Contents

CHAPTER 1

INTRODUCTION TO HYBRID OPERATION AND DIAGNOSTICS

Welcome to the advanced Hybrid operation and diagnostics-training course. This course is intended to get you started diagnosing Hybrid vehicles. New technology requires training. Use this training course to become comfortable enough with today's Hybrid vehicles to take them into your shop for diagnoses and repair.
Studying Hybrid technology, operation, and components is the beginning to becoming comfortable with working on these complex vehicles. We said complex, because combining a gasoline engine, electric motors and computer controls to perform vehicle diagnostics, not just engine diagnostics.
Computers have given the automotive industry electronic fuel and ignition control that has offered large engine performance in smaller engine with reduced emissions. Now they supply an operating system that allows a vehicle to operate on gasoline or electric or both simultaneously. The study of Hybrid vehicles is the study of computer control systems.

OBJECTIVES

Study Hybrid vehicle operation and diagnostics to achieve an understanding of the following:

1. The technology
2. The components
3. The operation
4. How to diagnose

This course will cover a majority of the components and systems used by hybrid vehicles sold in the US today. The information in this training course will:

- Improve your knowledge about Hybrid vehicles.
- Show you how to be safe and avoid injury when servicing Hybrid vehicles.
- Start you on the path to diagnosing common hybrid failure patterns.

There must be a starting point for learning to work on new technology. This is it.
The objectives are:

- Gain knowledge to diagnose and repair Hybrid vehicles
- Improve your knowledge of Hybrid vehicles
- Learn to work safe around high voltage

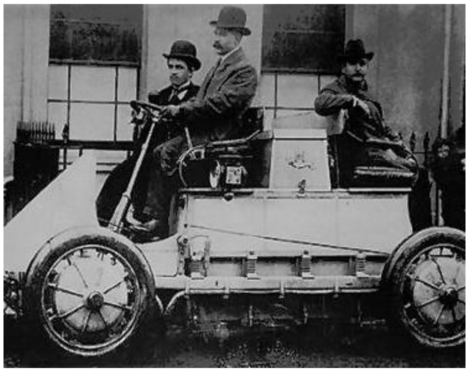
WHAT IS A HYBRID?

A Hybrid is any vehicle using more than one propulsion system. Diesel powered hybrids are now emerging into the market. Fuel cell vehicles may replace the internal combustion engine. Gasoline engines and electric motors are the type of Hybrids covered here. Future training courses will cover other Hybrid systems.

- Any vehicle that uses multiple or alternative propulsion systems may be called a Hybrid
- This course concentrates on Gas and Electric vehicles
- Other types such as Fuel-cell hybrids will be covered in follow up training

HYBRID VEHICLE HISTORY

In the middle 1800's electric vehicle were the best selling vehicles.



1898

Dr. Ferdinand Porsche from Germany designed a hybrid. It used an internal combustion engine that drove a generator that provided power to recharge the battery. The battery could deliver enough power to drive the vehicle over 30 miles. Battery technology is what held electric vehicle development back for many years. Batteries were the weak link. It was not until present day that batteries would catch up with the rest of technology to design and build modern Hybrids. Computer systems with communications that tied vehicle system together made modern hybrids possible.

1901 CURVED DASH OLDS

Henry Ford's internal combustion vehicles quickly over took the electric vehicles because Henry's cars did not need electricity. In 1901, R. E. Olds made the first mass produced car on an assembly line with the introduction of the Curved Dash Olds. Olds and Cadillac agreed to pay Henry royalties after Ford won a court battle to become the legal owner of the internal combustion powered vehicle patent. Henry Ford improved the assembly line by using a moving conveyer to move the vehicle through the plant. In 1913, Henry introduced the Model T that changed the automotive market. The internal combustion engine was the king of the automotive market, with low priced vehicles everyone could afford. The internal combustion engine displaced the electric motor because it had a greater driving range and it did not need electricity that was only available in major cities

BATTERY TECHNOLOGY

Electrical energy must be stored in a battery to propel an electric vehicle. Being able to store large amounts of electrical energy in batteries is what makes an electric vehicle possible. Battery technology lagged behind for years before manufacturers could mass-produce electric vehicle, without severe limits on travel range. NiMH technology is a huge improvement over conventional lead-acid and nickel-cadmium batteries. The latest generations of batteries are a step in the right direction. Today's hybrid is an electric and internal combustion engine powered vehicle.
The lack of battery advancement held back electric development for years

- It wasn't until battery technology caught up that mass production of electric vehicles were possible
- Early hybrids on busses used heavy lead acid batteries that require more maintenance
- Limited driving range is the main drawback of electric vehicles

Limited driving range remains the major disadvantage of electric vehicles.

The function of NiMH technology is relatively simple. These batteries are essentially electrochemical cells. Using an alloy, which absorbs hydrogen, for the negative electrode, you are avoiding the usage of cadmium. Compared to conventional nickel and cadmium batteries, NiMH technology batteries have two or three times the capacity. These batteries last much longer and produce more power as well.
NiMH batteries are in demand because of they have a lower impact on the environment than poisonous Cadmium use in Ni-Cad batteries.

LITHIUM-ION BATTERY

Research work on the lithium battery began in 1912. It was not until the 1970s when the first non-rechargeable lithium batteries became commercially available. Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest energy density for weight.

Early attempts to develop rechargeable lithium batteries failed due to safety problems. Because of the inherent instability of lithium metal, especially during charging, research shifted to a non-metallic lithium battery using lithium ions. Lithium-ion is more stable than solid lithium but, use safety precautions when charging and discharging them. In 1991, the first rechargeable lithium-ion battery became available.
The energy density of lithium-ion is typically twice that of the standard nickel-cadmium. There is potential for higher energy batteries. With cell, voltage of 3.6 volts per cell battery packs can be smaller than NiMH batteries. Lithium-ion is a low maintenance battery. The self-discharge rate is less than half compared to other batteries. Despite its overall advantages, lithium-ion has its drawbacks. It is fragile and requires a protection circuit to maintain safe operation. Built into each pack, the protection circuit limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge. In addition, the ECU monitors cell temperature to prevent temperature related problems.
Manufacturers are constantly improving lithium-ion. New and enhanced chemical combinations are introduced every six months or so. With such rapid progress, it is difficult to assess how well the revised battery will age.
Important Lithium-ion facts;

- Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest energy density for weight
- The voltage range for charging is between 3.4 to 3.6 volts

Battery capacity and battery weight are the main drawbacks too all electric vehicles. Most consumers want more than a 100-mile driving range, like the Nissan Leaf offers. As new battery technologies emerge, the use of all electric vehicles will increase. Battery expense is the reason the Chevy Volt is more expensive than other electrics and hybrids.

- Battery improvement will continue and the automotive industry will see longer drive cycles
- Battery technology and diagnostics will be discussed latter in the course

CHAPTER 2

DEFINING A HYBRID

Non-Hybrid VS Hybrid Powertrain

The differences in the powertrain between a conventional and Hybrid vehicle is the major difference between the two. With a conventional vehicle, the power delivered to the drive wheels is linear. The engine develops the power by changing the potential energy in gasoline to heat during the combustion process. Hot expanding gasses force the piston downward. The engine's crankshaft changes the linear motion into rotary motion. The differential divides the power between the drive wheels. The transmission selectes high torque for low speed operation.

Because the Hybrid vehicle has more than one propulsion system, the transmission has a different design. Many Hybrids do not have a transmission. They have a power splitter. The power splitter will be discussed latter in the program but for now understand it replaces the transmission or works in conjunction with it.

The power splitter can accept power from the gasoline engine and the electric motors and deliver it to the wheels. The computer controlling the power splitter decides if only engine power, elect motor power, or both simultaneously is delivered to the wheels

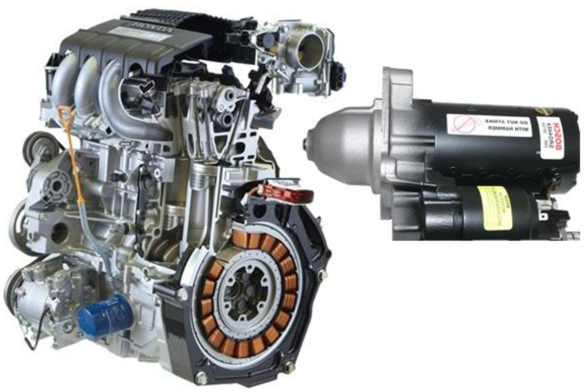
ELECTRICAL POWER DIFFERENCES

The electrical system of the conventional vehicles has two major components. The 12-volt battery and the alternator to keep the battery charged. This system supplies electrical power to the accessories and the engine's different systems. The internal combustion engine drives the alternator.

CONVENTIONAL STARTER MOTOR

The conventional vehicle uses a starter motor to start the engine.

STARTING THE HYBRID'S ENGINE



A 12-V starter is used on some hybrids, but most hybrids eliminated the 12-V starter.   The hybrid control computer operates the electric motor is a special mode to cause the ICE, internal combustion engine, to spin for starting.

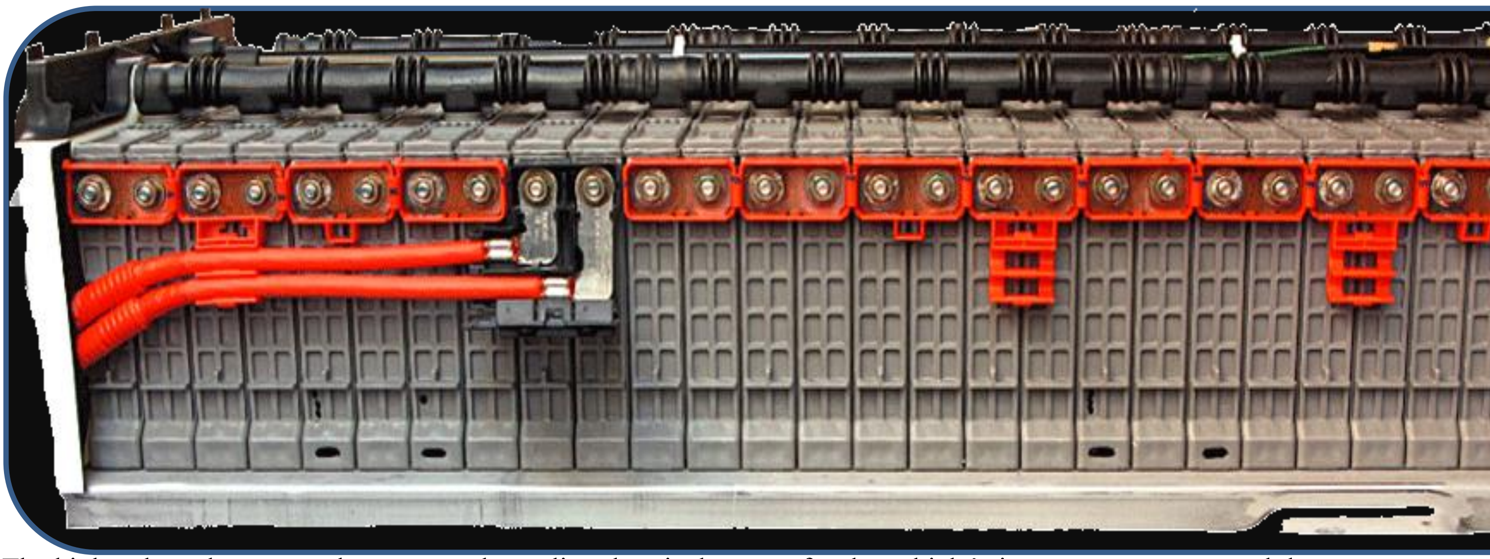
Some Hybrids with a single electric motor continue to use a 12.0-volt starter with the electric motor. This arrangement has no power splitter. A power splitter permits operation on either gas or electric or both. This highlights a difference in hybrid designs, not all hybrids operate in the same manner.
 Hybrid manufacturers make design decisions based on performance, expense and capability. Sometimes weigh has an influence on vehicle design.
Single motor hybrids are less expensive and weigh less but they have less capability.

Hybrid vehicles use a 12.0-volt battery and a DC-to-DC converter to change high voltage into 12 V DC.

The computers and vehicle accessories operate on 12 V like conventional vehicles.

HYBRID ELECTRICAL POWER

Hybrid electrical power is a high voltage battery pack, voltages range from 42 V DC to 330 VDC.



The high voltage battery packs stores and supplies electrical energy for the vehicle's inverter, converter, and the electric motors. As the vehicle is driven, an electric generator creates electricity and delivers it to the inverter to change the A/C voltage to D/C. This charging system works similar to the 12.0 volt charging system as it is computer controlled to keep the battery pack at a normal state of charge. .

HYBRID COMPONENTS

Different components are required for the Hybrid vehicle. An inverter converts DC voltage to AC voltage. The battery pack is DC and the electrical motors create AC. The converter acts as the power source for the 12-volt system. The converter changes the high voltage from the battery pack down to voltages for the 12-volt system. Permanent magnet brushless AC motors propel the vehicle and create electricity.
Electric oil pumps keep the engine oiling system flowing during engine off when the vehicle is at a stop. The cooling system pump does the same. On today's vehicles, the term fly-by-wire indicates that there is no mechanical linkage between components... As an example, the Toyota Prius is truly a fly-by-wire brake system. On many Hybrid vehicles, the air conditioner compressor is electrical driven so that it can operate when the vehicle is at a stop. The high voltage battery pack can have as little as 42 volts to several hundred volts, which carry high current making it a potential danger.
Common components;

Converter
PMBLAC motors, most hybrids have more than one
Different engine oiling systems
Different cooling systems
Brake-by-wire
AC operation with gas engine off
High voltage battery packs
Dangerous high voltage and current

HYBRID VEHICLE

A hybrid is a vehicle using multiple propulsion systems. In the automotive industry, this is usually an internal combustion engine (ICE) and electric motors. In transportation and heavy equipment, it could be a diesel engine. In the future, the electric motors coupled with new technology such as a fuel cell. Because of the name hybrid, almost any combination is possible in the future. Although hybrids have been in the planning for years, only now are they becoming popular because battery technology has advanced to the point where a hybrid vehicle is practical.
Hybrid electric vehicle (HEV)

A vehicle that uses more than one power source to propel the vehicle

Examples:

Electric and Gasoline Internal combustion engine (ICE)
Electric with diesel
Hydraulic pressure storage with diesel or CNG
In the future maybe a fuel cell with electric

Most hybrids generate electricity during braking.

VEHICLE READY

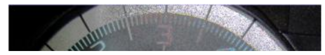
Starting a Hybrid vehicle (Getting the vehicle Ready), there may be no sound at start up because most hybrids shut off the engine when it is stopped. The vehicle will react when the accelerator is depressed

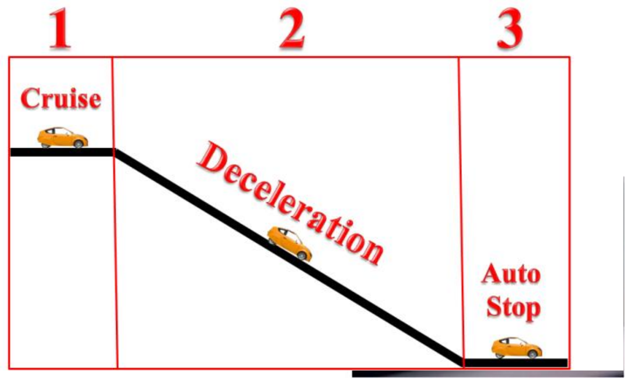
KEY AND KEY FOBS

Hybrid vehicles will have either a normal ignition key with a tumbler or a FOB that inserts into an ignition switch in the dash. Both systems will wake up the OBD-II engine control system as well as the Hybrid control system.

A vehicle is “Ready” when the high voltage relay(s) connect the high voltage battery pack to the Hybrid electric machine. The vehicle is not “Ready” when the relay(s) are open disconnecting the high voltage battery pack to the Hybrid electric machine. In the “Ready” mode, the internal combustion engine can start for a number of reasons.

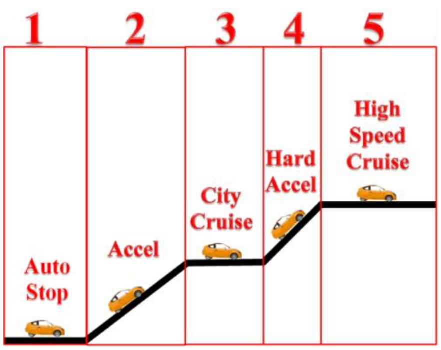
An EV indicator on a tachometer
An Auto stop indicator on a tachometer
A READY light





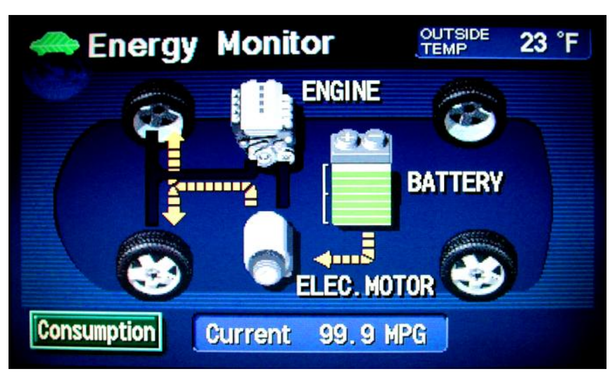
These indicators inform the driver the Hybrid vehicle is ready to drive. The gasoline engine may or may not be running. The vehicle will accelerate when the accelerator pedal is pressed. The engine off mode is “Auto stop”.

AUTO STOP



Auto stop/start;
The vehicle is in the READY mode and the gasoline engine may or may not be running. In this mode the engine’s oil and cooling system pumps may be operating. The air conditioner may operate in auto stop.
Acceleration;
Two Mode Hybrids will accelerate in electric mode if; the air conditioner is not in the “MAX” mode and the high voltage battery pack is at a normal state of charge. The vehicle will not travel very far before the gasoline engine starts. A mild Hybrid vehicle will not accelerate on electric and starts the gasoline engine before moving.
City cruising speeds;
This is where a Hybrid vehicle gets the best fuel economy. In this electric assist mode, the gasoline engine operates with the Ackerson/Miller effect and is efficient not requiring much fuel. The electric motor assists the ICE supplying additional fuel economy.
Hard acceleration;
The ICE is operating in normal mode and not the Ackerson/Miller mode. In normal mode, the ICE supplies normal power levels without the Miller effect. The electric motor is assisting the ICE allowing the vehicle to drive with normal power. The electric motors receive additional boost voltage from stored energy in capacitors. Boost voltage can be as high as 650.0 Volts.
High speed cursing;
The ICE operates normal during hard acceleration without the Ackerson/Miller effect. The electric motor supplies electric assist without the extra boost from the capacitors.

HYBRID ENERGY MONITOR



Many hybrids have an energy monitor showing the source of propulsion power, this is the monitor used on a Prius. It shows the propulsion is coming from the high voltage battery powering the traction motor. The fuel mileage indication is high because the ICE is off.

REGENERATIVE BRAKING MODE

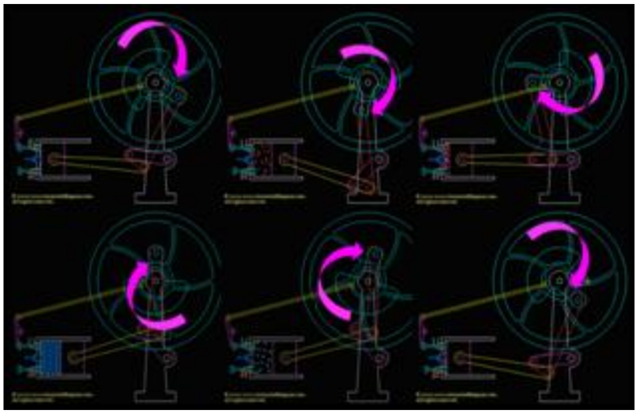
When decelerating from cruising speed;

When the accelerator pedal goes back to idle position, the Hybrid vehicle enters the regenerative braking mode.
Regenerative braking mode;
During deceleration, two things happen.
The Hybrid control module uses electricity and magnetic force to slow the vehicle. A normal stop from 60 MPH uses 90% electrical braking and 10% hydraulic braking.
The vehicle generates electricity during deceleration, which is rectified to DC Voltage, and is used to charge the high voltage battery pack.
The ICE shuts down during deceleration if the air conditioner is not in “MAX” mode and the high voltage battery pack is in a normal state of charge.
Auto stop/start mode;
The vehicle is in the READY mode and the gasoline engine may or may not be running. In this mode the engine’s electric oil and cooling system pumps may be operating. The air conditioner may operate in auto stop; hybrids vary in the operation of the A/C compressor.

CHAPTER 3

MODIFYING THE GASOLINE ENGINE (ICE)

James Atkinson invented in the Atkinson cycle engine in 1882. The Atkinson cycle provides efficiency at the expense of power, and some modern gasoline hybrid applications use a version of this engine.
Uses a unique crankshaft design, using levers to connect the piston rod to the crankshaft, the expansion stroke is longer than the compression stroke. This design achieves a greater thermal efficiency than a standard Otto cycle engine. Atkinson's original design had limited success. Modern engines use variable valve timing to produce the effect of a shorter compression stroke, than the power stroke, increasing fuel economy.



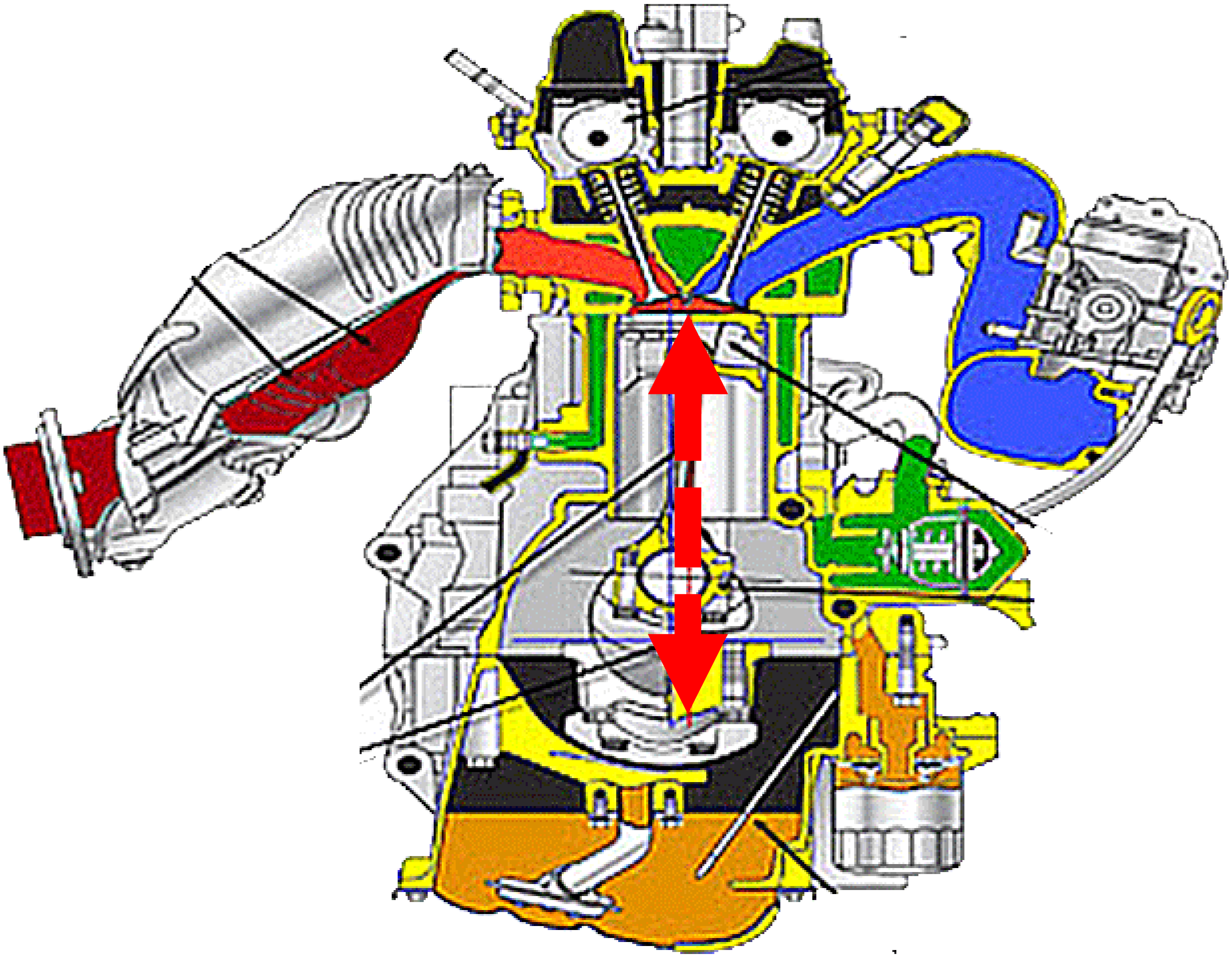
Manufacturers market the Hybrid to last longer than the average vehicle (10 Years or more)
The Hybrids are supposed to use less fuel and produce fewer emissions
In order to accomplish this they have modified the gasoline engine (ICE)
The 4-cycles of the Atkinson has 5 phases

1. Intake
2. Back-flow
3. Compression
4. Expansion (power stroke)
5. Exhaust

The backflow event allows air/fuel mixture to re-enter the intake manifold reducing the compression ratio. This reduces the power and torque of the engine increasing fuel economy. The other benefit of using the Atkinson design is that the engine does not have to work as hard and last longer.

MILLER DESIGN

Miller an American engine designer took the Atkinson design a step further by grinding the lobes on the camshaft to keep the intake valve open during the first part of the compression stroke. Since this would keep the engine as a



low compression engine thus a low power/torque engine he added a supercharger. This offered an efficient engine at low speeds and gave performance at higher speeds.
Both Atkinson and Miller designed engines designs are rejected by manufactures because of the performance that modern driver have come to expect. Manufactures are able to take advantage of the theory of the design, keeping the intake valve open longer, with Variable valve timing.

He accomplished changing the valve timing by modifying the cam lobes.
Super charged Miller engines offset the shorter compression stroke.
Mazda has a turbo Miller engine.

INCREASING ENGINE LIFE

When the crankshaft rotates the large end of the piston rod makes a circle because of the off set on the rod journal. The piston thrusts against the cylinder bore on the power stroke causing wear. This thrusting wears the cylinder out of round. To reduce this, designers will offset the alignment between the centerlines of the wrist pin, piston and crankshaft main bearing. This off set reduces engine out of round wear and gives the engines a longer life span.
Some hybrid engines have a 10 to 12 mm crankshaft offset to reduce side loading of the piston for long engine life.

CHAPTER 4

VARIABLE VALVE TIMING

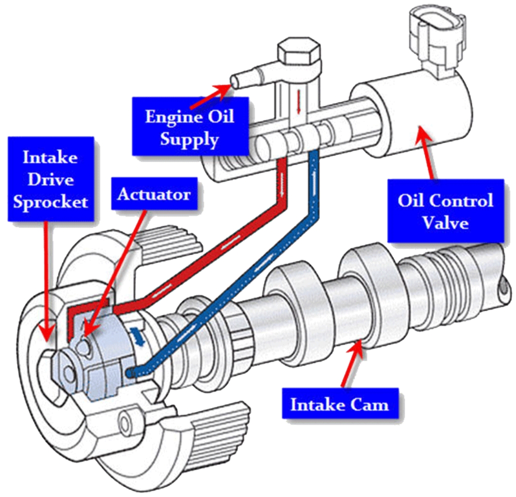
Hydraulic forces change valve timing to achieve the Miller effect. The Atkinson-Miller affect holds the intake valve open longer than the compression stroke for efficiency. Variable valve timing makes this possible through greater control of the intake valves. Keeping the intake valve open at the beginning of the compression stroke and closing for more power/torque by rotating the intake camshaft with a Phaser using the engine's oil.

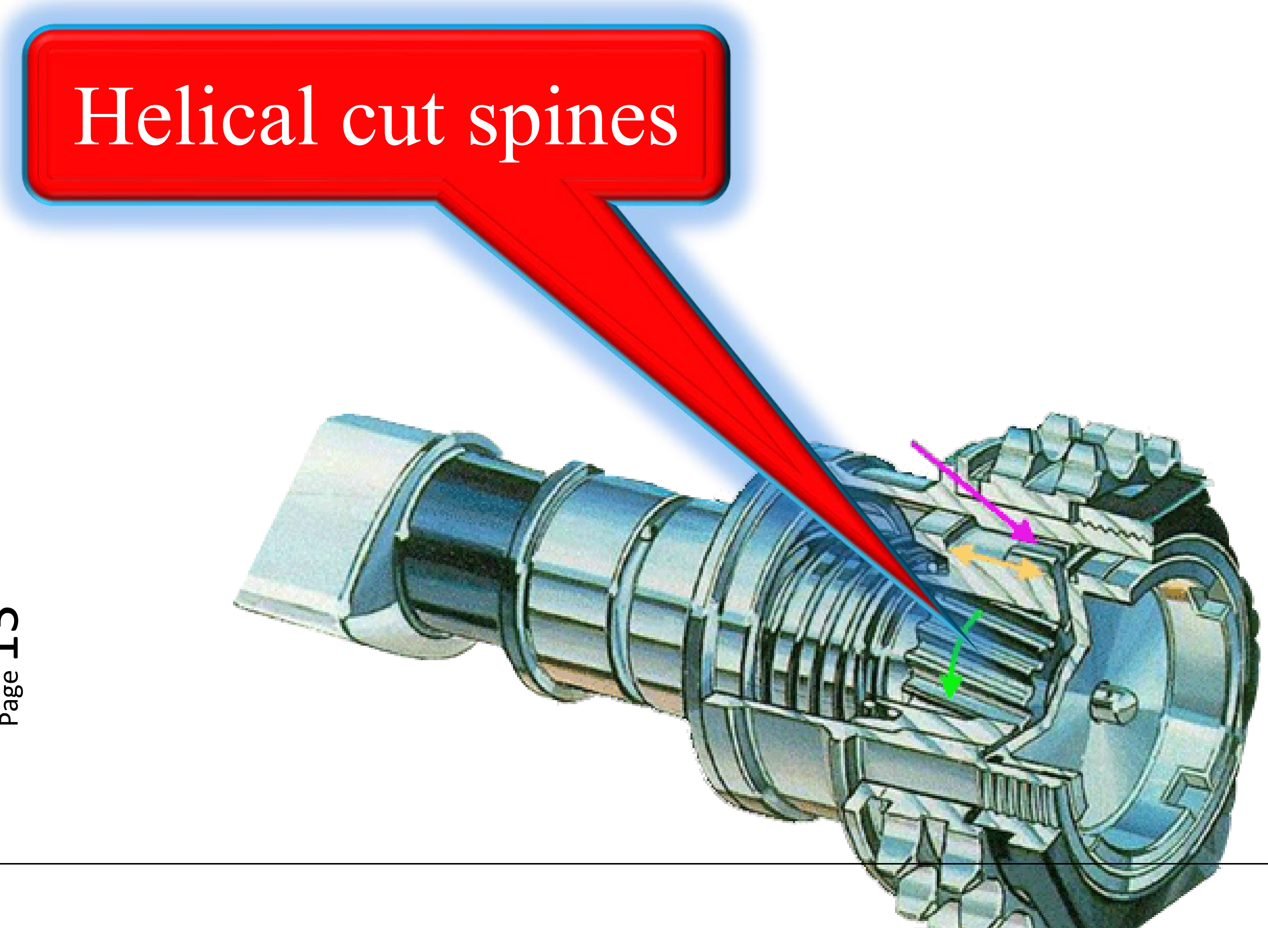
Some of today's hybrids use variable valve timing (VVT)

VVT limits the power loss at higher speeds and during high power demands

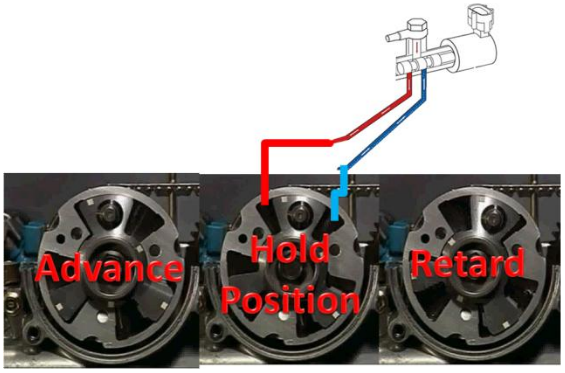
Toyota, Ford and others refer to their engine as Atkinson/Miller engines

The VVT Phaser and camshaft both have helical cut spines. As hydraulic force pushes them together, the camshaft rotates. The cam lobe rotates and changes the valve timing.





A computer controlled solenoid opens and close hydraulic circuits in the Phaser. Pressure on a confined fluid is equal in all directions. When pressure is equal on both sides of the actuator it does not move, and is called the “Hold” position. When computer changes the duty cycle of the solenoid the spool valve moves changing the oil flow direction increasing or decreasing the pressure on one side of the actuator forcing it to rotate. When the actuator rotates, it rotates the camshaft changing valve timing.



The solenoid is duty cycled controlled. When the duty cycle is at 50%, the camshaft is in the “Hold” position having equal pressure on both sides of the actuator. Increasing duty cycle above 50% advances the cam and decreasing the duty cycle retards the cam. Once the cam is in the selected position the duty cycle returns to 50% and “Holds” it in that position.

CHAPTER 5

ON BOARD DIAGNOSTICS II

The internal combustion engine is a normal OBD-II controlled engine. Computers control ignition, fuel and emission control.

Computer controlled:

Ignition

Fuel

Emission control

OBD-II Diagnostic Test Modes;

1. Show current data
2. Show freeze frame data
3. Stored Diagnostic Trouble Codes
4. Clear Diagnostic Trouble Code
5. Continuous monitor test results
6. Non- Continuous monitor test results
7. Show pending Diagnostic Trouble Codes
8. Control operation of on-board component/system
9. Vehicle information request
10. Permanent DTC's

CHAPTER 6

WHAT MAKES A HYBRID VEHICLE DIFFERENT?

The main difference is that a Hybrid has an electric machine to propel the vehicle.

The electric machine is:

A High Voltage Battery Pack
A DC to AC Inverter
A DC-to-DC Converter
And Permanent Magnetic Brushless A/C Motors
Special Computers to manage the vehicle

This electric machine is a standalone system that can operate with or without the gasoline engine. The cooling system for the electric machine is in the cooling chapter of this course.

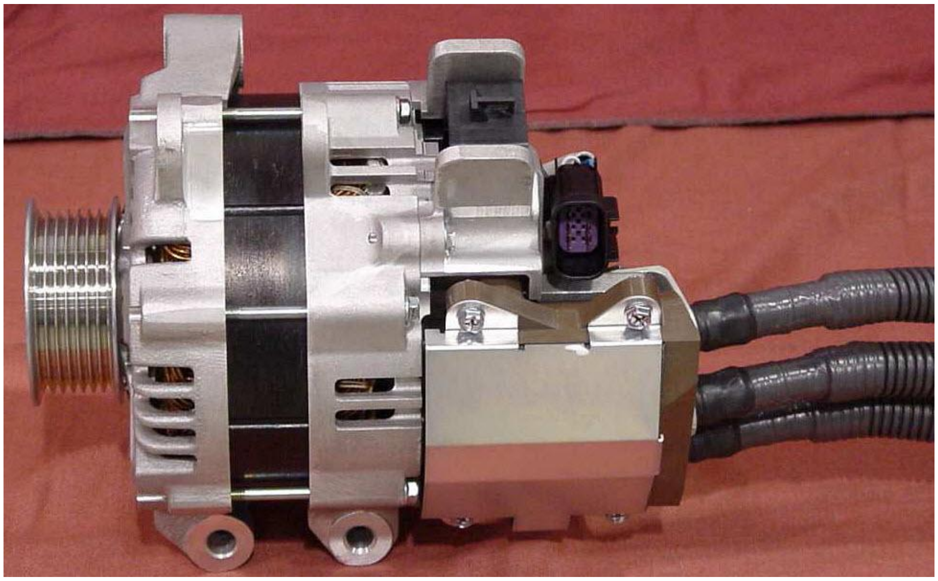
Hybrids do not need an alternator to charge the 12-volt battery or supply electricity for the accessories. The converter replaces it by converting the high voltage in the high voltage battery pack to the required 12- volts. Understand that 12- volts is nominal. Just like the 12 volts on a non-Hybrid vehicle, it is a working voltage between 12 and charging system voltage.

Most hybrids eliminate the 12-volt starter motor. The electric machine can do that by rotating the two electric motors in opposite directions on a two mode Hybrid. On a mild Hybrid, the Belted Alternator Starter performs the task.

There are Hybrids that have a 12-volt starter motor. It sees minimum use. When the engine starts for the first time, the 12-volt starter motor cranks the engine. To start the engine after an auto stop the Hybrid's electric motor does the job. There is an advantage of having a 12-volt starter motor. The ICE can be jumped started" where as a vehicle without one cannot be.

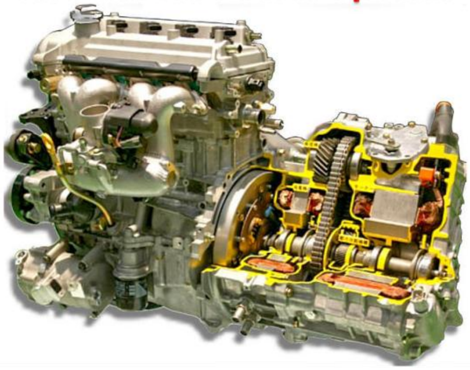
Accessories use the 12-volt battery and the 12-volt starter, if the vehicle uses a starter. The name of the accessory battery is the auxiliary battery. The battery can be in the engine compartment or the vehicle's cabin and sometimes in the trunk.

Different manufactures use different configurations of electric motors. The simplest is the Belted Alternator Starter motor. A single motor cranks the engine, charges the 12 V battery and supplies electricity to the accessories. It also supplies 15-20 HP of electric assist to the ICE. The BAS is on the side of the engine and is belt driven like a non-Hybrid vehicle.



Belted Alternator Starter

Two Motor Power Splitter



Strong Hybrids have at least two electric motors. One called the large and the other called the small motor. The larger motor propels the vehicle and generates the charging voltage for the high voltage battery pack during deceleration. The smaller motor charges the battery pack and controls for the power-splitting device, which blends the engine and motor together. Electric motors may mount to the side of an engine, between the engine and bell housing, or inside transmission housing. Four-wheel drive vehicles will have a third electric motor to drive the other axle.

When the motor mounts between the engine and transmission housing, it is a large magnet and requires a special puller to separate it. Do not lay it on a metal bench because it will attach itself making it difficult to get off. Use a special puller when installing the motor because when the powerful magnets are attracted to the metal it will jump towards it. If your finger or hands are between them you could be serious injured.

A DC-to-DC converter is an electronic circuit, which converts a source of direct current (DC) from one voltage level to another. It converts the high voltage of the battery pack to the lower 12.0 volts for the auxiliary battery and accessories. On some Hybrids, the converter is a separate component and others combined it with the inverter.

An inverter is an electrical device that converts DC to AC; the converted AC can be at any required voltage. The inverter on a Hybrid converts the DC voltage from the battery pack to AC for use by the AC electric motors. The inverters also convert the AC back to DC to charge the battery pack. The computers communicate through a network. Like non-Hybrid vehicles, Hybrids have multiple networks using different protocols.

All Hybrid vehicles have a high voltage battery pack or a main battery. The voltage may be as low as 36.0 volts or up to several hundred volts. The main battery stores electricity for use by the electric motors. The size of the main battery is dependent on size and design of the vehicle. The higher the voltage stored the longer the vehicle can operate on electric only. Larger SUV type Hybrids require a larger main battery because of the weight the motor must propel the vehicle. Some hybrids have lower voltage battery packs to reduce weight and expense.

