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Advanced Electrical Technical Information for International's High Performance Trucks – A Self Taught Course

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Preface

Special thanks are given to Joe Bell, Electrical Test Engineer at International Truck and Engine Corp, Fort Wayne, Indiana, for preparation of this document to be used by International Technicians. Joe's effort to research and present this information is evidence of the sophistication of our new electronics system for the New High Performance Trucks, and the determination to equip the technicians who maintain it with the best possible resources.

This book should be used in conjunction with service information already available in paper, on CD, and on the ISIS Home page, such as wiring schematics, troubleshooting guides, etc. This book is not meant to replace published service material. All information was correct at the time of printing as applicable to International's new High Performance Trucks.

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Overview of Electrical System

The electrical system on International's new line of High Performance Trucks is much different than that used on previous models. Multiplexing in the form of a twisted-pair of wires (data link) is used throughout the vehicle to minimize the amount of electrical wiring and provide an easy way to add electrically controlled features. Several independent data links are used throughout the vehicle. A body systems computer called the Electrical System Controller (ESC) is used to control several electrical system functions such as headlights, taillights, windshield wipers, and A/C clutch. The ESC directly supplies the high side (+12V) for these high current loads (each output up to 20A). The ESC also provides several relatively low current outputs in the form of low side control (ESC provides a ground path) for devices such as relay coils. Inputs to the ESC include low current hardwired switches and sensors, or information from one of the vehicle data links. Optional dash-mounted switch packs provide information to the ESC via one of these data links. The programming in the electrical system controller can be changed to accommodate new features that may be added to the vehicle after it leaves the assembly plant. A new Electronic Gauge Cluster (EGC) requires only a few wires to control all the stepper-motor driven gauges and warning LEDs (Light Emitting Diodes). Other electronic controllers on the vehicle such as the ABS, automatic transmission, and engine controllers have been upgraded to make more use of multiplexing. Figure 1 illustrates an overview of the High Performance Truck electrical system. The five devices shown below are just an example of how a truck might be configured.

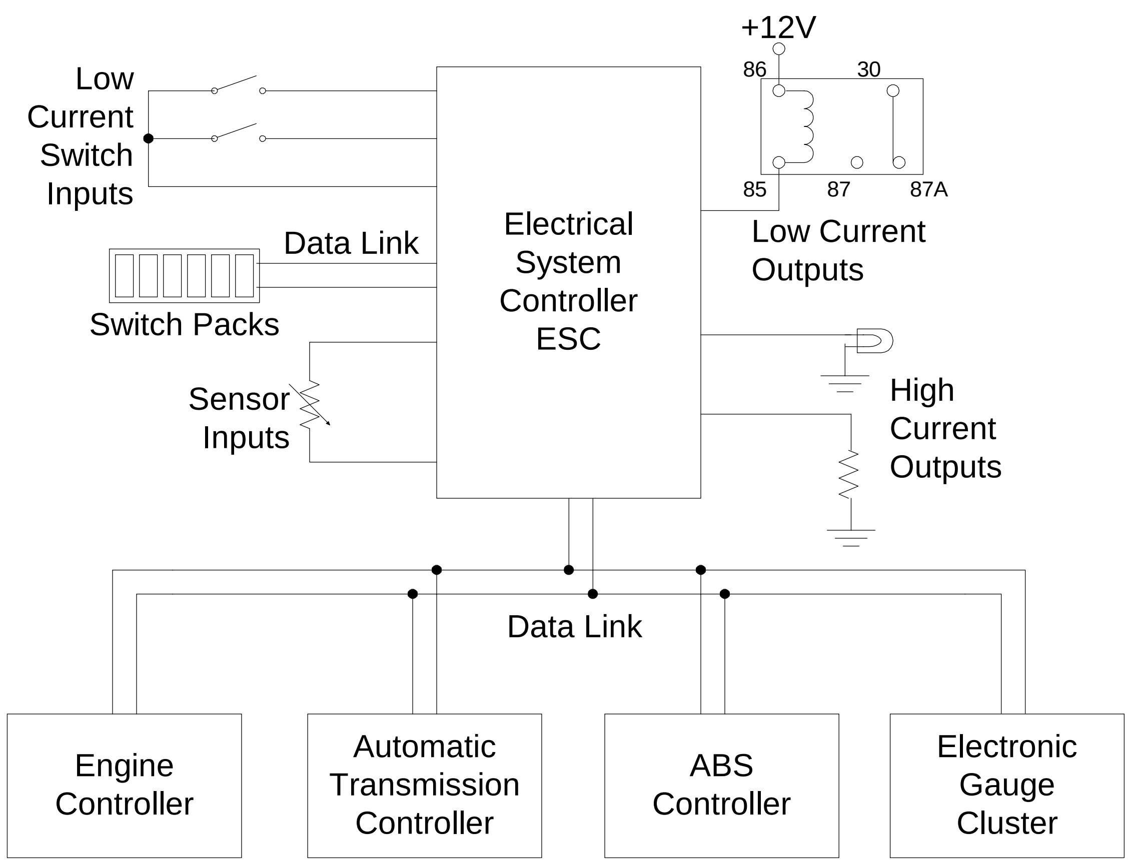

Figure 1 Overview of Electrical System

Multiplexing

International's new line of High Performance Trucks depends on multiplexing to communicate information between the truck's various electronic controllers. Multiplexing in this sense refers to a communication technique where one signal path is used to carry information between several electronic controllers. The type of multiplexing we are concerned with is called time division multiplexing. Time division multiplexing can be defined as communication devices time-sharing a common signal path such as a pair of copper wires. This pair of wires is often referred to as a data link. Each communication device takes turns using the common signal path or data link to transmit its information. This information is in the form of digital-encoded data. Digital means that only two states, high and low or on and off, are used to communicate information. This is similar to Morse code which also uses two states, dots and dashes, to communicate information. Digital-encoded data means that the specific pattern of highs and lows have a specific meaning, similar to the pattern of the dots and dashes of Morse code representing letters and numbers. To communicate using Morse code, each operator must know what the specific pattern of dashes and dots represent. The same is true in digital communications. Each device connected to the data link interprets the pattern of highs and lows and "knows" what these patterns represent. Figure 2 illustrates the voltage levels measured across a pair of data link wires where several electronic controllers are transmitting information. The instances where the voltage measured across the data link is high represents one state, like a dash in Morse code. The instances where the voltage measured across the data link is low represents the other state, like a dot in Morse code. Each controller takes turns using the common data link wires to transmit its digital-encoded information. Unlike Morse code though, the amount of time required for a digital communications device to transmit information is so short that it almost appears as though several devices are communicating on a common data link at the same instance in time.

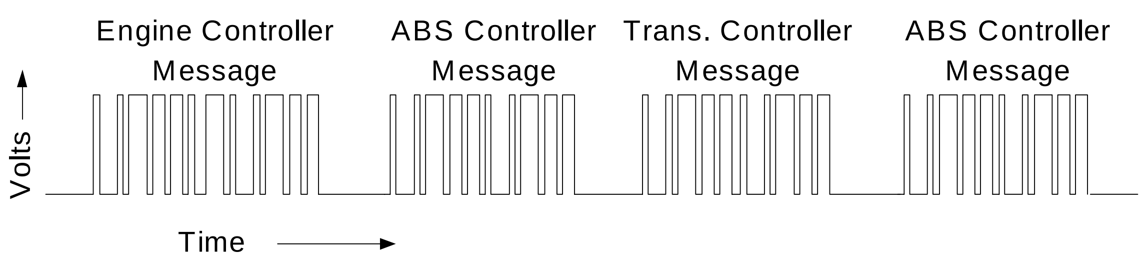

Figure 2 Time Division Multiplexing

Multiplexing is nothing new to the industry. The SAE J1708 (J1587 or ATA) data link is an example of time-division multiplexing and has been used for several years on previous International models to communicate engine information to the gauge cluster. However, an improved high-speed network standard for trucks called SAE J1939 has been established.

SAE J1939

The Society of Automotive Engineers (SAE) has developed a standard for a high-speed multiplexed communications network for trucks called J1939. J1939 is the name assigned by SAE to the series of specifications that define this high-speed network. SAE J1939 is similar to SAE J1708 in that both are serial communications links. Serial communication means that the digital data (one's and zero's) are transmitted and received one bit at a time. The big difference between J1708 and J1939 is that J1939 is capable of transmitting information at a much higher rate than J1708. If you are familiar with Internet connections, think of J1708 as a 10 year old modem and J1939 as a DSL connection. To put the rate of data communication difference in non-computer terms, J1939 is like a 4.5-second ¼ mile top-fuel dragster while J1708 is like a 2-minute ¼ mile tricycle. SAE J1939 is based on a communications protocol called Controller Area Network or CAN. Protocol refers to the rules that the devices must follow in order to communicate with other devices. The CAN protocol describes a system in which any electronic controller on the network may communicate a message anytime that the network is not being used by another controller. Each controller contains a CAN transceiver (transmitter/receiver) chip which is designed to follow the CAN protocol. There is no master control device in a CAN network. A CAN network is like a shop with no boss. Instead of a boss, each controller knows what has to be done and what the rules are.

Before getting too deep into the CAN protocol and thinking about what it would be like to work at a shop without a boss, let's take a detailed look at the physical data link cable defined by the J1939 specifications.

J1939 Data Link Cable

Like J1708, the J1939 data link consists of a twisted pair of insulated, multi-stranded copper wires. One of the wires or conductors has yellow insulation, the other has green. The yellow insulated conductor is identified as CAN_H; the green is CAN_L (or CAN + and CAN -, respectively). There are two types of cable that meet the specifications of J1939. These two types of cable are shielded or non-shielded. With the shielded type cable, a non-insulated copper wire is wrapped around the twisted pair. This non-insulated copper wire is referred to as the drain wire. The three-wire set is then wrapped with a layer of metallic foil. This foil is referred to as shielding. A plastic jacket is then molded around the shielded-twisted pair of wires to provide wear resistance and to hold everything in place. Shielded cable meeting the specifications of SAE J1939 is identified as J1939/11. Non-shielded cable consists of the twisted pair of conductors with a molded plastic jacket. Non-shielded cable meeting the specifications of SAE J1939 is identified as J1939/15. Earlier-build High Performance Trucks utilize shielded J1939/11 cable outside of the cab and non-shielded J1939/15 cable inside the cab. Later-build High Performance Trucks utilize non-shielded J1939/15 cable both inside and outside the cab.

The high rate of data communication over J1939 require the data link cable to be a little more complicated than just a couple of copper wires. The individual bits (ones and zeros) on the J1939 data link are transmitted at a rate of 250K (250,000) bits/second. By comparison, J1708 data is transmitted at a rate of 9600 bits/second. Because of the high rate of data communication over J1939, high frequency effects such as the amount of capacitance between the two data link conductors (wires) must be taken into account. Otherwise, the shape of the digital waveform gets deformed and the CAN transceiver located in each controller may not be able to determine the difference between a logic one and a logic zero (not a good thing).

Like J1708, the two J1939 data link conductors are twisted together. This twisting of the conductors is done for two reasons. The first reason for the twist is to help provide immunity to magnetic fields. The level of voltage induced into an electrical conductor by a changing magnetic field greatly depends on the distance between the conductor and the magnetic field source. By twisting the wires together, any voltage induced into the wires by magnetic fields will be about equal level on both wires. This is because the twist guarantees that both wires will be approximately the same physical distance from any magnetic field source. This "common mode" voltage induced into both data link wires will be rejected by the electronics in the CAN transceivers located in each controller. The CAN transceivers are designed to only look at the difference between CAN_H and CAN_L, not the voltage levels referenced to ground. This voltage is referred to as the differential voltage. In the example shown in Figure 3, one controller is transmitting a message on the data link. A changing magnetic field causes voltage (noise) to be induced into both conductors. This induced voltage shows up as noise both on scope 1 and scope 2 when each scope is referenced to chassis ground. Since the same level of voltage is induced into both conductors, the differential voltage measured across the data link conductors remains at 0V as shown in scope 3. Otherwise, the noise could be interpreted as a logic high pulse and change the meaning of the message.

