is designed to operate in a closed loop (i.e., primarily to test only the Battery Pack) in an electrically “quiet” environment, noise that is placed on the chassis could interact with the AC Active system. However, this is dependent on how the AC Active system filtering is designed and how easily the ECP signal can be acquired and processed by the AC Active system. This could be predicated on the proximity of where the ECP injection point is to the Battery Pack and other HV components. When the vehicle is powered OFF the design of the ECP Module would be a continued injection of its signal onto the vehicle chassis. This signal injection could be “sensed” by the AC Active Isolation Fault Detection System on the body, depending on the architecture arrangement of the HV system and ECP Module signal injection point(s).

Specific to the OBD DLC ECP Module, when the ECP Module is connected to the 16 Pin DLC, it can act as a “pass through device” for connecting other test devices. The installation of the ECP DLC Module means that other auxiliary devices dependent upon DLC Pin 4 & Pin 5 for ground and signal ground connections may not be installed without disconnecting the ECP Module, based on the requirements for off-board OBD devices outlined in the SAE J1978 Standard document.

Conclusions

Based on the electronic operation of the Active and Passive Isolation Fault Detection systems, and the interactions with the ECP Module, **the conclusions are**:

1. Based on the operation of either the battery-connected or OBD DLC ECP Modules, with respect to the operation of the ECP Module operation and the vehicle Passive Isolation Fault Detection system, the ECP Module will not effect the operation of the vehicle Passive Isolation Fault Detection system. The ECP Module signaling is one of a significant number of signals using the body for grounding while the vehicle is operating, and combining this with the Passive system utilizing passive components that are connected across the HV bus. It has been concluded that, based on the operation of the ECP Module and the Passive Isolation Fault Detection System, the ECP Module will not effect the operation of the Passive system.

2. The Active Isolation Fault Detection system is operated only after the HV and vehicle systems have been powered OFF. The Active system can also operate for up to 20 minutes after the HV and vehicle systems are powered OFF. The Active system is an extremely low Hz and low amplitude signal that is used by the Battery Controller to primarily determine the impedance between the Battery Pack and the body. However, the Active system can also be used to determine the impedance of other components on the HV bus as part of the Isolation Fault Detection system. It has been concluded that, 1) based on where the Active system is connected in relation to the Battery Pack and other HV components, 2) the number and types of filters used in the Active Isolation Fault Detection system to filter external chassis noise, and 3) if an Original Equipment Manufacturer (OEM) is using the Active system to determine the impedance between HV components (other than the Battery Pack) and the body it is possible that the Active system could be effected by the operation of the ECP Module. However, it is highly probable that an OEM would have included the proper Low and High Pass filtering circuits in the Active system to ensure that extraneous signals are filtered (such as those from the ECP Module) to ensure that the Active Isolation Fault Detection system is not effected. If the AC Active circuit has a robust filter design, it would reject any high frequencies from the ECP module (via 2^{nd} order filtering) prior to the signal reaching the software algorithm for final processing and diagnostics. Therefore, there would be no

negative effects of the ECP Module with respect to the AC Active Isolation Fault Detection System.

3. Neither the battery-connected nor OBD DLC ECP Module is connected to the HV power bus or any HV components. Therefore, its low operating DC resistance of 433Ω will not impact the sensing or dynamic operation of the DC Passive or the AC Active isolation detection systems.

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