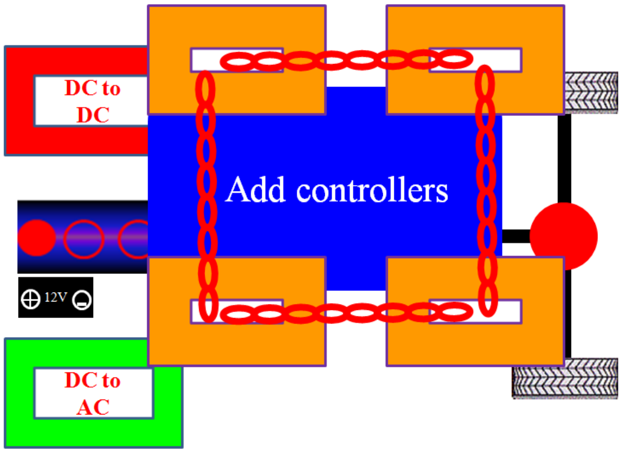
CONTROLLERS

The Hybrid is a computer-controlled vehicle. So much so that on some Hybrids when the driver presses the brake he is not moving brake fluid to the wheel cylinders and calipers. A computer does that. There will be a Hybrid computer, which has a higher priory than other computers on the vehicles. The high voltage battery pack ECU monitors battery temperature, state of charge, and has the drivers for the battery pack's cooling fan. Motor controller which may be a part of the Hybrid controller blends the electric and ICE for propulsion.

HV BATTERY PACK CONTROLLER

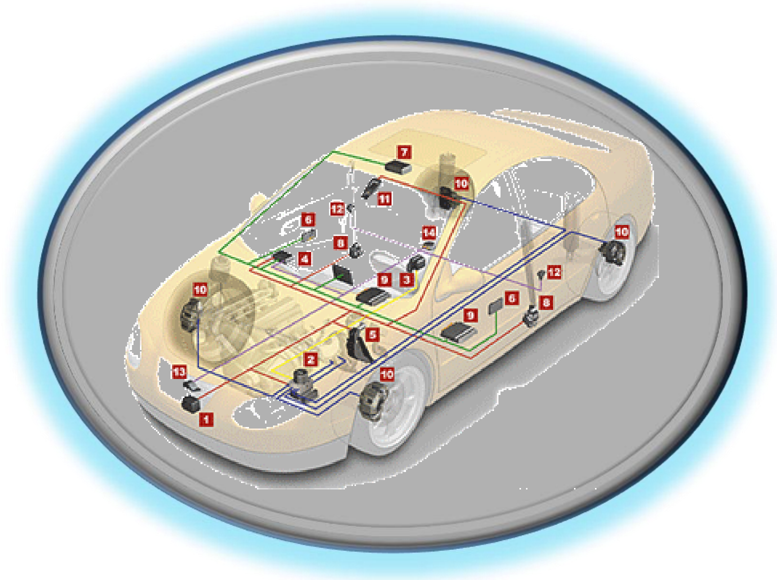
The HV battery pack controller monitors the temperature and the states of charge (SOC) for the battery pack. Both temperature and SOC is critical to the life of the battery pack. High temperatures causes the battery modules to overheat and gas out the electrolyte greatly reducing the life of the modules. The HV battery modules remain the state-of-charge between 52% and 68% state of charge. Not allowing the batteries modules to work at near their full limit gives them a longer working life span. With the manufacturers designing the vehicle for long life, the battery pack controller monitors the SOC and reports to the Hybrid controller when it drops below 50% so it can command the ICE to start for recharging. The battery controller houses the drivers for the HV battery pack's cooling fan, which helps to maintain normal temperature.

HYBRID SYSTEM CONTROLLER



The Hybrid controller combines the electric motors drive force with the internal combustion engines driving force. The Hybrid system controller processes information from other modules on the communication Bus. This is the main controller having priority over all other controllers. Its responsibilities involve almost every aspect of the vehicle. As an example, the hybrid controller interfaces with the HV battery pack controller through the high speed CAN Bus. If the Battery Controller reports that the battery's states of charge is lower than 50% the Hybrid controller would send a message to the PCM requesting Gas and Spark for the ICE, while commanding the

smaller electric motor to spin counter clockwise and the large motor to spin clockwise cranking the ICE. If the driver selects a forward gear and steps on the accelerator pedal requesting torque the Hybrid controller would command; a small electric motor to engage the forward gear and another small motor to open the throttle to obtain the torque. Braking and deceleration are just as controlled as acceleration.



The complex electric motor controls are in the Hybrid controller or it can be a standalone unit. The Motor/Generator controller controls the motors to deliver the torque requested by the Hybrid System Controller for propulsion and regenerative braking.

CHAPTER 6

COMMUNICATIONS NETWORK

The different manufactures of Hybrids all use different communication protocols.

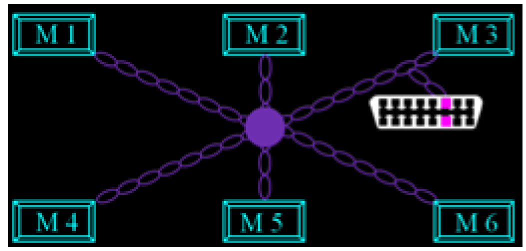
J1850 VPW
GM Class 2
Daimler and Chrysler, PCI, SCI, CCD, High speed CAN, Medium speed CAN, CAN diagnostics
J1850 PWM
Ford SCP, Keyword Protocol 2000, UART Based Protocol, LIN as Master or Slave, K-line, High speed CAN, Medium speed CAN
GM's ALDL or UART protocol, GMLAN, High speed CAN, Medium speed CAN
Asian and European Imports use a version of ISO9141, High speed CAN, and Medium speed CAN

When a manufacture design hybrid, they can use their own versions of communication protocols. All of them use high speed CAN for Hybrid communications. To be able to diagnose and repair all protocols a specialized communication class would be required.

Let us focus on high speed CAN.

CAN, 2-wire high speed CAN, (CAN-C, ISO11898, J1939, or J2284)

The communication networks on a vehicles interface with others. They communicate through a gateway processor and programming to interface with each protocol used on the vehicle. The gateway can receive one message on the ISO9141 Bus and send it to the Hybrid module on the high speed CAN Bus. As with a non-Hybrid vehicle, the Hybrid systems and sub-systems communicate on different protocols. This class focuses on the high speed CAN Bus.

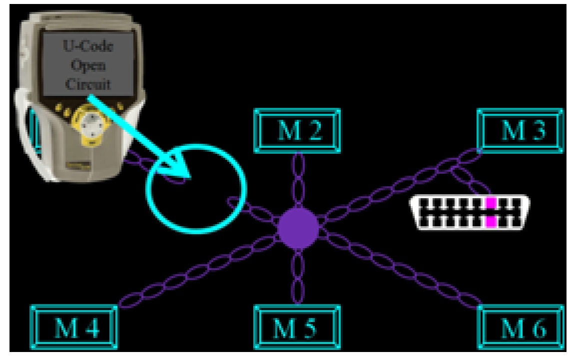


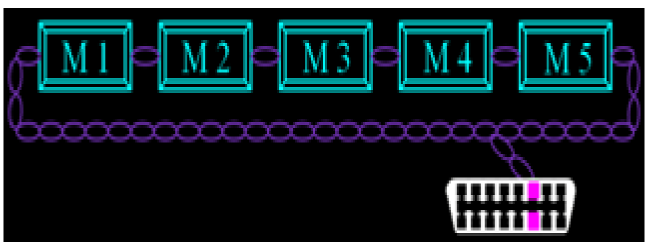
CONTROLLER AREA NETWORK (CAN)

CAN is one of five standard protocols used in the OBD-II vehicles.
J1850 PWM
SAE J1850 VPW

ISO9141
ISO15765 Medium speed CAN
ISO11898 High speed CAN

CAN wires are twisted together at a certain number of twist per inch to reduce noise interference. A high-speed protocol operates at 500kb per second.





There is one high speed CAN Bus on the vehicle and any CAN module can place a message on the Bus. Communication is through Zeros and Ones. The first part of any message is an identifier of which module placed the message on the Bus. Modules are programmed to recognizes only certain messages. Modules have a set priory. As an example, the Hybrid controller would have a high priory and other modules have a lower priory. The level of priory only becomes a factor when placing a message on the Bus. The module with the higher priory gets to place a message on the Bus first. Programmers establish the module's priory by the importance of the message.

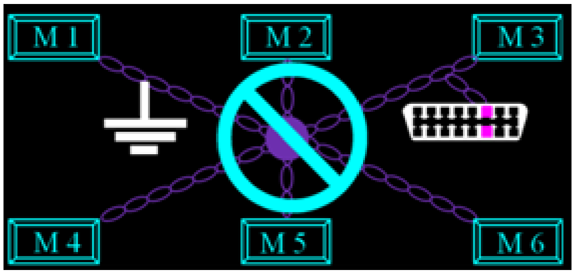
CAN Bus Daisy Chain configuration

Daisy chain is a term meaning the connecting of modules to each other in a series or chain. If one module fails to communicate, the others may continue by being in the daisy chain. An open module or circuit does not stop communications. A shorted module or circuit will stop all communication on the Bus until the fault is isolated.

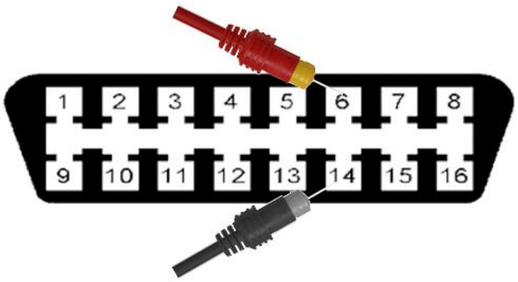
CAN Bus Star configuration

When connected in a Star configuration all modules connect to a central point. Like spokes on a wheel, they all connect to the hub. If one module fails to communicate, the others may continue by being on their own circuit of the star. An open module or circuit does not stop communications. A shorted module or circuit will stop all communication on the Bus until the fault is isolated.

Each of the circuits has its own signal.

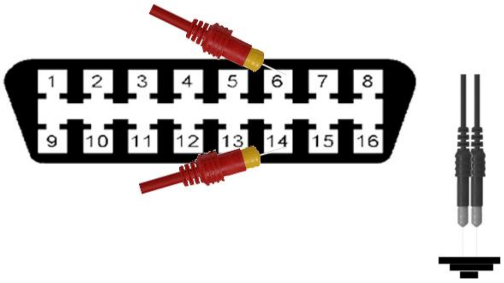


CAN Hi Idles at 2.5 volts. Idles indicates that no message is being sent, the Bus is “Quite”.
To send a message the CAN Hi signal increases to 3.5 volts.
CAN Hi is on Pin 6 of the diagnostic link connector (DLC).
CAN Lo Idles at 2.5 volts. Idles indicates that no message is being sent, the Bus is “Quite”.

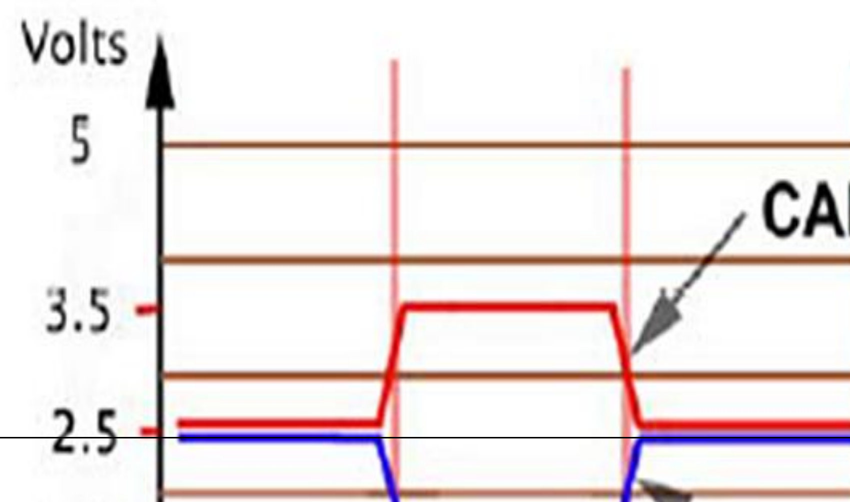


When a message is being sent the CAN Lo signal decreases to 1.5 volts.
CAN Lo is on Pin 14 of the diagnostic link connector (DLC).
CAN Hi and CAN Lo are the mirror image of each other. They both idle at 2.5 volts. When CAN Hi increases to 3.5 volts CAN Lo decreases to 1.5 volts becoming the mirror image of each other.
Recessive when the Bus is “Quite” and dominate when the Bus is “Talking” can be use to describe the states of the Bus.

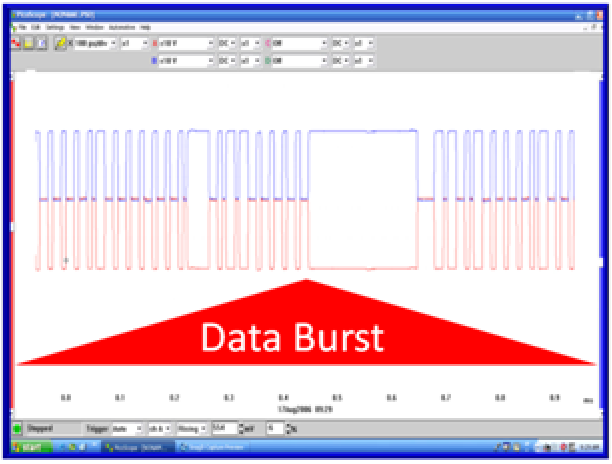
View the CAN signal on a digital storage scope for an accurate diagnoses. Connect the positive lead of the DSO to cavity 6 and the negative lead to cavity 14 of the DLC. This connection displays the difference in the two signals, while this is a valid connection, many scope use case ground as the negative lead. This can cause problems if the case contacts chassis ground on the vehicle. We suggest connecting two channels with one for each signal and use normal ground for the negative lead.

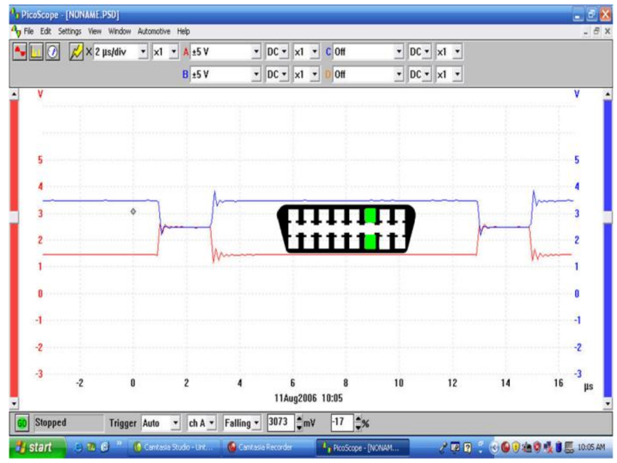


A second method to connect the DSO is to use two channels. Connect one channel to Pin 6 and the other channel to Pin 14 of the DLC. This connection uses chassis ground as the negative lead and is less likely to cause accidental grounding problems.



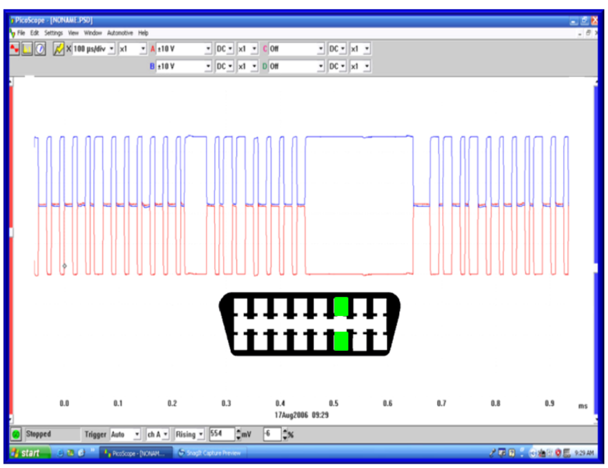
The resulting scope pattern shows two signal identified by their color differences. Set your scope sweep speed to view a complete data burst to identify the signal configuration.





Verify the waveform's amplitudes are correct for both signals. In order for the modules to place messages on the Bus, it must spend time both recessive and dominate. Modules can only place a massage on the Bus when it is recessive. This means that if the Bus never goes recessive only one module may place a message on the Bus. See the Charter Box pattern.

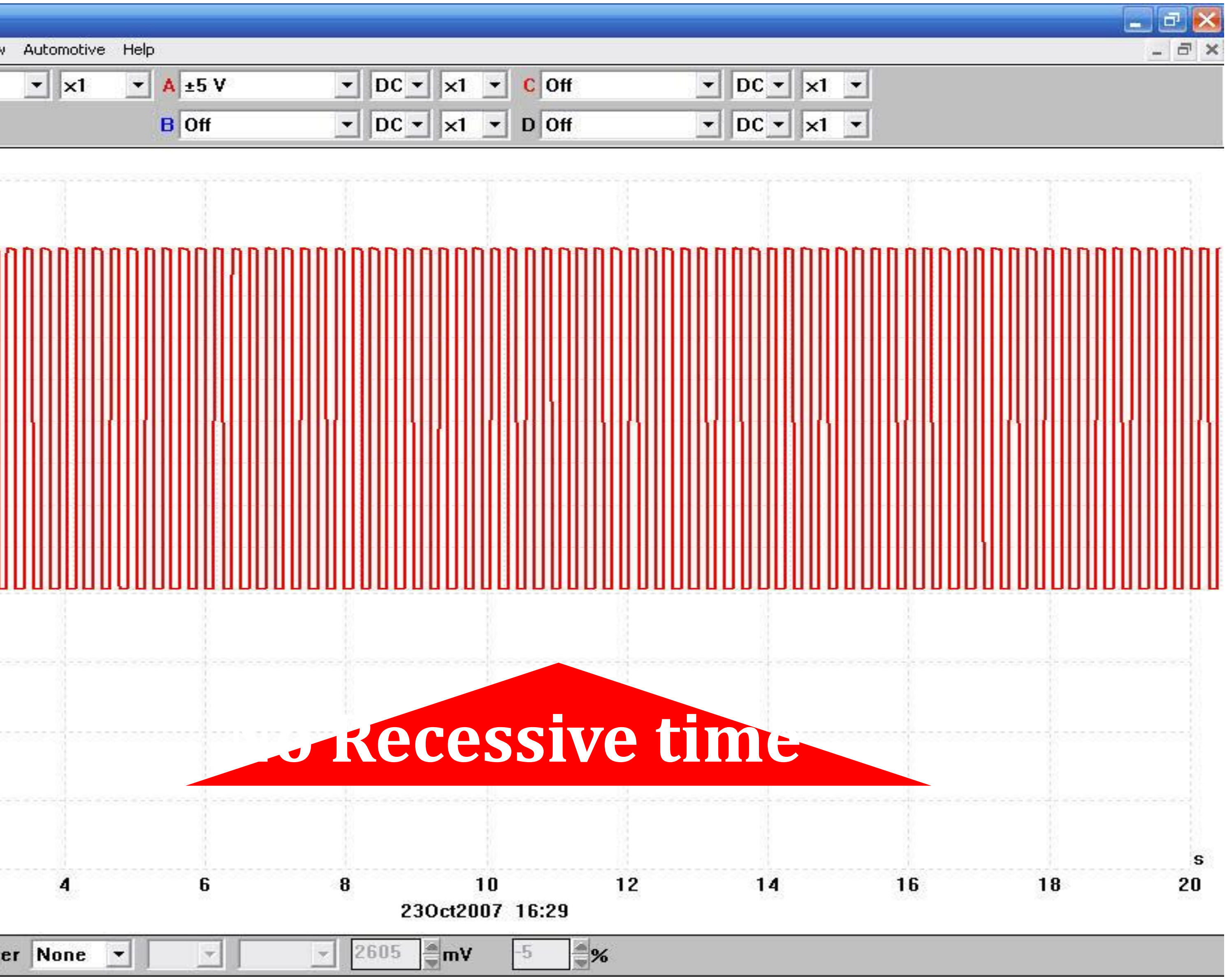
CAN Hi on cavity 6 of the DLC should toggle between 2.5 and 3.5 volts. 2.5 volts indicates that the CAN Hi signal can spend time recessive while 3.5 volts indicates that CAN Hi can go dominate.



CAN Lo on cavity 14 of the DLC should toggle between 2.5 and 15 volts. 2.5 volts indicates that the CAN Lo signal can spend time recessive and 1.5-volts indicates that CAN Lo can go dominate.

If the signal amplitudes are normal, there should communications. The problem may be wires, splices, connectors, or the internal circuits of a module.

Do not expect a steady signal, communications data comes in data burst.

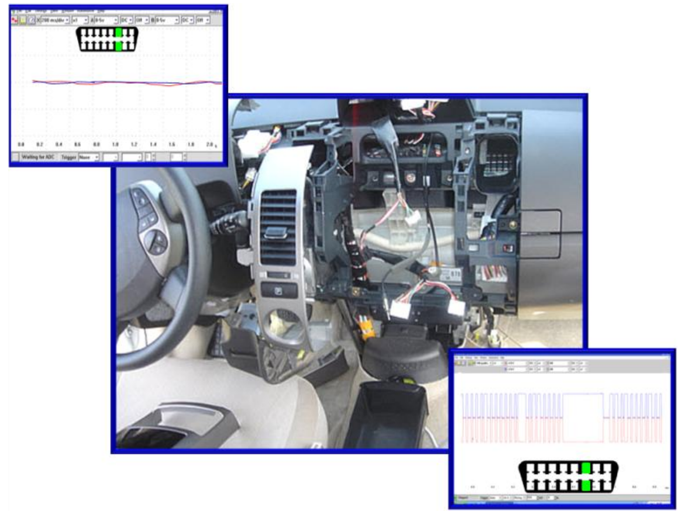


Chatter Box

This is a communications failure from a different type of network, but it is a prime example of a chatterbox. A chatterbox has no recessive time, which is required for another module to get access to the data bus.

A buss with zero volts can't communicate (Shorted)

Because communication circuits carry, a sophisticated signal they have the same problems that a lamp circuit has. Any fault that may appear in an electrical circuit may appear in a communication Bus. Opens or shorts are common especially on vehicles that have been in an accident and were in a body shop. Modules that have been



damaged through an impact can be shorted or have open circuits. Having two different circuits the high speed CAN Bus could have one circuit working normally and a problem on the other. Just like a lamp that does not come on when the Bus is open or a shorted it cannot communicate.
The bus will continue to communicate if a fault on one of the two circuits. The communications would be slower but continue with one circuit. No communications are possible when the CAN signal circuits shorted is ground.
Special note;
The design of the bus can cause the signal to go to 5 volts if there is an open data circuit. Two modules on the bus have termination resistors that create the 2.5-volt recessive point.

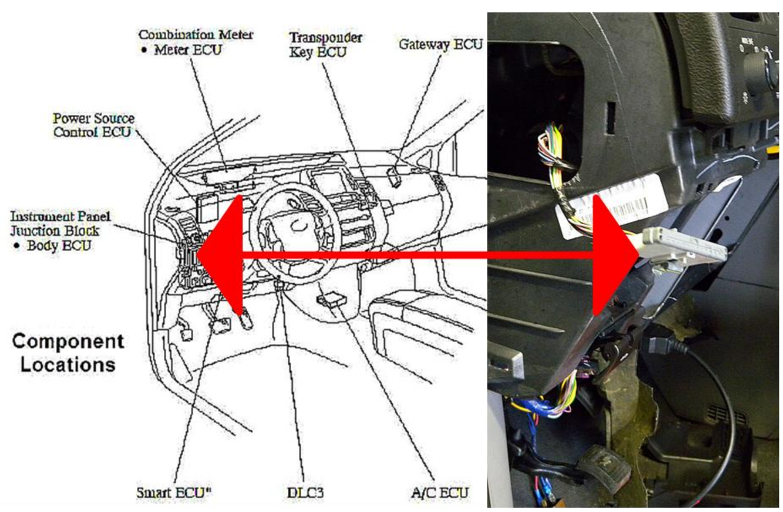
The star configuration sometimes uses a junction block that joins the modules to the bus.

JUNCTION CONNECTOR

Open the junction connector to isolate the module when there is a problem on the bus. Remember, two of the modules have the termination resistor to create the 2.5-volt recessive point, so many of the module signals will go to 5 volts with the junction connector disconnected. Use vehicle specific information to determine terminated modules.

TESTING WITH A SCAN TOOL

One important step in diagnosing a problem on the Bus is to verify that basic communication is possible between the modules. Use the ping utility designed into each module to test communications between modules and scan tools. A ping message is an Echo type message where if the sender (Scan Tool) sets a fault code if it does not hear its message echo back. Pinging is a function programmed into the module like any other software algorism. The ping diagnostic utility is to identify which modules can read and send messages.
Look for special functions like Pinging, Roll call, All System Tests, or All System DTCs



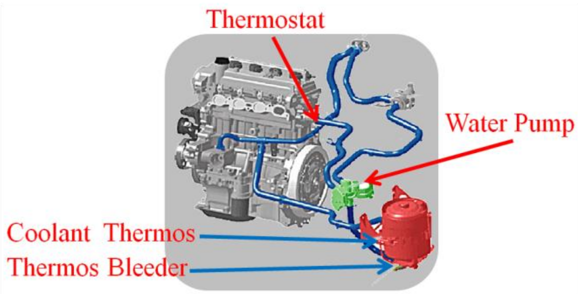
Use it to identify which module has a problem communicating!

If the Bus does not communicate with the Scan Tool, the bus will not ping or do other functions for diagnostics. Viewing the waveform while disconnecting each module one at a time is the only option. This can be a lengthily process. The task consists of turning the vehicle's power off, finding the module , and disconnecting it, turning the vehicle's power back on to see if the waveform returns to normal. If it does not, reconnect that module and move to the next module. If the waveform returns to normal, connect a Scan Tool and attempt to read DTCs for help pin pointing the fault.

CHAPTER 7

HYBRID COOLING SYSTEMS

Because the engine and electric machine must use different thermostat settings, they cannot use the same cooling system. Engine's have a setting of approximately 220°F while the electric machine uses a 300°F setting. Other than the thermostat, the two systems are the same. Use the recommended coolant specified by the manufacturer. Radiators, water pumps, overflow containers, and tubing and hoses make up each system.



The water pumps use electric motors rather than belt driven pumps. The electric motor gives the computer greater control over flow allowing it to continue with the ICE off during auto stop.

An ICE will produce higher emissions at start up and an ICE on a Hybrid stops and starts several times during a typical trip. To keep the engine temperature warm, the coolant continues to circulate with the ICE off. Once the Hybrid machine is "Ready", the electric machine coolant will circulate continuously to dissipate the heat created by the electric machine.

The coolant thermos is on the 2004-2007 Prius. It is exactly what it sounds like; an insulated container that holds coolant and keeps it warm just like thermos bottle. A warm engine operates much more efficiently than a cold engine. When the engine is warm the pistons have expanded to their operating size, the piston to cylinder wall clearance is optimal and blow by is reduced. A warm engine will also use less fuel because fuel atomizes better in warmer temperatures. The more of the fuel that atomizes, the less fuel is required.

The 2008 models eliminated the thermos. Later models wrap the coolant piping around the catalytic converter.

This photo shows the Ford Escape Hybrid has coolant reservoirs for the engine and electric machine...
Use a cooling system service device like this simple low cost Air Lift system to bleed air from the cooling system.

Hybrids can set low coolant codes if there is air in the cooling system after servicing. It may take several trips to get all the air out of the system if you do not use something like the airlift system. Then some vehicles will still trap pockets of air.

CHAPTER 8

SERVICING THE ICE

The controllers will start and stop the ICE in normal start/stop mode.
Use the "Service Mode" to work on the ICE or any of the other conventional systems the vehicle.
Do not drive the vehicle while in the service mode.
Ford Escape 2005-2008
Ensure the "Econ" mode is off

Place A/C in "MAX" mode with fan on high speed

Alternate Ford Method
Warm up the ICE
Key "ON" ICE off
Within 5 seconds of turning the key on fully depress the accelerator pedal for 10 seconds
Within 5 seconds press the brake, place Trans in "drive" and fully depress the accelerator pedal for 10 more seconds
Release accelerator place Trans in "P"
An Amber colored Wrench Lamp will illuminate
Idle stop is now disabled
GM BAS system
Allow the ICE to idle when the engine is normal operating temperature for 2 minutes
Idle stop is disabled
GM 2-Mode system
Open the hood
These vehicles have a hood lock
When the hood is open, idle stop is disabled
Prius 1998-2003
Ensure A/C is not in the "Econ" mode
Place the A/C in "MAX A/C"
Start engine
Idle stop is disabled
Prius 2004-2008
Complete this procedure within 60 seconds
Set the emergency brake
Turn ignition to run
Do not place foot on brake pedal
Push power button twice

Place Trans in “P”
Fully depress accelerator pedal twice
Press the brake and press the power button once
Idle stop is disabled

Highlander 2006-2008

Complete this procedure within 60 seconds
Turn ignition to run
Place Trans in “P” fully depress the accelerator pedal twice
Place Trans in “N” fully depress the accelerator pedal twice
Start engine
Idle stop is disabled

Camry 2007-2008

Complete this procedure within 60 seconds
Press the power button twice to turn on the ignition
Place Trans in “P” fully depress the accelerator pedal twice
Place Trans in “N” fully depress the accelerator pedal twice
Start engine
Idle stop is disabled

Lexus RZ 400h 2006-2009

Complete this procedure within 60 seconds
Turn on the ignition
Place Trans in “P” fully depress the accelerator pedal twice
Place Trans in “N” fully depress the accelerator pedal twice
Place Trans in “P” fully depress the accelerator pedal twice
Start engine
Idle stop is disabled

Lexus GS 450h 2007-2009

Complete this procedure within 60 seconds
Press the power button twice to turn on the ignition
Place Trans in “P” fully depress the accelerator pedal twice
Place Trans in “N” fully depress the accelerator pedal twice
Place Trans in “P” fully depress the accelerator pedal twice
Start engine
Idle stop is disabled

Altima 2007-2008

Ignition must be off for 2 seconds
Press the power button twice to turn on the ignition
Place Trans in “P” fully depress the accelerator pedal twice
Place Trans in “N” fully depress the accelerator pedal twice
Place Trans in “P” fully depress the accelerator pedal twice
Start engine
Idle stop is disabled

CHAPTER 9

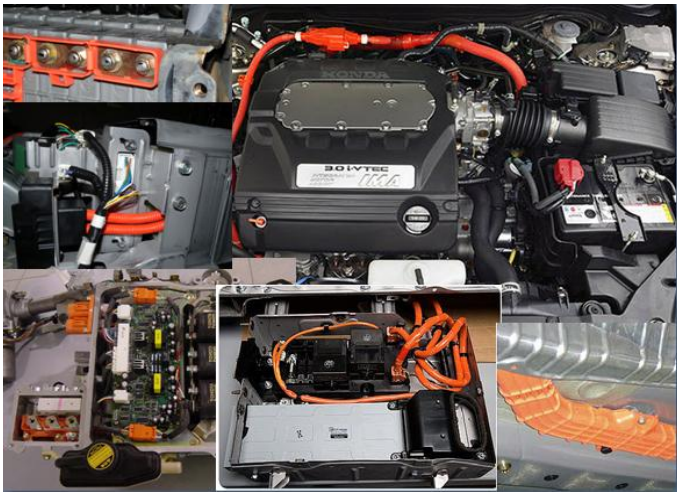
ELECTRIC PROPULSION SYSTEM

Sub-Systems and individual components make up a hybrid vehicle.

The Battery Pack;

Stores and supplies the electric power.

Hybrid controller (microprocessor);



Control the actions of the electrical propulsion and ICE together. These are computerized vehicles where more computers perform special functions than ever before.

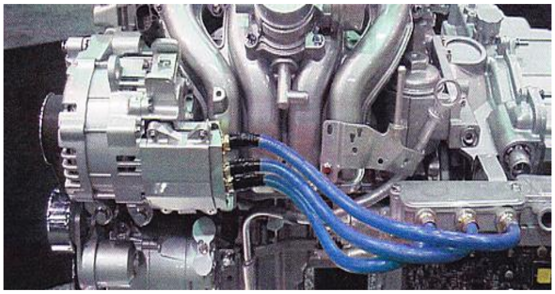
Electric control units (converters and inverters);

Control the electrical machine components. These do the conversion of the high voltage to the 12.0 volts system voltage. They operate the motors for propulsion and charging. Computers control the converters and inverters.

Motor / Generators;

Does the electrical work, Supplies the propulsion energy, and Supplies the electrical energy to re-charge the high voltage battery pack.

Transmissions / Transaxle;



A transmission or gearbox provides speed and torque conversion to use the principle of mechanical advantage. Not all Hybrids have a transmission some use a power splitter.

Power splitter;

A planetary gear set that mechanically blends the electrical motors and internal combustion engine.

The computers connect to the High Speed CAN BUSS. The CAN BUSS is a high speed BUSS that allows the controllers to communicate close to real time.

Working safely around a Hybrid is important. The high voltage of the system can injure technicians. Read, study, and understand how to be safe when working on or around a Hybrid vehicle.

CHAPTER 10

HYBRID SAFETY PROCEDURES

Hybrid vehicles have high voltage supplies that require a safe working environment. Not focusing or a miss step may lead to injury.

The SAE has set standards for the automotive industry when designing and building Hybrid vehicles. The most common known is the J 1673 standard. It states that circuits carrying high voltage must use a color identifier for the insulation material covering.

Technicians should obtain a copy of the SAE's J 1673 standard. They should read, understand, and follow all precautions laid out in the document.

Turn off Power to the Hybrid system before working on it. Follow the manufacturer's procedures for powering down the system. Two safe methods are to disconnect the 12.0 battery, remove the safety disconnect, and to remove the ignition key/fob and store it 20 feet away from the vehicle. This may seem like over doing safety, but you can never be too safe.

Exception to the Rule

Mild Hybrids that use a lower voltage are an exception to using an orange covering, this material is blue but sometimes they are orange. The belted alternator starter mild Hybrid has three 12-volt batteries for a total of 36-42 volts and can use blue covering material instead of the orange. To the technician Blue means the same as Orange, use caution!
This is a standard for voltage levels. It is important to treat all levels as dangerous. It keeps a technician alert to the fact that injury or death can result.

Voltage level Ratings

D/C **A/C**

60V V **30-43 High Voltage**

30 -60 V **15 – 23 V** **Intermediate**

0 – 30 V **0 – 30 V** **Low**

Current Affect on humans

If the shock starts the heart convulsing or fibrillating, blood flow stops. This causes brain damage and if it last an extended time can cause death. Technicians should be aware that all hybrid vehicles have the potential to cause harm and even death. Because of the danger, it is important to increase your resistance by wearing appropriate safety equipment.

Contraction of muscles	**1- 5 m amps**
Pain	**3-10 m amps**
Can't let go	**10-40 m amps**
Stop breathing	**30-70 m amps**
Ventricular Fibrillation	**75-100 m amps**
Stops the heart	**250-300 m amps**
Causes burns	**5000-6000 m amps**

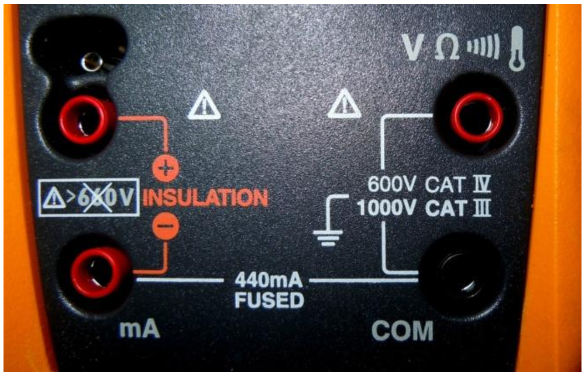
You must be aware of the dangers, but the vehicles design reduces the exposure to the high voltage circuits that often. When conditions require it, you must have proper safety procedures if there is the slightest chance of making contact with the high voltage circuits. Use lineman gloves anytime there is a remote chance of coming into contact with the high voltage. The leather protectors are there to reduce the wear on the rubber and prevent puncture leaks that would reduce the insulation properties of the gloves. Eye protection is more important than most people think. High voltage arcs at these power levels are very powerful!

Test the gloves because they have a shelf life. Electrically test the gloves following ASTM D120/IEC903 specifications using the manufacturer's recommendations. In the shop before using, the gloves for protection test them by rolling them up to see if they hold air. If the glove does not hold air, do not use it for electrical protection use a new pair.

The gloves may be considered restrictive for small detailed work but not for high voltage work on a Hybrid.
To avoid injury, wear rubber-soled shoes, cotton clothing. Do not wear rings, watches, necklaces, or large belt buckles, which can conduct electricity.

Use procedures to insure the manual safety disconnect switch is not replaced during servicing procedures. Use safety cone and tape to keep others away from the high voltage circuits of the vehicle. One safety procedure is to keep one hand behind your back when testing high voltage circuits. Develop shop rules that no one should be near the vehicle except the technician working on it.

These practices are the minimum that should be used any time you think there is a possibility of contact with high voltage. Talk with your city to ensure you follow all of their ordinances. Discuss working on hybrids with your insurance agent.



Wear eye protection

Any high voltage arching can cause fragments to fly into your eyes. Wear eye protection because of possible high temperature sparks from a short circuit.

What to do in case of an eye injury

If a particle gets into your eyes, immediately use a portable eye flush dispenser or call for help if needed to get to an eyewash station.

Flush your eye with eyewash solution for 15 minutes. Have someone call for medical attention while you are flushing.

CHAPTER 11

LIFTING AND JACKING

High voltage circuits run under the vehicle. When jacking or lifting a Hybrid ensure that the arms of the lift do not make contact with the wires.

The lift is pressing on the high voltage wiring harness in this picture.

CHAPTER 12

TOOLS AND EQUIPMENT

Working and being safe while working on a Hybrid vehicle requires the correct tools and equipment. Thinking about the budget for tools and equipment are an important part of any shops business plan. If the shop is going to take in, diagnose, and repair Hybrids, use tools and equipment designed and constructed for high voltage work. The International Electro-technical Commission (IEC) should rate meters. They are the commission that tests and labels meters for safety. They do not concern themselves with damaging a meter. Their concern is the safety of the user. CAT rating is concerned with potential arc-over conditions that might cause the meter to explode which can lead to injuries.

In the research center, we each have our favorite tools. The old standby equipment may not be safe working with high voltages. Make sure your meter has a CAT-III certification.

There are a number of technical points to consider when selecting a meter for use in your shop. There are volumes of information available for learning about International Electro-technical Commission (IEC). Selecting a CAT III meter for use in Hybrid testing is the recommended CAT category.

CAT I	Low power electronic device
CAT II	Single Phase AC (household socket)
CAT III	Three phase AC distribution (HYBRIDS)

High voltage battery packs have voltages that are higher than household voltage. Full 2-mode hybrids have 200 volts to 330 volts, medium hybrids with electric assist motors are under 200 V, and these vehicles cannot launch under electric power alone. Most hybrids will have over 200 VAC for their battery pack. Larger vehicles require higher voltage to produce the power required for electric propulsion.

Honda ex 2006+ Civic, Accord	144 volts
Honda 2006+ Civic, Accord	158 volts
Toyota Prius to 2004	275 volts
Toyota Prius 2004+	201 volts
Toyota Highlander, Lexus RX 400h	288 volts
Ford Escape Mercury Mariner	330 volts

Higher voltage batteries are more expensive and add vehicle weight.

INSULATED TOOLS

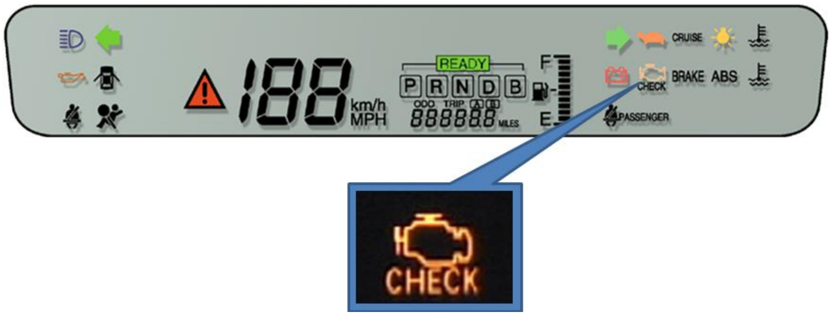
Insulated tools will help avoid injury when working on the high voltage battery pack

CHAPTER 13

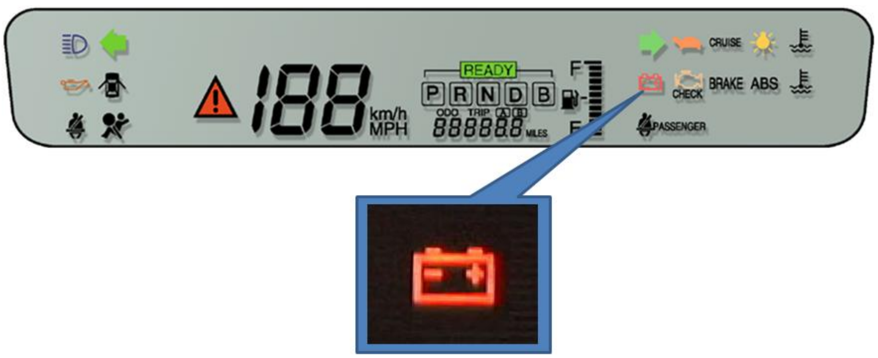
HYBRID WARNING INDICATORS

The vehicle has built in self-tests that can aid the technician in determining faults. Warning lamps on the dash can alert a technician to safety problems. Look for warning lamps before starting any work on a Hybrid.