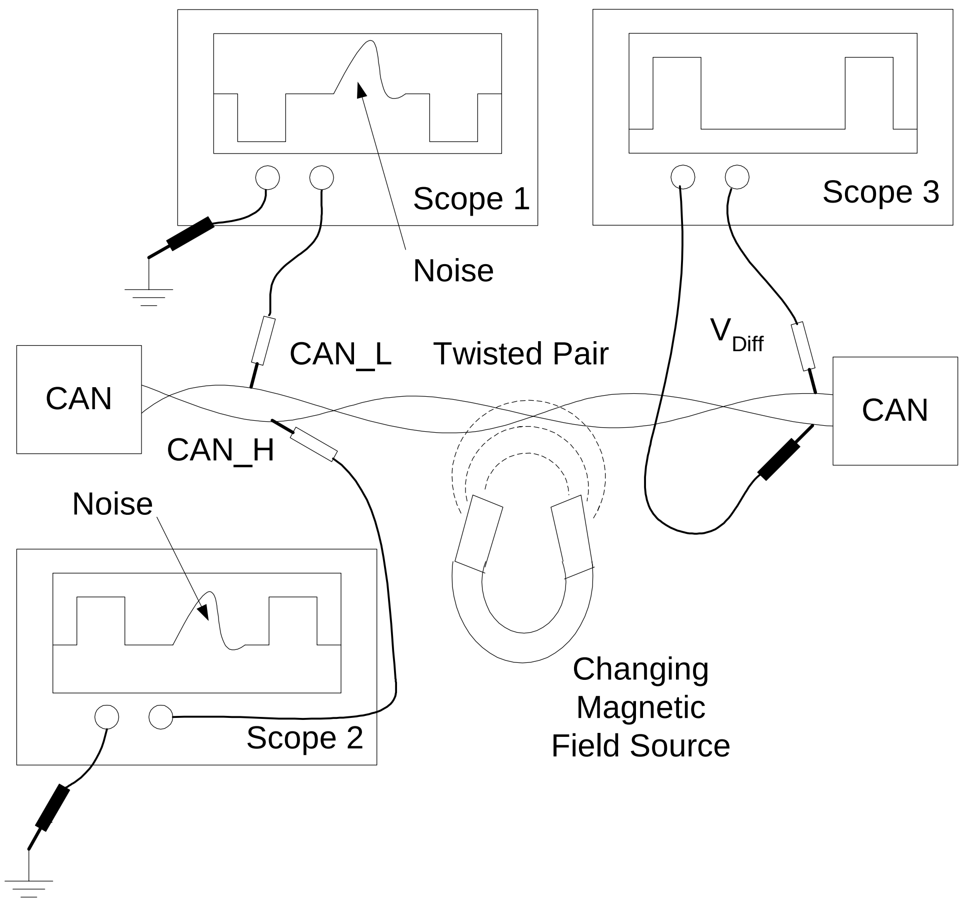

Figure 3 **Differential Voltage With Noise Present**

The second reason for twisting CAN_H and CAN_L together is to maintain the correct distance between the conductors. This distance between the two conductors has an impact on the level of capacitance between the conductors. As the distance between conductors increases, the amount of capacitance between the conductors decreases.

Another factor that contributes to the capacitance between the conductors is the insulation material. The measurement of the ability of the material between the two conductors or plates of a capacitor to store electric charge is called the dielectric constant. Seemingly similar materials may have very different dielectric constants. Therefore, J1939 wire insulation material must be of a specified type so that the correct value of capacitance is maintained. Substituting J1939 specified cable with ordinary insulated wire could change the capacitance between the conductors. A high frequency cable that you are likely familiar with is TV antenna cable. Substituting ordinary wire for J1939 cable is similar to using ordinary wire for TV antenna cable. Although you may get a TV picture using ordinary wire as the antenna cable, the quality of the picture will suffer due to an incorrect value of capacitance between the two signal conductors. The same is true with J1939 cable. Using ordinary insulated wire for the J1939 data link cable can cause communications problems between the various modules.

High frequency transmission cable such as TV antenna cable is often specified in Ohms. The old style, flat twin-lead TV antenna cable was called 300-Ohm ribbon cable. The 300-Ohm refers to something called the characteristic impedance. You can’t measure this 300 Ohms with an Ohmmeter; it is a measurement of how the cable appears (regardless of length!) to a high frequency source. The cable insulation material (dielectric constant) and physical spacing between the TV antenna wire conductors maintain the desired amount of capacitance, just like J1939 cable. The same is true for the more familiar coaxial TV cable. One conductor is in the center; the other is the outside braided shield. A Teflon material between the conductors provides the dielectric constant. Coaxial TV antenna cable has a characteristic impedance of 75 Ohms. Once again, you can't measure this with an Ohmmeter. J1939 cable also has a characteristic impedance, which is 120 Ohms. You guessed it; this 120 Ohms also can't be measured with an Ohmmeter either. Think of this 120 Ohms as being what the cable looks like to high frequency sources. One point of caution though, don't confuse this imaginary 120 Ohms with the 120 Ohm terminating resistors which will be discussed later.

Network Topology

The way that a networked computer system is physically connected or laid out is referred to as the network topology. SAE J1939 uses what is called a bus type of topology. A bus topology means that there is only one main data link cable. This main section of cable that each controller connects to is referred to as the backbone (Figure 4).

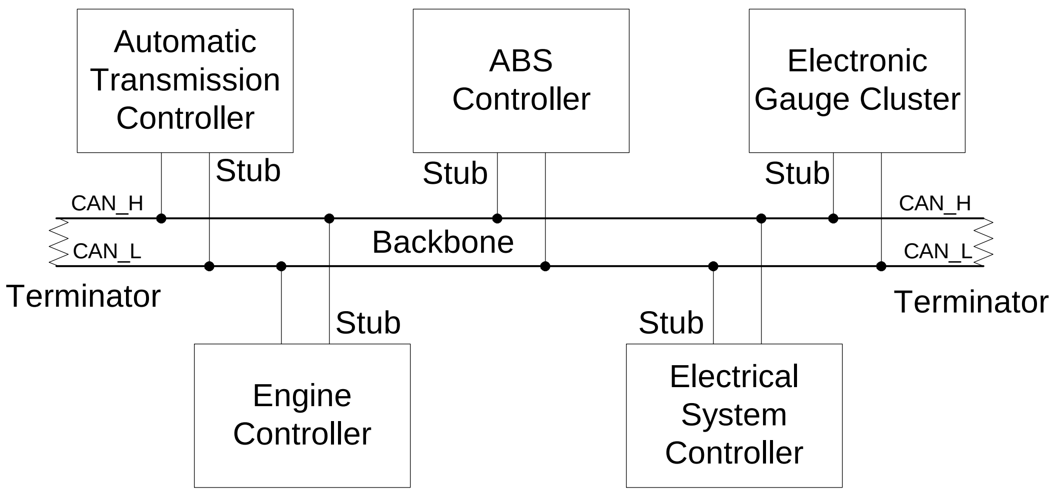

Figure 4 Bus Topology Example

The short sections of cable between the controllers and the backbone are called stubs. SAE J1939 requires that the backbone be no longer than 40 meters and that stubs be no longer than 3 meters. These requirements help maintain accurate data transmission.

Bus type topology also implies that no controller is in charge since there is no central network controller or hub like that found in some networked computer systems. None of the devices communicating on the J1939 data link network have absolute control or authority over the network. No single controller acts as a network boss. If for some reason the data link gets cut in half, devices on either side of the break should still be able to communicate with each other (but they cannot communicate with controllers on the other side of the break). Keep this in mind when troubleshooting potential J1939 data link problems.

Terminating Resistor

Another difference between J1708 and J1939 is the necessity to terminate each end of the J1939 backbone with a resistor. Each terminating resistor has a value of 120 Ohms. This is a “real” resistance, which can be measured using an Ohmmeter unlike the imaginary characteristic impedance mentioned earlier. One end of the backbone is located inside the cab near the fuseblock. The terminating resistor inside the cab is located in a connector cap and sealed with heat-shrink. This resistor is the same as that used on previous models of International medium and heavy vehicles equipped with J1939. The other end of the backbone is located near the engine controller on manual transmission vehicles or near the transmission controller on automatic transmission vehicles. The terminating resistor outside of the cab is contained in a cylinder shaped connector cap on vehicles equipped with shielded J1939/11 cable. This connector cap is directly attached to the J1939 Y-splice near the engine controller (with manual transmissions) or near the automatic transmission controller on vehicles with automatic transmissions. On vehicles with non-shielded J1939/15 cable, the terminating resistor outside the cab is identical to that used inside the cab and is located near the engine controller (with manual transmissions) or near the automatic transmission controller.

Terminating resistors are used on J1939 to minimize a phenomenon called standing waves. Standing waves can be thought of as reflections or echoes. These reflections can cause major problems on a communications system. Like an echo, a standing wave occurs in time after the original transmission. Trying to communicate on a system with standing waves present is similar to being at an outdoor event with several loud speakers spaced far apart such as those at a racetrack. It is sometimes difficult to understand the announcer because what is currently being broadcast from the speaker closest to you is mixed with the delayed sound waves from loud speakers farther away. What ends up at your ears is a garbled, unintelligible mess of sounds. If standing waves are present on the data link, devices can’t tell what is a reflection and what is the next piece of information. Terminating resistors cause the signal energy to be absorbed leaving no energy for reflections. To a high frequency source, each 120-Ohm terminating resistor looks like an infinitely long data link cable with a characteristic impedance of 120 Ohms.

In addition to minimizing standing waves, the terminating resistors also provide a relatively low resistance path for current to flow between CAN_H and CAN_L. This permits capacitance in the system to discharge rapidly. The length of time for a capacitor to discharge is directly proportional to the amount of resistance the capacitor is discharging through. The higher the level of resistance the capacitor is discharging through, the longer it takes for a capacitor to discharge. If the system capacitance cannot rapidly discharge when a device is trying to transmit a low level, the voltage differential between CAN_H and CAN_L will remain at a high level. This false high level may be interpreted by the device that is currently transmitting as a “stop transmitting, I’ve got something more important to say” command from another controller. This process is called arbitration and is covered in more detail in a later section.

Experience has shown that if only one J1939 terminating resistor is missing, the vehicle will likely not exhibit any observable symptoms. The shape of the waveform changes slightly due to longer capacitance discharge times and increased signal reflections. However, if both terminating resistors are missing, no communication is possible. Figure 5 shows what the waveform for one logic-high bit on J1939 looks like with both termination resistors present. Figure 6 shows the same J1939 data link with both termination resistors missing. When both termination resistors are missing, the length of time for the differential voltage between the conductors to decay interferes with the arbitration process, which causes all communications on the J1939 data link to cease.

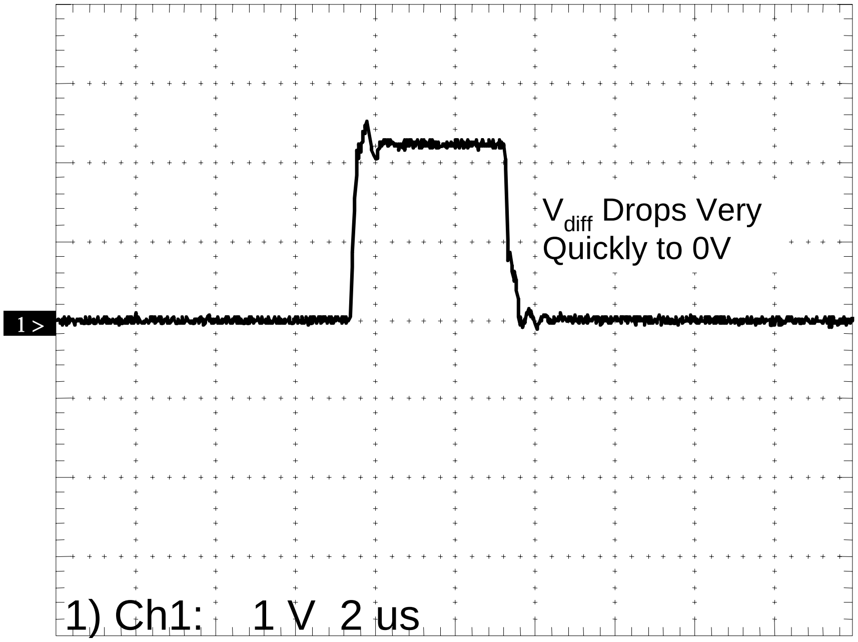

Figure 5 **Both J1939 Termination Resistors Present**

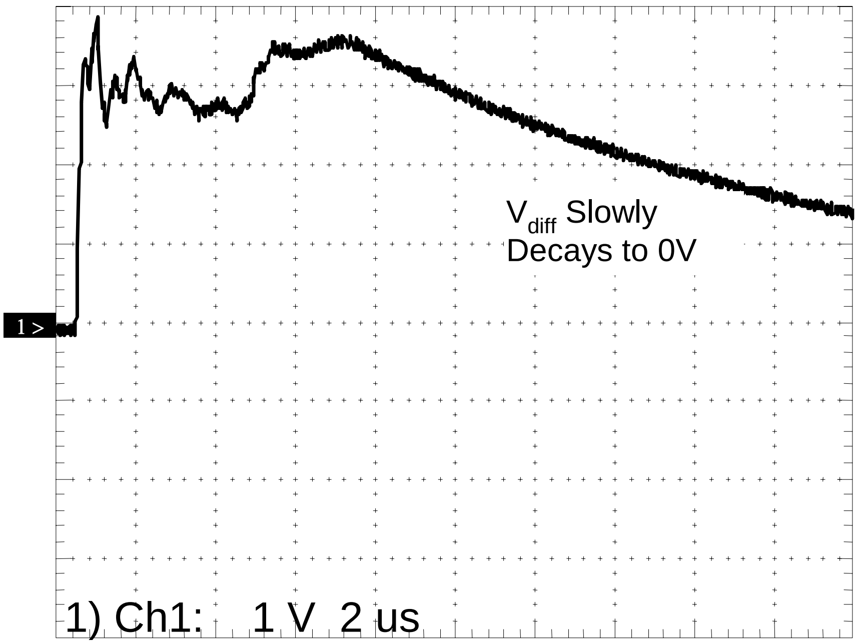

Figure 6 **Both J1939 Termination Resistors Missing**

Logic States
Logic states (0's and 1's) in CAN protocol are defined as dominant and recessive. A logic zero is the dominant state and a logic one is the recessive state. However, if you looked at the voltage differential on the bus, a logic zero is represented by a voltage differential of about 2V. A logic one is a voltage differential near 0V. This seems backwards, but all the devices know what the differential voltage (V_{diff}) levels mean. Figure 7 shows an example of a J1939 digital message waveform. The recessive state is also known as the rest state since the differential voltage is 0V.