Identify a System Malfunction before starting to work on the vehicle. Look at the warning lamps on the dash to make you aware of potential problems. If there is, a ground fault with the vehicle, technicians must understand that replacing a fuse can cause excessively high current to flow in the high voltage circuits and can cause injury.
Malfunction indicator lamp (MIL)
Engine control (OBDII) codes present
This is the standard OBDII malfunction indicator lamp indicating an internal combustion engine code.



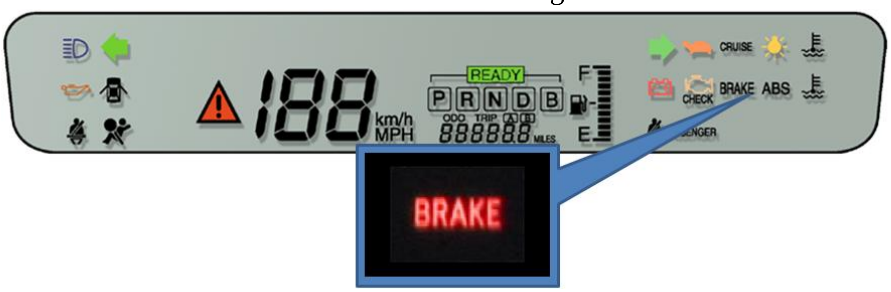
Auxiliary charging system malfunction
12-volt system problem detected
This may seen harmless, but it is critical, the hybrid computers and relays depend on the 12-volt system. If this fails, the vehicle will stop. This is the most likely service you will encounter the first few years of a hybrid vehicle's operation.

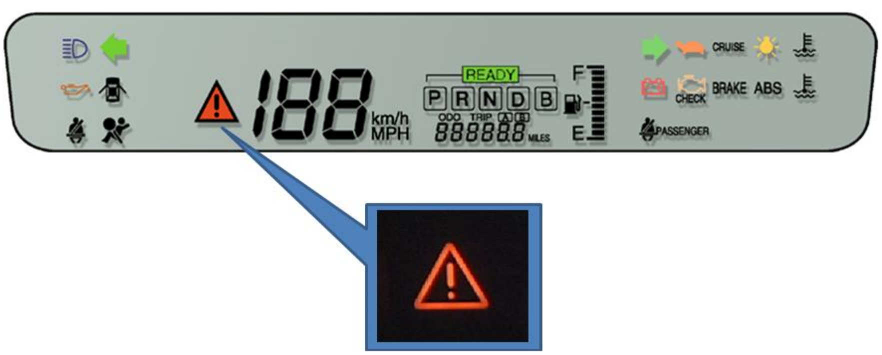


Brake system malfunction
Fault detected in brake actuator or hydraulics. Regenerative braking may not operate because the brake system is in failure mode.

Master warning

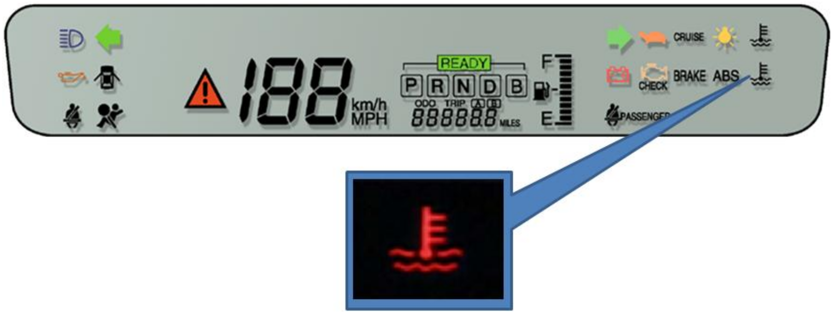
Fault detected in high-voltage electronics or hybrid control system
This can be a major problem or a trivial problem. You must check the Hybrid control and battery modules for codes to determine the exact fault.



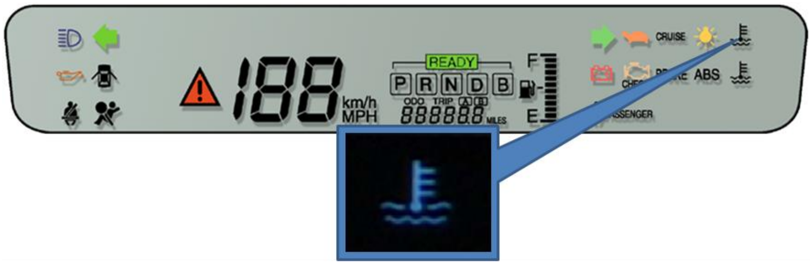


RED coolant warning light
Engine coolant temperature is above 244º F. Engine overheat is serious, because the vehicle will travel a limited distance on electric propulsion alone. A likely outcome will be a discharged high voltage battery if the driver attempts to limp home on the electric propulsion alone.

BLUE coolant warning light
Engine coolant temperature is below 113º F



Remove Ignition Key and FOB



The computers may wake up in the presence of the key, called a Smart Key that does not need to be in the ignition to operate the vehicle. Keep the smart key a safe distances from the vehicle. Avoiding the time required to look up each manufactures recommended distance use 20 feet as a safe distance.

Remove the ignition key and FOB from the vehicle. Some manufactures offers a warning to keep them at least 20 feet away the vehicle so that the controllers do not "wake" up. Ford extends the brake calipers for a brake test when the key goes to the run position.

Ready Light Status

Always ensure that the "Ready" lamp is off before working on the high voltage circuits. If the "Ready" lamp is on every high voltage (Orange) wire is "Hot". Become familiar with the" Ready" indications of the different hybrids.

Most hybrids have some kind of "Ready" indicator lamp to alert the driver when the hybrid system is on (high voltage active). Make sure the Ready light is out, the ignition is off and the key is out of the vehicle before you start any service or repair work.

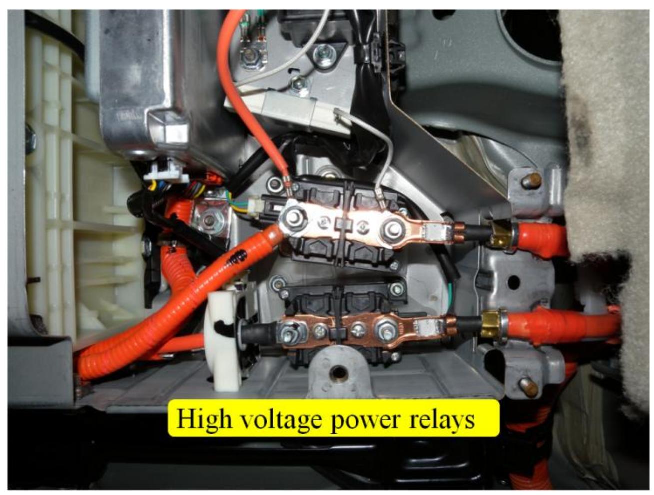
Not all vehicles use a “Ready” lamp to alert the driver. Some put an auto stop indicator on the tachometer. The words auto stop replaces the zero on the tachometer. The tachometer measures and reports engine RPM just like any other tach. When the vehicle is in auto stop, the tach indicates “AUTO STOP” meaning that the vehicle is ready for operation. The engine may or may not be running.

This vehicle is “ready “with the engine off, but ready to launch when the accelerator pedal is pressed.

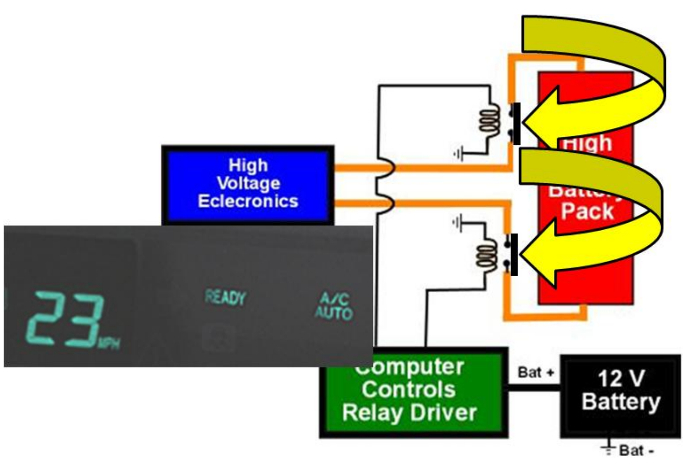
CHAPTER 13

POWER CONTRACTORS (SYSTEM MAIN RELAYS)

The “Ready” indicator reports the state of the power relay or relays (power contactors). Mild Hybrids, low voltage systems may use only one relay.
When the relays are open, high voltage is isolated to the battery pack. When closed the relays connect the battery pack to the electric machine.



The relays are a 12-volt circuit controlled by the Hybrid computer. The drivers may be in the HV battery control computer or a driver module.

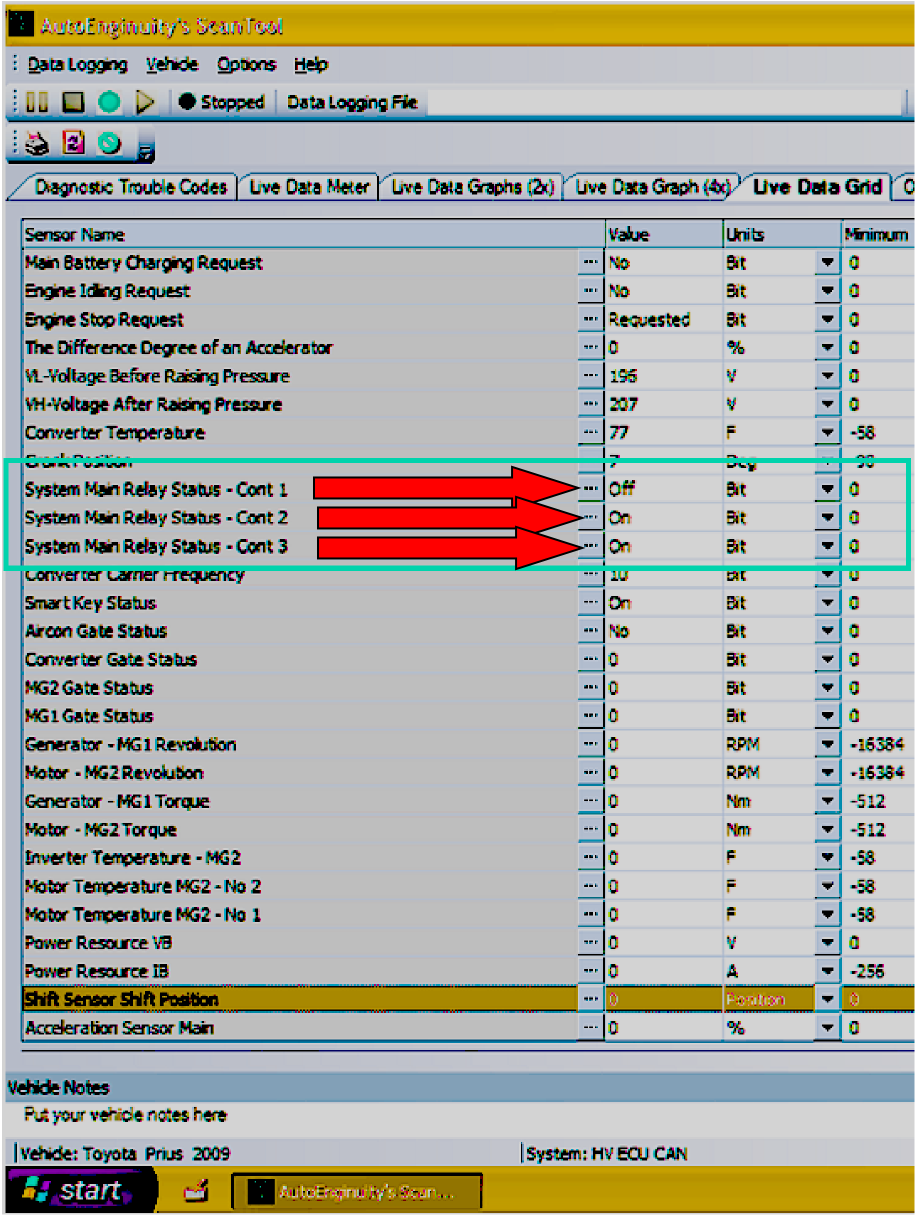


The “Ready” indicator reports when the electronic control connects the HV battery pack to the electric machine. Remember, the engine may be off until you accelerate or some other condition causes the ICE to start. “Ready” indicates the vehicle is ready to drive away

A discharged 12-volt battery can keep the Hybrid vehicle from activating the relay to get in the “Ready” mode. If there is not enough voltage in the battery to close the relays, the electric machine is not going to power up. The 12.0 battery may be “boosted” to supply enough voltage to close the relays. If there is enough voltage in the HV battery pack, it will be capable of cranking the ICE. Once the ICE starts, the vehicle may be driven. If the computer recognizes the voltage in the 12 V batteries is low, it may suspend auto stop. If the 12- battery is too low to supply power to run the ignition and fuel systems then the vehicle will be disabled and require a tow.

System Main Relay scan data

Scan Data is available on some vehicles. This Scan Data shows the state of the three power relays on a Prius Hybrid. System main relay two and three are the relays that connect and disconnect the HV battery pack to the electric machine.



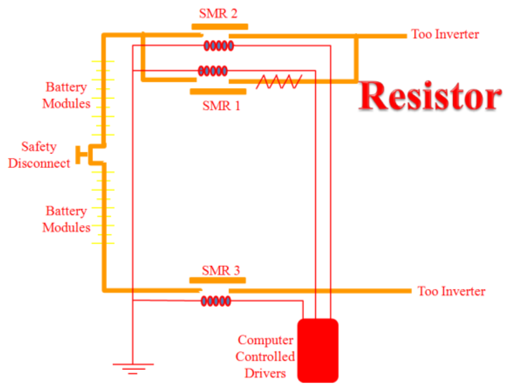
SMR 1 is a pre-charge relay with a pre-charge resistor in series to reduce arcing.

SMR 2 and 3 contactors are on the positive circuit and negative HV circuit.

SMR 1 closes for a short time to check for and electrical short on the HV circuits.

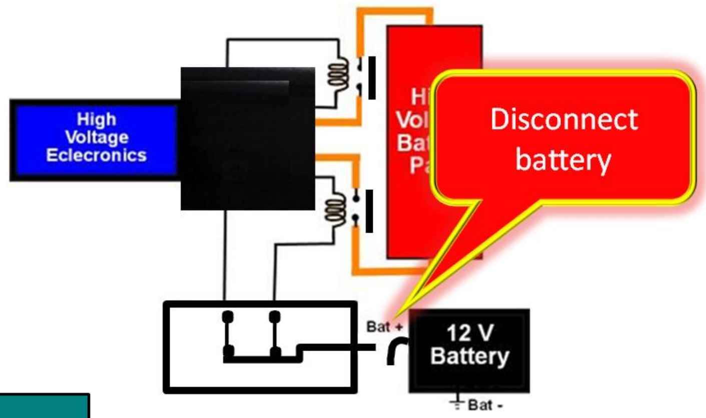
If the circuit is normal:

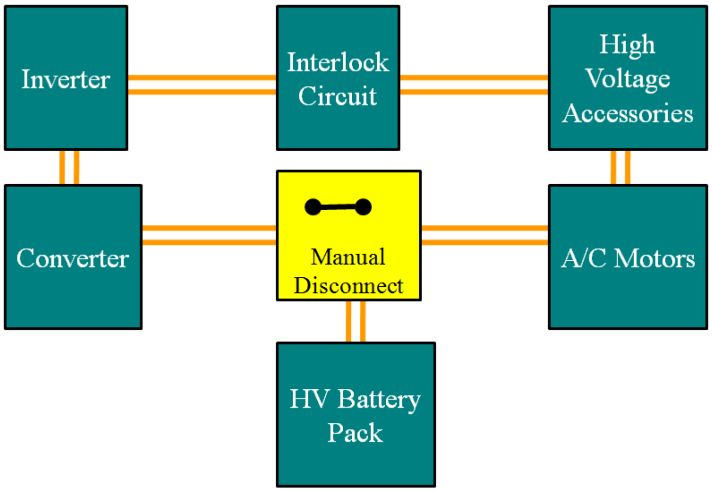
SMR 1 closes to avoid a surge of current to the electric machine by placing a resistor is the circuit. Next, the Hybrid computer closes system relays three and one first. This circuit configuration does not allow the entire voltage from the HV battery pack to rush into the inverter because of the resistance in system relay 1. The computer then closes system main relay 2 and opens system main relay 3. This control happens quickly; watch Scan Data for the switching action.



The diagram shows the controls and location of the resistor in the SMR 1 relay wiring. Large capacitors are charge when the relay contacts close, the resistor limits the initial current inrush to reduce arcing of the contacts.

One safety measure is to disconnect the 12-volt battery when service the high voltage circuits, this will insure the main power relays cannot close accidently.





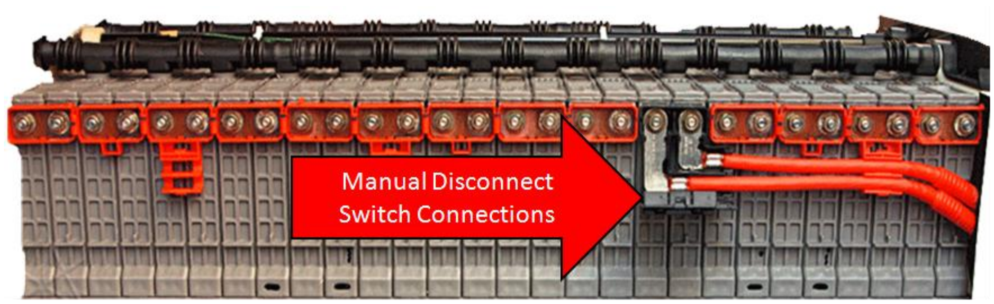
CHAPTER 15

HIGH VOLTAGE BATTERY PACK SAFETY DISCONNECT

The manual safety switch disconnects the HV battery Pack from the rest of the electric machine. When the switch is installed, the HV Battery Pack can supply voltage to the system through the power relays. With the switch removed, the HV battery Pack is isolated from the rest of the system. <u>Opening the battery pack is still dangerous</u>.

Inside the HV battery, pack the battery modules sit side-by-side connected in series. With the safety switch removed, the battery module divides into two sections. On some vehicles, they divide into equal halves. Dividing the battery modules into sections is not what isolates the HV battery pack from the electric machine. With the switch removed, the interlock system opens. When the Hybrid controller detects the open circuit in the interlock it will not close, the power relays isolating the HV pack from the system.

The manual disconnect switch opens the high voltage circuit. The battery pack still has lethal voltage present with the case open. Wear safety gear when you service the battery pack with the case removed.



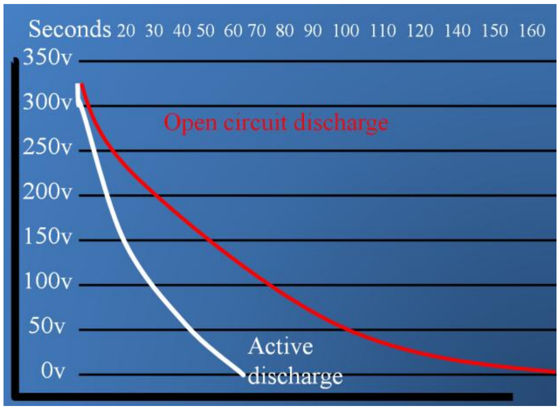
The individual disconnect switches may look different when viewed in a schematic because the manufacturers will do it their way. You should know that the switches are there and to remove them when working on the vehicle. Remember, things that were belt driven on internal combustion engines will use the high voltage battery pack. A/C blowers and compressors can run with the IC engine off. The accessory circuit receives power from the voltage converter that creates the 12 V accessory supplies.
To be safe first disconnect the negative cable on the auxiliary 12-volt battery
Then locate the service plug and remove the plug (insulated gloves should be worn)

HIGH VOLTAGE CAPACITORS

The boost converter (explained later) uses High Voltage Capacitors for storing the boost voltage. The technician must wait 5 to 15 minutes after removing the safety switch for the capacitors to discharge. Some manufacturers use an active circuit to discharge the capacitors within 5 minutes after the Hybrid controller sees the interlock circuit open. Other just allows the capacitors to discharge requiring up to 15 minutes. Waiting 15 minutes for them to discharge is the safe thing to do.

Vehicles have a manual disconnect switch that will isolate the high voltage battery pack. A technician must know and remember that removing the safety switch does not automatically discharge the high energy that is in the capacitors. Only time can do that.

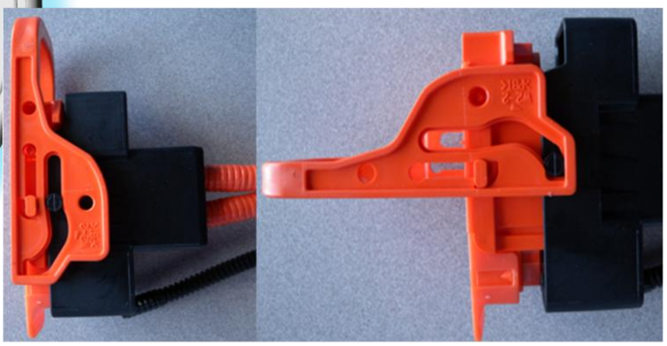
Most manufacturers also recommend waiting 5 to 15 minutes before working on the high voltage circuits after the battery has been isolated or disconnected. This gives the high voltage capacitors time to discharge. The chart shows an example of the capacitors discharging the time required. You can see that after 40 seconds there is 150 V remaining in the capacitor. Even when the high voltage battery pack is disconnected, the capacitors are in the circuit.



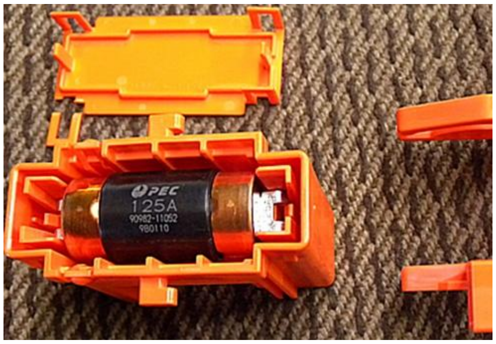
Measuring the capacitor voltage as they discharge took 17 minutes for the meter to read Zero volts. At the 15-minute mark, the meter read 0.083 volts. <u>You should not use a jumper wire to drain the charge; the capacitors store high current, severe arcing may occur.</u>

Some manufactures recommend that the switch be in the technician's pocket so that a different technician cannot come along and re-install it. The first technician may not know it was re-installed and work on the vehicle as if it were not. Every shop should design a set of safety rules for their shop and all technicians should understand and follow the rules.

2004 and up Prius

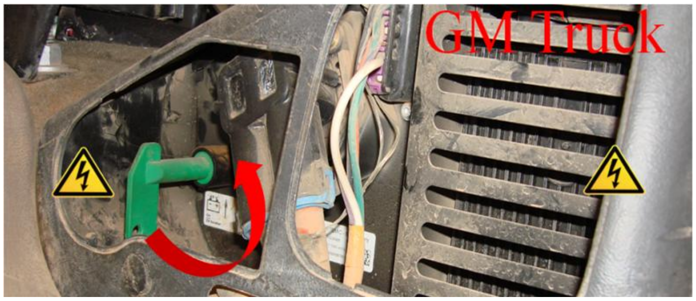


This is a corroded fuse located inside the manual safety switch. Yes, this caused a code to set for main fuse open!



Honda uses a different safety switch. The switch maybe located behind the back cushion of the rear seat. Remove the two screws, the locking cover and push the switch to the off position.

The Ford Hybrid vehicle uses a Sanyo battery pack with a round safety switch.



The switch itself has a position indent on it. Turn the switch counter clockwise until the indent is pointing to the un-lock position. Lift the switch out of the battery pack. Position the indent with the" Service and shipping" position and press the switch back into the battery pack for storing. Panasonic now owns Sanyo so newer models may change.

The fuse ford is also in the manual safety switch.

This safety switch is on a mild GM hybrid pickup truck. The battery pack is under the rear seat. Remove the access panels on the right side of the truck to remove the switch.

This is a new Chevrolet SUV the battery pack is under the rear seat. The safety switch is on the right side of the vehicle. This is a new Panasonic battery pack.

CHAPTER 16

AUXILIARY BATTERY 12 VOLTS

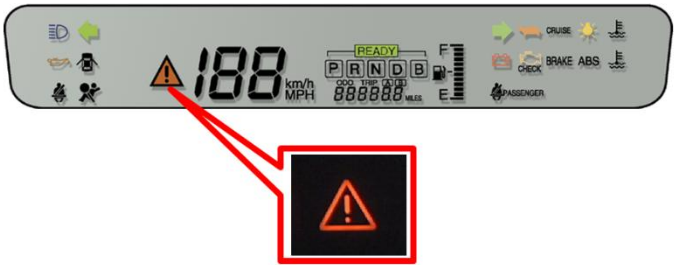
We refer to this, as a 12-volt knowing is rarely 12 volts. We do this to highlight the fact that it is not part of the high voltage electrics. Hybrids use the common lead acid type batteries used in the automotive industry for years when placed in the engine compartment. When the auxiliary battery is in the luggage or passenger compartments, an AGM battery is used.

The AGM battery looks like a regular sealed battery. Some manufactures change the size of the terminals making the battery preparatory to the vehicle.
The Absorbed Glass Matt (AGM) construction allows the electrolyte suspended in close proximity with the plate's active material. In theory, this enhances both the discharge and recharge efficiency. AGM batteries deliver their best life performance if recharged before allowed to drop below the 50% discharge rate. After an AGM battery reaches 50% state of charge the discharging accelerates and the battery can go dead very fast.
The sealed battery mounts in the luggage or passenger compartments.

The AGM battery has a low internal electrical resistance. Do not fast charge an AGM battery because its inability to vent it can cause it to explode. Test glass mat batteries with an internal resistance type tester (as opposed to a load tester).
For safety, disconnect the 12-volt battery before working on the High Voltage circuits.

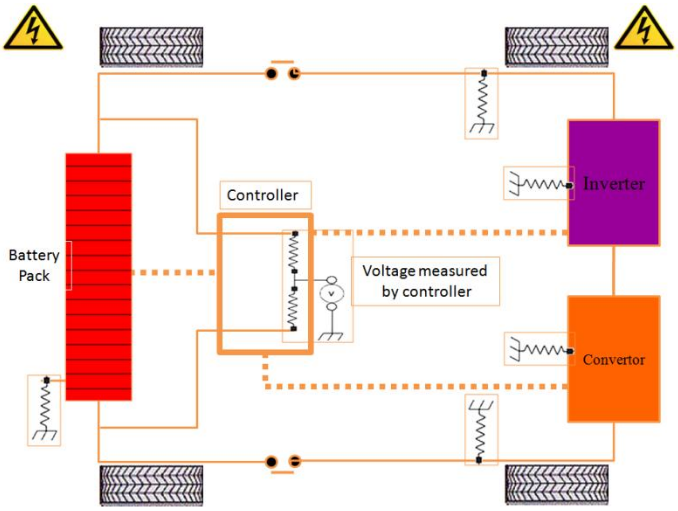
There are special AGM chargers

Charge them slowly



CHAPTER 17

GROUND FAULT DETECTION



High voltage isolation detection is an important part of safety. The ground fault detection monitors the vehicle chassis for contact with the high voltage circuits. These circuits will monitor to see if any high voltage is "leaking" to ground. The system monitors both the DC and AC high voltage circuits. These systems monitor voltage to see if the chassis ground voltage exceeds the specific threshold value. Ground faults will illuminate the master warning light. Remember, other faults can also turn on the light.

The fault detection system reports to the hybrid system controller.

The DC-to-DC converter monitors itself; the codes are stored in the hybrid control ECU.

The DC to AC inverter monitors itself, pull hybrid control ECU codes

The Battery pack controller monitors itself, pull battery pack codes

Ground fault circuits;

When a fault is present, the controller will take different actions based on the vehicle condition. The controller will set codes based on the fault detected.

With the Transmission is in "PARK"

The controller will disable the two power relays, turning off the ready light

If the vehicle is not moving (0 MPH)

The controller will disable the ICE

The controller will set a DTC

If the vehicle's hood is, open

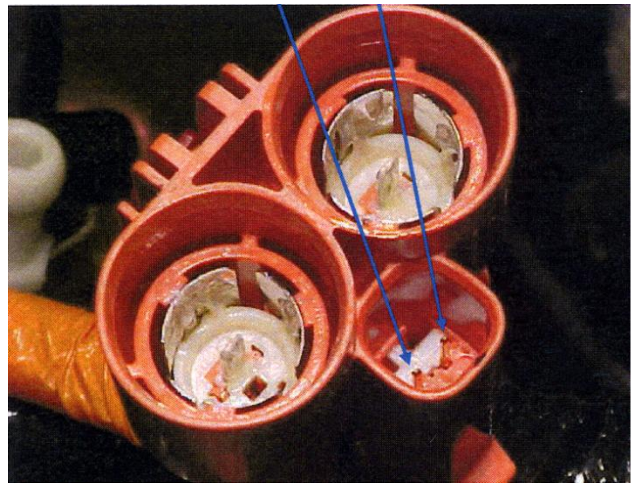
The controller will open the power relays and disable the ICE

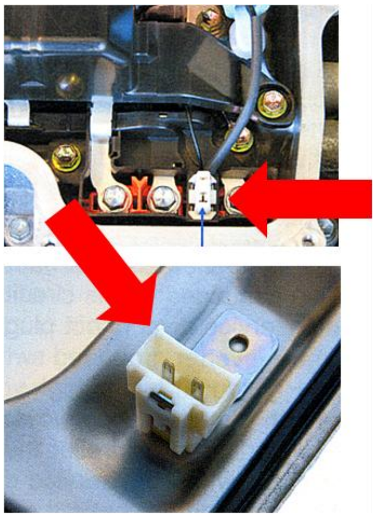
DTCs will be set

This fault can be the reason a hybrid vehicle fails to respond to the start command!

Chapter 18

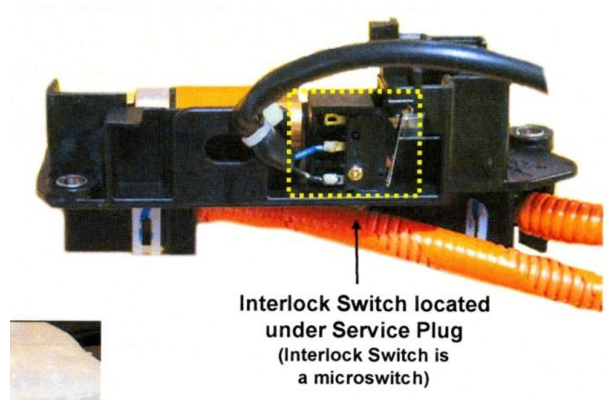
Safety Interlock System

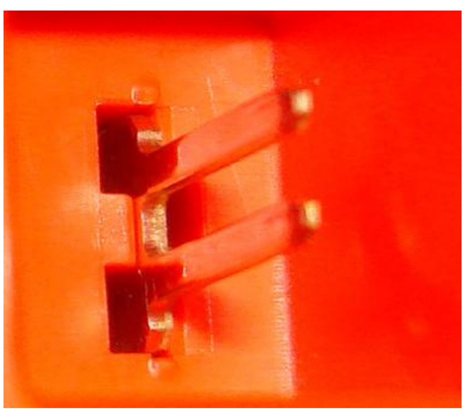




The High Voltage Cut Off system uses conductors or switches to detect opens in the High Voltage Circuits. This is a safety system that keeps the power relays from closing with an open high voltage circuit.
With a breech detected, the Hybrid controller takes action to keep the vehicle safe. If the engine is running, it will set a fault and set a DTC. It also opens the power relays, turning off the ready light. If the vehicle is moving, it will allow it to continue until a stop, then it will disable the ICE. If the vehicle is not moving, it will disable the ICE right away.

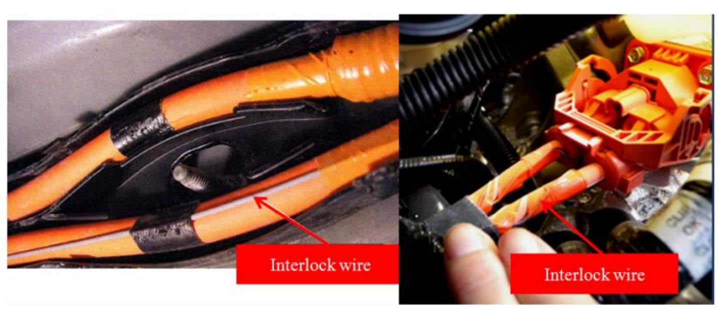
The connectors for the high voltage wiring harness have small pins for the interlock wining.

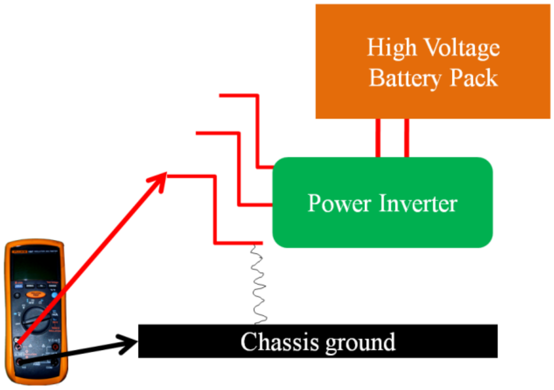




Local Interlock System
A local interlock uses discrete switches to detect breached high voltage circuits or components.
If a breach has been detected

The controller (ECM) signals Communication Bus and the Hybrid controller opens the power relays and discharges the capacitors
The local interlock detects covers removed from modules that have high voltage circuits. The manual safety disconnect switch protects the high voltage battery pack.





Take care when replacing the manual safety disconnect, you can have a problem if they do not mate with the connector. The interlock circuit keeps the technician safe when working on the high voltage circuit. If the Hybrid controller detects a breach of the circuit, it takes action to isolate the high voltage to the battery pack. If certain DTCs are set or the air bags deploy the Hybrid controller will open the system main relays.

Air bags deploying or water intrusion into the control modules will also open the main power relays to shut down the vehicle.

CHAPTER 19

LOSS OF INSULATION (LOI)

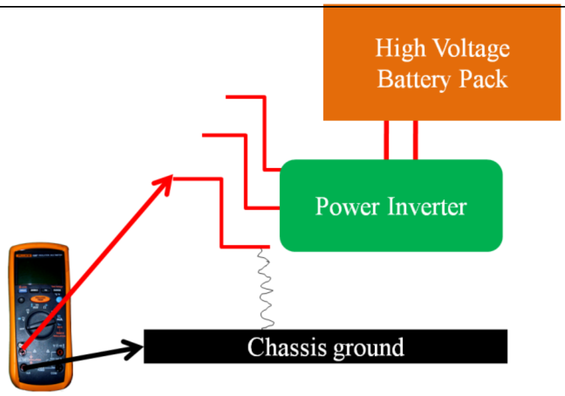
The High Voltage circuits do not use a common ground. The circuit starts on the positive side of the HV battery pack and returns to the negative side of the pack in a loop. When the ground fault system detects high voltage leaking to ground and sets a DTC for the location the technician must diagnose and make the repair.

\

Test for high voltage insulation leaks with special test equipment. Test the circuit with a high voltage ohmmeter that measures mega ohms. The capacitors must discharge before testing for LOI. Your standard ohmmeter is not adequate for the job; you need a high voltage insulation tester.

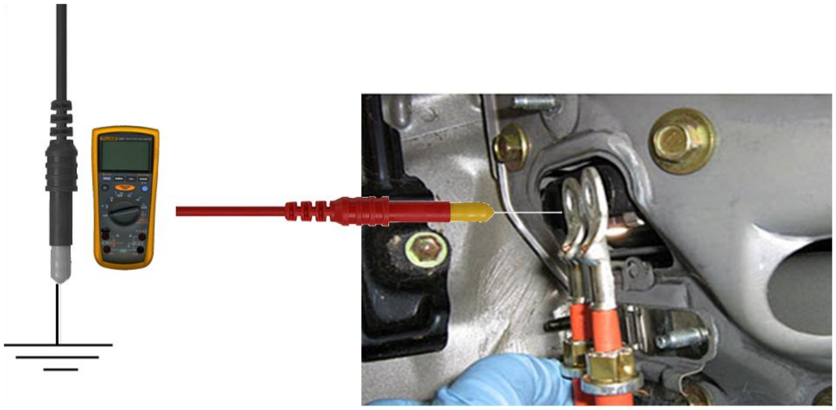
INSULATION TESTER

CAT III rated at 1000 volts.



The meter measures insulation resistance of the wiring in mega ohms.
It has different voltage levels of voltage for testing (You Select).
The insulation test uses separate lead connections and controls for leakage testing.
Connect the tester to the high voltage circuit to be tested and chassis ground.

Use diagnostic trouble codes to try to identfy the circuits that need to be tested

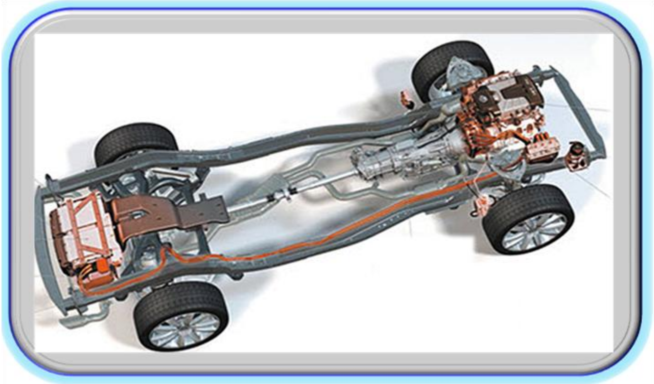


This is a test for one of the three motor stator windings circuits. Each one of the circuits in the connector would require testing. Test all high voltage circuits identified by codes for loss of insulation. Make the connection seen here and then press the insulation test button. The tester will determine the resistance of the circuit.

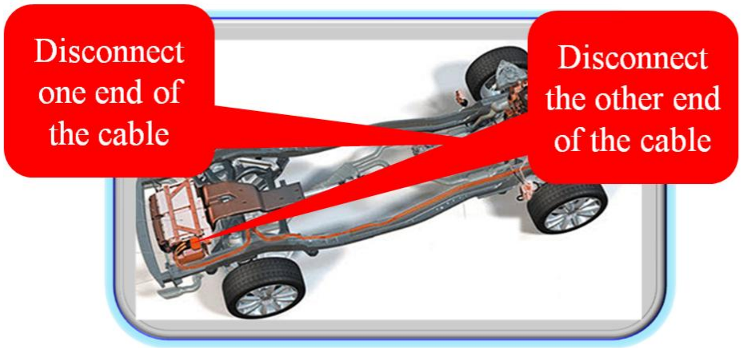
Follow all of the safety rules during the LOI test

We will go through a typical problem with a ground fault. You have a vehicle with a master warning light and a Diagnostic Trouble Code (DTC) relating to a ground fault.

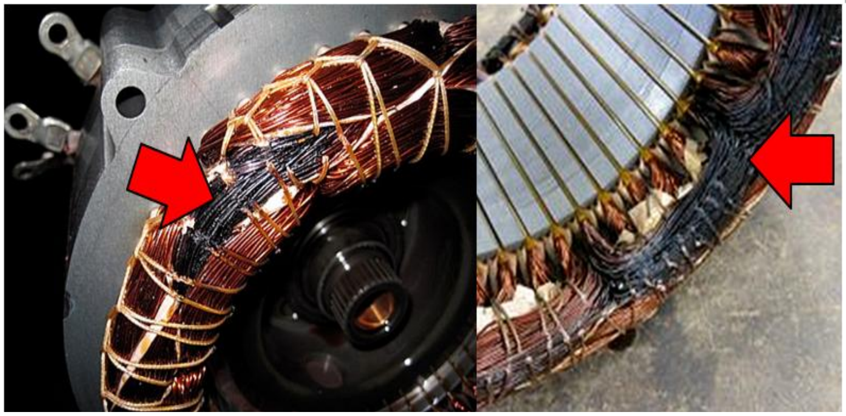
Use a vehicle specific schematic to identify the problem area. Prepare the vehicle for testing by removing the safety switch, which will open the interlock circuit. With an open interlock the controller will not attempt to close the power relays.



Disconnect the Battery to be sure the main power relays are open. Then, wait for the capacitors to discharge.
Measure the high voltage with a voltmeter to check for the capacitor's high voltage.
Connect the test leads to vehicle side of the main system relays.
To test the power cables from the battery pack to the inverter/converter assembly, disconnect both ends of the cable.



Connect the insulation tester to the wiring harness connector and chassis ground.
Use this test to locate damaged frame wiring harnesses and shorted stator in the motor



Use vehicle information to select the voltage range and resistance to expect. We have found the resistance readings are accurate on all voltage ranges, but select lower voltage to protect electronics inside control units.

CHAPTER 20

Different manufacturers will use different descriptions for hybrids. Some may call a mild hybrid a micro hybrid. Some may call a Strong a full hybrid.
Understanding the characteristics of the Hybrid your working is important because you need to have an understanding of operation. <u>Not all Hybrids propel itself on electric drive only.</u> Thinking that they do can lead to thinking there is a problem with a vehicle when there is not. The reason there are such big differences is expense and weight. Mild hybrids use lower voltages, which reduce expense and weight, but they give up function.

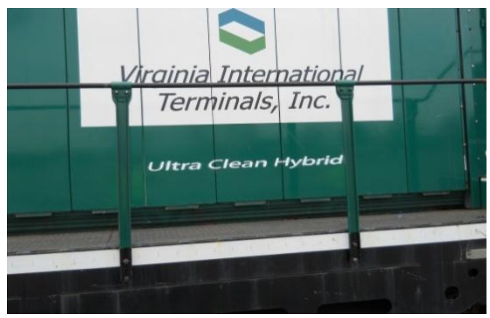
Vehicle Characteristics	Mild, under 100 V	Medium, under 200 V	Full, over 200 V	Plug-in Hybrid
Auto engine shut down	**YES**	**YES**	**YES**	**YES**
Regenerative braking	NO	**YES**	**YES**	**YES**
Traction motor assists	**YES**, LIMITED	**YES**	**YES**	**YES**
Launch with Electric	NO	NO	**YES**	**YES**
New Generation Hybrids				
Operate at 10 miles on electric	NO	NO	NO	**YES**

Terminology of new functions is necessary as with any new technology in the automotive industry.
Mild hybrid:

Provides electric assist to the ICE
Auto stop

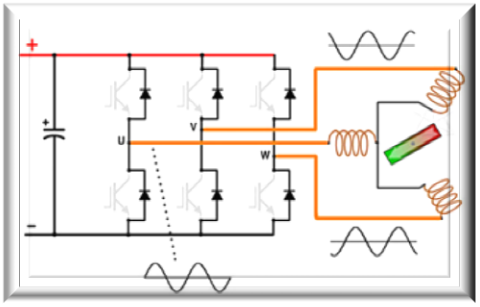
Strong/full hybrid:
Provides electric drive, ICE drive, or both

Auto stop
Likely to use hybrid electric motors to start ICE



Some manufacturers will divide hybrid vehicles by their voltage. As an example, a mild hybrid is a vehicle with less than 144 volts for high voltage hybrid and anything-over 144 volts sir a strong hybrid.
<u>Series hybrid:</u>
The ICE isn't connect to the transmission/transaxle
The ICE powers the generator
Most cases use the electric drive instead of a transmission
Some hybrids use a transmission with the electric motor, Honda, Nissan, 2- mode GM, Chrysler, Daimler and BMW. Diesel-electric locomotives were hybrids that used electric motors to eliminate the transmission to connect drive force to the wheels. The electric motors were referred to as "traction motors" to identify their special function. Electric motor have their maximum torque at start up, while internal combustion engines develops their maximum torque in mid to high speed range.
New generations of hybrid trains use large battery packages to run the train with a diesel motor to keep the batteries charged. Hybrid locomotives of this type are switching engines that have intermittent use with long idle times.

Series / Parallel:
Can use the electric drive mode only (series)
Can combined both the electric drive with the ICE drive (parallel)



Hybrids have many commonalities between them. The Motor/generator, Inverter, High voltage Battery packs, and the Converters will have the same operating principles. Manufactures vary the look of the components and how their configured on the vehicle but, they all operate the same. Three phase electric motors driven by an inverted assembly perform the same functions. Large motors have heavy-duty drive components and small motors have smaller components, but they have the same operating principles. Hybrid vehicles using motor/generators, Inverters, High voltage Battery packs, and the Converters will have the same operating principles.

CHAPTER 21

HYBRID ELECTRIC MOTORS

Permanent Magnet Brushless Alternating Current motors (PMBLAC)

The drive motors used in hybrids are A/C brush-less permanent magnet motors. They operate on magnetic fields that require a very complex control circuit. The magnetic principle that like poles repels and opposite attract generates motor torque. The shape, length, width, and thickness of the magnets will vary depending on torque and RPM requirements.

Three-phase power has three legs carrying power, each with the same sinusoidal waveform, but 120 degrees out of phase with each other. When one leg is at the peak of the wave, another is 2/3 the way towards the bottom on its way down, and the third is 1/3 the way up from the bottom on its way up.

Three-phase AC motors are used because they are more efficient than single-phase motors. Heavy industrial applications use three phase motors because of the high efficiency.

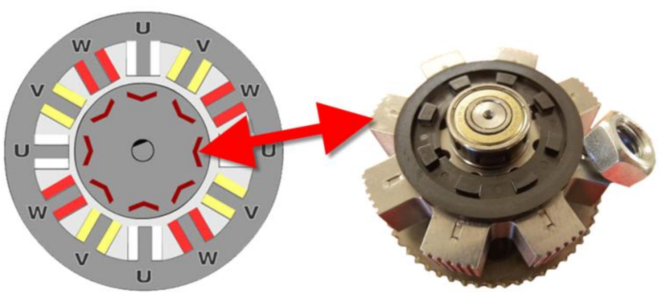
Hybrid vehicles require special drive electronics to change the DC voltage from the high voltage battery pack into high power AC voltage.
The motors provide vehicle propulsion in positive, negative, or zero torque. The unit also provides regenerative braking power to re-charge the high voltage battery pack during deceleration and braking.
When you are speaking about the motor itself:

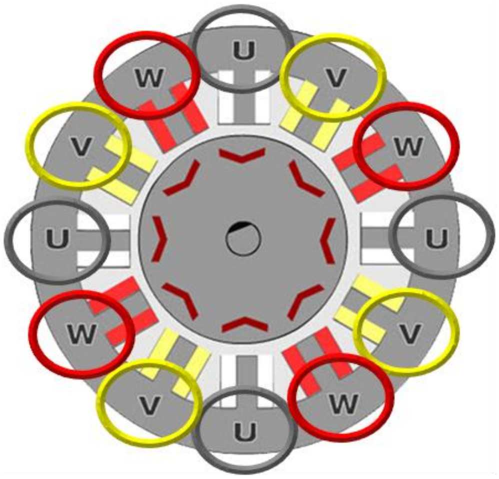
Positive Torque position: When opposite poles attract each other.

Negative Torque position: the magnetic poles repel each other.

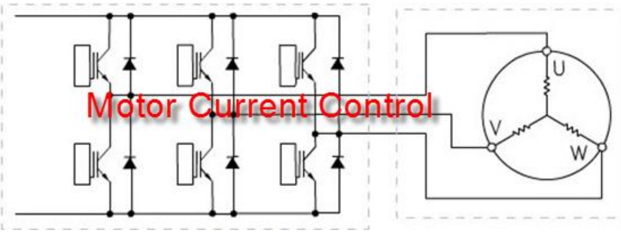
Zero Torque position: the stator has no magnetic force created.

The major components for the motor are a stator, rotor, and the housing to hold it all together. The minimum stator poles (Electro magnets) would be four. In Hybrid application, the minimum numbers of poles is 12. This small amount of poles sure used



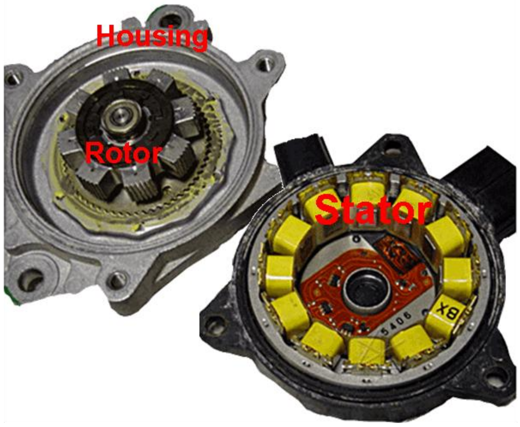


in a small motor like the gear selector motor.
There will always be a combination of 12 poles in the stator. Typical examples of the usage are 12, 24, 36, 48, 60, 72, 84, and 96 poles. A Prius has 48 poles in its traction motor. GM uses 96 poles in a stator for one of its pick-up trucks.
Motor speed is determined by multiplying the number of poles by the AC frequency of the three-phase AC voltage. Lower AC frequency increases the current flow in the stator by reducing the inductive lag to start current flow.



Hybrids use brushless motors to extend motor life because the vehicle manufactures want hybrid vehicles to last at least 10 years 200,000 miles. In the photo, we can see fuel pump motors where the brush has worn to the point it has damaged the commentator. The carbon brushes do not carry the high current needed to power large motors. The rotor has permanent magnets where the magnetic field is fixed. Poles are arranged in alternate positions. The pattern is North-South-North-South patterns to change magnetic polarity as the rotor rotates.

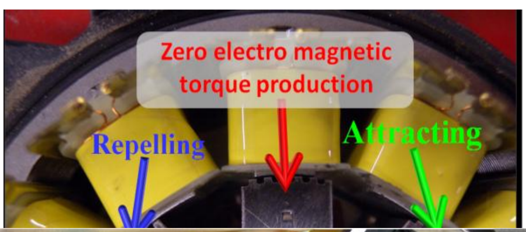
Electrical control for the stator varies the strength, polarity and timing of the electro magnets. The electro magnets can be weak or strong depending on the amount of current it receives. Change the stator magnetic polarity by changing the direction of the current for the stator electro magnets.
Brushless motors rely on electronic commutation, which involves precise control of the magnetic polarity and strength of the stator electro magnets.

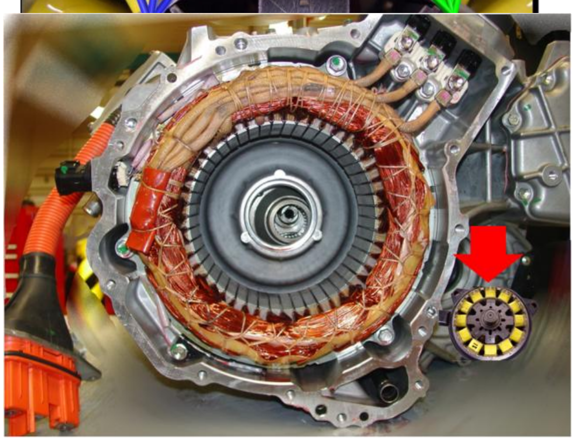


The three phase stator windings labeled U-V-W have multiple winding connected in parallel and positioned around the stator. This allows more electro magnet/ permanent magnet interactions during rotation of the motor. Notice the highlights of each phase in the picture. The position of the magnets and stators align to create torque all around the motor.

The result of the multiple stator windings and permanent magnets in the rotor is to produce a magnetic reaction that produces torque that surrounds the rotor.

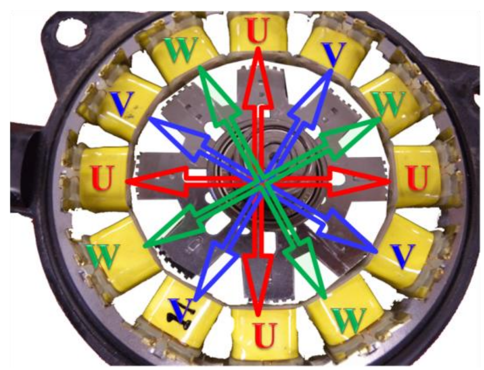
All the three phase motors operate on the same principles, the differences is size. Some motors use 1-2-3 instead of U-V-W, but the operation is the same. Toyota uses U-V-W. You need to know this so you will understand the codes that refer to the different windings; an example could be Low motor current in the U windings. This code would direct you to specific of windings to check for a problem.



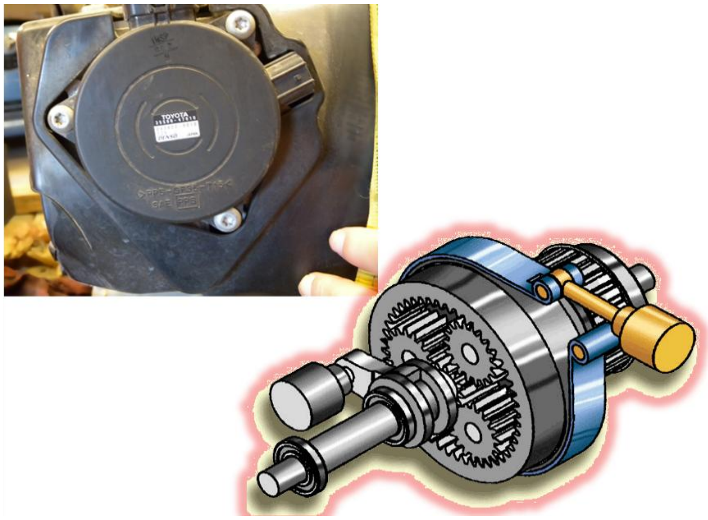


In this photo, we can see the three phase wires from the stator. There are 48 electro magnets on this stator, which means there are 16 each “U”, “V”, and “W” or “1”, “2”, and “3” circuits. Notice the amount of windings in the stator. Remember this image when studying regenerative braking. There is a lot of electricity created during regenerative braking because there are so many windings.

In the lower right corner is a park selector motor. Is has less magnets and windings making it a smaller. The more work that a motor is designed to do the more magnets, windings, and the larger it is. You can envision how 96 windings would surround the rotor.



This is the three-phase A/C compressor motor. The reason you see only two wires going to the compressor is those are the positive and negative leads from the high voltage system. This indicates the inverter is part of the compressor assembly, which separates it into the three phases at the compressor. The orange wire indicates high voltage from the battery pack. Other motors will use 12 volt to create the three phase AC for the motor.
The small motor we used as our three-phase example uses the 12-volt auxiliary supply.

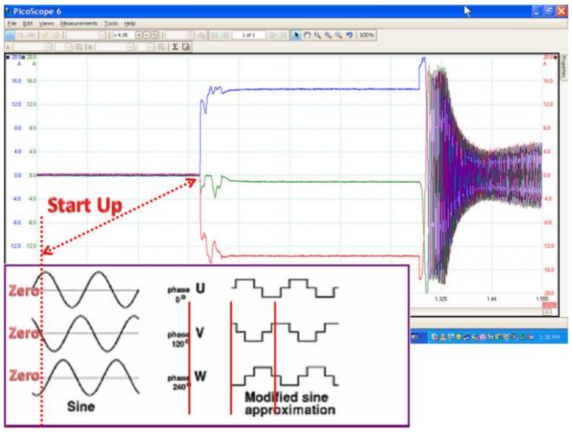


This motor has 12-electro magnets in the stator that operates the park select motor on a Toyota Prius. The motor mounts to the transaxle housing. The Hybrid control ECU drives the motor with high-powered AC voltage. The wiring to this motor is not orange. We are pointing this out to help you during diagnostics. We recently had an occasion where the park brake did not set properly when we were working on a vehicle. The 12-volt battery was down to 8.8 volts, and it did not have enough power to tighten the park setting on the vehicle, we attached a booster battery to get the park brake set.

The motor has fewer windings in the stator but because the park selector motor does much less work then does a traction motor we know there will be a lot less windings.

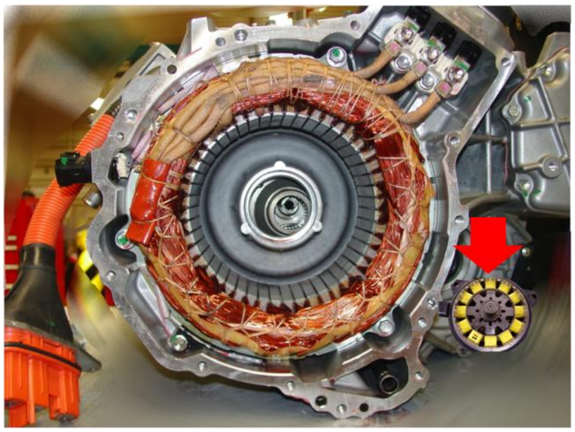
Notice the nut attracted to the permanent rotor magnet. This is an excellent example of the differences in the motors. The large traction motor has more windings and uses high voltage, but both motors function using the same principles.

LOOKING AT MOTOR PHASING ON A DSO



This waveform of the three phases is not to teach a diagnostic procedure but rather a demonstration of the phasing. The waveform shows when the motor starts up it gains torque almost instantly. This is the heavy work of getting a vehicle moving or an A/C compressor beginning to compress the refrigerant. After the initial high current, the motor current settles down and operates at a lower current.
The difference between a large traction motor and a smaller A/C compressor motor is the amount of current it draws. Higher power motors require high voltage and higher current to produce the power needed to propel the vehicle. This waveform confirms the theory of current in a three phase motor. One current is positive with another negative and the third is near zero.

CHAPTER 22



DC TO AC INVERTER

The electric control units, converters and inverters work together to control the electric motor.

The inverter and converter may be separate or a single assembly. The Hybrid controller ECU issues the commands for controlling the electric machine.

A power inverter converts D/C power or direct current to three phase A/C power or alternating current and back again during regenerative braking. The inverter is the component that controls current to the A/C motors.
On some models, the inverter has a separate inverter built in to change the high voltage D/C to A/C for the air conditioning compressor.
Ford has an integrated transaxle and inverter assembly
Honda is behind the rear seat
Prius is under hood

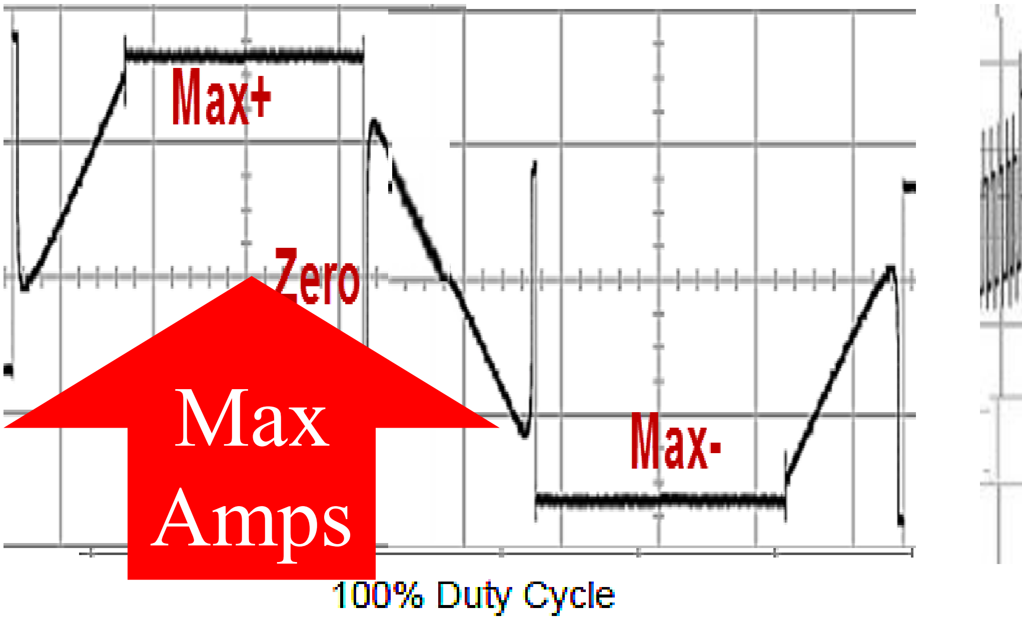
The inverter has electronic current pulses (pulse width modulates) to the motors. There are circuits that can reverse the direction of the current flow reversing the motor's direction. There are diodes used to change the A/C voltage created during regenerative braking to D/C voltage to charge the high voltage battery pack.
Converters replace the alternator that is on non-Hybrid vehicles. There are switches inside the converters to pulse the high voltage that was stored in the battery pack down to 12 volts to charge and operate the 12-volt system.
The insulated gate bipolar transistor or IGBT is a three-terminal power semiconductor device that is noted for high efficiency and fast switching, six IGBTs in the gray highlighted area of the diagram. Fast switching is important because the motors operate at very high RPM. Turning the electro magnets on and off in the motors requires fast switching at high power levels which produces heat during operation. The cases help dissipate the heat generated by the electronics.

The metal-oxide semiconductor field-effect transistor (MOSFET), pronounced MAWS FEHT, used in the DC-to-DC converter, is a special type of field-effect transistor. The MOSFET drivers pulse the high voltage from the battery pack through a step down transformer. The step down transformers create a lower voltage from the high voltage battery pack.

Ford and Toyota DC to AC inverters have a boost inverter (the red highlighted area) at the input to the motor inverter. The voltage is stored in the high voltage capacitor (tan highlighted area). The DC to AC inverter is the grey highlighted area.
The torque that an electric motor produces is proportional to the amount of current supplied. The Hybrid controller ECU controls inverter current. The Hybrid control ECU manages torque with data from the APP sensors. The PCM calculates the ignition and fuel events for the ICE while the Hybrid controller commands the inverter for electric motor control.

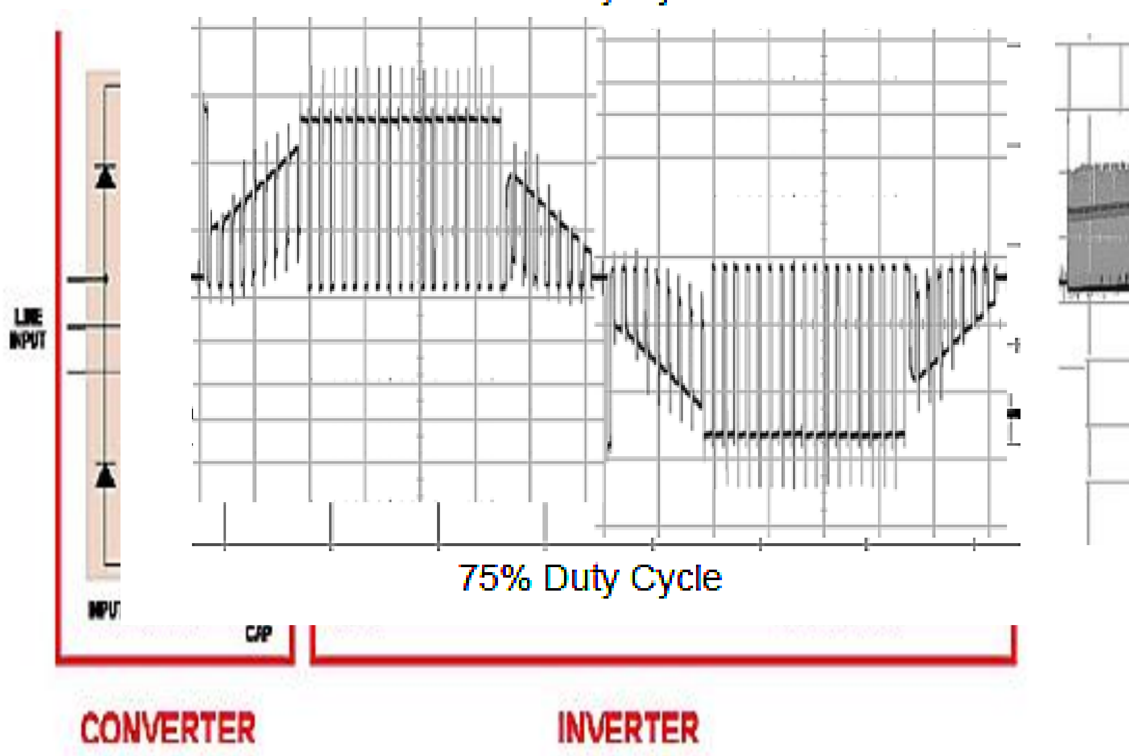
Drive Signal Characteristics

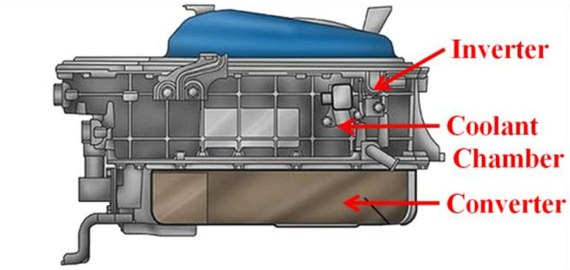
During acceleration, the hybrid control ECU selects either the ICE of the electric machine to propel the vehicle, in some cases both the ICE and the electric machine are selected. To increase the electric motor's RPM, the inverter increases the frequency of the current of the drive signal by turning on and off the IGBT sets.

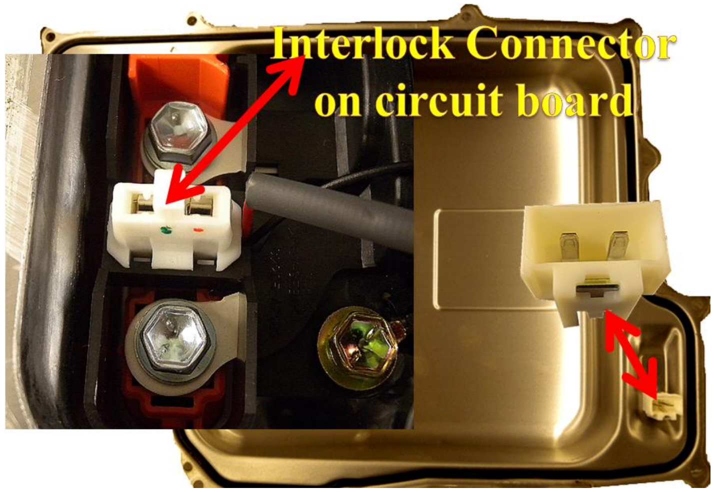


DC to AC Inverter Units

These are examples of power inverter assemblies. The units may look different, but they all have the same function. Some power inverters housed in the transaxle.





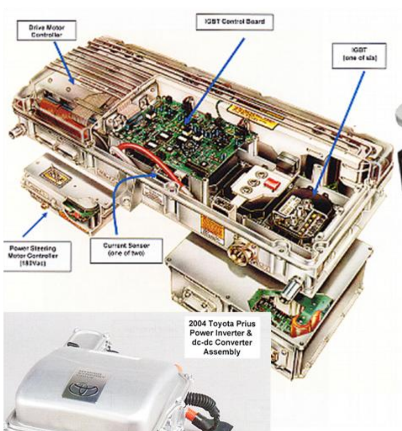


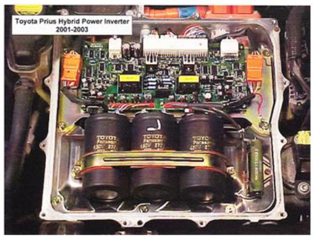
The housing prevents the intrusion of moisture. The housing also acts as a reservoir for the coolant for the high power electronics. Safety interlocks are use in the housing to prevent accidental contact with high voltage. Removing cover will open the interlock circuit that opens the system main relays to disconnect the high voltage battery pack.

INSIDE THE INVERTER

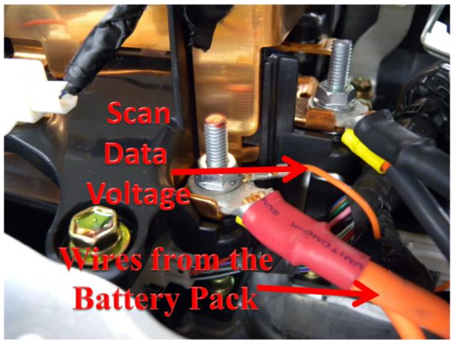
The boost capacitor is the large black module on top of the electronics. **<u>We monitor the voltage on this capacitor with scan data. Scan data frequently eliminates the need to open the case</u>.** These are sensors inside this unit to detect moisture intrusion that act like part of the interlock system.
The electronic circuit boards are located under the boost capacitor. These circuits keep track of motor position and control the action of the IGBT transistors to control motor operation.

Notice the heavy bus bars used to connect the high current circuits. The data is processed by the electronic circuits are also available in scan data. We are covering the information here to help you understand where the information is developed. The data on the individual motor circuits for current and voltage are available in scan data along with motor speed for the main motors. Inverter assembly temperatures are monitored for overheat condition and sets diagnostic trouble codes.





Scan data connections are located at the critical points insides the inverter. Each vehicle manufacturer has unique scan data is for diagnostics.

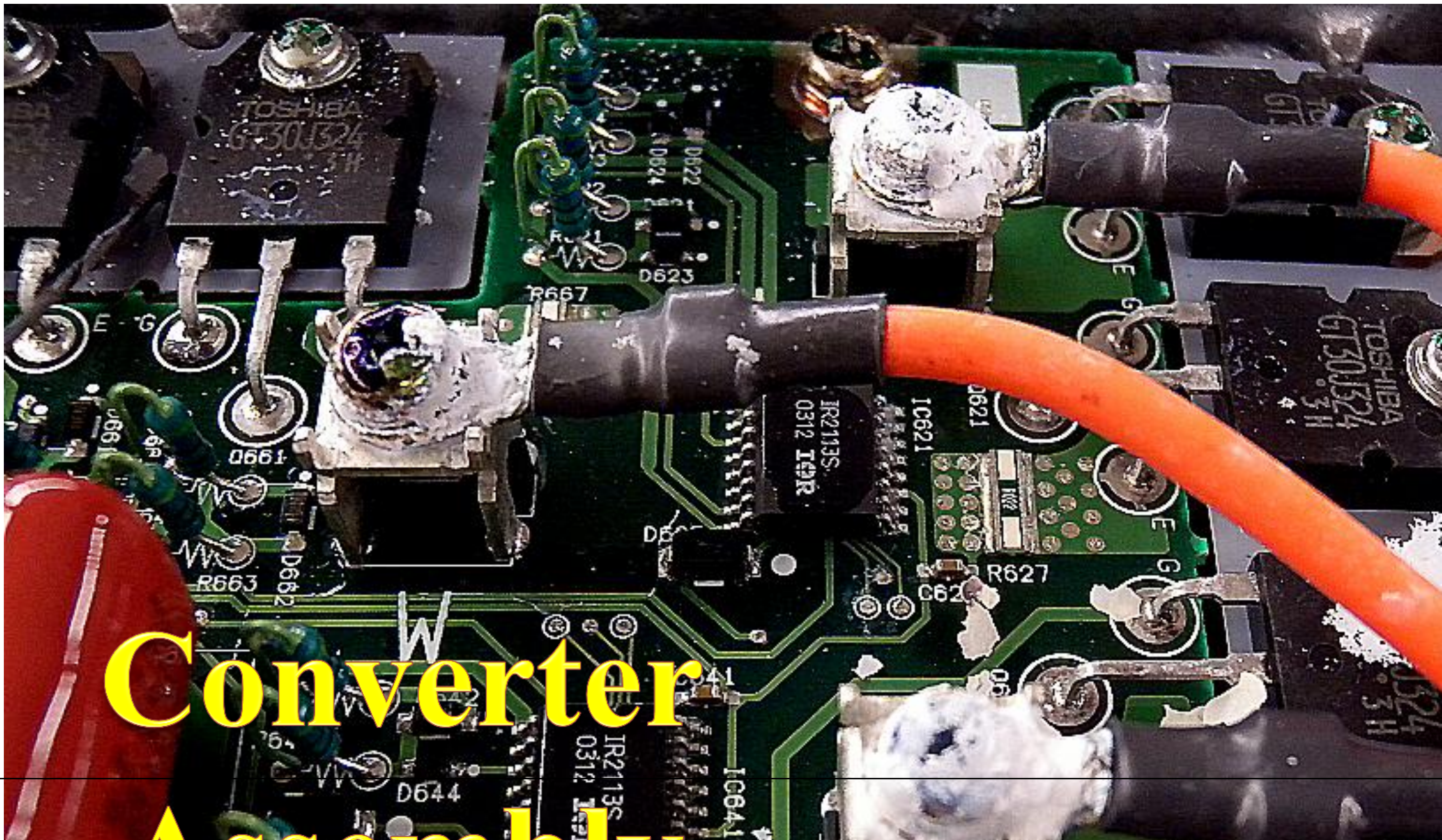


This is an example of a scan data point for voltage. This is the input voltage from the high voltage wiring, remember, the other end of this wire is in the battery pack where is also measured for scan data by the voltage battery ECU. Understanding this level of detail will help you make valid diagnostic decisions without having to open the high voltage control units. If voltage is normal at the battery pack, it should be the same here, unless there is a wiring problem. There are times where you can use this information to locate connection problems. We have occasionally found connections that cause a problem.

Here are the connections that take the three phase AC to A/C compressor. The A/C compressor on this vehicle has a problem, it does not have full current flow. Notice the connection inside the inverter, they are corroded. Remember, we looked here because sca data showed low current which indicates a possible connection problem.

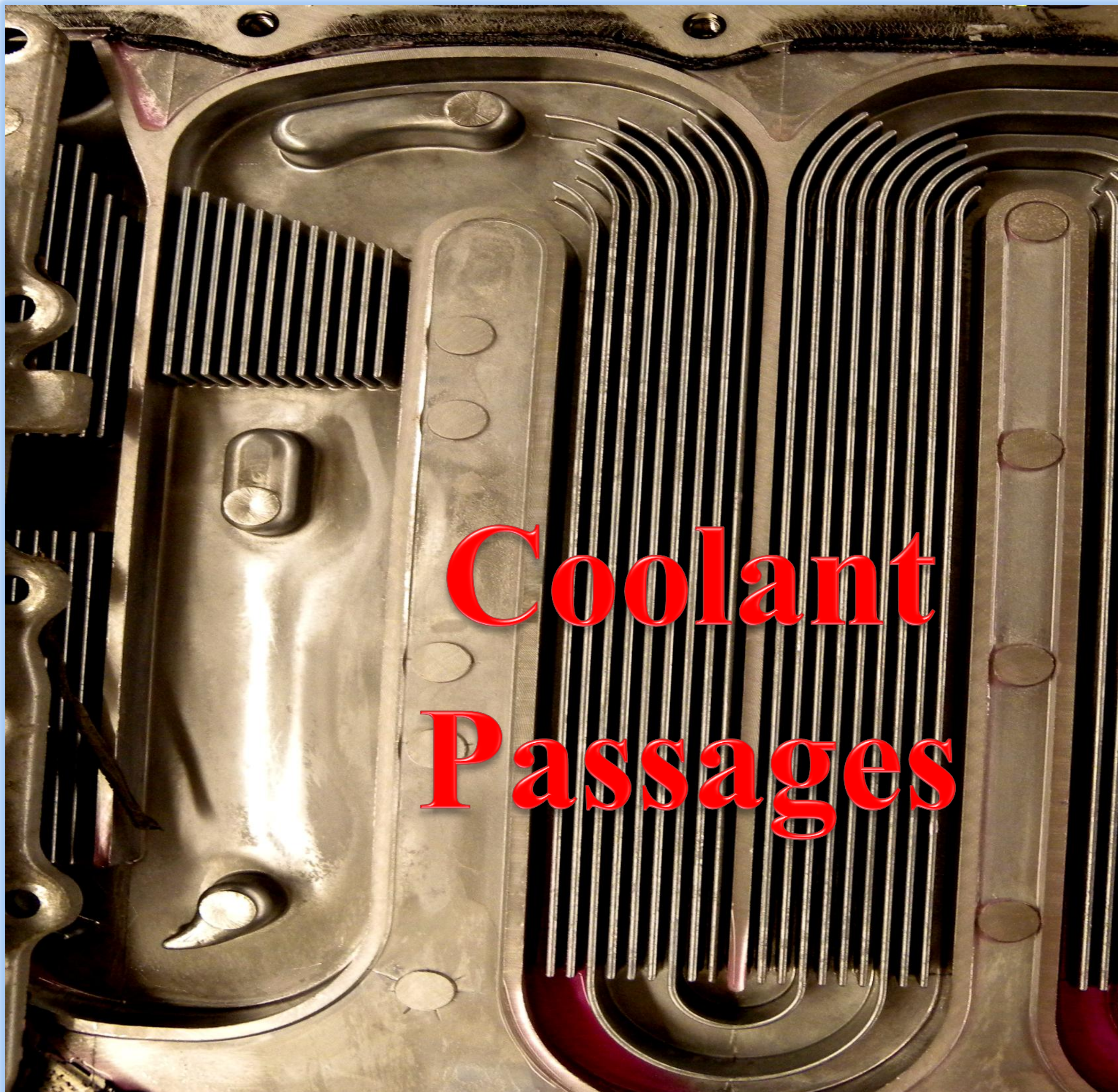
This is an example of how we use scan data to stay out of the high voltage circuits. Remember, we had to do all the safety steps before opening this inverter. We removed the manual disconnect switch, disconnected the 12 volt battery and waited for the capacitors to discharge.

The DC-to-DC converter for the 12-volt power source is inside the housing. The output wiring is color coded for low voltage, meaning, it is not orange. Check for proper auxiliary voltage, 14 volts when the “ready light” on, indicating the vehicle is ready. The normal voltage is dropped to13.5 volts during high temperature operation.



The bottom of the housing draws the heat from the high power circuits. The coolant circulates in cooling channels in the bottom of the housing. Toyota has the coolant reservoir connected to the housing to cool to the assembly. Be sure it seals properly if damaged in a collision. Coolant is specified by each manufacturer, so follow their recommendations. There have been cases of corrosion causing overheat problems and leaks.

Electric machine coolant uses part of the radiator cooled by airflow, so do not overlook airflow and radiator problems.



The coolant needs to be clean to keep the passages free flowing. Coolant is critical to maintaining a safe temperature in the assembly. During regenerative braking, we have recorded power levels as high as 35,000 watts. High power levels do not last for long and the coolant in the assembly must dissipate the heat.

The only reason to open the inverter assembly is when scan data shows data that indicates a problem inside. Follow the usual safety rules. Sometimes the cause of the problem is visible without much specialized training, like the example here A/C compressor three phase motor connections inside the assembly.

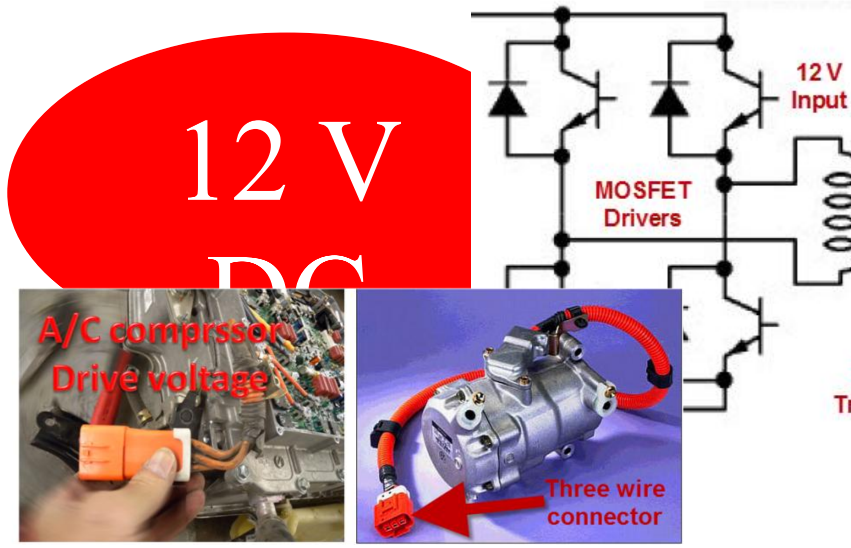
The case cover also shows evidence of corrosion. These findings give sufficient reason to condemn the inverter assembly. We do not recommend putting an assembly this badly corroded back into service.