Notice in Figure 7 that the time for one bit to transmit is two time divisions of the scope display. The setup information below the trace indicates that the scope time base is set to 2µs (2 microseconds or .000002 seconds or two millionths of a second) per division. Also notice that the width of each bit is two divisions of the scope grid. This means the time for one bit of information to transmit is 4µs (4 microseconds). If it takes 4µs to transmit one bit, then 250K bits can be transmitted in one second (1 bit ÷ .000004 seconds = 250,000 bits/second). This just proves that devices on J1939 really do transmit at a rate of 250K bits per second.

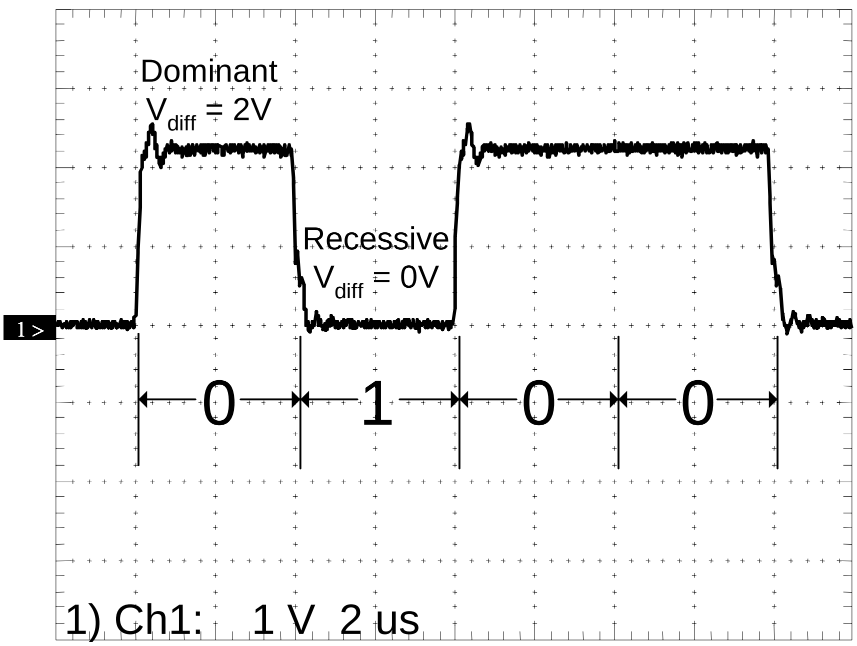

Figure 7 Logic States

Arbitration
All devices connected to a J1939 data link have an equal opportunity to transmit a message when the data link is not being used by another device (data link is idle). There is no master bus controller in a CAN network. If each device has equal opportunity to transmit on an idle data link and if there is no one in charge, sounds like we're asking for trouble. If two devices start transmitting as soon as the data link is idle, won't messages collide? This problem is solved by establishing a priority level for messages and by each device comparing what it is transmitting to what it is receiving. The lower the priority number, the greater the importance of the message. Therefore, a priority of zero is the highest priority. Any device that wishes to transmit a message, <u>regardless of the message priority</u>, must first wait until the data link is idle. Given the speed (high rate of data communications) of J1939, this wait time is very short in duration (microseconds). The speed of J1939 is what makes a CAN network possible. When the data link is detected as being idle, any device wishing to transmit a message will send the priority of the message first. If other devices start transmitting at the <u>exact same time</u> with lower priority messages, they will stop transmitting immediately upon detecting that another device with a higher priority message is also

transmitting. The controller with the higher priority message is causing the bus V_{diff} to go to 2V (dominant state) at the same time the controller with a lower priority message is letting the bus go back to the rest state of $0V_{diff}$ (recessive). The device or devices that stopped transmitting will wait until the data link is idle to try transmitting its message again. This process of permitting a device with a message of higher importance to transmit <u>should two or more devices start transmitting simultaneously</u> is called arbitration. The arbitration process does not require the message of higher importance to have to start over if it has won arbitration. No damage to the higher priority message occurs in the arbitration process so the winning device does not have to start transmitting the message over again. This process is referred to as non-destructive bitwise arbitration.

Arbitration ensures that the most important information such as active traction control does not have to wait very long on less important data such as the windshield washer reservoir level. The process of arbitration is illustrated in Figure 8. Keep in mind that with CAN protocol, a logic zero is represented by a V_{diff} of 2V and a logic one is represented by a V_{diff} of 0V. In the rules of arbitration, a dominant bit (logic zero) always wins over a recessive bit (logic one). In the example below, the engine controller, ESC, and ABS controller have all started transmitting on an idle data link at the exact same time. The engine is transmitting a message with a priority level of 1 (00000001 in binary). The ESC is transmitting a message with a priority level of 49 (00110001 in binary). The ABS is transmitting a message with priority level of 3 (00000011 in binary). The ESC loses arbitration after the first two bits and stops transmitting anything else on the data link. The ABS controller loses arbitration after the first 6 bits and also stops transmitting on the data link. The only data link traffic is the message being transmitted by the engine controller. The losing controllers have stopped transmitting after detecting that a message with a higher priority is being transmitted by another controller on the data link at the same time.

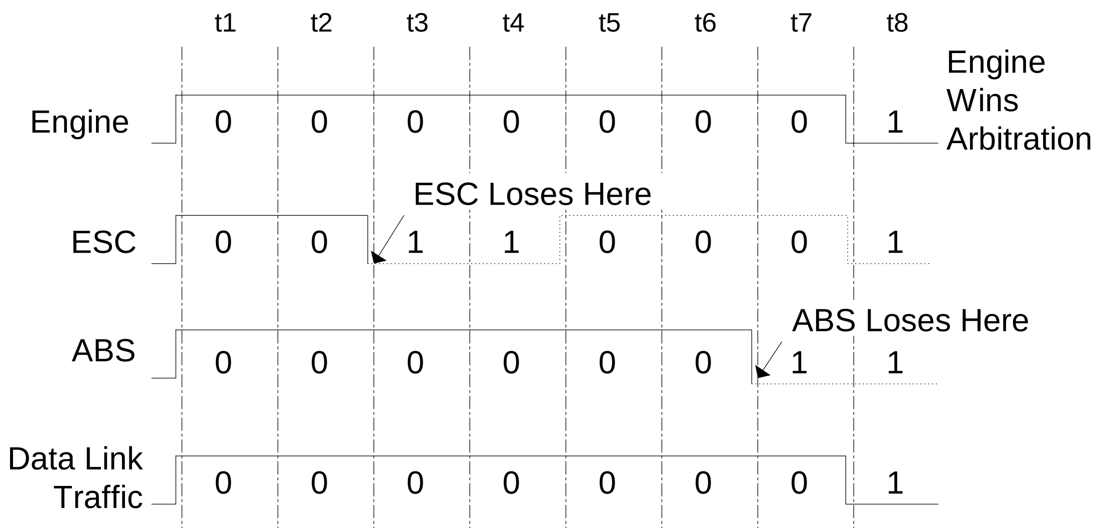

Figure 8 **Arbitration**

<u>Message Structure</u>

After the message priority, the Parameter Group Number or PGN is transmitted. The PGN defines what data the message will contain, similar to the subject heading on an e-mail message. SAE J1939 defines most of the PGNs used in the truck industry. For example, the J1939 message pertaining to cruise control and vehicle speed has been assigned a PGN of 65265 by SAE.

After the PGN, the message source identification is broadcast next. Each device on the bus has a unique source identification number. SAE J1939 defines these source numbers. For example, engine controller #1 has a source ID number of 00. If necessary, the arbitration process can extend all the way through the message to the source data. If two devices begin transmitting a message with identical priorities and PGNs, the source of the message must be different. Therefore, the source with the highest priority (lowest source address number) will win arbitration under these circumstances.

After the priority, PGN, and source address, the actual data is sent. The data is eight bytes in length (8 bits equal 1 byte). The data contain the actual message information, such as engine coolant temperature, vehicle speed, etc. The data is coded, but the software in each device needing the message knows how to decode the data into actual temperatures, speeds, etc. SAE makes this data standard within the industry.

Instead of using decimal numbers like 65265, people who work with digital systems often use another numbering system called hexadecimal or hex. Hexadecimal uses the digits 0-9 and the letters A-F to represent binary numbers (1's and 0's). These sixteen different characters (0 to 9 = ten characters, A to F = six characters) provide a base 16 counting system. This permits each pair of hexadecimal characters to represent 1 byte (8 bits) of data. The decimal number 65265 is 1111111011110001 in binary or FEF1 in hexadecimal. FEF1 is much easier for humans to work with than its binary version. Figure 9 illustrates an example of J1939 message structure taken from a CAN development tool. The priority, PGN, source, and data are shown in hexadecimal format. The second column marked Mes ID for the highlighted message is 18FEF100. The first two characters of the message is the message priority, which is 18 hex. The next four characters are the PGN, which is FEF1 hex. This indicates that the message contains cruise control data. Any device that cares about cruise control information will pay attention to this message. The final two characters of the Mes ID are 00 hex, which indicates the source of the message is the engine controller as defined by SAE J1939. The last column is the actual data. Eight groups of two-character hexadecimal numbers each represent one byte (eight bits) of data regarding cruise control related information such as vehicle speed, cruise and brake switch status, etc. The SAE J1939 specification defines what each bit of the eight bytes of data represent.