INVERTER CONTROL STRATEGIES

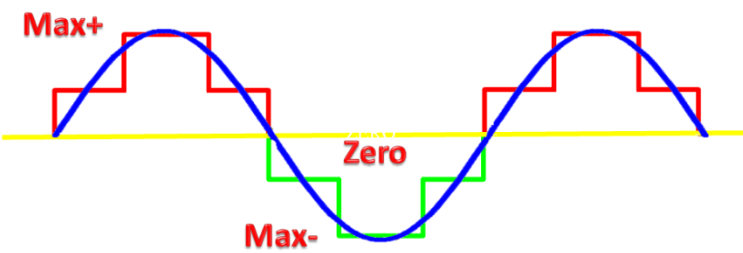
There are six voltage steps for control. The voltages levels will vary with the voltage of the high voltage battery pack. The HV battery voltage determines the maximum voltage. The signal from the motor control module determines current flow and frequency. The effect will cause the magnetic field around the coils to change polarity. The bipolar transistors change the direction of current flow to change the magnetic polarity of the electromagnets. The controller signal creates the modified sine wave.

Although the voltage steps are not a true sine wave, it approximates the effect of a sine wave. It is important to note that the signal goes above and below zero like a sine wave. The bipolar transistors accomplish by changing the direction of current flow.

Pulse width modulation controls current flow. The duty cycle takes the voltage back to zero for a short period to reduce the current. The maximum amp flow occurs when the voltage is 100% on and is not duty cycled back to zero volts.
The more times the voltage is duty cycled back to zero, the lower the current flow. Current flow is directly proportional to the time the voltage is at full value.



Each of these signals represent one cycle. The frequency of the cycles determines motor speed along with the number of U-V-W pairs in the stator. The frequency determines speed while current flow determines the toque of the motor. The accelerator position sensors signals provide the electronics information needed to compute motor speed and torque.



Calculating motor speed, multiply the U-V-W pairs times the frequency of the drive voltage to get motor speed. A frequency of 200 Hz with 16 pair of U-V-W winding will produce a motor speed of 3,200 RPM. A frequency of 750 Hz will result in a motor speed of 12,000 RPM. The current flow controlled by the duty cycle will determine torque.

A/C COMPRESSOR INVERTERS

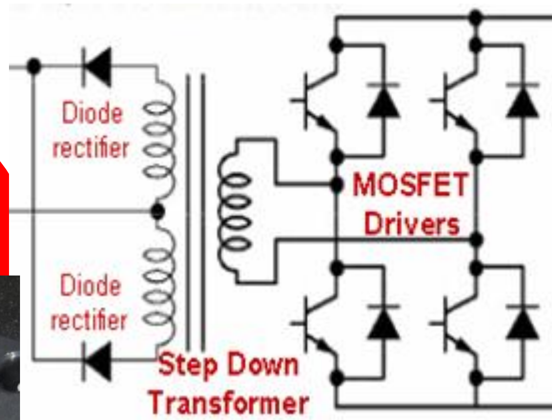
The A/C compressor inverter may be separate or a part of the electric machine inverter assembly. We can determine the location of the A/C compressor converter by observing the high voltage wiring. Two high voltage wires going to the A/C compressor indicates the inverter is part of the A/C compressor assembly.

D/C TO D/C CONVERTERS

High Voltage Batteries power the DC-to-DC converters. The converter replaces the belt driven alternator to power the auxiliary 12 V voltage system. The normal voltage when the "ready" light is on is 14 volts with 13.5 volts during high temperature operation. There are other applications for DC-to-DC converters and not all converters reduce the voltage. Some increase the DC voltage to a higher DC voltage.

Early Ford Escape Hybrids has a circuit in the converter that allowed for the charging of the high voltage battery pack with the 12-volt battery. A jump-start button is located behind an access panel at the top of the driver's kick panel. Pushing the button begins an eight minutes charging cycle of using voltage from the 12-volt battery to charge the high voltage battery pack. It is important to have a vehicle or jump pack unit connected to the 12-volt battery to avoid draining it of power.

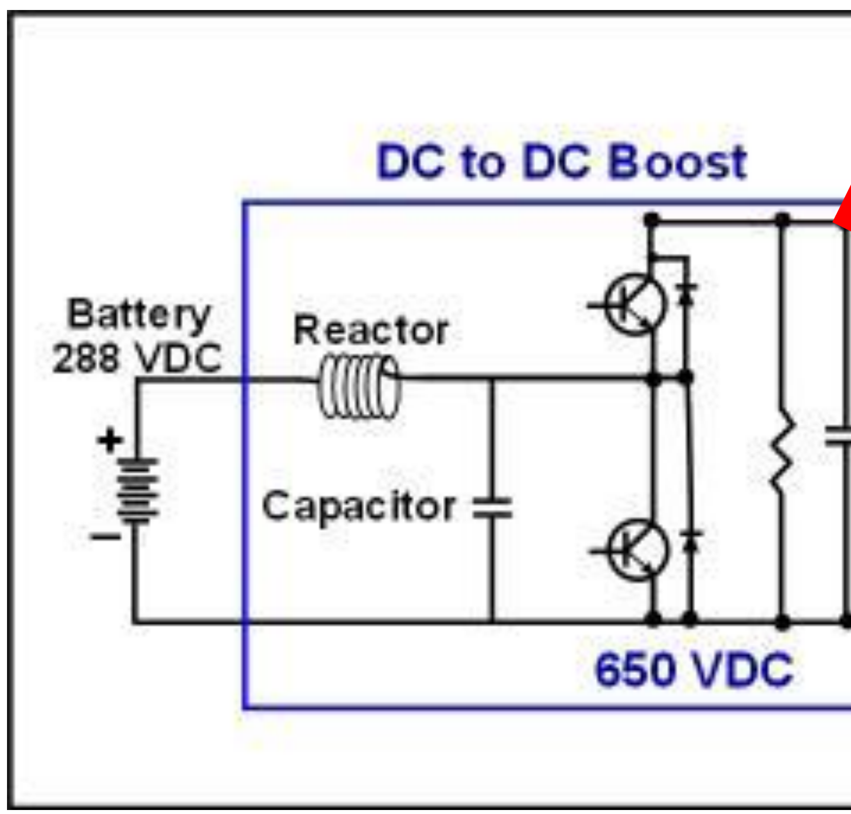
12



200 Volts

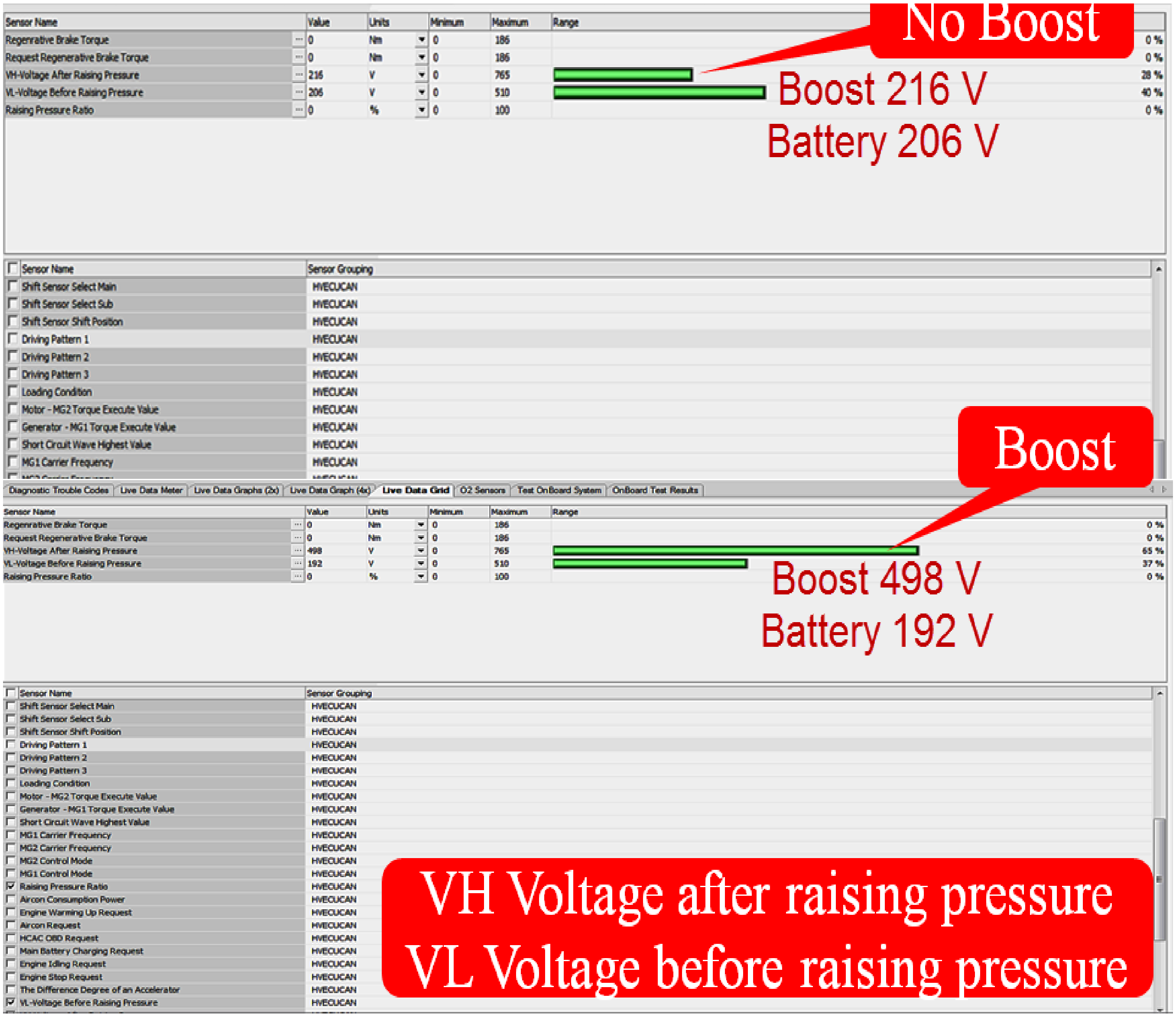
DC to DC Boost

Boost converters increase the high voltage supplied to the electric drive motor to deliver high power during acceleration. The hybrid control ECU controls boost as the voltage battery is dropping in voltage because of the high load current required for hard acceleration. The Toyota Highlander uses a 288 V DC high voltage battery. The Highlander and Escape use a 650 V boost.



The inductive kick of the reactor is rectified by diodes and stored in the large capacitors. The capacitors supply the burst of current when the bipolar transistors switch motor drive current. Large capacitors store the additional voltage until the boost converter delivers it to the traction motor for increased torque. Notice the discharge resistor in the circuit; we see it in the older Prius inverter photos.

SCAN DATA OF BOOST VOLTAGE



CHAPTER 23

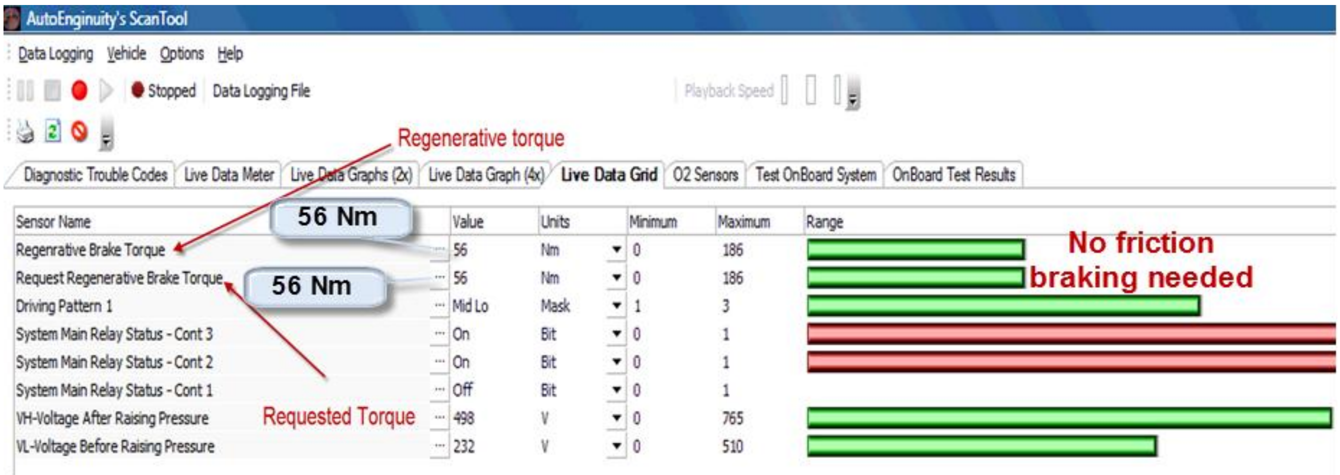
REGENERATIVE BRAKING

Regenerative braking does two things; slows the vehicle while generating electricity. Slowing the vehicle is the electric brake portion of regenerative braking. Generating electricity is the other. The traction motor connects to the drive wheels through a power splitter or a transmission.
When the vehicle is decelerating, the wheels are turning the traction motor. The traction motor changes kinetic energy of the vehicle motion into electrical energy.
The Hybrid controller changes circuits in the inverter to direct the electricity from the motor through a rectifier bridge to convert the created AC voltage to DC voltage to charge the high voltage battery.

The major difference between a motor and a generator is how it is controlled. The Hybrid Control ECU changes the motor into a generator that uses the motion of the vehicle to turn the generator. The generator is a heavy load when the generation power is high, so by varying the generator power generation the hybrid ECU varies the regenerative braking load. Scan data shows the load as regenerative brake torque measured in Newton meters. The Brake Control ECU sends a request for braking force to the Hybrid Control ECU listed as requested regenerative braking. The Brake Control ECU will apply hydraulic brake force to supplement the energy absorbed by the generator.

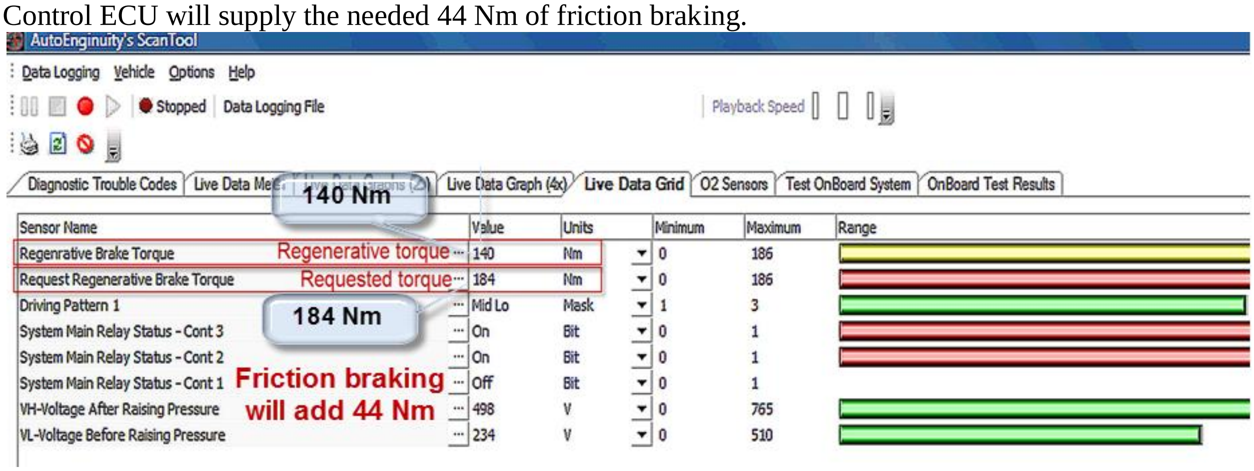
REGENERATIVE TORQUE VS REQUESTED TORQUE SCAN DATA

Scan data displays the data used by the Hybrid Control ECU and the Brake Control ECU to manage the braking of the vehicle.



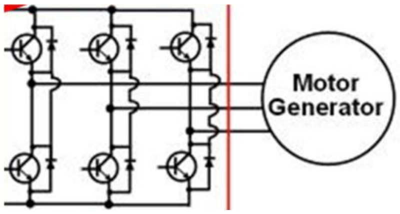
Regenerative torque is supplying all the torque requested to slow the vehicle.
Regenerative braking eliminates friction braking at the front wheels. Remember, most hybrids are front wheel drive and this braking only applies to the front wheels, the Brake Control ECU will manage the braking of the rear wheels.

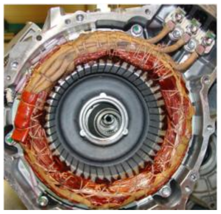
The next scan data example has a higher requested torque that the regenerative braking can supply. The Brake Control ECU will supply the needed 44 Nm of friction braking.



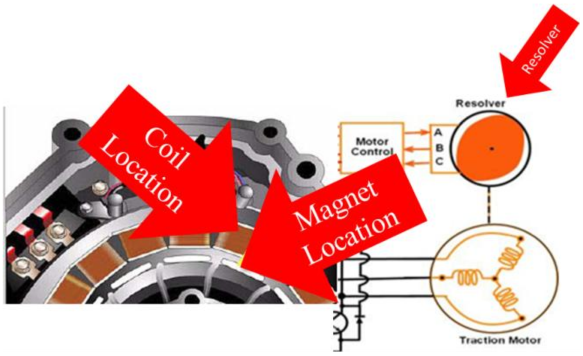
The power inverter must change the motor into a generator for braking. Regenerative braking is software program that controls the IGBTs in the inverter. The generator can generate 20,000 watts during hard braking at 60 MPH.

During negative torque, the battery pack continues to supply power to the stator. This electricity generated charges the high voltage battery.





The appearance of the six rectifier diodes next to the IGBTs look just like a diode trio in an alternator. The reason for this is an automotive alternator is a three-phase generator.



CHAPTER 24

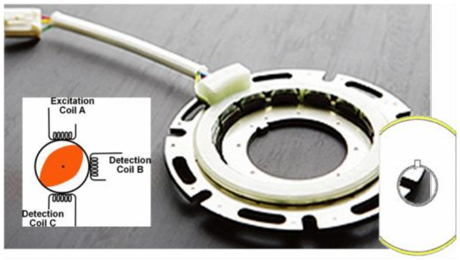
ELECTRIC PROPULSION SENSING

The Hybrid controller must know the motor's direction, RPM, and angular position for the inverter to control the motor.
Most hybrid systems use a resolver
Detects:

Motor direction

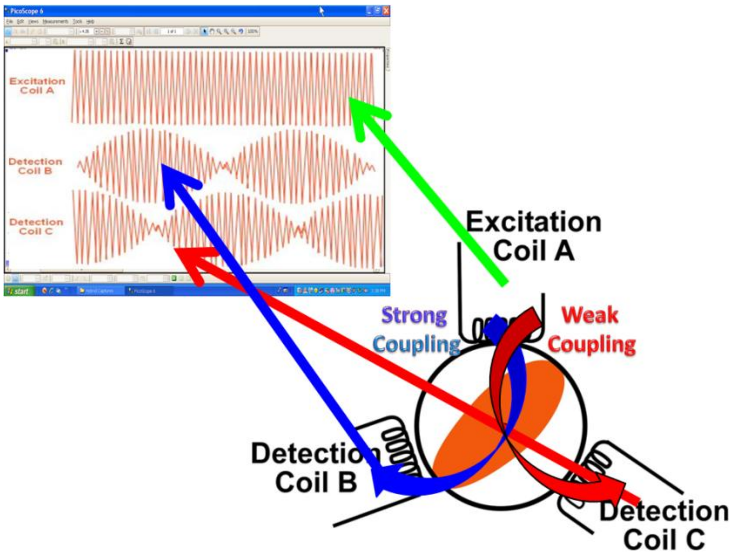
Angular position

RPM



The lobes on the reluctor will rotate within the sensor itself to vary signal coupling. The number of lobe relates to the resolution of the sensor.

The inverter must synchronize the magnetic field of the stator with position of the permanent magnets in the rotor. The resolver attaches to the rotor and rotates with the rotor. The resolver's signal is used to determine which magnetic pole north or south is coming up on any given electro magnet to control motor operation.
The resolver has three coils. The inverter electronics generates the signal for the excitation coil. The excitation coil uses variable reluctance coupling to coil B and coil C. Coil B and C act as pickup coils to detect the excitation signal. The position of the two coils cause them to have varying voltage because of their relative position to the excitation coil The Hybrid controller compares coils B and C signals to each other and then to the excitation signal to determine the motor's direction, angular position, and RPM. The signal from coil B is the sine signal while the signal from coil C is the cosine signal.



The signals reach their highest aptitude 90 degrees apart. Signal amplitude changes relate to the relative position of the reluctor while the frequency of the signal relates to the excitation signal. The excitation signal is a higher frequency to improve the resolution of the signal.

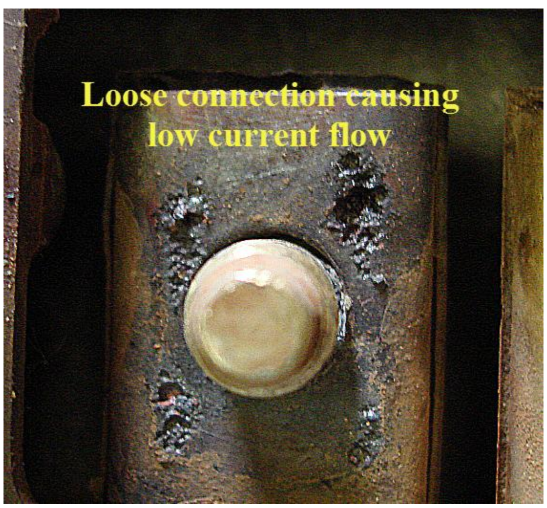
High voltage and Current measurement

The Battery Control ECU does current measurement inside the high voltage battery pack. The Hybrid Control ECU measures current at the motors.

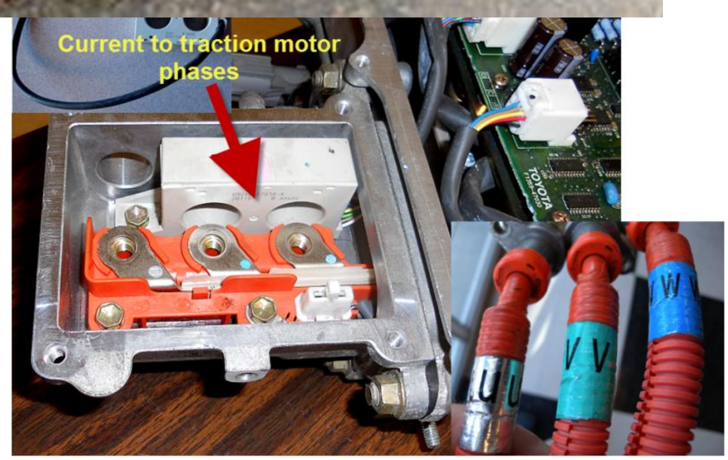
To control the voltage and current to the motors the controller requires input information. These sensors measure the current in the high voltage circuit and reports to the controller. These are typically Hall Effect type sensors.

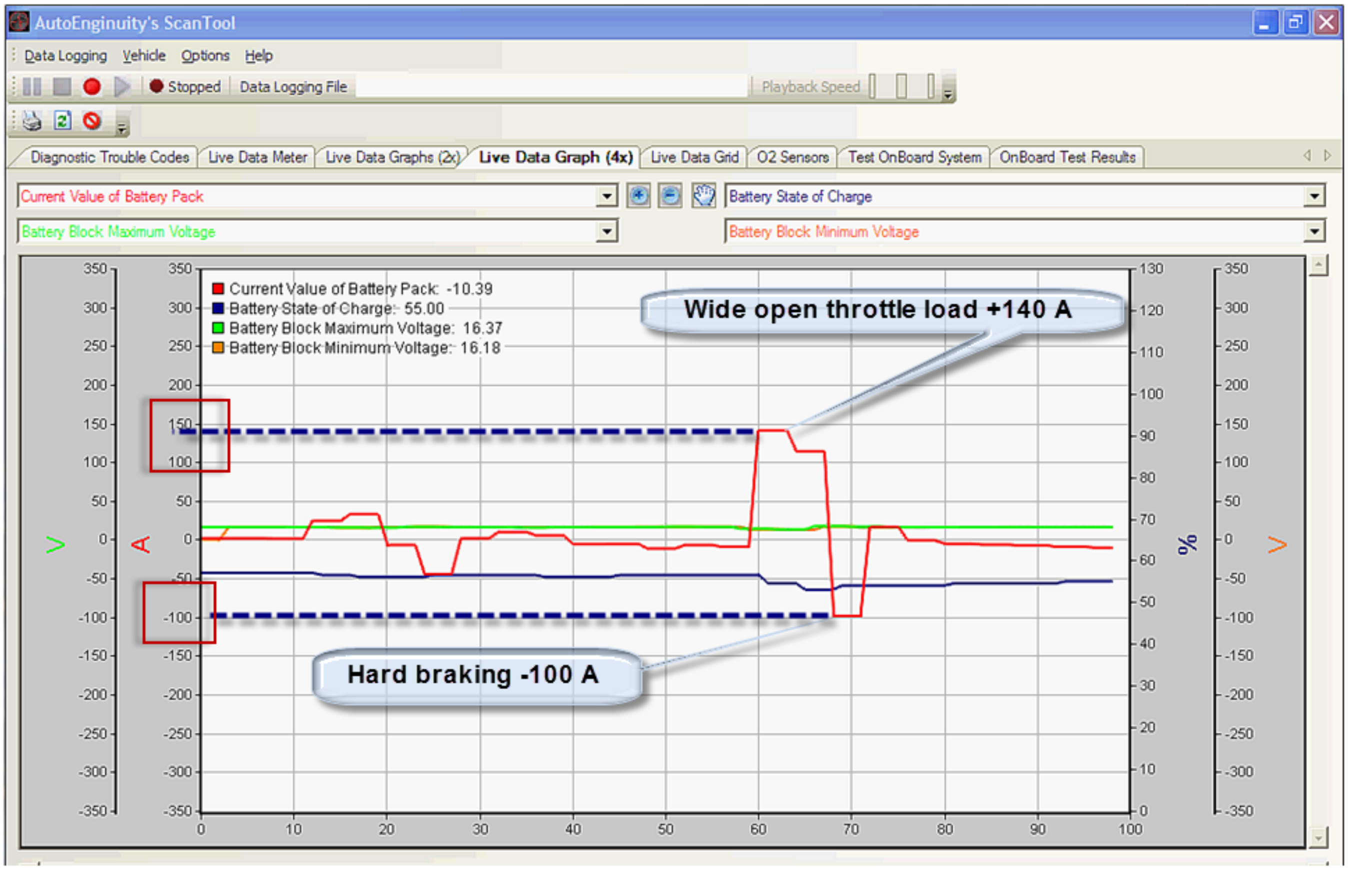
The hybrid control ECU measures the 3-phase current to the traction motor. The Hall Effect only measures two wires. The current flows in one wire and out another, so two sensors are sufficient.

Current flow diagnostics locate problems when current flow is out of the expected range. Here are a couple of examples.



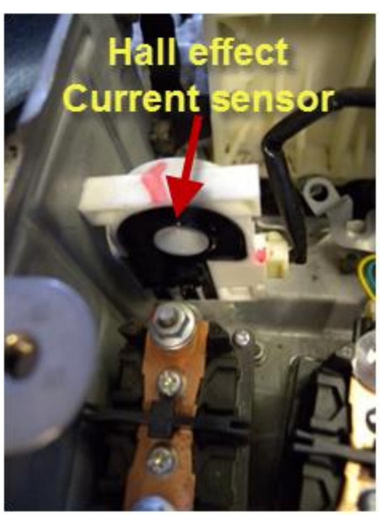
Shorted stator windings are an example of problems causing excessive current flow. This is an example of shorted stator windings that caused an excessive current flow code.





The current sensor’s signals are in Scan Data. The current being measured through the sensor may be positive or negative. It is positive when the current from the battery pack is supplying the motor with drive power. Current flow is negative when the motor is generating electricity for recharging the battery pack.
The 100 amps generated during hard braking is generating 22,600 watts of power for short time.

VOLTAGE SENSING



Battery Pack Data

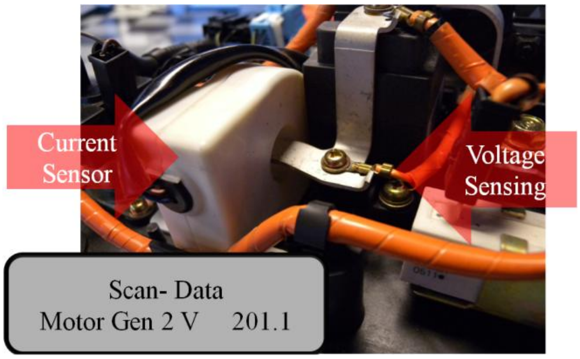
HV Battery state of charge	55.2	%
HV Battery block max	15.1	V
HV Battery block min	14.9	V
HV Battery max temp	91	F
HV Battery min temp	52	F
HV Battery Volts	308	V
HV Battery current	3.52	A
HV Battery contact	closed	

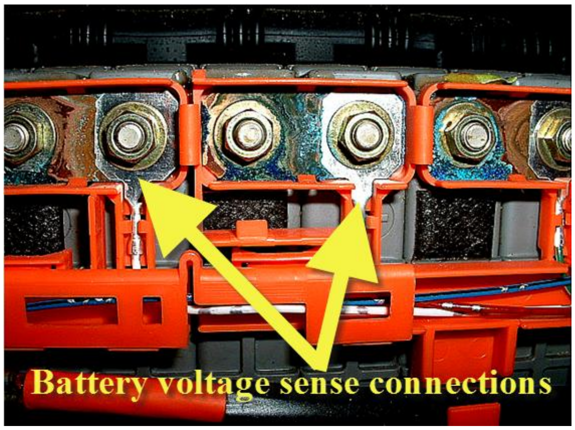
Voltage sensing is also an important input into the Hybrid controller. High voltage data is in Scan Data. The battery pack control ECU uses battery block voltages to monitor battery voltage balance. Voltage imbalance identifies batteries that do not match the chemical activity of other batteries in the battery pack. We will discuss voltage imbalance later in the battery section.

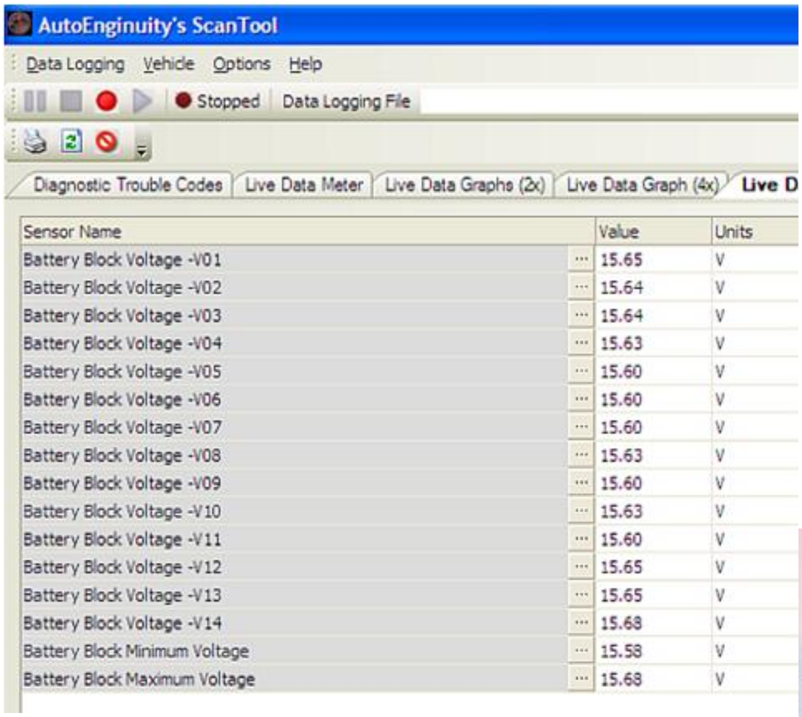
In order to regulate battery charging and discharging of the battery control ECU must have the voltage at each battery module (Block). Watch for erratic voltage block readings when there is corrosion of the voltage sense connections.

There is scan data to check the battery voltage to help diagnose problems. We want to stress again the fact that you need to understand the capabilities of scan data to stay out of the high voltage areas until it is necessary. This scan data is from the high voltage battery control ECU; it shows battery block voltage as the highest block and the lowest battery block. HV battery block max is 15.1 V while HV battery block min is 14.9 V.

There are additional scan data values that display the voltage of each battery block.







AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File

Diagnostic Trouble Codes | Live Data Meter | Live Data Graphs (2x) | Live Data Graph (4x) | Live D

Sensor Name	Value	Units
Battery Block Voltage -V01	15.65	V
Battery Block Voltage -V02	15.64	V
Battery Block Voltage -V03	15.64	V
Battery Block Voltage -V04	15.63	V
Battery Block Voltage -V05	15.60	V
Battery Block Voltage -V06	15.60	V
Battery Block Voltage -V07	15.60	V
Battery Block Voltage -V08	15.63	V
Battery Block Voltage -V09	15.60	V
Battery Block Voltage -V10	15.63	V
Battery Block Voltage -V11	15.60	V
Battery Block Voltage -V12	15.65	V
Battery Block Voltage -V13	15.65	V
Battery Block Voltage -V14	15.68	V
Battery Block Minimum Voltage	15.58	V
Battery Block Maximum Voltage	15.68	V

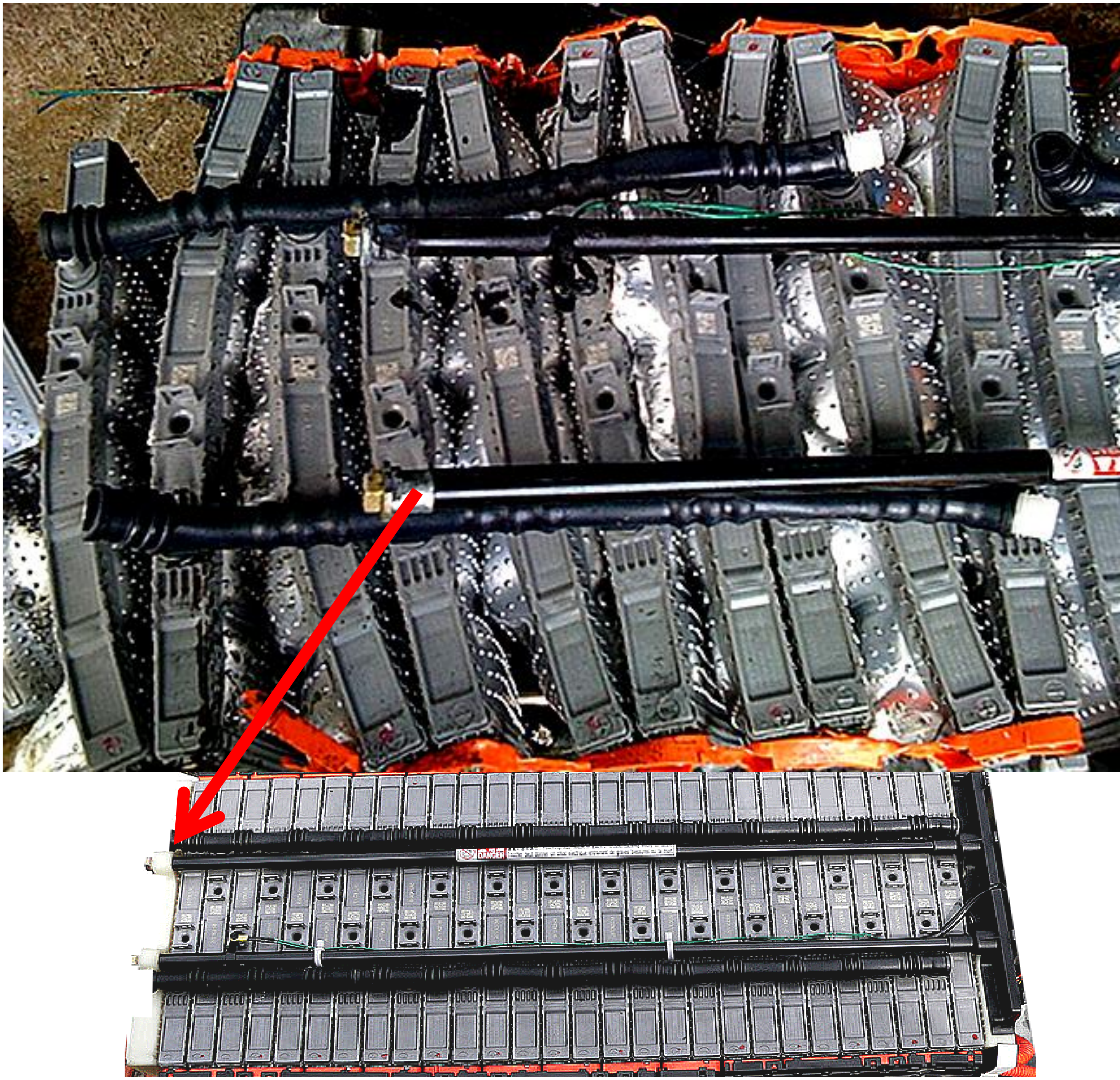
The block voltages range from 15.58 V to 15.68 V. There is data for all 14 blocks of the battery pack. If you add up all the voltages in each block, it will total battery pack voltage. Series connected battery blocks add their voltages together.

The maximum difference in block voltage must be under 0.3 V. Higher differences can result in overheating or low capacity of the battery pack. Lower battery capacity means the vehicle cannot operate on electric drive only mode for the expected amount of time.

We will discuss battery voltage and state of charge in detail in the battery chapter.

Battery testing with scan data may not be universal, but the basic rules apply to all vehicles. This is battery data on a hybrid train at the port of Virginia. We use the same rules; Balance the battery voltage and be use battery chemistry is even. Battery rack #35 is 0.46 volts below the average, this battery tested weak when they tested battery resistance. All batteries charge and discharge in series where every battery sees the same current flow. The two batteries under charged at installation. Balance the charge on batteries before installing them. Battery testing follows these rules regardless of where they are used, Hybrid cars, trains; busses and garbage trucks use the same type of testing.

The voltage sense connections can become corroded and fail to make good contact. Have you ever tried to fix a good flashlight after an alkaline battery leaked electrolyte? The alkaline electrolyte corrosion makes electrical contact difficult. If the scan data voltages look wrong, check for corrosion before replacing batteries. Be sure to find the source of the leaking electrolyte.



CHAPTER 25

BATTERY PACK COOLING

The Battery Pack's Thermal System may be passive or active. Most Hybrids have an active system consisting of one or more fans. Some systems have a dedicated air conditioning system to manage the battery pack's temperature.

The charging and discharging of the HV battery pack creates heat, which can damage the battery modules. Battery modules overcharged and created extreme temperature. The overheated battery modules distorted and tore out of the mounting rods holding them in place.

Cooling Fans and Vents

Battery packs have vents and one or more fans to draw cabin air across it.
The vents must clear of obstructions. Some vents like Ford Escapes, draw in outside air and have an air filter that can restrict airflow when they are dirty. The Prius I has the battery vents behind the rear seat. Placing garments over the vents restrict airflow.

Typical Battery Temperature DTCs

P3060 - Battery temperature sensor circuit malfunction
P3076 - Abnormal airflow by battery cooling fan
P3077 - Battery cooling fan motor circuit malfunction

Battery Cooling Fans

Battery packs can have one or more fans to keep the battery cool. The system is this picture has three cooling fans for this large battery pack.
The location of the vent for air intake varies by vehicle manufacturer and some require maintenance.

FORD ESCAPE VENT

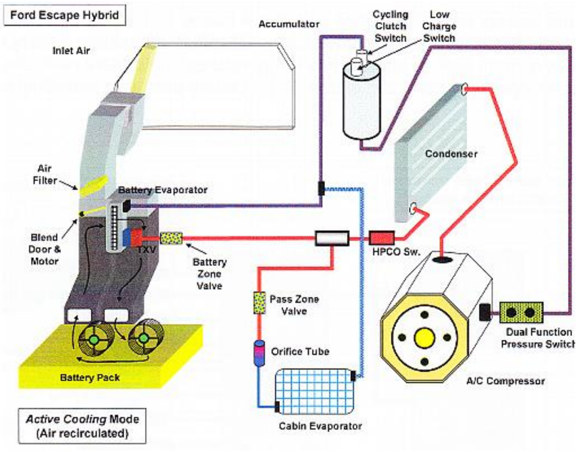
The Ford Escape has a vent on rear of the vehicle to draw air into the battery pack. Outside air that needs filtering to prevent build up of dust in the cooling fans and battery pack.

As you can see from this example that was causing a battery overheat code, the filters get quite dirty and many people do not even know this filter exists.

Toyota systems that draw air from the passenger compartment may not use a filter. The fan's squirrel gage may clog and cause the battery pack to over heat and set DTCs.

The point of all these examples is to point out the lack of maintenance on the battery cooling system. Toyota usually has a cabin air filter, but that does not correct for dust and dirt intake when the windows are open. Check for these problems when you have a battery temperature code.

The Ford Escape has an A/C evaporator for the passenger compartment and the battery compartment.



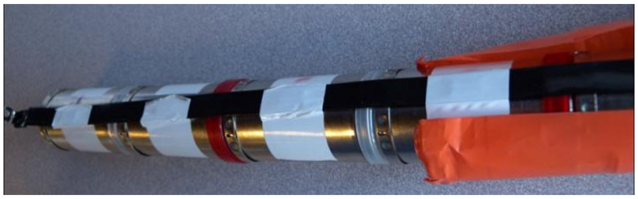
CHAPTER 26

BATTERY PACK TEMPERATURE MONITORING

Battery pack overheating will damage the battery modules. There will be multiple temperature sensors on the battery pack (Prismatic). Cylindrical cell batteries cell have its temperature monitored at each cell. Manufacturers design their battery pack temperature monitors to protect the battery modules. Battery temperature sensors connect to the Battery Pack Controller. The Battery Pack Controller reports to the Hybrid control ECU that makes decisions based on the pack's temperature.
The temperature sensors are two wire thermsistor sensors. They send a voltage to the battery pack controller that converts the voltage signal into temperature.

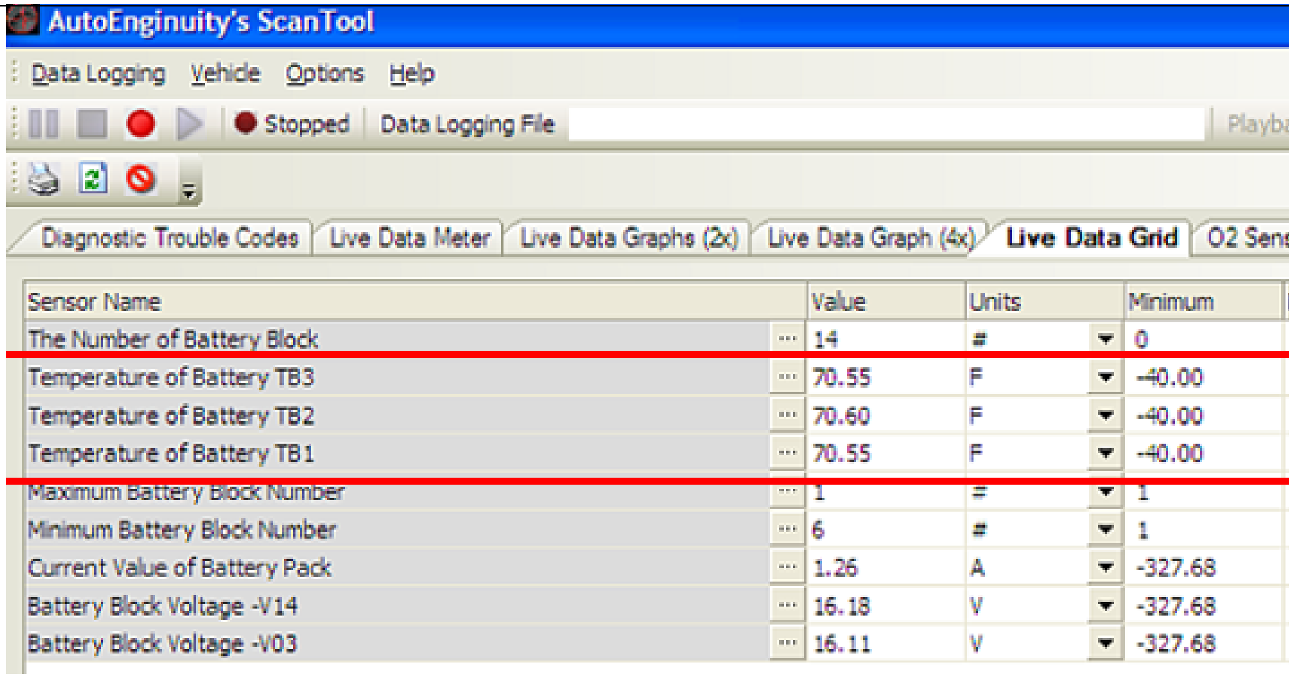
A Cylindrical battery stick has a temperature-sensing strip taped directly to each battery cell. The battery controller averages the signals from the different areas of the battery pack.

BATTERY TEMPERATURE SCAN DATA



This is an example of typical scan data.
Bat Temp 1 92.12 F

Bat Temp 2 90.07 F
Bat Temp 3 91.98 F
The temperature values do not normally vary widely but battery problems can create differences.

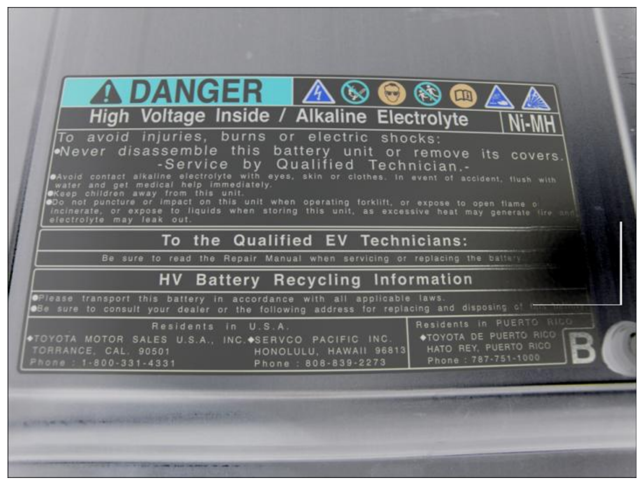


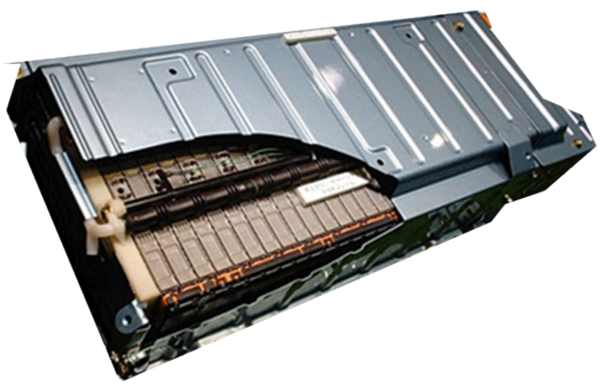
Sensor Name	Value	Units	Minimum
The Number of Battery Block	14	#	0
Temperature of Battery TB3	70.55	F	-40.00
Temperature of Battery TB2	70.60	F	-40.00
Temperature of Battery TB1	70.55	F	-40.00
Maximum Battery Block Number	1	#	1
Minimum Battery Block Number	6	#	1
Current Value of Battery Pack	1.26	A	-327.68
Battery Block Voltage -V14	16.18	V	-327.68
Battery Block Voltage -V03	16.11	V	-327.68

Chapter 27

High Voltage Batteries

The batteries and battery packs come with a warning of high voltage and the proper method of recycling them. The warning alerts the technician to use the correct service and safety procedures when diagnosing and replacing the battery pack. The recycling warning explains that the battery pack should be recycled in accordance with all applicable laws. It states that you can consult the dealer if you have questions.

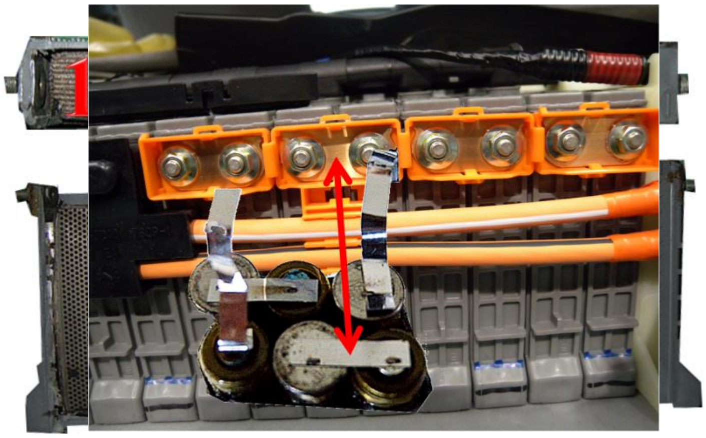




The high voltage battery pack is an arrangement of individual cells. Battery chemistry causes differences in voltage output. This class will focus on the two most common batteries used for automotive hybrids. Some bus and train designs use lead acid batteries, but they are too heavy for automotive applications. The layout of the battery pack is a compromise between voltage and current capabilities and vehicle weight.

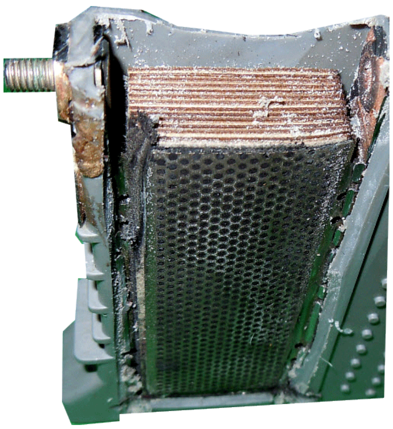
Hybrid batteries have a specific voltage and a maximum amperage rating. Using the Ford Escape Hybrid as an example the battery pack is 330 volts rated at 180 amps. This means that all of the battery cell voltages add up to 330 volts when fully charged. Each battery cell can carry a maximum of 180 amps. Hybrids are high-powered systems, the Escape has a 59,400 watt rating, almost enough to power three homes. The power is available for short periods but at very high wattages.

The exception to the short duration is some of the large lead acid batteries used in buses and trains, this example is rated at 1,200 amps at 8 V or 10,320 watts for an hour (batteries are wired in series to increase the voltage output). Each of these batteries weighs almost a hundred pounds, far too heavy for automotive applications. Each cell in this battery is 2.4 to 2.5 volts during a charging cycle at 360 amps.



BATTERY BASICS

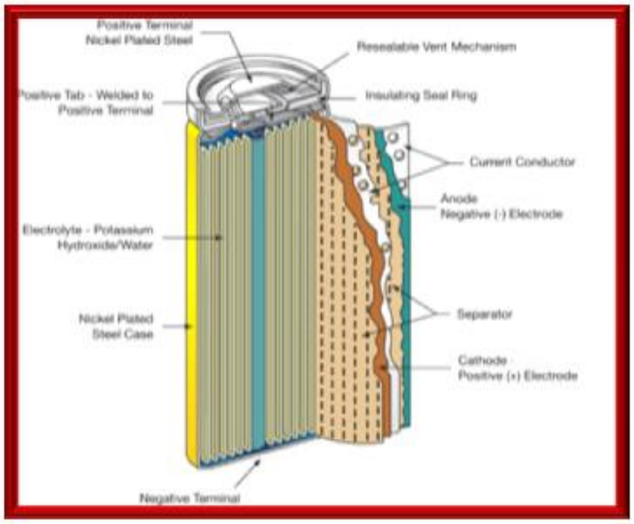
Each cell has a positive terminal and a negative terminal. The terminals are used to connect the cells together is specific arrangements to either increase the voltage out or increase the current capacity. (Series or Parallel)
A series connection connects the cells together so the total current must flow through all cells, this increases the voltage output but the current capacity is the same as an individual cell.
Cells connected in parallel divide the current flow to increase current capacity, but the voltage output is the same as an individual cell.
Most Hybrids connect the cells in series. As Hybrid battery technology advances, we will see them connected in parallel, like the batteries in the Chevy Volt.
Nickel metal hydride batteries have a nominal voltage of 1.2 volts per cell. Connecting six of the individual cells in series will make a battery module or brick that has 7 to 7.5 volts depending on state of charge.



A nine-volt battery is a good battery arrangement to study, because everyone knows everything about nine volt batteries. Connecting cells in series increases the voltage but the current capacity is equal to a single cell.
A nine-volt battery is a group of six AAA batteries connected in series. The voltage is six times the 1.5 V cell voltages. The current capacity is equal the current capacity of one AAA battery. Do not let the final packaging of a battery confuse you; this is not a different type of battery chemistry. A nine-volt battery is a unique arrangement to increase the voltage output. We have similar arrangements in the batteries on hybrids.

Before we go any further, we need to remember something, the assumption is that all the batteries in a group are working normally; but this is only true when the batteries are normal. When batteries are older or defective, the cell voltages can be imbalanced. We will be using scan data to check for differences in battery packs on hybrids.
Hybrid batteries use series connections like the 9-V battery. Series connections increase the voltage output, but not current capacity. The hybrid battery modules use large copper strips much larger than our 9- V example. The battery brick voltages add together to produce the high voltage needed with the current capacity equal to the capacity of one battery cell.
Most HV Battery Packs have the battery modules in series circuits, except for newer vehicles like the Chevy Volt.

There are two types of battery modules use in Hybrids Prismatic and Cylindrical. The only difference is in the shape. Both types use the same chemical reactions.



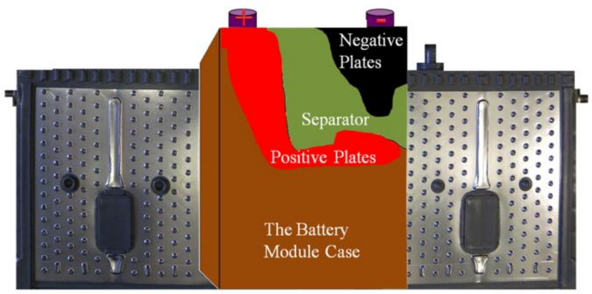
PRISMATIC BATTERY MODULE

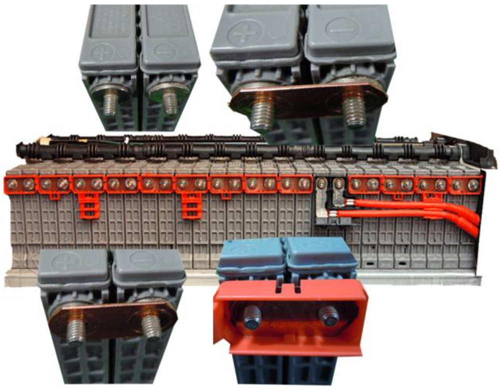
The material of the plates are very thin. This makes it possible to have a lot of plate area in a small module. Arranged to lie on top of each other the plates and separators pressed together and attached to terminals

The battery construction is a compromise between voltage output and current capacity. The layers increase the surface area of the electrodes. The tight layers have a very large surface area, which translates into high current capacity. Current capacity determines how long a full hybrid battery pack can propel the vehicle with the electric motor without starting the IC engine.

The prismatic modules use series connections inside the battery pack.

One of the advantages of the prismatic battery pack is that it runs cooler. Some have separator pads between the modules for additional airflow. Do not expect all prismatic battery packs to have the separator pads.



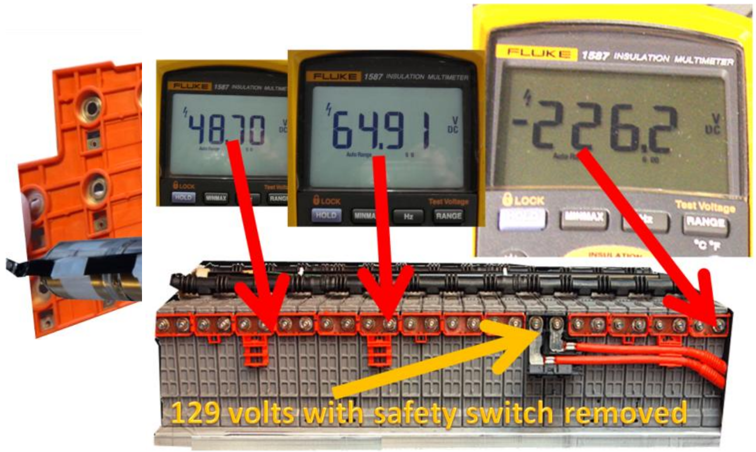


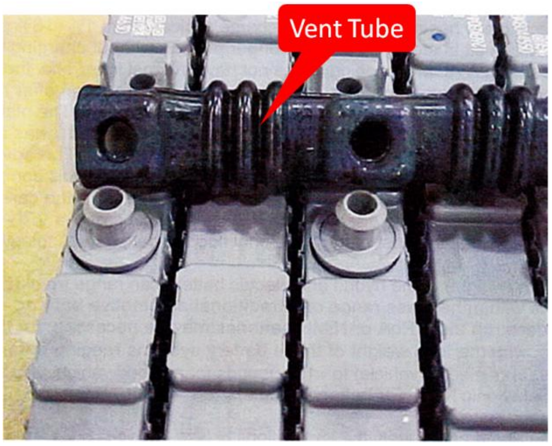
CYLINDRICAL CELL

Like the prismatic battery modules, the cylindrical cells have very thin electrode material. This makes it possible to have a lot of plate area in a small area. The plates connect to the terminals at each end of the cell.

Cylindrical modules have five or six cells in series.

The cylindrical battery module (stick), made by Sanyo, consists of individual nickel metal hydride cells. The cells are similar in shape to a size D flashlight battery. Each individual battery cell, contained in a stainless steel case, is 1.2 volts. The Ford Escape has five cells in a module and 50 modules in the battery pack. The total voltage of the battery pack is 330 volts. Cells have a maximum rating of 180A, which is the rating for the battery pack.

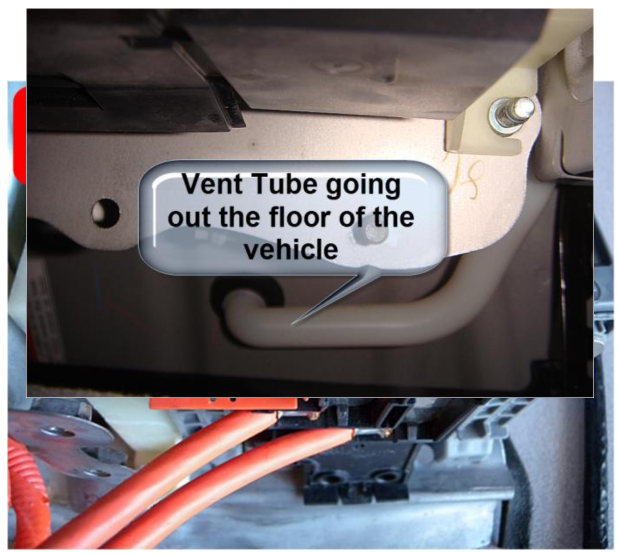




The frame of the HV battery pack is isolated from the high voltage. The frame mounts to the vehicle chassis and is safe. Remember, you removed the pack from the vehicle for a specific reason. Just to ensure safe handling of the high voltage pack, set it on wood.

Scan Data for a prismatic battery pack has PIDs for Battery Blocks. The term comes from calling one module a brick and two modules together form a block. A block would be 7.2 +7.2 volts, which equals 15.4 volts. We refer to a battery module as a brick; it takes two bricks to make a block.

If the technician uses a DVOM and starts at the first module the reading should be near the normal 7.2 volts for one module. Connecting a DVOM to more modules in a row, increases voltage by the voltage of the added brick.



Scan Data reads block (2-bricks) voltage starting from the negative output lead. Scan data voltage readings reference the previous block voltage closer to the positive terminal and display the added voltage. If the values do not look normal when diagnosing consider that, the battery controller or the Scan Tool may be the problem. If the controller or Scan Tool is suspect, remove the covers for the battery pack and test with a DVOM. Remember to wear the lineman class Zero gloves when removing the covers.

Avoid the danger of contacting high voltage when the battery pack covers opened. Removing the manual safety switch only eliminates part of the danger; the exposed terminals are still dangerous.

The battery modules have openings at the top for venting. Two vent tubes run the length of the battery pack collecting the gas that vents out of each module. Early models used a hard plastic tube that leaked the gas into the battery pack, as it got older. A softer rubber tube replaced the hard plastic and eliminated the problem. The two tubes go into a “T” fitting at the end and a tube goes down through the floor of the vehicle to vent the gas to the atmosphere.

BATTERY CHEMISTRY

The Nickel Metal Hydride, (NiMH) batteries are common in Hybrid battery modules today. NiMH batteries have good recharge life and high current capacity. Lithium batteries are moving into the Hybrid market place because of technological advances.

A Nickel metal hydride (NiMH) battery is a type of rechargeable battery similar to a nickel-cadmium (NiCad) battery. NiMH batteries to have a higher capacity than NiCads and do not have the memory effect problem. When NiMH batteries have lower energy density and a higher self-discharge rate than lithium ion batteries, NiMH and lithium ion batteries have less maintenance required than lead acid batteries used in earlier electric and hybrid vehicles.

When fast charging, it is advisable to charge the NiMH batteries with intelligent (computer controlled) chargers to prevent over-charging which could damage the battery. This makes them suited for a Hybrid vehicle because the charging of the HV battery pack is computer controlled

A common battery module has a nominal capacity ranging from 5.0 Ah to 6.5 Ah at 1.2 - 1.3 volt. The actual useful capacity can be significantly lower depending on the discharge rate. NiMH batteries have an alkaline electrolyte.

Nickel metal hydride batteries have a high self-discharge rate of approximately 30% per month and more. This is higher than that of NiCad batteries, which is around 20% per month. The self-discharge rate is highest for full batteries and drops off somewhat for lower charges.

The electrolyte used in the NiMH battery module is an alkaline of potassium and sodium hydroxide. The electrolyte is absorbed into the battery cell plates and forms a gel that does not normally leak, even in a collision.

In a lead acid battery, the energy is stored in the electrolyte and chemical changes of the plates. When the plates accumulate lead sulfate on the plates, the battery is sulfated and no longer serviceable. In the NiMH battery, the energy is not stored in the acid but on the plates themselves. That makes the alkaline electrolyte only a conductor.

The electrolyte used in the NiMH battery module is an alkaline of potassium and sodium hydroxide.

Each cell has anodes, separators and cathode plates. Each cell is a 1.2-volt battery. Six cells make up a battery module.

When the electrolyte covers the plates they can store and transfer electrical energy. If the electrolyte level falls below a portion of the plate is not covered which reduces the cell's capacity to accept a charge and deliver load current. Think of it like a copper stranded wire that has missing strands. The wire's cross section is reduced which reduces the current carrying capacity lowering the load that can be driven.

NICKEL-METAL HYDRIDE BATTERY

The nominal voltage per cell is 1.2 – 1.3 Volts under a "controlled environment"

Cells are in groups identified by the shape of the group.

- Prismatic
- Cylindrical

Cells can be in a 6-pack or 5-pack configuration

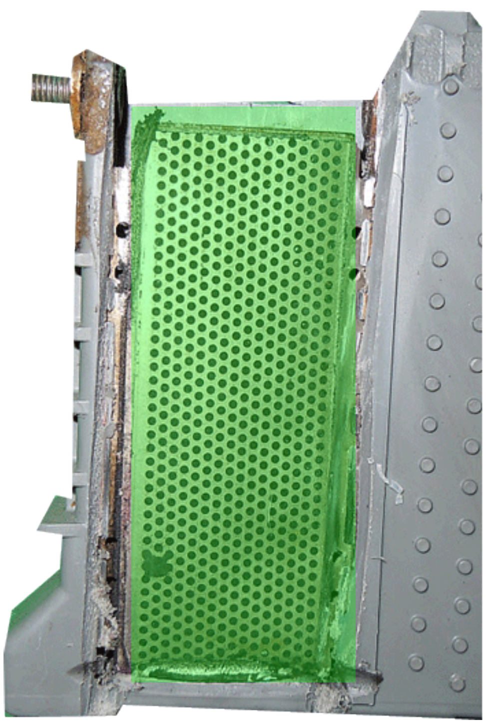
- 1.2 V X 6 = 7.2 to 7.5 V (Prismatic) (Cylindrical)

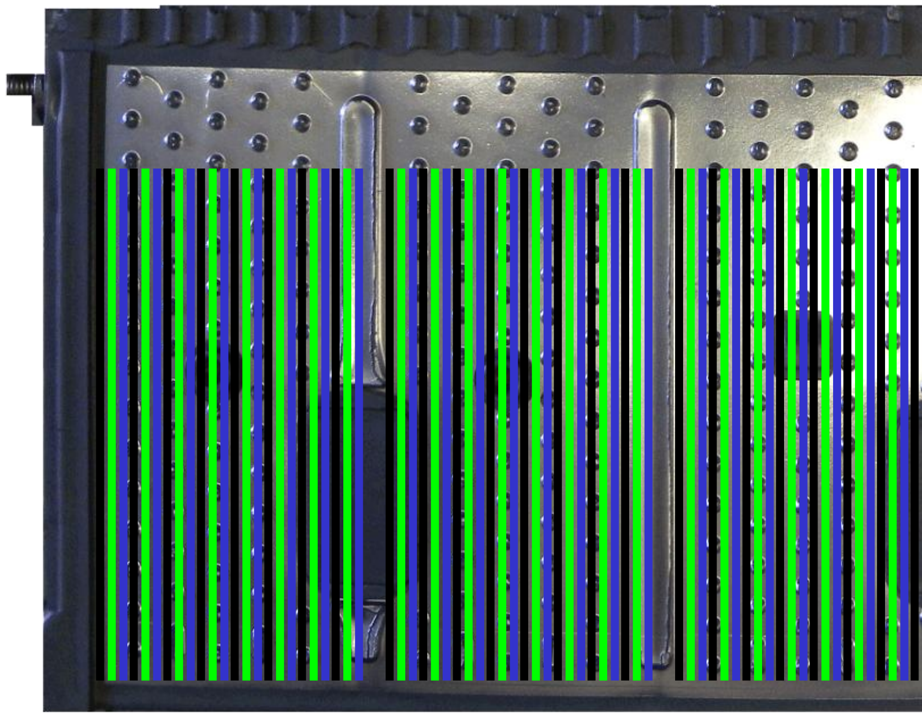
1.3 V X 5 = 6.25 to 6.75 V (Cylindrical)

A key phrase is a “controlled environment”. The electronic control is going to manage the temperature and state of change. The state of charge has a big impact on battery heat. Heat affects state of charge. The battery’s state of charge should stay within 20% to 80%. This is the maximum range and not the normal range. The normal range is 52% to 68% state of charge. Operation outside the 20% and 80% state of charge range generates high heat and shortens battery life.

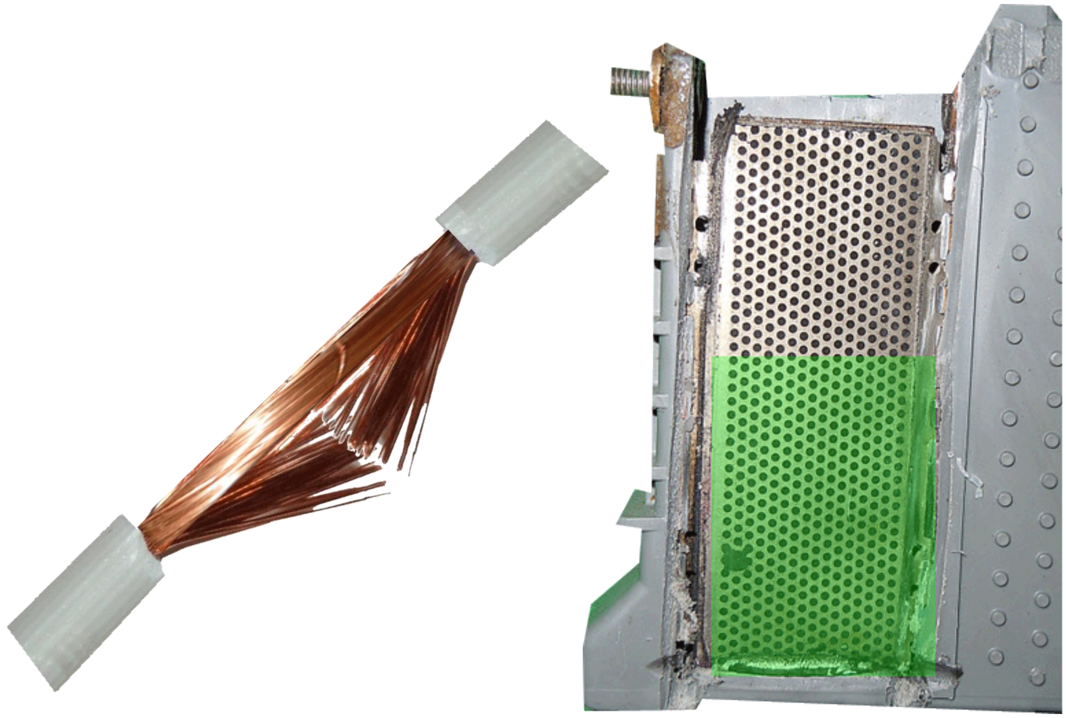
The HV controller program keeps the battery pack at the normal 52% to 68% state of charge that keeps the battery temperature within normal range and gives it a longer working life span. If the vehicle is to last at least 10 years, engineers do not want the battery pack working near its maximum capacity that would shorten battery life. A battery that is continuous undercharge will have a shorter life span. So keeping the HV battery pack between 52% and 68% state of charge will offer the greatest longevity.

STATE OF CHARGE (SOC)





The state of charge is not steady. As with a 12-voltage, charging system, the SOC is higher during charging and lower when not charging. The graph shows that when the SOC gets near its maximum of 68% the controller



reduces the charging rate to bring it back to the ideal 60%. When the SOC gets near its minimum limit the controller increases the charging rate. The Hybrid controller uses the HV battery pack's SOC as an input to Hybrid operation.

CONTROL ACTIONS FOR SPECIFIC STATE OF CHARGE LEVELS

The HV battery pack controller monitors the state of charge and reports to the Hybrid controller. The Hybrid controller makes decisions based on the HV battery pack's state of charge.
This is a chart of the state of charge recorded during a typical drive cycle. During acceleration, the battery pack state of charge may drop slightly, and then rise when the vehicle decelerates. Scan data displays charge and discharge levels. Use this chart to understand symptoms that relate to control system actions when the state of charge is outside the expected ranges.
Shut down all vehicle operations when the HV battery pack's state of charge decreases to 6%. There is not even enough voltage to start the ICE so it can drive the generator for recharging.
Shut down electric traction motor when state of charge is 35%. There may be enough voltage for the small motor/generator to crank the ICE for it to start. If the ICE does start at 35% state of charge there will be no electric assist from the traction motor. Reduce electric traction motor use w hen the state of charge falls to 40%, Electric drive off will not happen and the auto start/stop function will be suspended.

At 50%, ICE starts to recharge the HV batteries. This is why the ICE starts and runs when the vehicle is at a stop. Suspend the auto start/stop function at 50%, state of charge Suspend the auto start/stop function until the HV batter pack's state of charge is above the normal 52%.

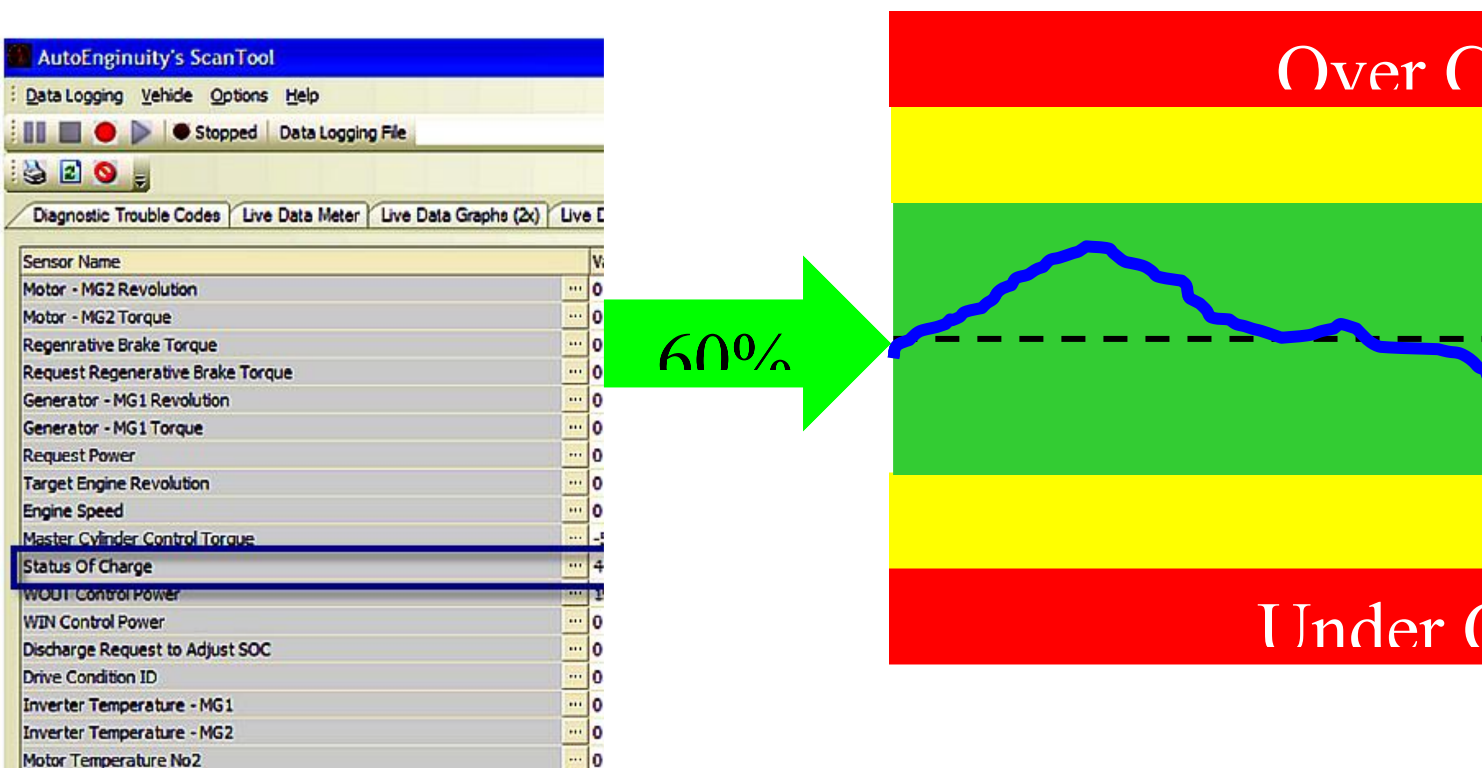
You can only expect the vehicle to operate normally if the HV battery pack is at a normal state of charge. If the owner's complaint is lack of power on acceleration and the diagnoses is that there is not any electric assist, it makes sense to check the state of charge first. There may be nothing wrong with the traction motor or its controller. It may be simply that the HV battery pack is not within a normal state of charge.

Regenerative braking stops when state of charge reaches 80% or higher. The Hybrid controller is in control of regenerative braking and if it sees that the HV battery pack's state of charge is higher than normal, it will not compound the problem by adding additional charge.

A state of charge of 94% is like 6%, all vehicle operations shut down.

- 6% all vehicle operations shut down
- 35% electric traction motor shuts down
- 40% electric traction motor use reduced
- 50% ICE starts to recharge the HV batteries
- 52 to 68% normal operating range
- 80% regenerative braking stopped
- 94% all vehicle operations shut down

SCAN DATA BATTERY STATE OF CHARGE

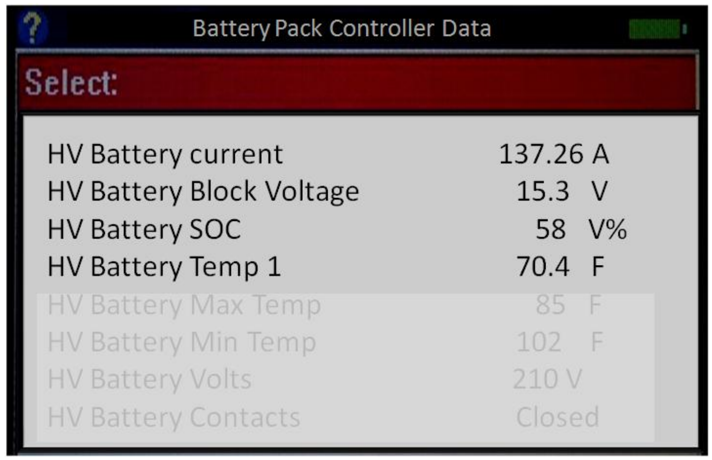


CHAPTER 28

TESTING HIGH VOLTAGE BATTERIES

Testing the HV battery pack in the vehicle is easier but requires a Scan Tool. The Scan Tool must be able to read the manufacturer enhanced scan data. The amount and specific data varies between vehicle manufacturers. As an example, Toyota supplies PIDs for battery block and battery internal resistance data. Other manufacturers do not supply these PIDs so in vehicle testing is not always possible.

IN VEHICLE DIAGNOSTICS



The HV Battery pack's state of charge should be within the normal 52% to 68% range before doing this test. If it is not drive, the vehicle until the HV battery pack's state of charge comes up to normal. Test results will not be accurate if the state of charge is low. Do not test cold batteries. If possible, test the battery pack at 72°F. If the battery pack is cold drive the vehicle with the heater on until the battery pack temperature gets as close to 72°F as possible. During the road test drive the vehicle under a light load (35 to 45 mph light throttle). This will give us the highest HV battery pack voltage because during light load light throttle the traction is not drawing a lot of current. Block voltage will be higher when current flow is low. Drive the vehicle under heavy load (Hard acceleration). During hard acceleration, the traction motor draws high current and when current draw is high, voltage is lower.

Scan data test procedure

Connect the Scan Tool and select the vehicle

Select these PIDs

- State of Charge
- Battery temperature
- Battery Voltage
- Battery current draw

The state of charge and battery temperature is ideal in this example.

Perform a test drive

Drive the vehicle:

Under a light load (in service bay)

Current low -Voltage high

Under heavy load (Hard acceleration)

Current high -Voltage low

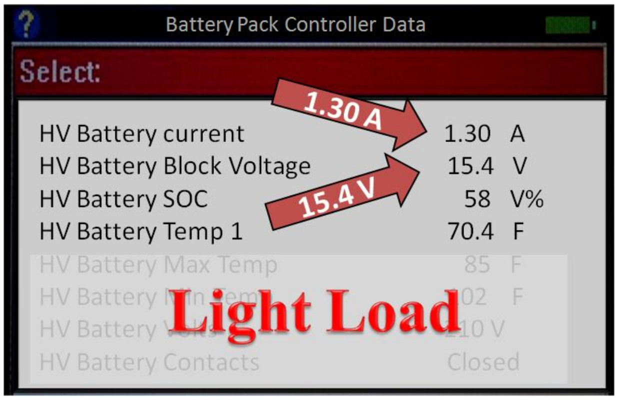
During the road test drive the vehicle under a light load (in service bay). This will give us the highest HV battery pack voltage because during light load light throttle the traction is not drawing a lot of current. When there is a light, current draw voltage is high. Drive the vehicle under heavy load (Hard acceleration). During hard acceleration, the traction motor draws high current and when current draw is high, voltage is low.