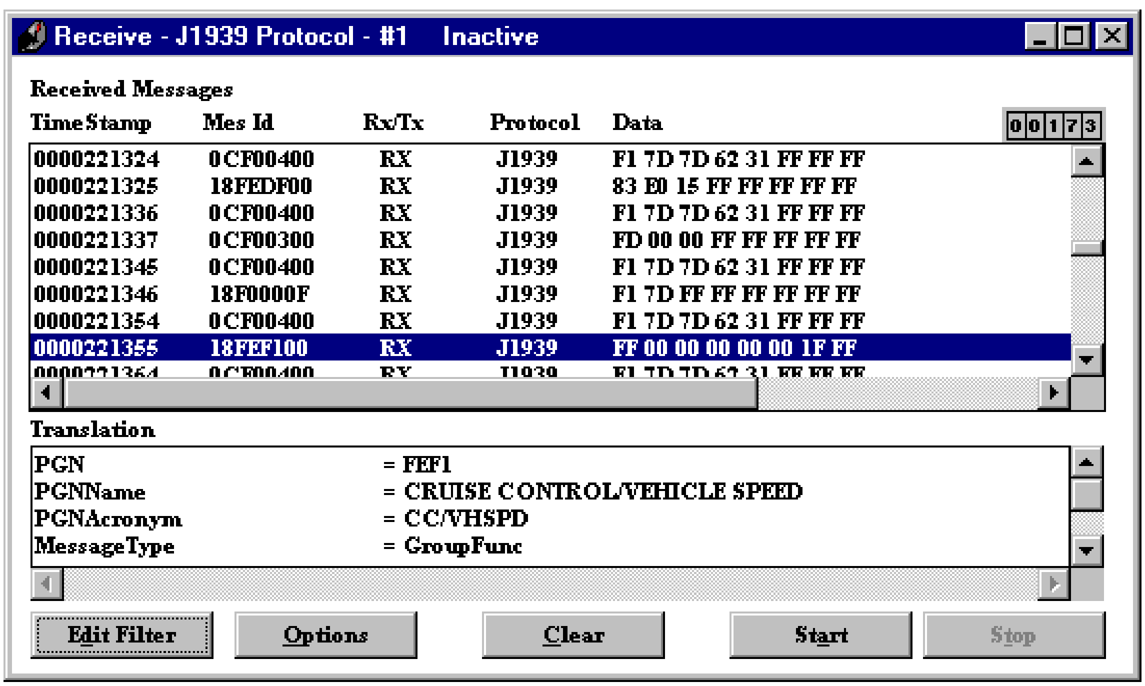

Figure 9 **J1939 Message Structure**

Error Checking

Digital messages transmitted on J1939 data link may be corrupted by electromagnetic interference (EMI), standing waves (reflections), or by other means such as intermittent opens or shorts between the two conductors. J1939 (CAN) uses several techniques to detect and handle these potential errors. If an error is detected by any device connected to the J1939 data link, the corrupted message is discarded and the message is retransmitted. One of the techniques used to detect errors is called cyclic redundancy check-sum or CRC. Each device on the data link calculates a unique check-sum for each message at the completion of the message. If the check-sum calculated by any device differs from that calculated by the originating device, it indicates that something different was received than what was actually transmitted. The message is then retransmitted. This is the digital communications equivalent of saying “no, that’s not what I said”.

Excessive errors can cause the system to slow considerably resulting in delayed responses. After detecting a large number of errors, a controller may stop transmitting and receiving bus traffic entirely until power to the device is cycled.

Naming Convention for the J1939 Data Links

The main J1939 data link that connects the engine controller, electrical system controller, and electronic gauge cluster is called the J1939 Drivetrain data link. This data link is present on all High Performance Trucks. Depending upon how the vehicle is configured, the J1939 Drivetrain data link is also connected to the Allison automatic transmission controller, and Bendix or Wabco air ABS controller. Two optional proprietary modules, the pyrometer-ammeter module and the auxiliary gauge-switch pack, are also connected to the J1939 Drivetrain data link.

An optional proprietary data link meeting the physical specifications of J1939 is found on some vehicles. This data link is called the Body Builder data link. Like the Drivetrain J1939 data link, the Body Builder data link may be shielded or non-shielded type cable depending on when the chassis was built. The Body Builder data link also has two terminating resistors. One terminating resistor is located near the outside 36-way ESC connector. The other terminating resistor is contained in a connector cap at the last module on the network. The ESC is the main device on the Body Builder data link. Other proprietary devices are controlled by the ESC via this private data link. These proprietary devices are discussed in greater detail in the *Body Builder Applications* section.

Other Data Links

In addition to the J1939 data link(s), data links meeting the specifications of SAE J1708 are also used on the High Performance Trucks.

J1708 Drivetrain Data Link

The ATA J1708 data link used on previous models to permit communications between the drivetrain controllers and gauge cluster is also present on all High Performance Trucks. The wire insulation of the twisted pair is dark blue and gray in color. Like previous models, the J1708 Drivetrain data link does not require terminating resistors. The primary purposes of this data link on the High Performance Trucks is diagnostics and powertrain module reprogramming. The J1708 data link connecting the engine controller, Allison WTEC controller, and ABS controller is called the J1708 Drivetrain data link. The J1708 Drivetrain data link is <u>not</u> connected to the Electrical System Controller or Electronic Gauge Cluster.

Switch Data Link

A proprietary data link meeting the specifications of SAE J1708 and J1587 is used on most vehicles to permit communications between the Electrical System Controller, optional switch packs, and optional power door pods. These proprietary devices are discussed in the *How It All Works Together* section. This proprietary data link is called the Switch data link. The wire insulation color of the twisted pair is also dark blue and gray in color. It is important to understand that the Switch data link and the ATA J1708 Drivetrain data link are two different data links and do not share the same information.

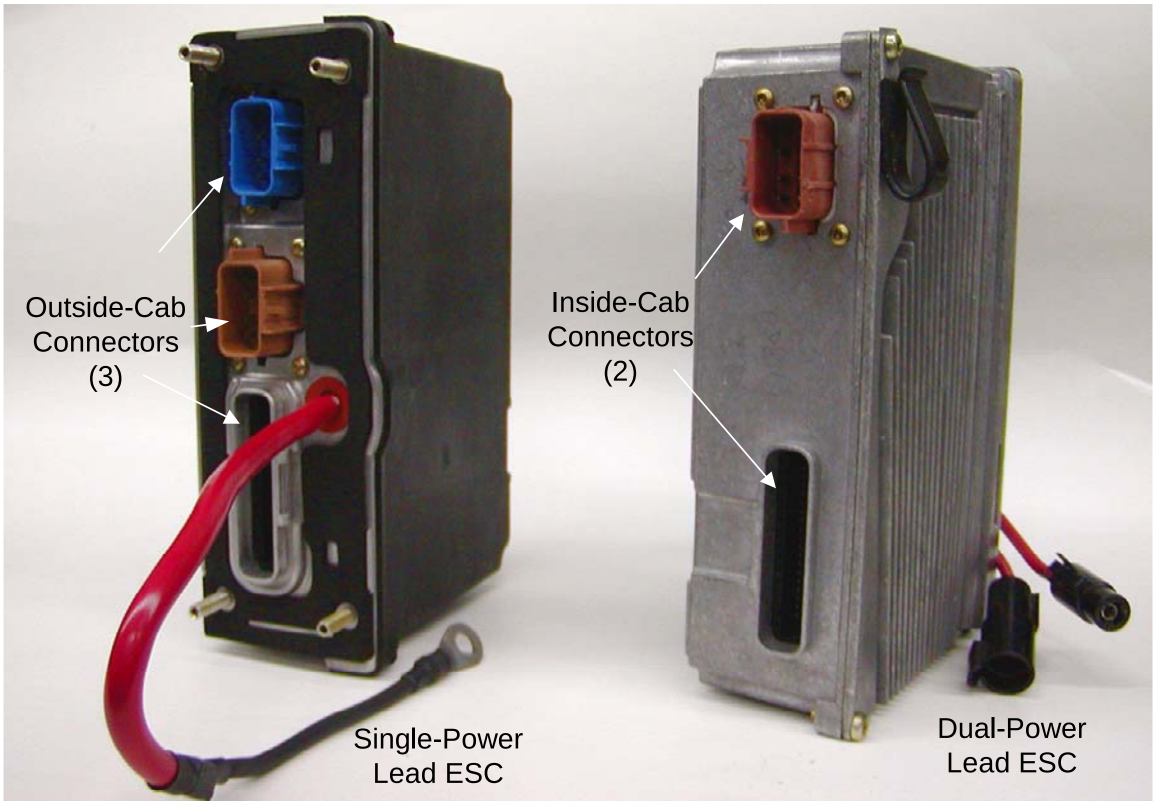

Figure 10 Electrical System Controller

Electrical System Controller (ESC)

The Electrical System Controller (ESC) is a body systems computer used to control many of the vehicle electrical system functions. Figure 10 shows two Electrical System Controllers. Early versions of the ESC utilize two battery power leads as shown in the right side of Figure 10. Some later versions of this dual-power lead ESC have integrated fusible links on the two power supply leads instead of connectors. Another version of the ESC scheduled for release in mid-2003 has a single-power lead as shown on the left side of Figure 10. The external case of the single-lead ESC is of plastic and aluminum construction. The external case of the dual-power lead ESC is constructed entirely of aluminum. The revised single-lead ESC also has some enhanced functionality, which will be discussed later.

The ESC is located at the left-lower dash panel beneath the kick-panel. The ESC is mounted through a cut-out section of the dash panel. Besides the battery power cable(s), all ESCs have five electrical connectors. Three of the ESC connectors are mated to the dash harness (outside of cab) through the cut-out section of the dash panel. The other two ESC connectors are mated to the cab harness (inside of cab). The battery power lead(s) are either mated to the dash harness connectors or are bolted to the Mega-Fuse junction with ring terminals.

Note that all illustrations of the ESC internal circuitry shown in the accompanying illustrations throughout this book are simplified somewhat for clarity. Signal conditioning circuitry, analog to digital converters, etc. are not illustrated so as not to overly complicate how the ESC functions.

Electrical 101

Before jumping into the inner workings of the ESC, we should review some electrical concepts. To make that easier, let's also look at some hydraulic concepts. Figure 11 illustrates a simple hydraulic circuit. A pump supplies pressurized hydraulic fluid through a pipe with two restrictions. There is only one path for the hydraulic fluid to flow through. Any fluid that leaves the pump must pass through both restriction 1 and restriction 2. If we were to measure the rate of hydraulic flow (i.e. gallons per minute), we would find that the flow rate was the same everywhere in the circuit. This is because any fluid that leaves the pump must return to the sump and there is only one path back to the sump (unless there is a leak). We will call this a series hydraulic circuit since all the components are in series (one after the other).

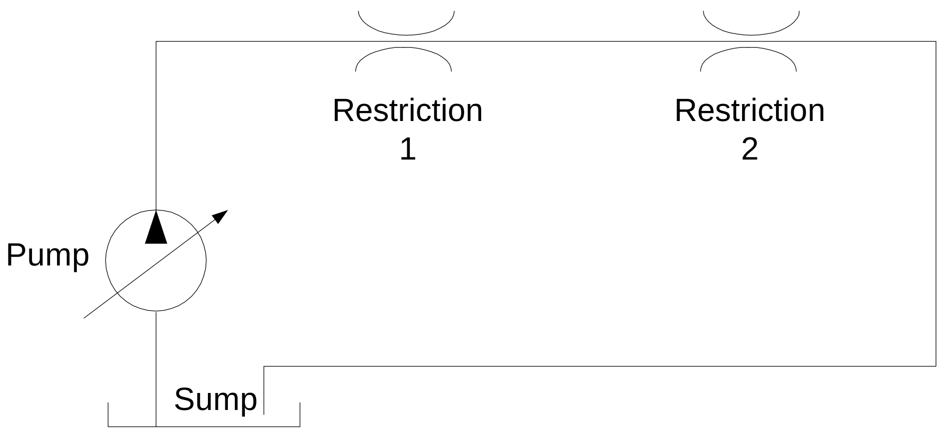

Figure 11 Hydraulic Circuit

Since we have hydraulic fluid flowing in this circuit, we would expect the piping between the pump and the restrictions would be pressurized and the piping between restriction 1 and restriction 2 would also be pressurized, when compared to the atmospheric pressure. If the pipe between restriction 2 and the sump were not pinched or otherwise restricted, we would expect almost no pressure in that section of pipe. Figure 12 shows the hydraulic pressures in the piping for our circuit. Each pressure gauge is indicating the pressure in each section of pipe referenced to atmospheric pressure. We call this pressure referenced to atmospheric pressure the gauge pressure. If the pressure is being measured in pounds per square inch (psi), we could abbreviate the gauge pressure as "psig". We can see that Gauge A indicates that the pressure in the section of pipe between the pump and restriction 1 is 75psi greater than atmospheric pressure or 75psig. Gauge B indicates that the pressure in the pipe between the two restrictions is 50psig. Gauge C indicates that there is almost no difference between the pressure in the pipe and atmospheric pressure since there is almost no restriction in the pipe between Restriction 2 and the sump.