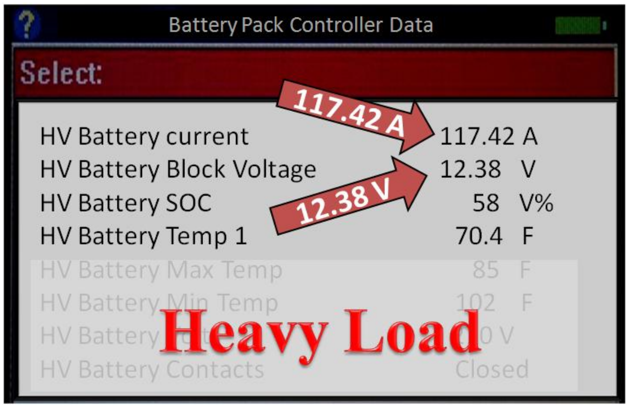
BATTERY CURRENT DURING TEST DRIVE

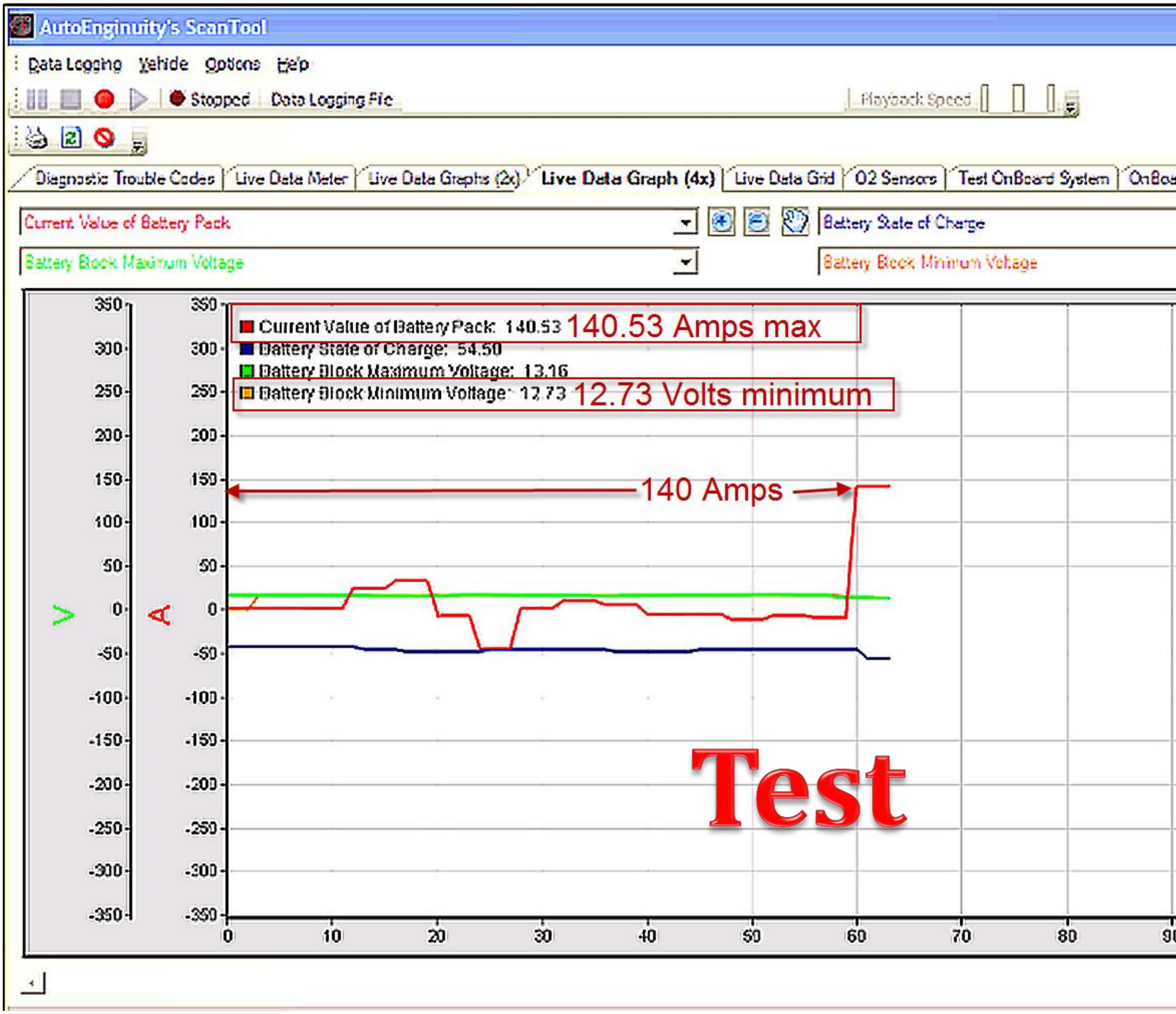
When the battery is providing power to the traction motor current readings are positive and range around 100 to 200 amps **(Use this data for battery testing)**
During regenerative braking current readings are negative and range around -90 to -110 amps, this indicates we are putting current into the battery (This data is for information and not for the test)

During full load test, ensure that the minimum block voltage does not go below 10.80 Volts. If the voltage goes below the minimum, the test results are not dependable.

GRAPH OF TEST DRIVE DATA

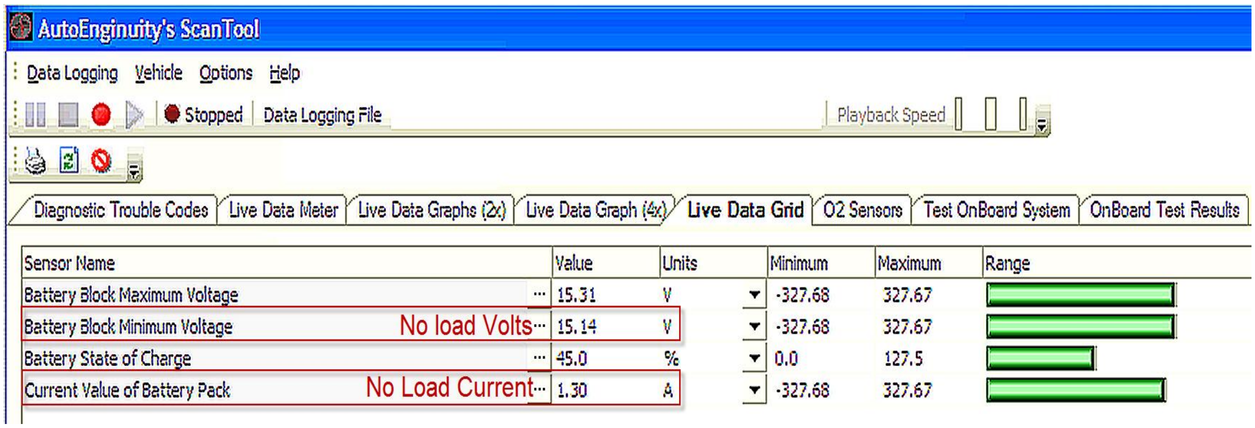






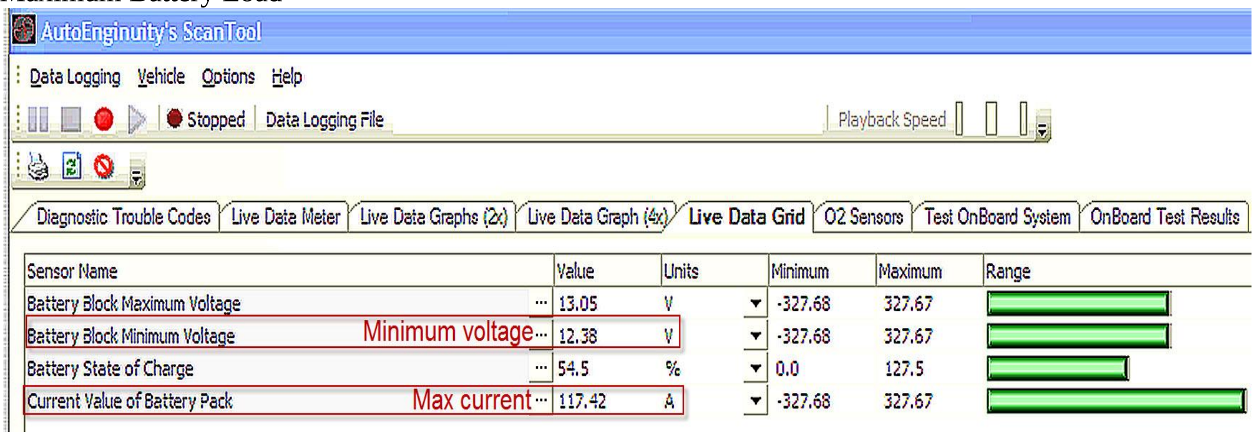
Example of Calculating Internal Resistance

Minimum Battery Load



No load volts= 15.14 V
No load current= 1.30 A

Maximum Battery Load



Max load volts= 12.38 V
Max load current= 117.42 A

MEASURING DATA FOR INTERNAL RESISTANCE CALCULATION

Calculate the battery's internal resistance:
Determine the Delta (Δ) voltage and Delta (Δ) current. The Delta voltage is determined by subtracting the full load voltage from the light load voltage. The Delta voltage is determined by subtracting the light load current from full load the current.
Test drive the vehicle and record the Data and do the math to determine the internal resistance

Obtain the Delta (Δ) voltage and current
Determine the internal resistance of your battery pack (expected range is 15 to 40 milliohms)
Do the math to obtain the Delta (Δ) voltage and current using the two scan data screens from the test drive.

CALCULATE BATTERY INTERNAL RESISTANCE

Divide Delta volts by Delta amps

2.76÷116.12= 0.0238 ohms or 23.8 milliohms

Normal internal resistance is 15 to 40 milliohms
Toyota has a scan data PID for battery block internal resistance. We do the internal resistance calculation for other manufacturers.

TOYOTA BATTERY SCAN DATA

The data displayed is form the **AutoEnginuity** PC based scan tools.

Delta (Δ) volts		Delta (Δ) Amps	
15.14 V	No Load	117.42 A	Max Load
-12.38 V	Max Load	-1.30 A	No Load
2.76	Delta Voltage	116.12	Delta Amps

Sensor Name	Value	Units	Minimum	Maximum
Battery Block Voltage -V01	15.45	V	-327.68	327.67
Battery Block Voltage -V02	15.41	V	-327.68	327.67
Battery Block Voltage -V03	15.39	V	-327.68	327.67
Battery Block Voltage -V04	15.39	V	-327.68	327.67
Battery Block Voltage -V05	15.42	V	-327.68	327.67
Battery Block Voltage -V06	15.38	V	-327.68	327.67
Battery Block Voltage -V07	15.38	V	-327.68	327.67
Battery Block Voltage -V08	15.38	V	-327.68	327.67
Battery Block Voltage -V09	15.39	V	-327.68	327.67
Battery Block Voltage -V10	15.40	V	-327.68	327.67
Battery Block Voltage -V11	15.37	V	-327.68	327.67
Battery Block Voltage -V12	15.44	V	-327.68	327.67
Battery Block Voltage -V13	15.42	V	-327.68	327.67
Battery Block Voltage -V14	15.46	V	-327.68	327.67
Internal Resistance R01	0.026	Ohms	0.000	0.255
Internal Resistance R02	0.025	Ohms	0.000	0.255
Internal Resistance R03	0.025	Ohms	0.000	0.255
Internal Resistance R04	0.025	Ohms	0.000	0.255
Internal Resistance R05	0.025	Ohms	0.000	0.255
Internal Resistance R06	0.025	Ohms	0.000	0.255
Internal Resistance R07	0.025	Ohms	0.000	0.255
Internal Resistance R08	0.024	Ohms	0.000	0.255
Internal Resistance R09	0.025	Ohms	0.000	0.255
Internal Resistance R10	0.024	Ohms	0.000	0.255
Internal Resistance R11	0.025	Ohms	0.000	0.255
Internal Resistance R12	0.025	Ohms	0.000	0.255
Internal Resistance R13	0.025	Ohms	0.000	0.255
Internal Resistance R14	0.026	Ohms	0.000	0.255

Vehicle Notes

Put your vehicle notes here

Vehicle: Toyota Prius 2009 | System: HV Battery CAN

OUT OF VEHICLE BATTERY DIAGNOSTICS

Testing the HV battery pack out of the vehicle is must be done when the test results from testing in the vehicle are not enough or undependable. Working with the HV battery pack requires you to remove the safety disconnect switch, wait 15 minutes for capacitors to discharge, wear class zero gloves, place HV battery pack on wood, and use insulated tools. When the safety disconnect switch is remove the high voltage is isolated within the battery pack itself. That means you will be working with high voltage. Follow all of the safety guidelines to avoid injury.

- Remove the safety disconnect switch
- Remove the HV battery Pack from the vehicle
- Wait 15 minutes for capacitors to discharge
- Wear class zero gloves
- Place HV battery pack on wood
- Use insulated tools

The battery pack is dangerous to work with unless you follow safety procedures.

Work with Individual Battery Modules

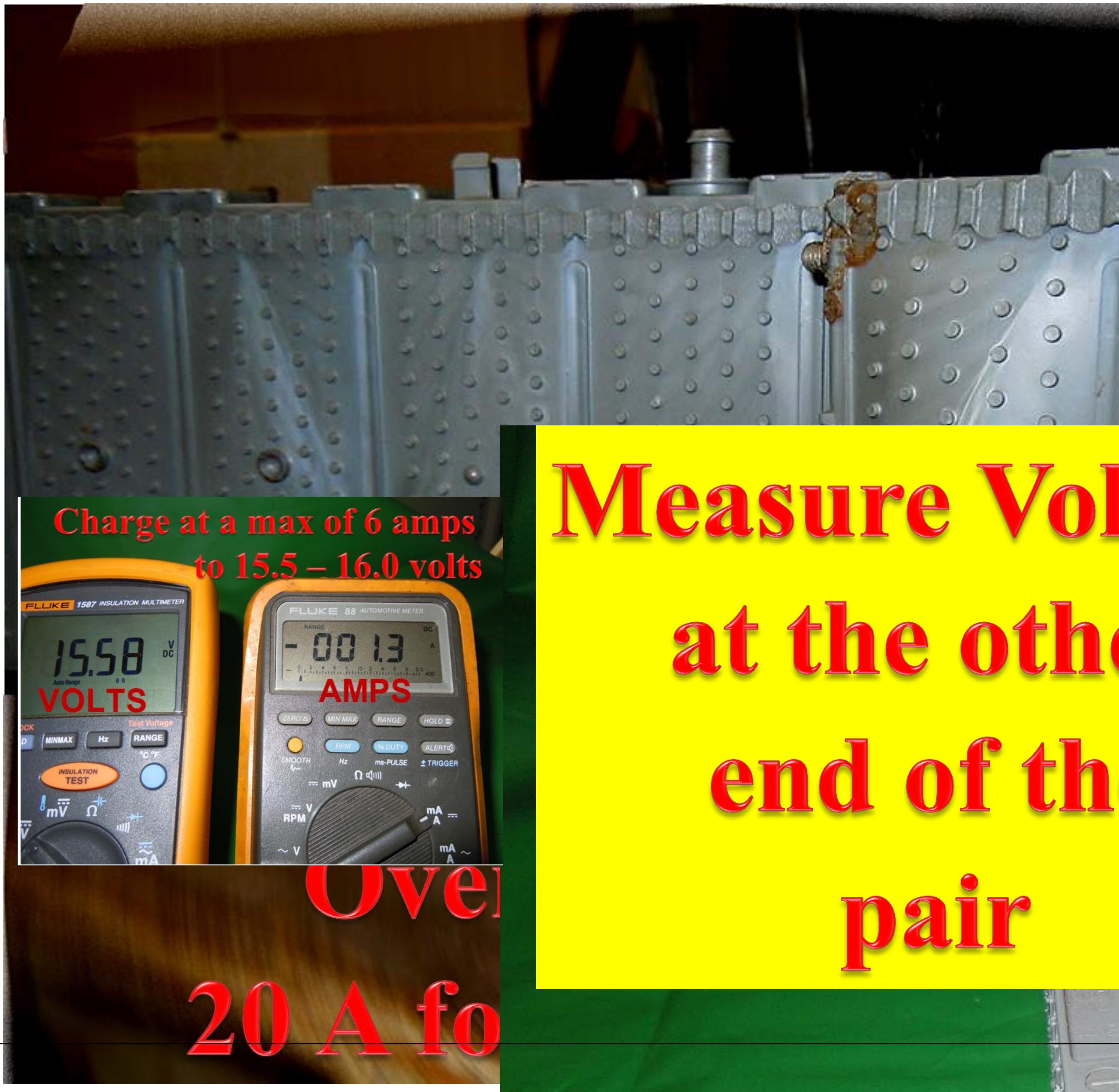
After disassembling the HV battery pack you will be working with individual battery modules
Do not contact more than one block of batteries at a time, this has the same danger posed by a 12 battery
You won't need the class zero gloves

- **Don't use battery modules that are below 5.4 V (10.8 V for a block) which is the lower limit on cell voltage, they will have a short life span if they can be recovered**
- **Internal resistance varies with temperature**
- **Try to test fully charged batteries at room temperature**
- **This is an example of a low charged battery that may have a short life span if it can not be recovered**
- **If batteries are below 7.5 volts, charge them**
- **Charge at a maximum of 16.0 V at 2-6 amps**

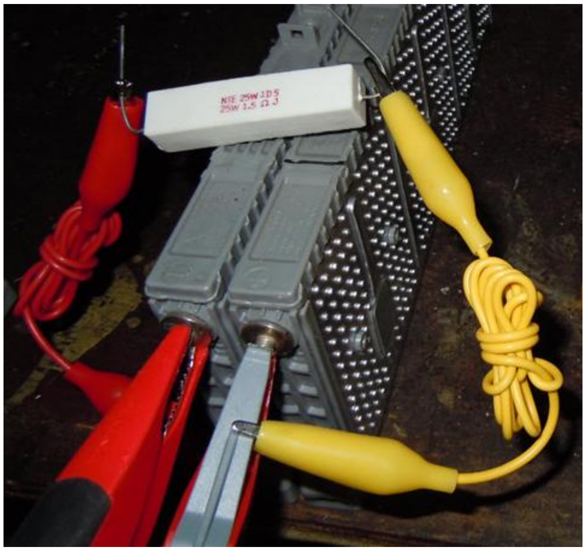
Monitor battery temperature and do not allow the battery to overheat.

TEST 2 BATTERY MODULES AT A TIME

Overcharging overheats the batteries very quickly. We look at scan data showing 140 A draws. The battery ECU monitors temperature and state of charge and manages these high current conditions.
Two modules tested together duplicates the testing done by the battery ECU
The test results will represent the combined resistance of two batteries together
If the test fails, retest each module alone to see which one or both failed
Make measurements at the other end of the pair of modules.
If battery voltage is under 15.5 volts, charge the modules.



Allow the voltage to stabilize after being charged. Then record the no load voltage for the resistance calculation.



The unloaded voltage is 15.58 V with no current flow.
Use a high wattage resistor to apply a load to the batteries. We used a 1.5 Ω resistor rated at 25 watts as our load.

Apply the load resistor and measure the new voltage and current values.

The current in this test is 9.6 amps with voltage at 15.29 volts.

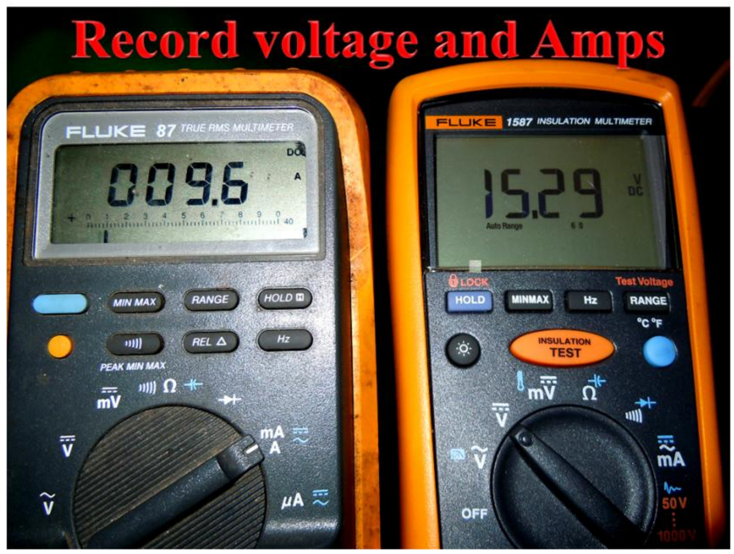
CALCULATE DELTA Δ VOLTS

15.58 V — 15.29 V = .2900 Δ volts

CALCULATE INTERNAL RESISTANCE

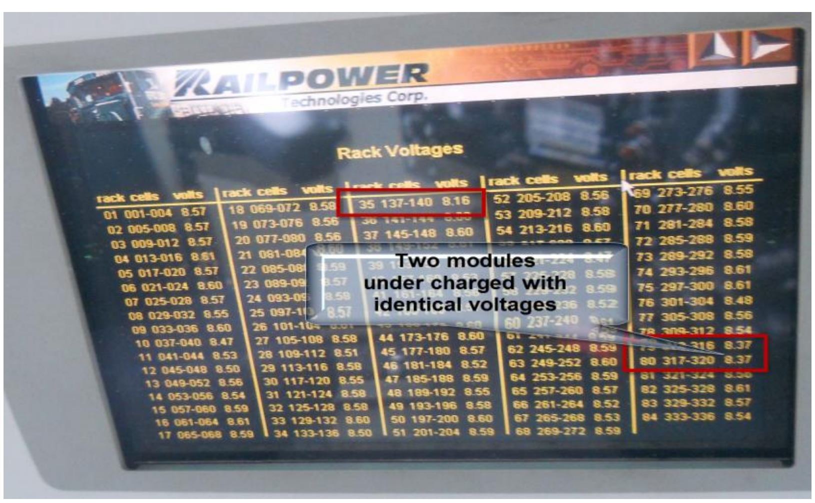
.29 Δ volts ÷ 9.6 A = 0.0302 or 30 milliohms

These salvage batteries can be used to replace defective battery modules in a vehicle that has battery block resistance of 26 mΩ to 34 mΩ. This pair would not work in a battery pack with block resistance near 20 mΩ. The differences in load voltages is too large. Match the internal resistance as close as possible.



BALANCE STATE OF CHARGE

Connecting batteries in series requires the batteries be close to the same voltage. Series connected batteries receive the same charge/discharge current, an under charged battery will never catch up with the rest of the battery pack. Balance problems will set a DTC when there is a 0.30 volts difference in battery block voltages.



The two battery modules in the example are at 8.37 volts when most other modules are at 8.5-8.6 V. Modules installed several months earlier to replace weak modules.

CHAPTER 29

PROBLEM VEHICLE CASE STUDY

The Hybrid controller has set DTCs for problems with the HV battery pack. A DTC is an indicator of what the controller tested and failed. Use it to gain a direction for the diagnostics. DTC's are good starting points.

- The following is a case study that required HV battery pack testing
- When there is a problem with the state of charge there will be DTCs
- The vehicle were going to use has codes for imbalanced voltage and State of Charge problems

2003 Prius

Complaint:

“My car never shuts off”

Complaint in technical terms:

“The auto start/stop function is suspended”

Master warning light illuminated

First Step

Use a Scan Tool to “pull” Diagnostic Trouble Codes
Example of Unbalanced DTCs

- P0A80 The difference in voltage between 2 of the blocks in the battery pack is too high
- P3006 SOC Uneven

Our Code

- P0A80 The difference in voltage between 2 of the blocks in the battery pack is too high

The battery control module sets specific codes individual battery blocks. These codes and scan data lets a technician check the battery without opening the protective covering. Follow normal safety procedures once you need to work on the high voltage circuits. These codes help locate corrosion problems and voltage block problems
Examples of battery block codes:

- P3011- Battery block #1 is weak
- P3012- Battery block #2 is weak
- P3013- Battery block #3 is weak
- P3014- Battery block #4 is weak
- P3015- Battery block #5 is weak
- P3016- Battery block #6 is weak
- P3017- Battery block #7 is weak
- P3018- Battery block #8 is weak

Use scan data to verify problem battery blocks.

- A battery block is normally 14.9 V to 15.2 V

Codes for this vehicle:

- P3016- Battery block #6 is weak
- P3017- Battery block #7 is weak
- P3018- Battery block #8 is weak
- P3019- Battery block #9 is weak
- P3020- Battery block #11 is weak
- P3021- Battery block #12 is weak
- P3022- Battery block #13 is weak

Scan Data readout:
We highlighted a large portion of the low voltage blocks; this is enough to indicate we need to service the battery pack.

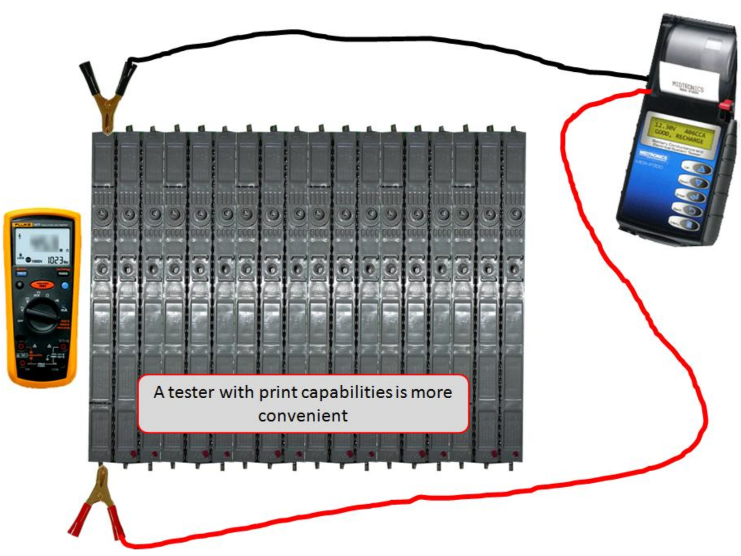
- The Scan Data indicates that the batteries do not have even voltage levels
- Each battery module in the battery pack requires testing

We must remove the cover for the battery pack

- Remove the Safety disconnect
- Wait 15 minutes to discharge capacitors
- Wear the class zero electrical protection gloves

LOW

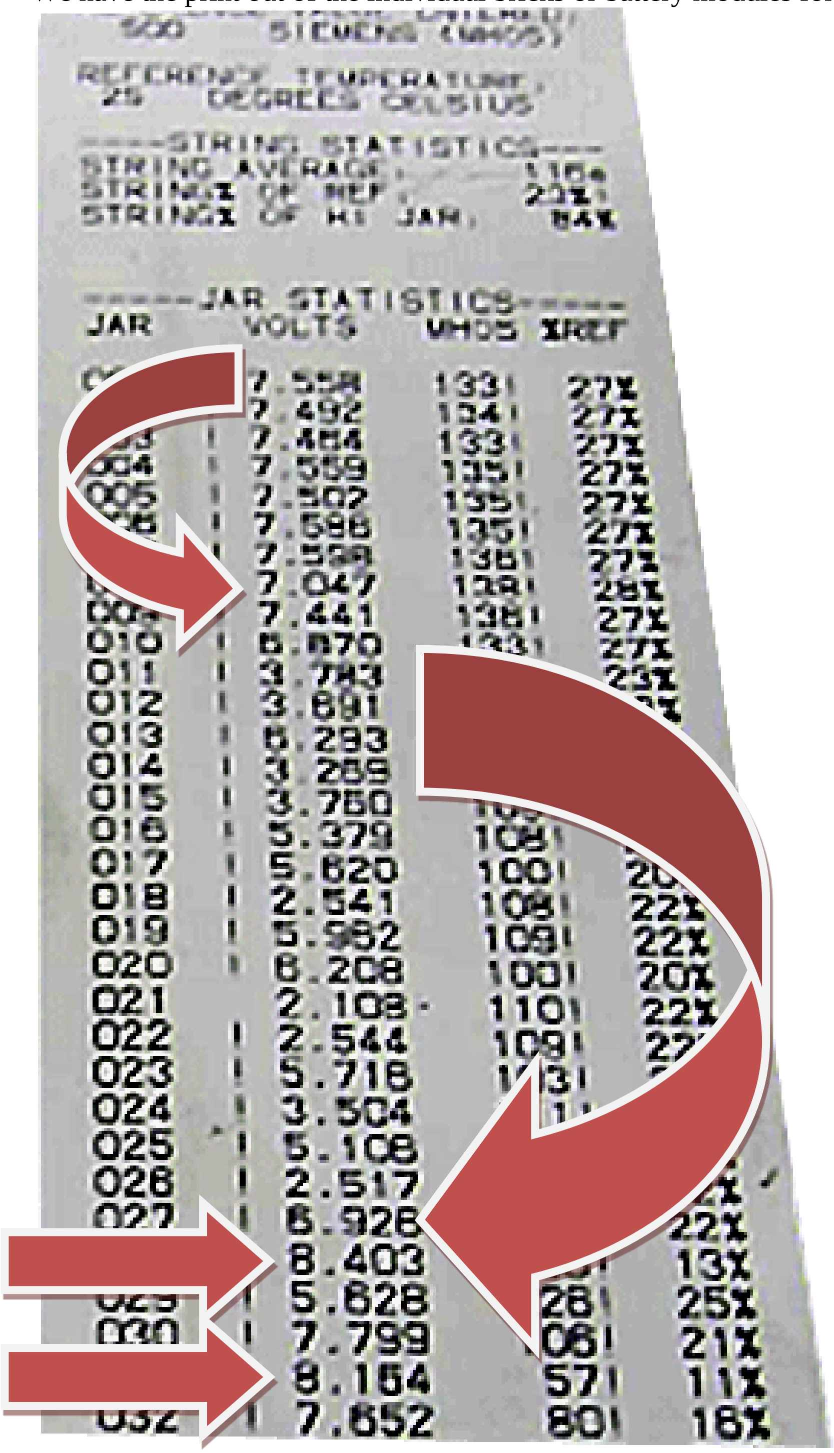
Battery Block Voltage V01	15.05
Battery Block Voltage V02	15.04
Battery Block Voltage V03	15.01
Battery Block Voltage V04	14.64
Battery Block Voltage V05	14.31
Battery Block Voltage V06	7.47
Battery Block Voltage V07	9.58
Battery Block Voltage V08	9.13
Battery Block Voltage V09	8.61
Battery Block Voltage V010	12.19
Battery Block Voltage V011	4.65
Battery Block Voltage V012	9.22
Battery Block Voltage V013	7.62
Battery Block Voltage V014	15.33
Battery Block Voltage V015	13.42
Battery Block Voltage V016	15.80
Battery Block Voltage MIN	7.47
Battery Block Voltage MAX	15.80



Each shop will have to make a decision about what to do next. It is an acceptable practice to replace the entire battery pack. Some shops have decided to rebuild battery packs. If you decide to rebuild a battery pack, understand new modules are all but impossible to get and you will have to charge and test several salvage modules to match the correct ones to the battery pack you are working on. Do not use new modules on older battery packs because they will not match the older batteries chemistry. Match replacement modules to the modules in the battery pack. If the chemistry is different between modules, a voltage imbalance DTC will be set. Modules must have near the same internal resistance to avoid setting the DTC. If your shop is going to rebuild the battery pack, test the battery modules. Use our internal resistance test to match batteries.

Scan Data does not supply the voltage for each battery module, but individual modules testing does.

We have the print out of the individual bricks or battery modules for the problem vehicle.



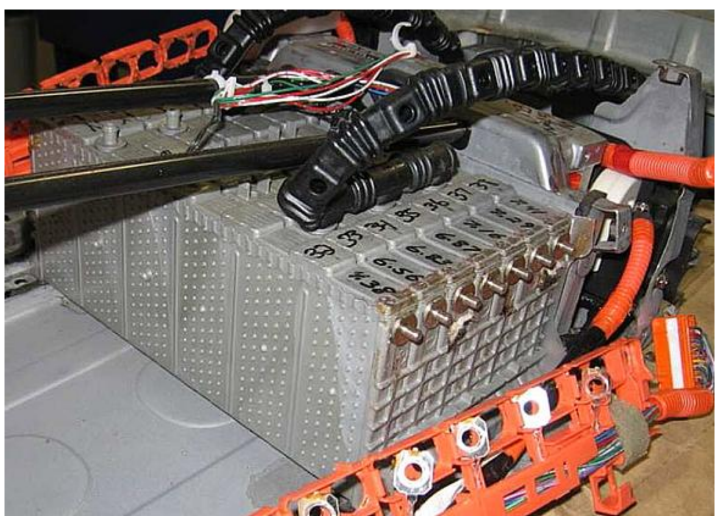
The first group is near normal. The second group is below normal. We have two modules with much higher voltages.

We did not see the high voltage modules in scan data. Individual problems can be lost when testing modules in blocks of two modules in scan data.

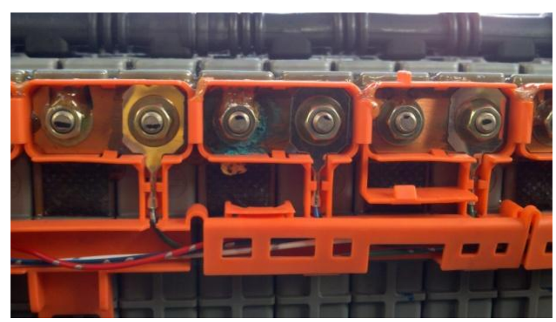
Two batteries leaked electrolyte, causing corrosion of the contacts on other modules.

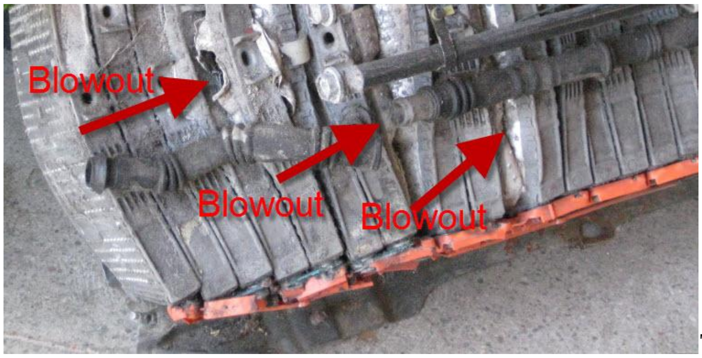
These are the copper connectors from the battery pack.
This occurs sometimes on older hybrids.
Corrosion causes poor contact to the batteries and the sense leads.

The scan data voltage sensor leads have a poor connection and fail to read block voltage. We suspect this may be the cause of overcharged batteries. The state of charge uses battery voltage as part of the SOC calculation.



There is Prius I TSB to treat the connections to prevent corrosion.
The correction was to clean everything, replace the bad components, and reassemble. Vinegar and water cleans up an alkaline electrolyte spill.
Overcharged batteries can be distorted and out of shape.

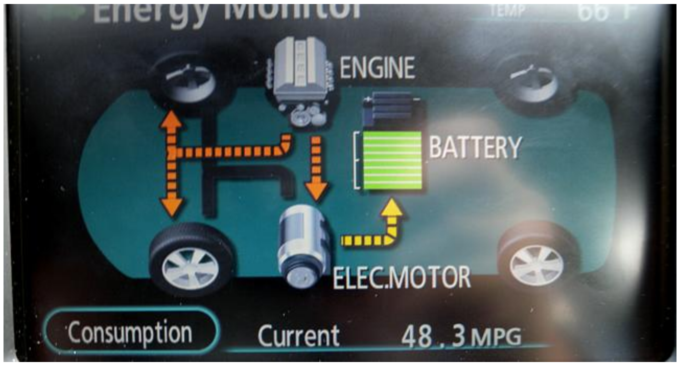




This battery pack is a total loss. We suspect poor voltage sense connections, and no one has offered a better theory so far.

NEW GENERATION LITHIUM-ION BATTERY

The new generation of hybrid batteries is the lithium ion battery. The voltage output is three times higher than the NiMH battery. This will enable manufacturers to build series-parallel battery packs that will provide the high voltage and improved current capability.



Added current capability will allow vehicles to operate longer without using the IC engine. The Chevy Volt uses lithium ion batteries to go 36 miles without starting the ICE.

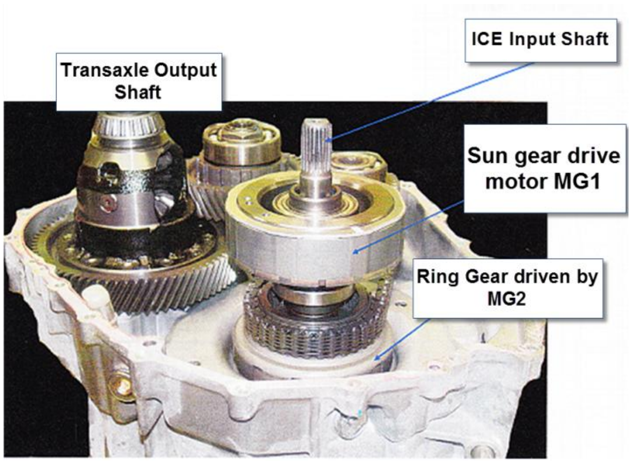
- Cell voltage is 3.6 volts, so it takes one third the number of cells in series for high voltage
    - Cells can be placed in series-parallel arrangement to increase capacity, which allows more time in the electric drive mode without using the internal combustion engine
- Chevy Volt goes 36 miles without the ICE running, mild acceleration (EPA city driving mode)
- A 6-cell battery would have 21.6 Volts
- A block would have 43.2 volts

Lithium ion battery overcame some technical problems. However, the cost is much higher than NiMH batteries. Early lithium batteries had a fire problem. If a metal object punctured them, a fire frequently started.
This is a picture made by the military; a 22-caliber rifle shot caused this fire. Newer batteries do not have this problem.

CHAPTER 30

POWER SPLIT DEVICE

The power splitter is a transaxle that determines the power source for the drive wheels



This display shows the drive power coming from the ICE. The arrow going back to the battery indicates the high voltage battery is charging.
The power split device is a planetary gear set
Any planetary gear set has three main components:

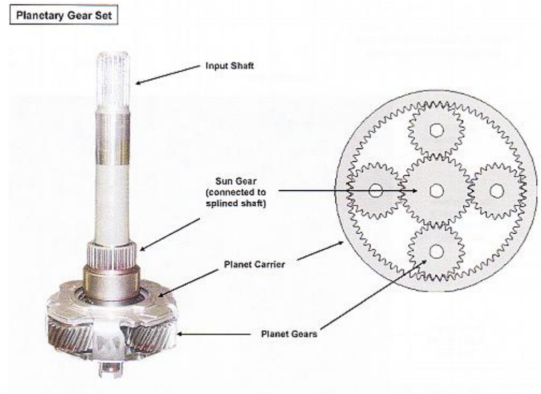
- sun gear
- planetary gears/ planetary gear carrier
- ring gear

The hybrid control module controls the actions of two electric motors to drive the power splitter. Control of the two motors determines the gear ratio for the gear set.

This is the transaxle assembly for a Prius. We are going to cover the individual components identified in the graphic.

Two Motor Power Splitter

MOTOR GENERATOR 1



Motor generator 1 (MG1) controls the planetary gear set by driving the Sun gear. It blends the torque of the ICE and motor generator 2. MG1 also functions as a cranking motor to start the ICE. It recharges the HV battery during cruise operation. It drives the sun gear forward or reverses in varying RPMs. We will cover these operating modes and discuss how these functions are accomplished

MOTOR GENERATOR 2

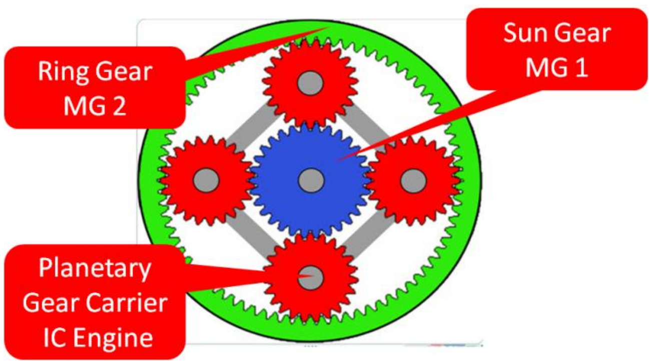
The motor generator 2 (MG2) drives the ring gear and provides torque assist to the ICE. It can provide propulsion torque in electric mode (ICE off). MG2 functions as a generator during regenerative braking mode. It drives the ring gear forward or reverses for different operating modes. We will cover these operating modes and discuss how these functions are accomplished

ICE, INTERNAL COMBUSTION ENGINE

The ICE drives the planetary gear carrier to propel the vehicle in ICE only or in conjunction with electric assist mode. The ICE drive the planetary gear set forward only. There is no reverse gear in the transaxle. When the vehicle is in reverse, it is in electric propulsion mode, the ICE cannot run backwards.

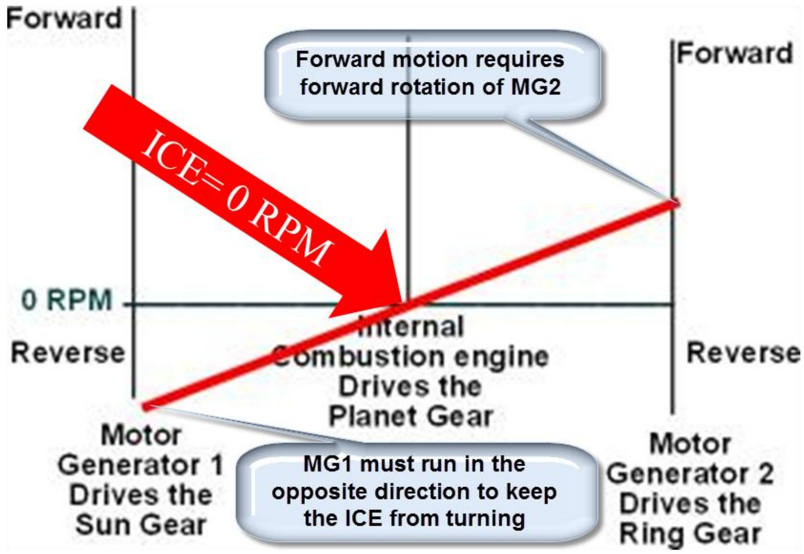
PLANETARY GEAR SYSTEM

Key Facts:
Sun Gear speed determines the rotation speed of the planetary carrier assembly.
Ring gear connects to the output shaft and will rotate when the vehicle is moving.
The planetary carrier assembly rotates at the speed of the ICE.
The Sun gear rotation speed in conjunction with the ring gear produces a virtual torque converter or continuously variable transmission. MG1 varies its speed to blends the torque of the ICE with the torque from MG 2.