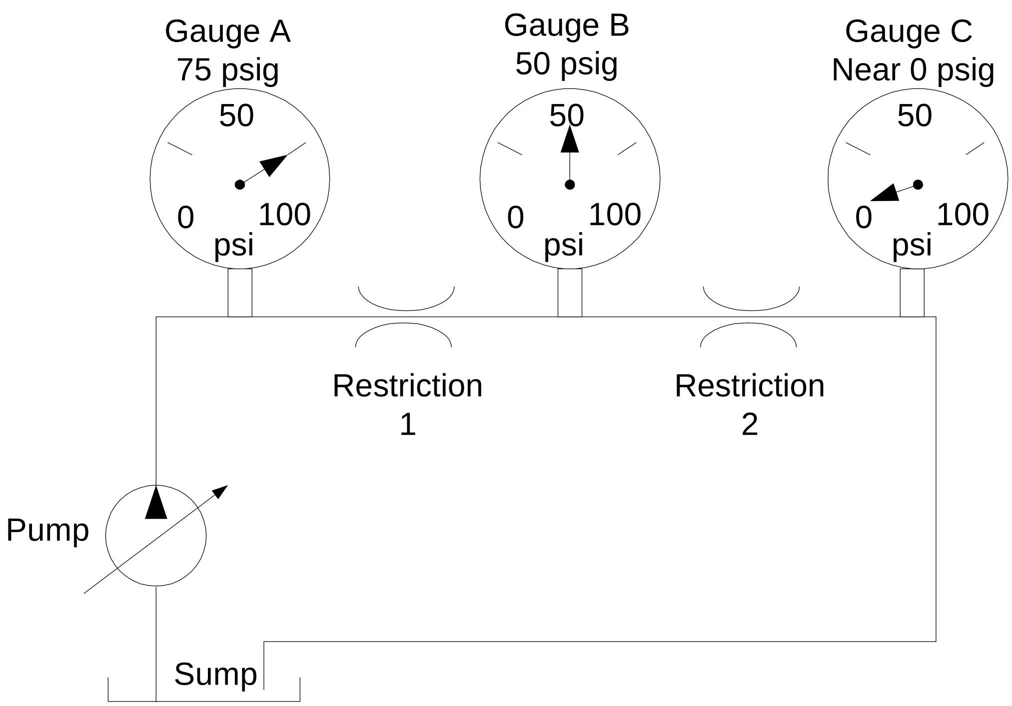

Figure 12 **Pressure Drops**

If we wanted to know how much pressure was being dropped across restriction 1, we would subtract the 50psi displayed on Gauge B from the 75psi displayed on Gauge A. This would give us an answer of 25psi. To find the pressure dropped across restriction 2, we would subtract the 50psi displayed on Gauge B from the near 0psi displayed on Gauge C and get an answer of about 50psi. The two pressure drops are not equal, which would lead us to believe that the size of the restrictions (diameter) are also not equal. Since restriction 2 has more pressure dropped across it than does restriction 1, restriction 2 is more restrictive (smaller diameter) than restriction 1.

Notice that the sum of the two pressure drops, 25psi and 50psi, is 75psi. 75psi is also the total pressure being supplied by the pump. The sum of the pressure drops is the same as the pressure at the pump outlet referenced to atmospheric pressure.

Instead of using two pressure gauges to measure pressure drop; we could use a differential pressure gauge. A differential pressure gauge has two pressure inlet ports like that shown in Figure 13. The differential pressure gauge indicates the difference in pressure between the two inlet ports, unlike a standard pressure gauge, which only has one inlet port and displays a pressure referenced to atmospheric pressure. The differential pressure gauge in Figure 13 indicates that the pressure dropped across restriction 1 is 25psi. A differential pressure gauge is often used to display the pressure drop across a filter. When the filter is plugged, the pressure dropped across the filter is high. The differential pressure gauge provides an easy way to quickly read the pressure dropped across a restriction. We only need one gauge and do not have to perform any subtraction to find the pressure drop.

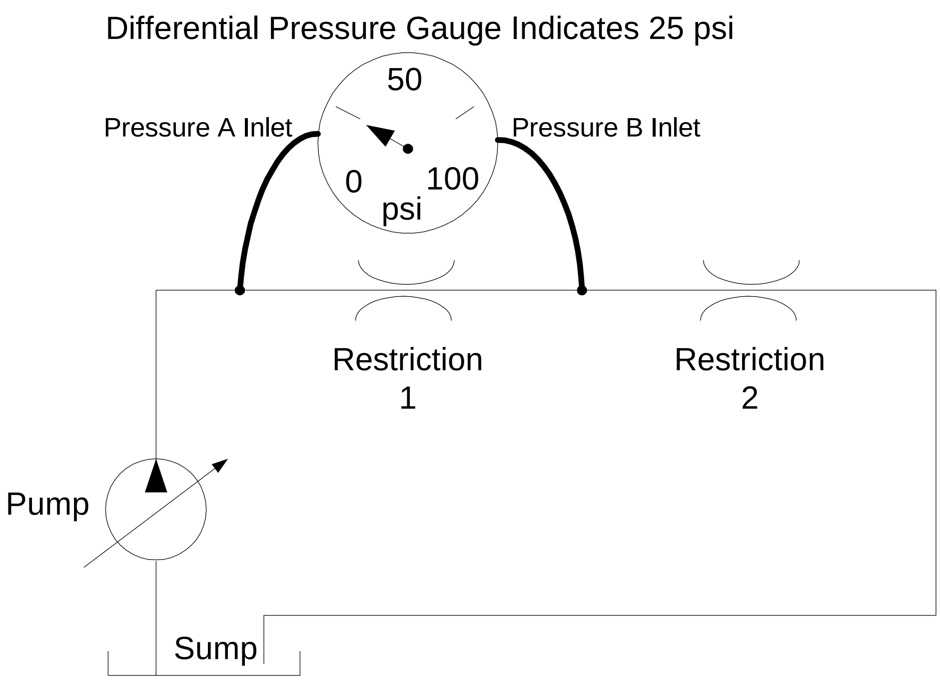

Figure 13 Differential Pressure Gauge

Now let's look at an electrical circuit. If we place two resistors in series with a voltage source such as a battery, an electrical current will flow through these resistors. Since this is a series circuit, there is only one path for electrical current (measured in Amperes or amps) to flow through. The unit of measure of electric current, the Ampere, is like a unit of measure of liquid flow such as gallon per minute (GPM) since both are a measure of a quantity of something per unit of time. The amplitude of this current is the same through every component (wires, resistors) since there is only one path for current to flow through. This is all very similar to the series hydraulic circuit we looked at earlier. The voltage source is like the hydraulic pump, the resistors are like the restrictions, the current is like the fluid flow, and the wires connecting the voltage source to the resistors are like the piping.

If an electrical current is flowing through a resistor, then a voltage is dropped across that resistor. The term "dropped" describes a difference in voltage or electrical pressure that exists from one side of this resistor to the other. We can measure this voltage drop in two ways, similar to how we could measure the pressure drop across a restriction in a hydraulic circuit. Figure 14 illustrates using a voltmeter to measure the voltage dropped across the 1000 Ohm resistor by taking two separate voltage measurements referenced to ground or the negative terminal of the voltage source. One measurement is taken at the top of the resistor or the side of the resistor that is closest to the positive terminal of the voltage source and the other measurement is taken at the bottom of the resistor or the side of the resistor which is closest to the negative terminal of the voltage source. The voltages are both referenced to ground, which is similar to measuring a pressure referenced to atmospheric pressure. If we subtract the voltage measured at the bottom of the 1000-Ohm resistor from the voltage measured at the top of the 1000-Ohm resistor, we will find the voltage dropped across the 1000-Ohm resistor. In this case, the value is 10.91V.

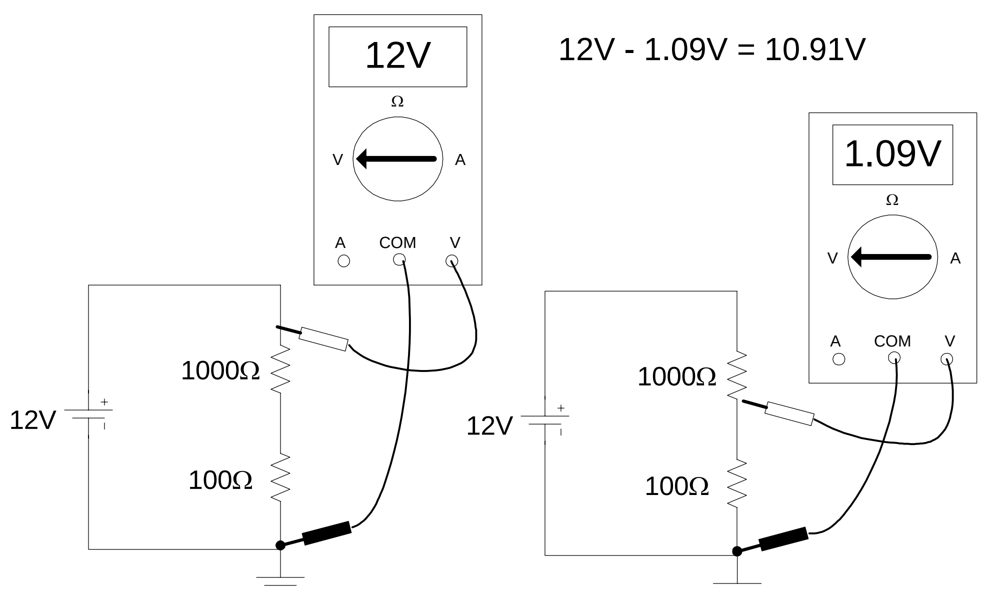

Figure 14 **Using a Voltmeter to Measure a Voltage Drop the Hard Way**

We could also measure the voltage dropped across the resistors by using the voltmeter in a manner similar to a differential pressure gauge. Instead of measuring everything referenced to ground (voltmeter negative lead always connected to ground), we can use the voltmeter to measure the voltage dropped across the resistor by placing the negative lead of the voltmeter on the side of the resistor closest to the negative terminal of the voltage source instead of ground as shown in Figure 15. This will let us read the voltage dropped across each resistor without taking two separate readings and subtracting. If we measured the voltage dropped from the ground side of the 100-Ohm resistor to the battery negative, we should read about 0V. This is assuming that we have a “good” ground circuit with very little resistance (restriction). This is similar to the near 0psig measured in the pipe back to the sump in our hydraulic circuit. The more resistive the ground circuit, the greater the voltage that is dropped on the ground circuit leaving less voltage available for the rest of the circuit.

If we add the voltage drops shown on the meters in Figure 15, the sum is 12V which is the same as the voltage source. This is similar to what we saw with the hydraulic circuit where the pressure drops added up to the outlet pressure of the pump. This is another characteristic of a series electrical circuit. The sum of all the voltage drops will equal the source voltage. This would be true regardless of the number of series resistors.

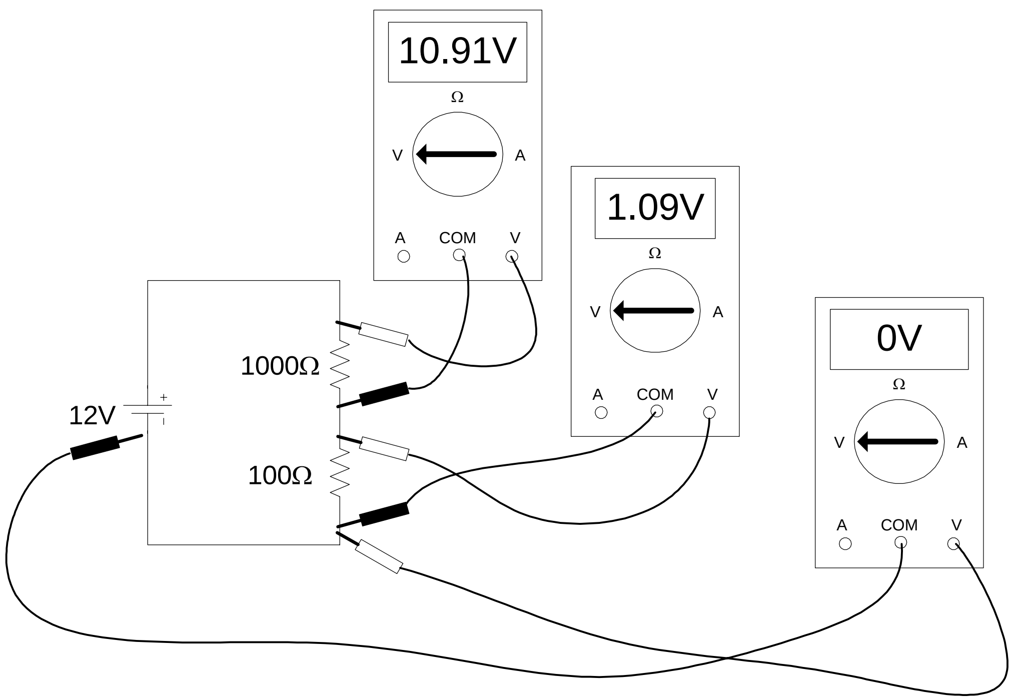

Figure 15 **Measuring Voltage Drop Using the Meter Like a Differential Pressure Gauge**

You were probably wondering when Ohm's Law would be mentioned. That would be now. Ohm's Law describes the relationship between voltage, current, and resistance in a mathematical form. To review, Ohm's Law can be written as:

Voltage = Current X Resistance or Volts = Amps X Ohms

Ohm's Law allows us predict what the voltage drop would be across a resistor by multiplying the current flowing thorough the resistor measured in Amps times the resistance value in Ohms. We know the value of the resistors in Figure 15, but we do not know the value of the current flowing through the circuit. To find the current, Ohm's Law can also be written as:

Current = Voltage ÷ Resistance or Amps = Volts ÷ Ohms

Applying Ohm's Law to the entire circuit instead of just one component requires us to know any two of the following: total voltage, total current, or total resistance to find the third unknown quantity. Since this is a series circuit, the total current in the circuit is the same as the current flowing through any component. To find the total current flowing through the circuit, we just need to divide the total voltage (12V) by the total resistance. Finding the total resistance in a series circuit is easy since all we have to do is add up all the resistor values. In the circuit shown in Figure 15, the total resistance is 1000 Ohms + 100 Ohms which is 1100 Ohms. If we divide 12V by 1100 Ohms, we get about 0.01091 Amps. This is the value of the current that flows through either resistor. We can then multiply this current by each resistance and calculate the voltage dropped across each resistor.

If we replaced the 100 Ohm resistor shown in Figure 15 with a 1000 Ohm resistor while the upper resistor remains a 1000 Ohm resistor, the 12V source voltage is divided equally across the two resistors as shown in Figure 16. This is a series circuit, so the current is the same through both resistors. Since the current is the same through both resistors and both resistors are the same value, the voltage drops are also identical and must add up to the source voltage. You can also use Ohm's Law to verify this. The total circuit resistance would be 2000 Ohms so the circuit current would be 0.006 Amps. Multiply this by 1000 Ohms and you get 6V. Adding the two voltage drops gives us the source voltage of 12V.

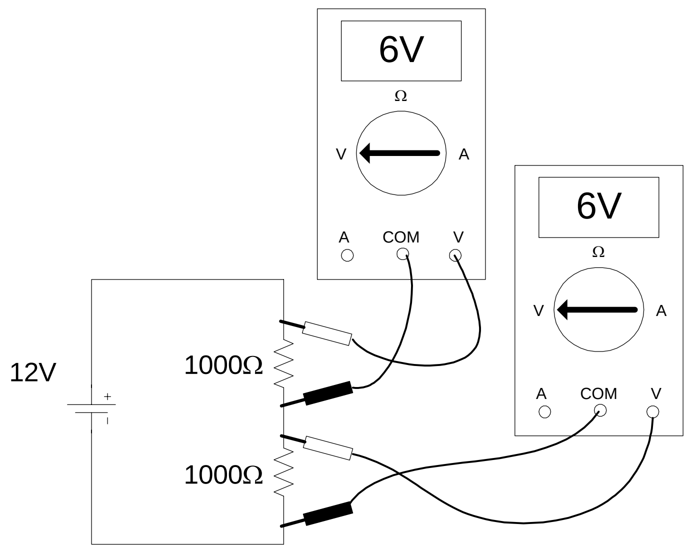

Figure 16 **Equal Resistors, Equal Voltage Drops**

If the value of the bottom resistor is further increased to say 100,000 Ohms (100K Ohms), Ohm's Law says that the voltage dropped across the larger resistor will be 100 times greater than the voltage dropped across the 1000 Ohm resistor as shown in Figure 17.

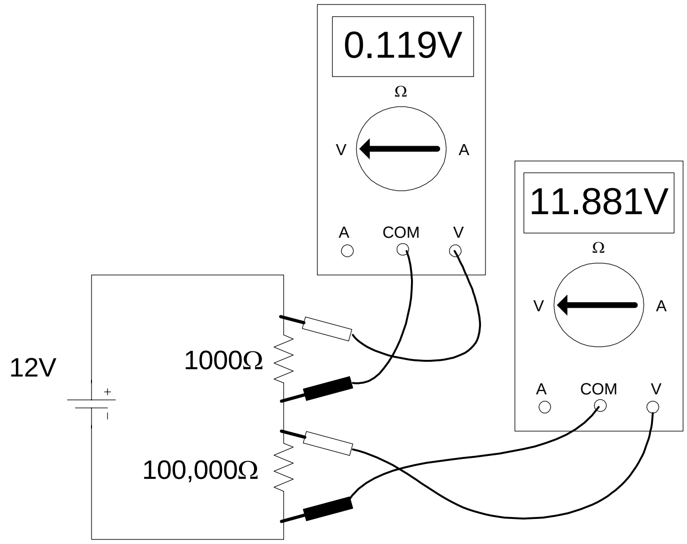

Figure 17 Most of the Voltage Dropped on Largest Resistor

If we increase the bottom resistor even more to say 100,000,000 Ohms (100 Mega Ohms), the larger resistor will have nearly all the voltage dropped across it (Figure 18). The upper resistor has about 0.12 millivolts or 120 microvolts (120 one-millionths of a volt) while the lower resistor gets the rest of the 12V. The lower meter is showing 12V, but the actual voltage would be about 11.99988V. This is close enough to 12V for our purposes though.

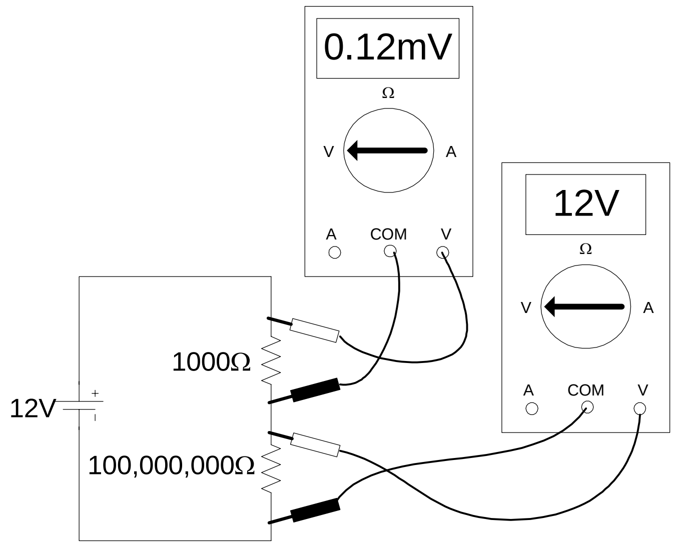

Figure 18 Nearly All Voltage Dropped on Largest Resistor

To simplify things, let’s change the way we have represented the circuit shown in Figure 18. Figure 19 shows the same circuit but with some minor differences. First, the circle at the top of the circuit on the right side indicates that there is +12V at that point of the circuit. We are not going to show a voltage source such as a battery, but we know that some voltage source is supplying the +12V at the top of the circuit. Secondly, the ground symbol at the bottom of the circuit on the right indicates that the circuit is connected to chassis ground. We are also assuming that the voltage source is also connected to chassis ground, so we don’t have to show the voltage source and the wiring to the voltage source. Lastly, the resistor values are displayed using metric prefixes. These metric prefixes reduce the number of zeros in the resistor value. The most common prefixes used when referring to resistors is K for 1000’s and M or Mega for 1,000,000’s. The voltage dropped across each resistor would be the same for the left side circuit and the right side circuit. In this case, the 100M-Ohm resistor would have nearly all the 12V dropped across it while almost no voltage would be dropped across the 1K-Ohm resistor.

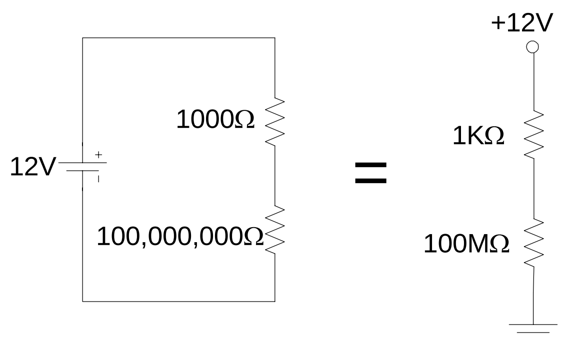

Figure 19 **Re-drawn Circuit**

A circuit with two resistors does not do very much other than divide voltage and create some heat. To make this exercise worthwhile, let's replace the 100M-Ohm resistor with an input to a microprocessor (abbreviated as µP) or microcontroller to be more exact. The microprocessor is the main logic component in the ESC. The microprocessor has inputs and outputs. We will talk about these inputs and outputs in more detail later. For now, lets just look at a single input. Figure 20 shows the microprocessor as a rectangle with a terminal A and a terminal B. Not worrying about what is actually located inside the microprocessor, let's think of there being a very large resistance, say 100Mega Ohms, between terminal A and terminal B of the microprocessor. The actual resistance between terminals A and B may not be exactly 100M Ohms, but it is a very large number and permits us to have an idea of how large the input resistance of the microprocessor is. Therefore, we can make the substitution shown in Figure 21. The circuit on the right side of Figure 21 shows an open circuit input (nothing connected externally). The microprocessor would read 12V at this input, just like the voltmeter shown in Figure 21.

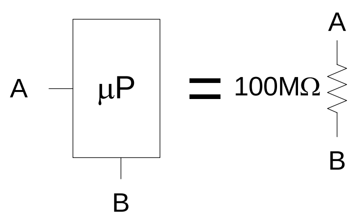

Figure 20 Microprocessor Input Resistance

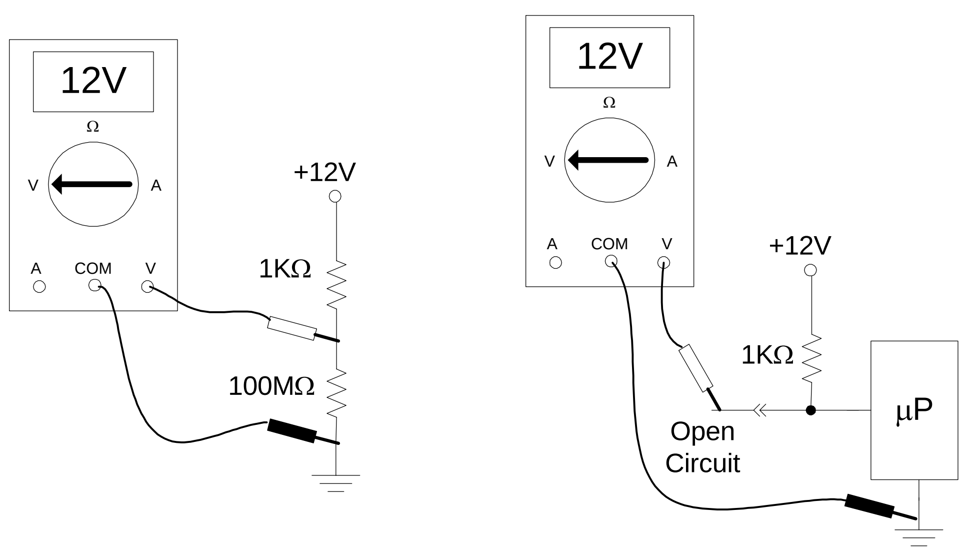

Figure 21 Microprocessor Input Voltage

Now let's take a quick look at a hydraulic circuit where the restrictions are in parallel with each other instead of in series. The circuit shown in Figure 22 shows that there is more than one path for hydraulic fluid to flow through, unlike the series circuit. The pressure dropped across both restriction 3 and restriction 4 would be the same as the pump outlet pressure, even if the restrictions were not the same size. However, the rate of hydraulic flow through each restriction would be different if the restrictions were not the same size. The restriction that offered the least restriction (largest diameter) would permit more fluid to flow (higher gallons per minute) than the other restriction.