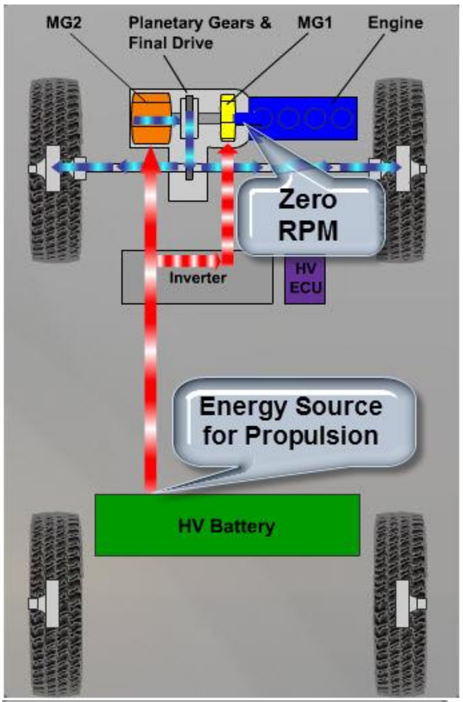


We use a graph to study the complex relationship of the motors and ICE. Forward, reverse, different speeds, and gear ratios are all a result of the different combination from the planetary gear set. MG1 and MG2 may turn in the same or opposite direction at different RPMs. All vehicle motion comes from on the planetary gear set.

ELECTRIC PROPULSION WITH ICE OFF

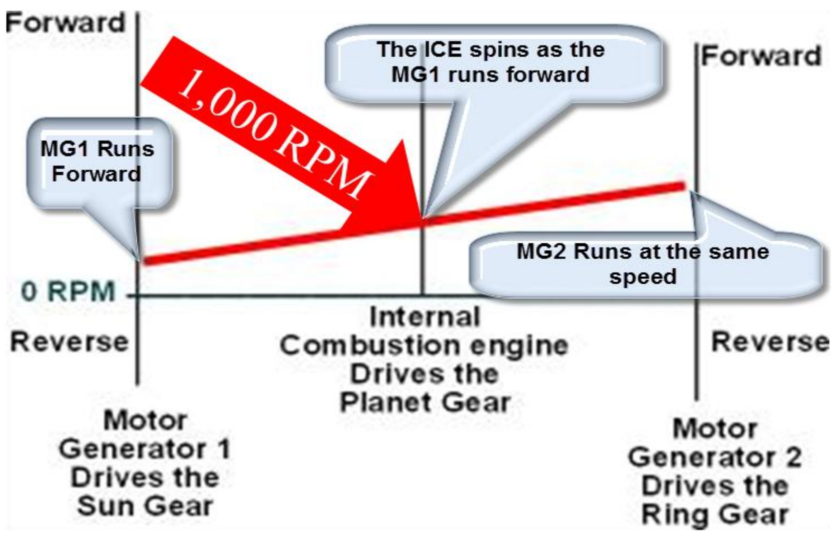


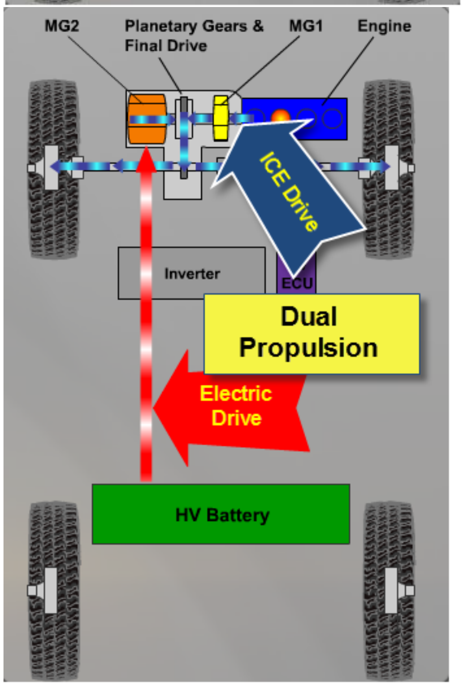
This graph shows the conditions necessary for vehicle motion with the ICE off. Remember, the speed of the two electric motors must result in zero ICE rotation. The forward motion of the vehicle comes from the torque of MG2 in the forward direction and MG1 in the reverse direction. MG1 reverse speed control keeps ICE speed at zero RPM.



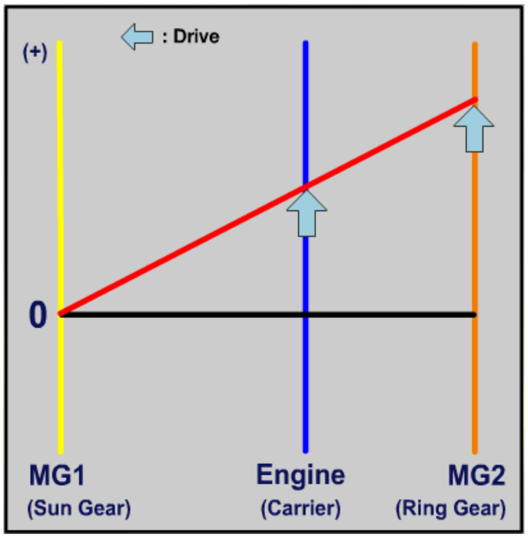
Power for propulsion comes from the high voltage battery pack. High voltage battery capacity limits the time electric propulsion. The inverter assembly will activate the boost function to keep drive propulsion stable as battery voltage decreases. The ICE will start when the load is too high or battery voltage drops too low.

The ICE starts when MG1 runs forward.





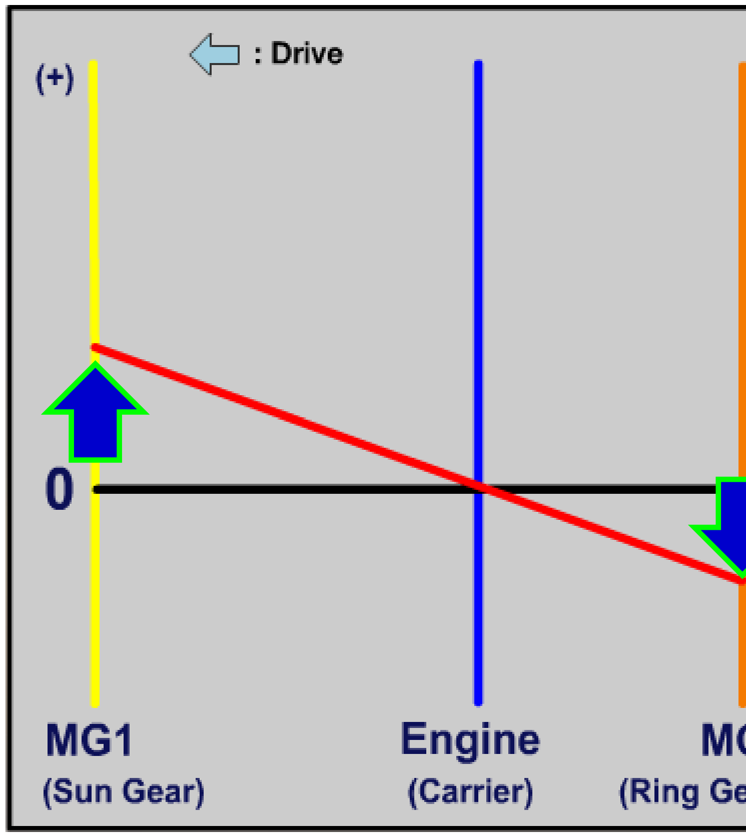
The ICE supplies drive power and the electric machine supplies drive power. The starting speed for the ICE may as much as 1,000 RPM. If battery state of charge drops to about 40%, the ICE will take over drive power. MG2 will to zero torque when it is off while MG1 generates voltage to recharge the battery.



During hard acceleration, MG2 will power up as an assist motor for the ICE. During high power output, the horsepower of MG2 adds to the horsepower from the ICE. Full size pickups with a 350 HP ICE engine and a 60 to 100 HP electric motor the combined power is high.
The graph for hard acceleration shows the maximum output conditions of the combined operation.

Reverse Operation

To operate in reverse, MG2 runs in reverse while MG1 runs forward to keep the ICE at zero RPM.



We use the charts to help you understand scan data for the different operating modes. There are some simple rules to remember:

1. MG2 always turns in the direction of the vehicle movement.
2. The ICE can not run backwards, MG1 must run in the direction needed to keep the ICE at either zero RPM or at a forward speed.
3. MG2 can supply negative torque by acting as a generator to slow the vehicle.

Toyota and Ford have virtual CVT transmissions by using the power splitter Honda Uses a CVT transmission after the electric assist motor. The simpler systems have the same functions as the hybrid components discussed earlier.

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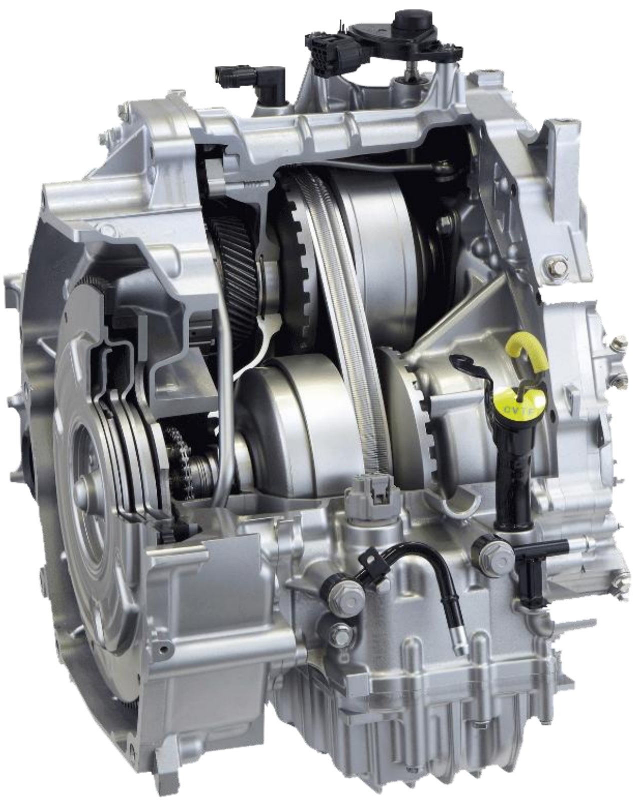
Chapter 31

Continuously Variable Transmission (CVT)

Automatic transmission have a complex set of gears, clutches and governing devices Most CVTs only have three basic components: A high-power metal or rubber belt, a variable-input "driving" pulley' and an output "driven" pulley.
CVTs use computers and sensors for control.

The variable-diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. A belt rides in the groove between the two cones. V-belts are preferred if the belt is made of rubber.
When the two cones of the pulley are far apart (when the diameter increases), the belt rides lower in the groove, and the radius of the belt loop going around the pulley gets smaller. When the cones are close together (when the diameter decreases), the belt rides higher in the groove, and the radius of the belt loop going around the pulley gets larger. CVTs may use hydraulic pressure, centrifugal force or spring tension to create the force necessary to adjust the pulley halves.
The engine's crankshaft connects to the drive pulley also called the input pulley. The input pulley connects the energy from the engine to the transmission. The output or second pulley is the driven pulley. As an output pulley, the driven pulley transfers energy to the driveshaft from the input pulley. The two pulleys work in tandem to maintain belt tension. When one pulley increases its radius, the other decreases its radius to keep the belt tight. As the two pulleys change their radii relative to one another, they create an infinite number of gear ratios.



When one pulley increases its radius, the other decreases its radius to keep the belt tight. As the two pulleys change their radii relative to one another, they create an infinite number of gear ratios.

We used this example to show how complex a mechanical system can be. The two motor generators work together to produce the same effect, without the complex pulley system.

There are simpler hybrids that use a much smaller motor to provide assist to the ICE. These simpler system will not operate in electric only mode. They will shut down the engines at stops to save fuel and restart the engine quickly. The electric motor can be located in front of the transmission like Honda. GM has motors that mount in place of the alternator.

CHAPTER 31

BAS, BELTED ALTERNATOR STARTER

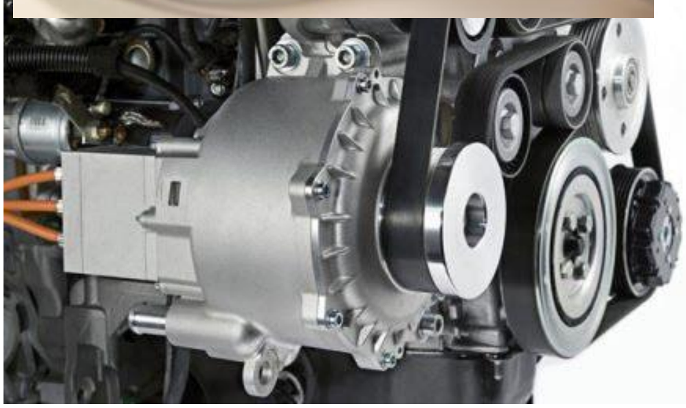
The Belted Alternator Starter Systems (BAS) designed by Delphi. It has been around on Saturn's for a while. The Chevrolet Malibu uses the BAS system for a low cost hybrid. The name explains the system. The system uses only one motor (Unit). The unit connects to the engine's crankshaft by a belt. It is the starter and alternator controlled like other hybrid motors by an inverter.

The BAS system allows a smaller ICE because it supplies a modest amount of electric assist. The ICE has Variable Valve Timing to improve efficiency. The BAS system adds auto stop/start for better fuel economy.

The ICE for the BAS system uses a 12 V starter motor to start the engine on first start. The first start up uses a 12 V starter motor to crank the engine. During stop/start operation, the motor unit cranks the engine.

The BAS system operates similarly to other "start/stop" systems; it shuts down the engine as the vehicle comes to a stop. Releasing the brake instantly (500 ms) restarts the engine. Other Hybrids under normal conditions will not start the ICE until the vehicle has stated motion on electric only. Therefore, the brake switch is not part of the ICE start system.

The 36 V motor/generator/starter units is capable of starting the 2.4L engine in less than 500 ms Battery voltage is 42 V while charging the batteries.



The BAS system is capable of providing modest electric assist during launch and acceleration. The BAS system cannot operate in pure EV mode.

The system provides about a 15-20% increase in MPG in the city. The system is reasonably simple and inexpensive; making BAS equipped vehicles the least expensive hybrids available (Less than $2000.00). The BAS system uses a conventional 4T45 Auto Trans although it has been modified to include a more efficient final-drive ratio and includes an electrically driven pump to provide pressure in auto-stop mode.

DRIVER INDICATORS

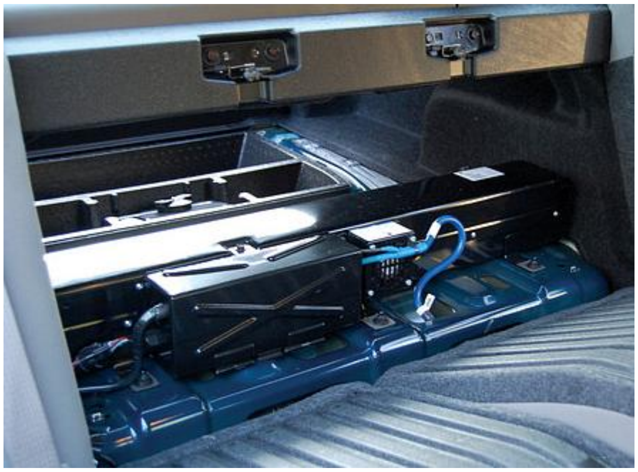
There is not a ready lamp. The tachometer has an auto stop position. When the ignition is on and the ICE is off the tachometer will be in the auto stop position. If the ignition is not on the tachometer will be in the off position.

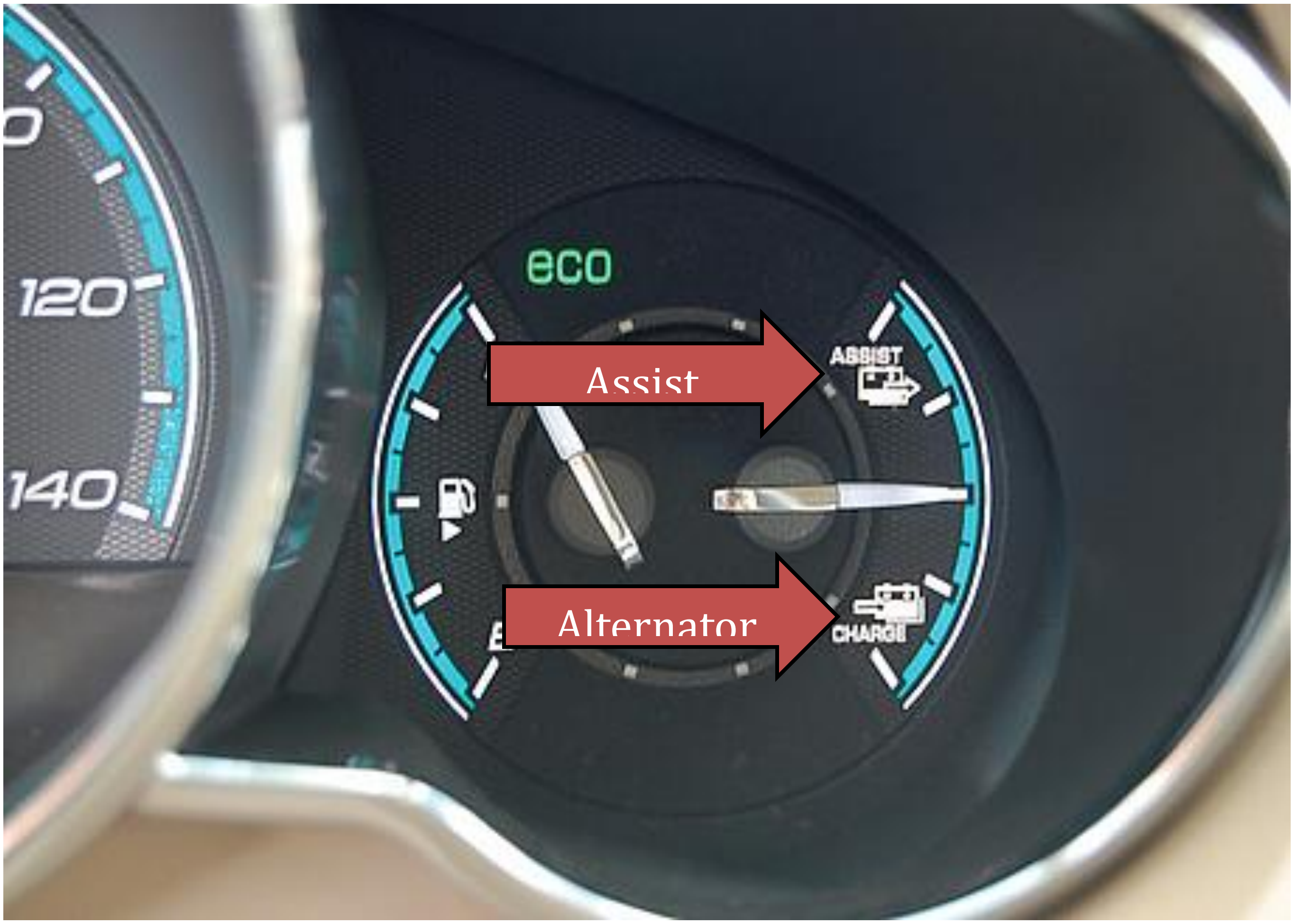
The ECO gauge informs the driver when electric assist is helping the engine. The ECO gauge shows the action as an alternator and as an assist motor.

BAS Major Components

The three major components are the battery pack, inverter, and the BAS unit.

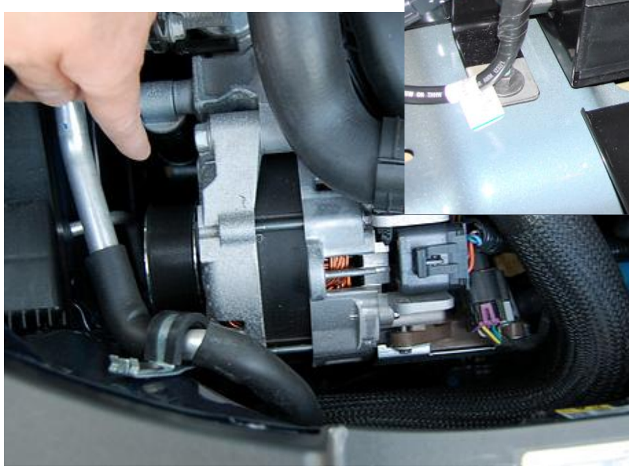
Battery pack





Starter/Alternator

DC to AC Inverter

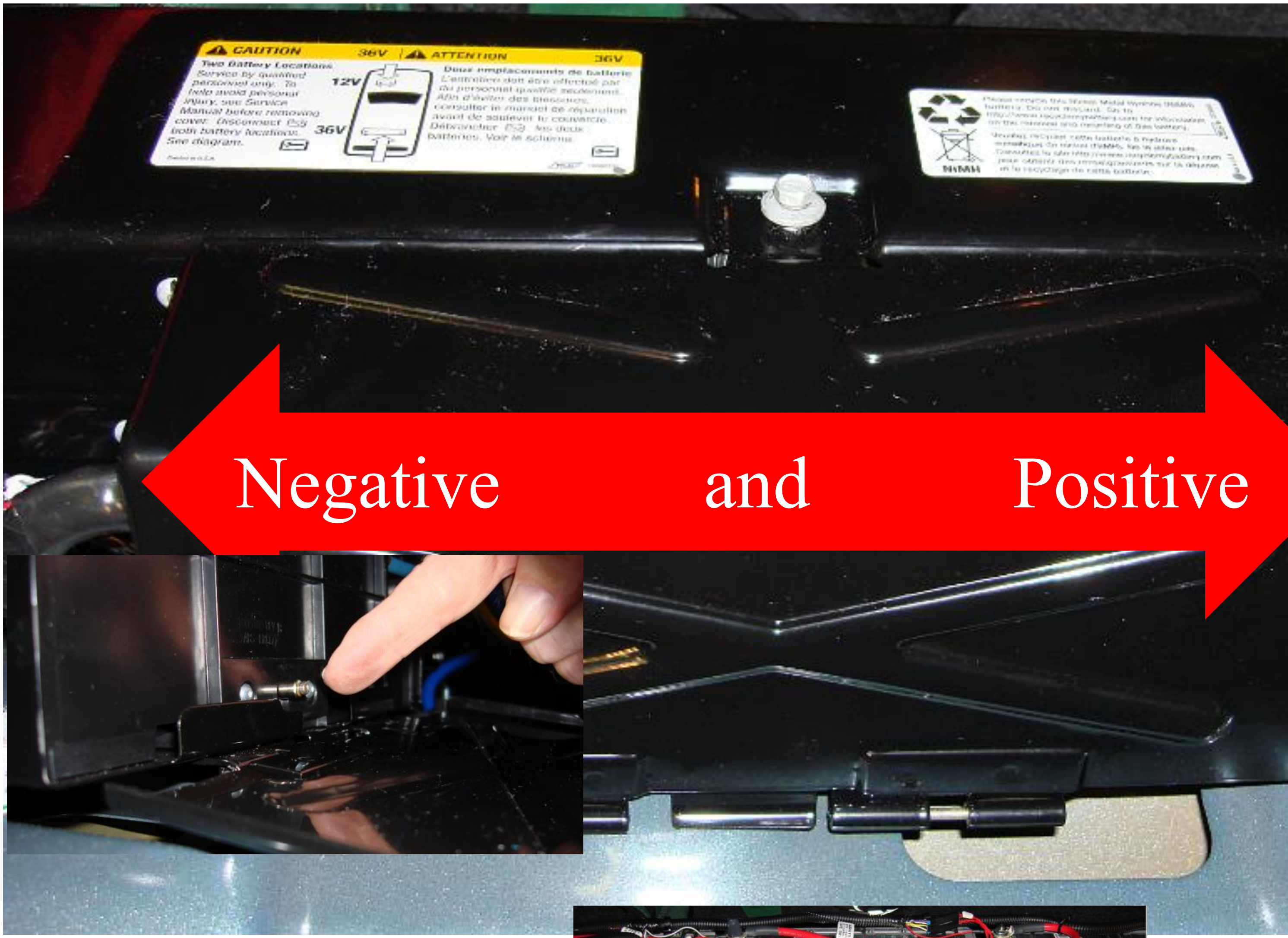


These components form an inexpensive hybrid vehicle with improved city fuel economy. The BAS systems have the same functions as the hybrid components discussed earlier.

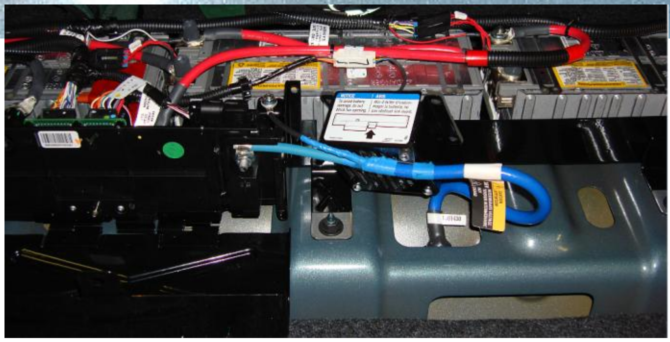
MALIBU BATTERY PACK

The Malibu's battery pack is in the trunk and faces the passenger's compartment. Lowering the back of the back seat accesses it. There is a cover held in place with a bolt. Removing the bolt will allow the cover to hinge down and expose some of the battery pack components.

When the battery cover is down, an interlock circuit opens and the Hybrid controller will not close the high voltage relays. The high voltage is isolated within the battery pack itself.



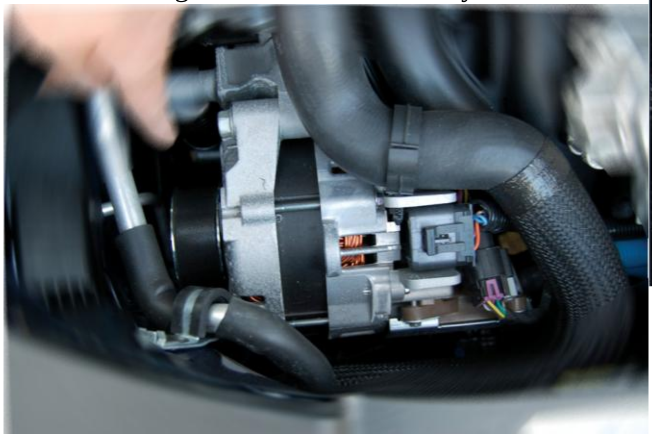
Safety interlock



The 36-volt system uses a common ground for the high voltage battery pack. This is unlike other Hybrids where the high voltage is isolated from common ground. There is one high voltage wire leaving the battery pack and going under the vehicle up to the inverter in the engine's compartment.

The battery cable goes into a protection tube. Even though the voltage is not a shock danger, it can be a fire hazard, if shorted to ground.
The 36 V wiring connects to the inverter assembly in the front of the vehicle. One power wire is required when chassis ground is used for the other conductor.

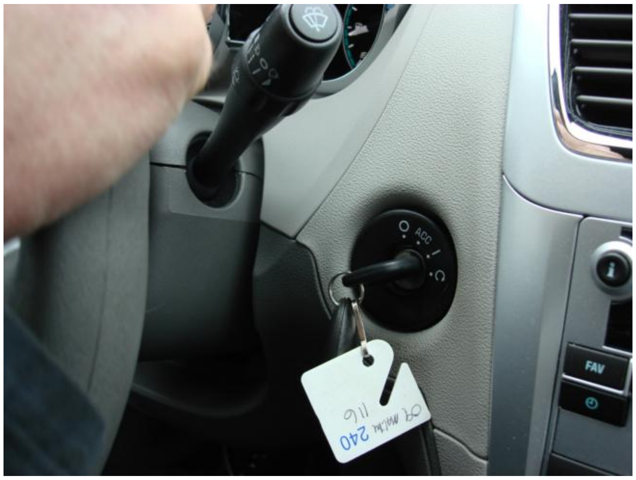
The inverter functions of converting DC voltage into AC voltage is the same as other hybrids. The difference is the voltages involved. The lower supply voltage limits horsepower. The AC voltage is three phase like other hybrids.



The three-phase wiring connects to the starter/alternator.

The drive belt is larger than belts used on regular vehicles. The belt tentisoner spring is much stronger than springs on regular vehicles.

The cooling system for the inverter uses an electric pump to circulate coolant through the inverter.



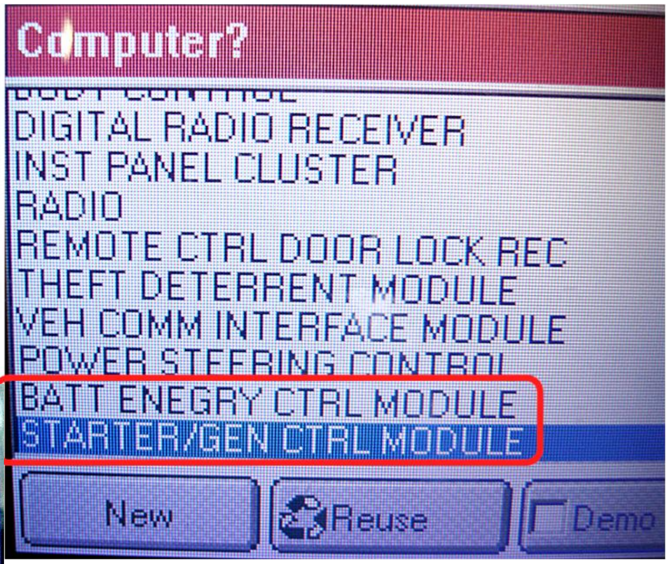
The components on regular hybrids operate the same way here but the voltages are lower.

STARTING THE BAS SYSTEM

The vehicle has a normal ignition switch that starts the ICE. The ICE will continue to operate until the vehicle moves. When the vehicle stops, auto shut down stops the ICE while the brake is depressed.
Starting power comes from a 12-V battery and starter for the start up and uses the 36-V battery pack for auto-start functions. The reasoning is to warm the engine before using the rapid restart with the 36-V batteries.

36-V Battery Pack

There are three 12-V batteries. The Batteries are AGM or absorbed glass mat batteries. Connecting the batteries in series produces 36 volts nominal with actual voltage being 42 -V during charging mode.



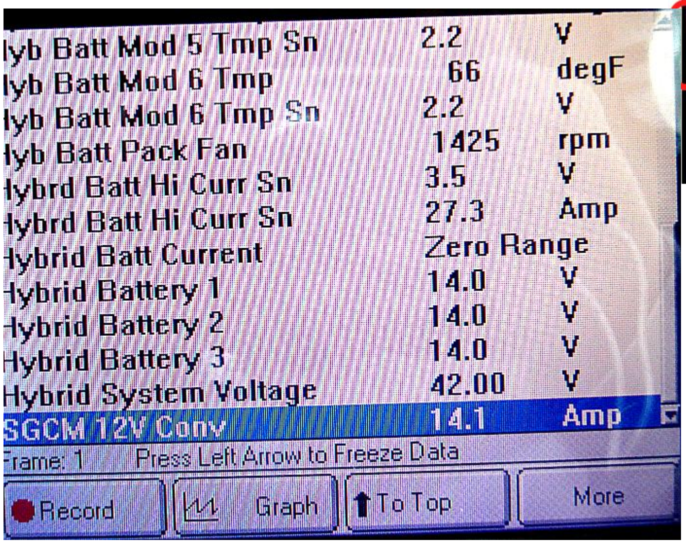
Scan Data is available for the BAS system. There is not a PID marked Hybrid controller.

BAS Hybrid Modules:

- Batt Energy ctrl Module
- Starter/gen ctrl Module

We select the battery control module on the scan tool. The scan data gives us data on the battery temperature sensors, Battery current, Battery pack cooling fan, Individual battery voltages and DC converter output voltage.

BAS Scan Data



Scan data values:

Battery temperature Module	66^0 F
Battery temperature volts	2.2-V
Battery pack cooling fan speed	1425 RPM
Battery high current sensor volts	3.5-V
Battery high current indication	27.3 A
Individual battery volts	14.0-V
Hybrid system volts	42-V
DC converter current	14.1 A

We use this data the way we did when we have 28 battery modules.

Battery Temperature Sensors

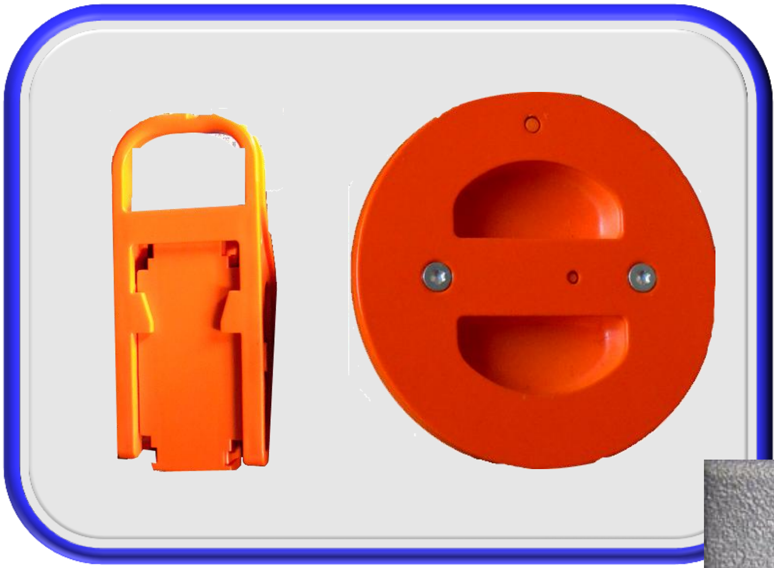
There are two battery temperature sensors for each of the three batteries. We have scan data for sensor volts and temperature indication. The sensors mount on the side of the battery.

The scan data indicates 66 degree F. We compare this to a 60-degree daytime temperature and conclude the reading is normal, considering air temperature and passenger compartment solar heating.

Compare the temperature indications after the vehicle is driven.

CHAPTER 32

HYBRID OIL CHANGE



Most common services do not require you to work with the high voltage circuits. Remember that the auto start/stop function can start the ICE for different reasons. There have been stories of the ICE started during an oil change but that should be history by this time. Keep the key/fob 20 feet away from the vehicle so that the controllers go to "sleep". See Servicing the ICE on how to place a certain vehicle into "Service Mode". Discharging the small 12 V battery only takes a few minutes, which happens frequently during servicing.

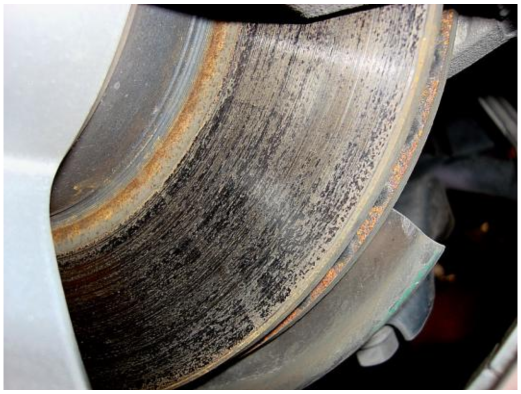
HIGH VOLTAGE SAFETY DISCONNECT

You can never be too safe. Disconnecting the safety switch is not difficult. Some shops have made it standard operating procedure to do so when the ICE <u>should not</u> be running.

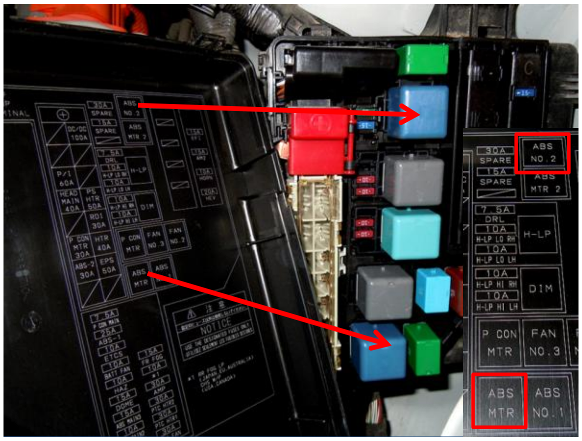
ENGINE OIL

Remember that motor generator cranks the ICE at 1000 RPM for starting. Heavier viscosity oil can place a drag on the engine slowing the cranking RPM causing starting problems. Unless there is a specific reason to use heavier viscosity oil, do not use different weight oil! For an example in the southwest summer, temperatures can get well over 100°F during the day. Fleet managers use heavier viscosity oil to extend engine life. Do not overfill the crankcase because that increases drag. Reportedly, there have been cases where thicker oil and/or overfilling have actually prevented a Prius engine from restarting. We recommend you follow manufacturer's recommendations.
Thick oil codes may indicate a transaxle problem such as binding components or motor generator problems.

CHAPTER 33



HYBRID BRAKES

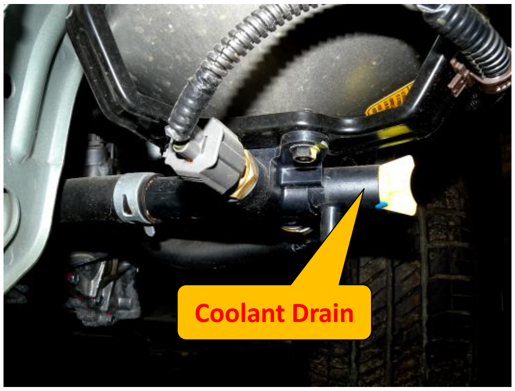


During a normal stop from 60 mph, the Hybrid controller may use 90% electric and 10% hydraulic braking. That means the hydraulic brakes are not used that much and the rotor's surfaces can be rough but not rusted. Knowing this is normal you will know what to expect. There are images going around showing the rotor in a very rusty condition. Do not be fooled thinking that is normal. If the brake rotor is extremely rusty, check to see if the caliper is malfunctioning. We took this photo of brakes to show you what we have found to be normal appearance.

The brake control ECU can activate the brakes without depressing the brake pedal. You can prevent this from happening by removing the ABS relays.

ABS RELAY REMOVAL

The safe way to service hybrid brakes is to remove the ABS relays that control the ABS pump motor. Ford cycles the brake when the ignition key switched on to check operation of the computer controlled brake activation.



CHAPTER 34

COOLING SYSTEM SERVICE

There are two Cooling Systems one for the internal combustion engine and one for the electric machine. Both cooling systems are serviced the same. Normal recovers, flush, and refill applies. Some Hybrid vehicle manufactures do not recommend servicing with a machine so read and follow the service procedures from the manufactures. Use the manufacture's recommended coolant. Many shops use bulk antifreeze to save money. This may not be a problem with the ICE, although the manufactures recommend against it. The electric machine is subject to electrolysis like any cooling system. The electric machine is a high voltage system and electrolysis has a greater potential for causing problems. Trapped air is the largest problem with coolant drain and refill operations.

The exception to a normal cooling service is the generation 1 Prius that has the coolant storage tank. The coolant storage tank mounts on the left front side of the vehicle. There is a valve to the tank on the bottom. It is the only way to empty the tank. After draining the tank, use something like an Air Lift to refill the system.

AIR LIFT REFILL SYSTEM

The Air Lift system uses shop air to create a vacuum in the cooling system. The control valve will feed new coolant in when turned to the refill position. Traditional refill methods usually set a low coolant code after a few miles of driving. We have reports of having to top the coolant several times after servicing.

CHAPTER 35

JUMP STARTING THE 12-V BATTERY

The 12-V system powers the coils of the system main relays to get the hybrid ready. The small 12-V battery on Toyota is for accessories and ECU power. The vehicle will not respond to the power switch with a discharged battery. Discharged batteries are a common reason for a service call for a no start. The 12-V battery is located in the trunk behind a cover. There is a jump-start terminal under the hood.

Open the red cover to gain access to the terminal.