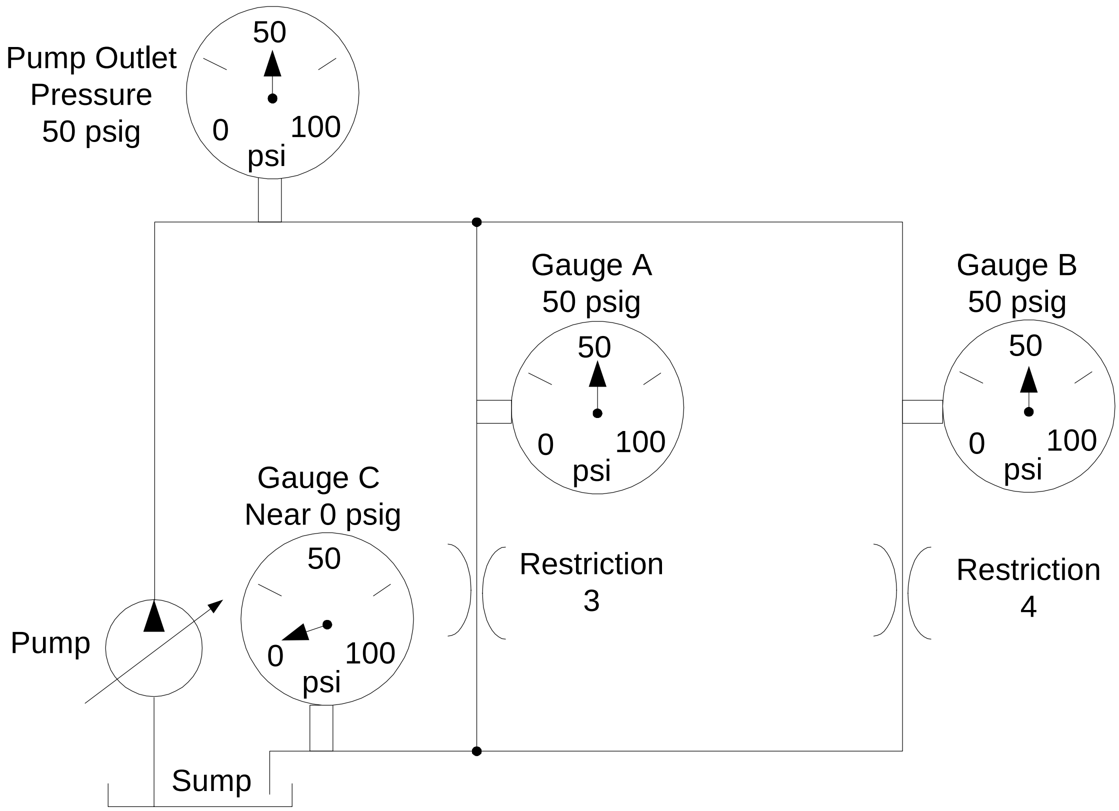

Figure 22 **Parallel Hydraulic Circuit**

In a parallel electrical circuit, there is also more than one path for current flow. Each parallel resistor has the same voltage drop, which is the value of the source voltage. Figure 23 illustrates a parallel electrical circuit. Unlike a series circuit, each parallel resistor has the source voltage dropped across it. However, the current divides up when it reaches a junction. If the resistor values are not equal, more current will flow through the smaller value resistor (less resistance) than the larger value resistor. Ohm's Law works for parallel circuits as well. The amount of current through each parallel resistor is simply the voltage divided by the resistance.

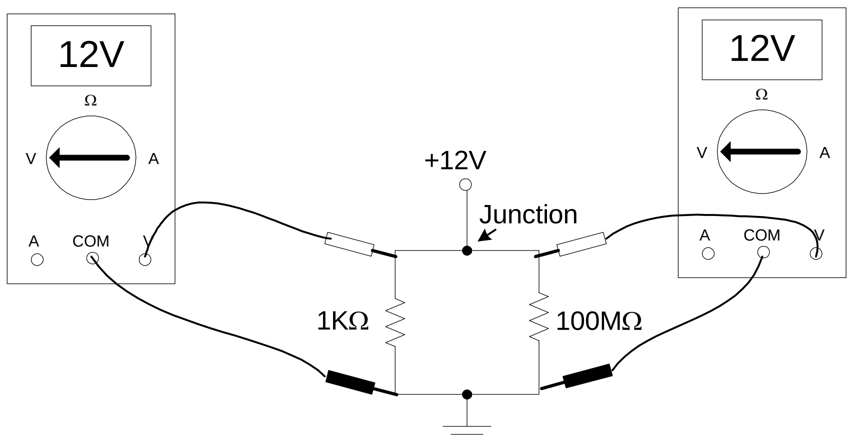

Figure 23 Parallel Electrical Circuit

When two resistors are in series, the total circuit resistance is the sum of the two resistors. However in a parallel circuit with two resistors, the total circuit resistance is a bit more complicated to calculate. One formula for calculating total resistance when there are only two parallel resistors is the product over the sum rule. This rule says that if we multiply the two resistors together and divide this result by the sum of the two resistors, the result will be the total equivalent resistance. The formula would look like this:

$$\frac{\text{Resistor 1 X Resitor 2}}{\text{Resistor 1 + Resitor 2}} = \text{Total Resistance}$$

The parallel resistance formula shows that the total resistance will always be smaller than the smallest parallel resistor. This is not math class, but if you entered the two resistor values shown in Figure 23 into the formula, you would find that the total resistance is 999.99 Ohms. This is nearly the same as 1000 Ohms. The point here is that since the 100M Ohms is such a large value, it has almost no impact on the total circuit resistance.

Most electrical circuits on a truck are wired in parallel so that each component such as a light is supplied with 12V. If headlights were wired in series with each other, each headlight would only have 6V dropped across it so it would not be very bright. We would also have the situation where if one headlight burned out it would prevent the other headlight from illuminating due to the single path for current flow.

If we combine a series circuit with a parallel circuit, it is called a series-parallel circuit. Figure 24 shows a series-parallel circuit. The lower 1K-Ohm resistor is in parallel with the 100M-Ohm resistor. This combination is also in series with the upper 1K-Ohm resistor. Since we have already determined that the parallel combination of 100M Ohm and 1K Ohm is about 1K Ohm, we can ignore the effects of the parallel 100M-Ohm resistor on the circuit and treat this as two 1K-Ohm resistors in series. The voltage dropped across each of the 1K-Ohm resistors would be about 6V. In reality, the voltage dropped on the lower 1K Ohm resistor would be just a hair less than 6V due to the parallel 100M Ohm resistor, and the voltage dropped across the upper 1K Ohm resistor would be a hair more than 6V. However, the voltage dropped across both resistors is so close to 6V that we will just call it 6V. Additionally, since the lower 1K-Ohm resistor and the 100M-Ohm resistor are in parallel the voltage dropped across the 100M-Ohm resistor would be the same as that dropped across the lower 1K-Ohm resistor (about 6V).

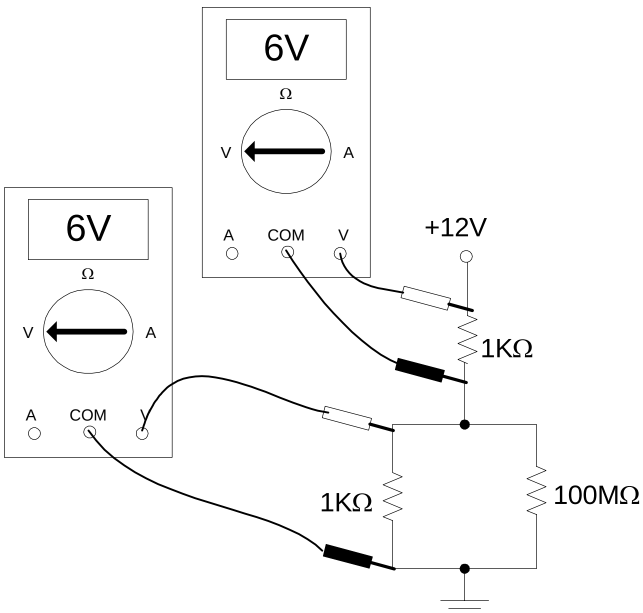

Figure 24 Series-Parallel Circuit with Large Parallel Resistance

The series-parallel circuit shown in Figure 24 is not the same as most other series-parallel circuits that you may encounter due to the large difference between the two parallel resistors. We basically ignore the large parallel resistor in this example. In other instances where the parallel resistance is not so large, ignoring a parallel resistance will cause you to get a wrong answer.

OK, let’s put these concepts to work.

Bias

An electronics term that you may not be familiar with is bias. When you hear the word bias, you may think of inclination, prejudice, or predisposition. This is the same idea for the term bias when applied to electronics. For our purposes, bias refers to the open circuit voltage level measured at an input. This open circuit voltage would be the voltage level referenced to ground that you (and the microprocessor) would measure with a voltmeter at the input with nothing else connected to the input. Think of bias as being the voltage level that the input is inclined to go to. When the input voltage is high with nothing connected to the input, we say that the input is biased high. Biased high means that an open circuited input will be pulled up to some positive voltage level. Figure 25 shows an example of a biased high input. With nothing connected to the input, the microprocessor reads about +12V. The 1K-Ohm resistor connected to +12V causes the input to "pull-up" to +12V when there is nothing connected to the input. The 1K-Ohm resistor is called a pull-up resistor. The pull-up resistor is in series with the very high resistance microprocessor input. Therefore, almost all the available voltage is dropped across the microprocessor input. As we will see later on, the 1K-Ohm pull-up resistor is necessary to act as a "divider" when we add an external component to the input.

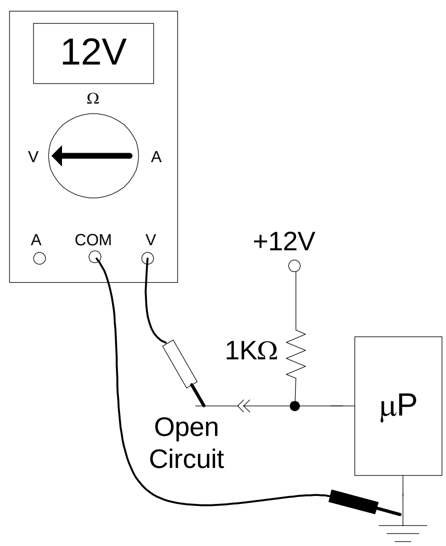

Figure 25 Biased High Input

If the input voltage were at ground potential (0V) with nothing connected to the input, we would say that the input is biased low as shown in Figure 26. The 1K-Ohm resistor pulls the microprocessor input down to 0V with nothing else connected to the input. The 1K-Ohm resistor in this example is called a pull-down resistor. The pull-down resistor is in parallel with the microprocessor input. As we know, the voltage measured across devices that are in parallel must be the same value. The pull-down resistor guarantees that the input voltage will be 0V when nothing is connected to the microprocessor input.

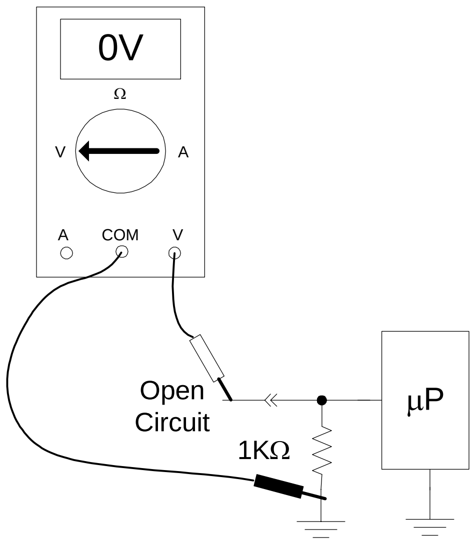

Figure 26 Biased Low Input

The type of input device (sensor, switch, etc) will determine if the device will be connected to a biased high or a biased low input. Devices that provide a path to ground require a biased high input. Devices that provide some value of positive voltage such as some transducers require a biased low input. We will look at the types of inputs in greater detail later.

Zero Volt Reference (ZVR)

Zero Volt Reference (ZVR) is the name given to the ESCs logic ground. ZVR is what the ESC microprocessor uses to reference input voltage levels. Think of ZVR as a clean, low noise ground. ZVR is connected to chassis ground inside of the ESC via the ESC ground wire. ZVR helps improve the accuracy of voltage levels measured by the ESC at its inputs.

The use of ZVR helps reduce susceptibility to electromagnetic interference and provides more accurate measurement of input values than if chassis ground were used as the sensor ground. If you are familiar with electronic engine controls, ZVR is similar to the signal ground used by engine controllers. Like signal ground, ZVR is a small gauge wire and is not designed to conduct much current. The more current that ZVR is forced to conduct, the higher its voltage level referenced to alternator or battery ground becomes. This in turn would affect the accuracy of all ESC inputs. ZVR has been given the circuit identification number of 9 and a color of gray to avoid confusion with chassis ground circuits that are white in color and have an 11-G circuit identification number. Don’t connect ZVR to chassis ground. It is designed to only be connected to chassis ground at the one location inside the ESC. Connecting ZVR to chassis ground outside the ESC can cause all kinds of hard-to-find problems.

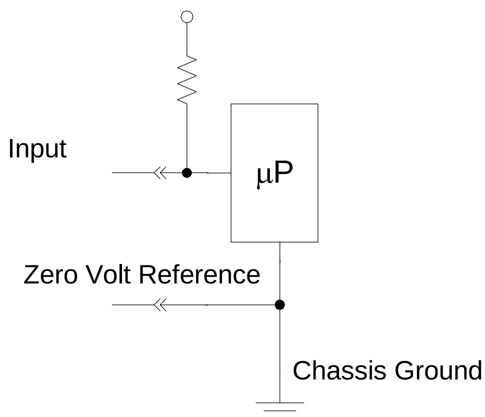

Figure 27 Zero Volt Reference (ZVR)

ESC Inputs

Inputs let the ESC know what is going on with the rest of the vehicle and what the driver has requested. Inputs are information for the microprocessor. ESC inputs are either hardwired or in the form of messages on one of the data links. In the case of hardwired inputs, we know that the input can be either biased high or biased low. The input can also be either a digital input or an analog input.

Digital Inputs

Digital inputs are inputs that are only capable of recognizing two levels, on and off. These two levels could also be referred to as high and low or 1 and 0. If the voltage measured at an ESC digital input is below about 1.2V, the input is considered off or low by the ESC microprocessor. If the voltage measured at an ESC digital input is above 4V, the input is considered on or high by the ESC microprocessor. Any voltage level in between these values (1.2V to 4V) could be either considered on or off by the ESC microprocessor, so we want to stay away from digital input voltages in this unknown zone. Switches are normally connected to digital inputs. A switch is a digital device since it can only be in one of two states, off or on. Examples of switches that are connected to ESC digital inputs include the dome light switch and electric horn switch.

If a resistor and switch are wired in series, the voltage measured across the open switch will be the same as the supply voltage as shown in the left side of Figure 28. This is because the open switch has an infinitely high resistance. If we think of this as a series circuit, the 1.2K-Ohm resistor is in series with an infinitely high resistance. We know from our discussions on series circuits that the largest series resistor gets the highest percentage of the voltage drop. Since the resistance of the switch (or actually the internal resistance of the meter) is much larger than 1.2K Ohms, virtually all the source voltage will be dropped across the open switch. If the switch is closed, the switch resistance becomes about 0 Ohms. Now virtually all the voltage is dropped across the 1.2K-Ohm resistor since it has nothing other than the closed switch resistance and the wire resistance to share the available voltage with. This is a very important concept. We have 12V across an open switch and 0V across a closed switch. If this does not make sense, construct a similar circuit and use your digital voltmeter to verify.

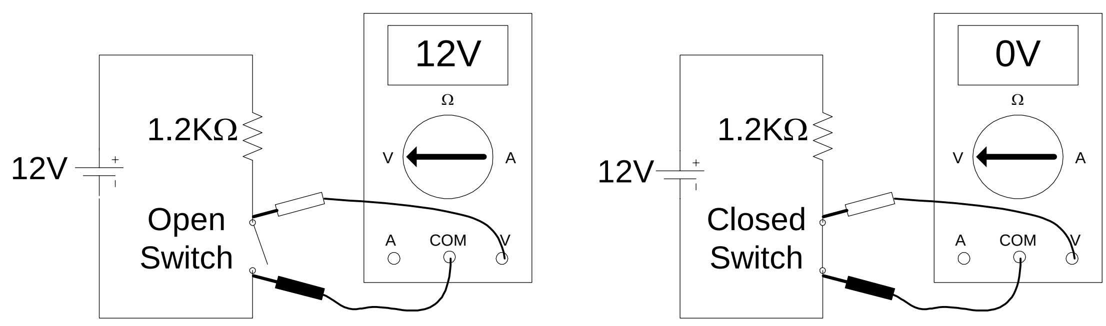

Figure 28 Switch and Resistor Series Circuit

The majority of ESC digital inputs are biased to accessory voltage (biased high). The pull-up resistor for most accessory biased digital inputs is a 1.2K-Ohm resistor. A switch designed to only carry a small amount of current is connected between the ESC digital input and ZVR. The switch and the ESC pull-up resistor form a series circuit. The ESC microprocessor input is in parallel with the switch since they share a common high side and ZVR. The voltage measured across devices that are in parallel must be the same so the microprocessor sees the same voltage at its input as that measured across the switch with our voltmeter. With the switch open, the ESC microprocessor sees a voltage level near accessory voltage level at its input (Figure 29). Once again, this is because the resistance of an open switch is near infinity. We also know that the input resistance of the microprocessor is very high. This means that nearly all of the available 12V will be dropped across the microprocessor input and the parallel open switch. This is much greater than the 4V or greater required at the ESC input to guarantee a logic high level at the microprocessor. The ESC microprocessor could then determine that the switch was open due to the voltage measured at this input.

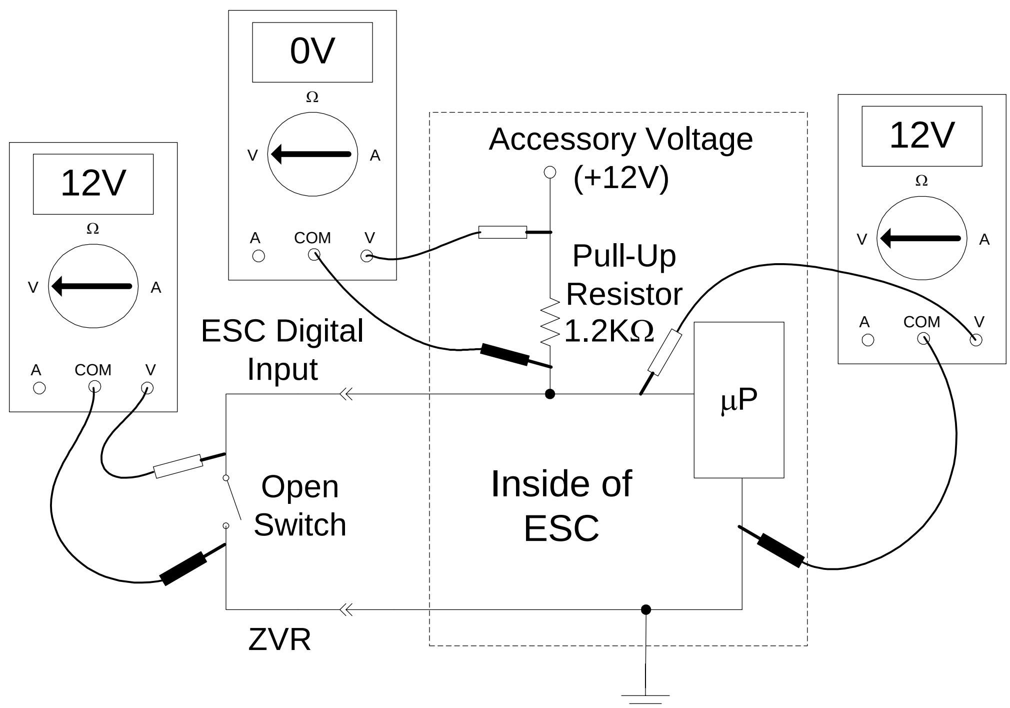

Figure 29 **Biased High Digital Input with Switch Open**

With the switch closed, the resistance of the switch drops to near 0 Ohms. The side of the pull-up resistor connected to the digital input is now shorted to ZVR through the closed switch. Since the ESC microprocessor input is in parallel with the switch, the voltage level at the microprocessor (µP) input is also near 0V with the switch closed (Figure 30). The closed switch is effectively shorting the microprocessor input to ground. The 0V measured by the microprocessor at this input is well below the 1.2V or less required at an ESC digital input to guarantee a logic low level at the microprocessor. The ESC microprocessor is then able to determine that the switch is closed based on the 0V at this input.

The pull-up resistor limits the amount of current that will flow through a closed digital input switch. For digital inputs using a 1.2K-Ohm pull-up resistor at an accessory voltage level of 12V, only 10mA (10 one-thousandths of an amp) of current will flow through the closed switch as shown in Figure 30.

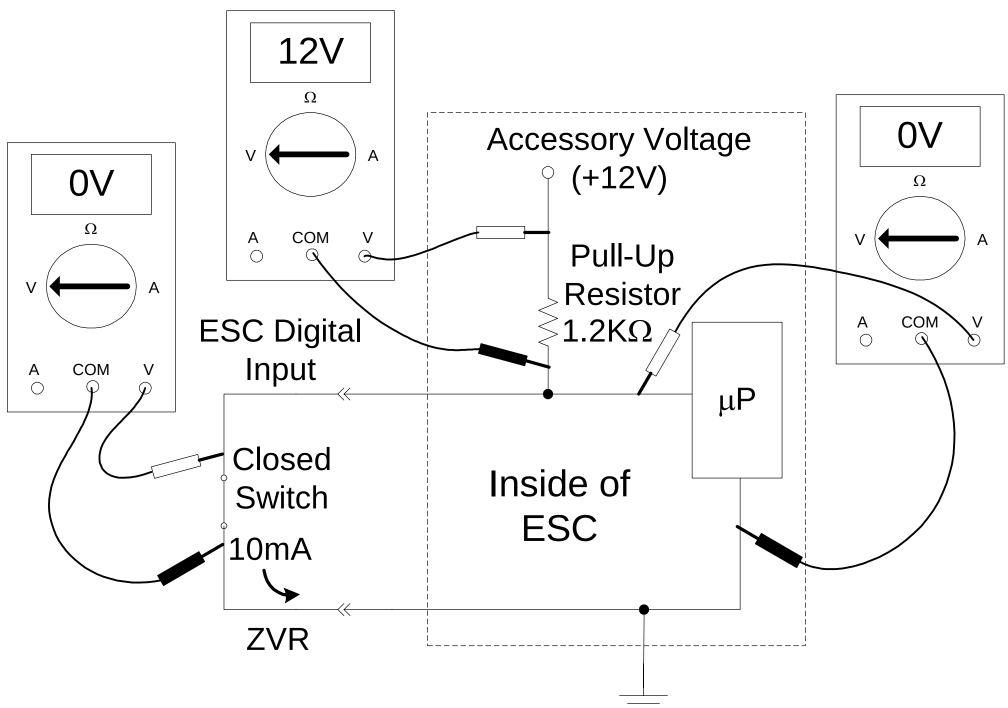

Figure 30 **Biased High Digital Input with Switch Closed**

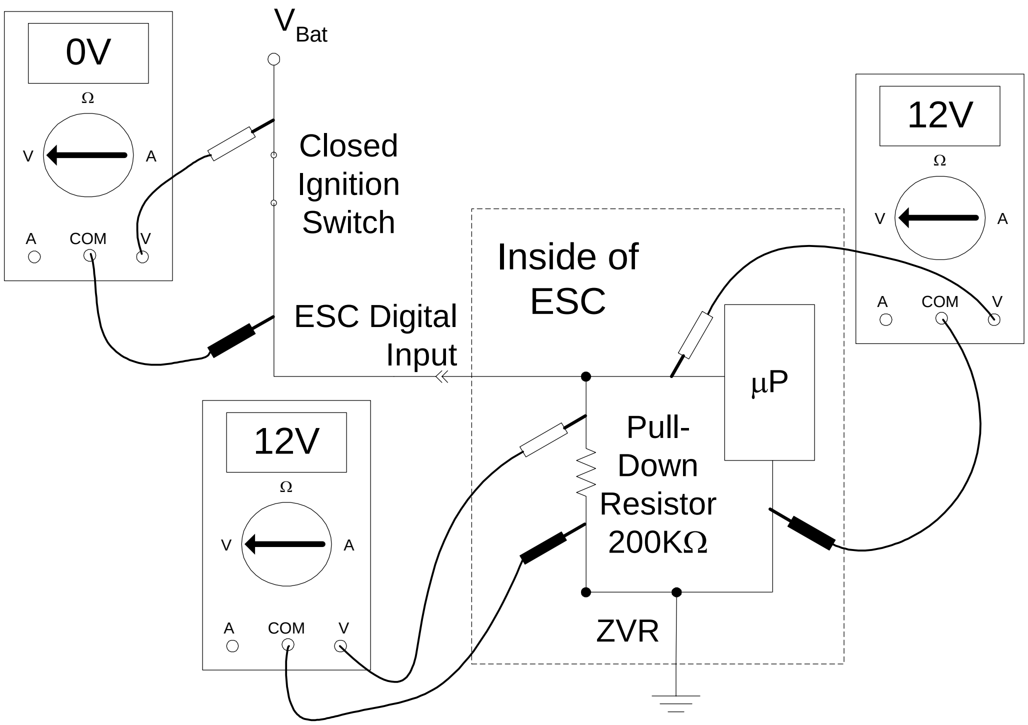

Figure 31 **Biased Low Digital Input with Switch Closed**

A small number of ESC digital inputs are biased low. In most cases, a 200K-Ohm pull-down resistor in the ESC pulls the input down to near ZVR voltage level with the input open circuited. An example of a biased low ESC input is the ignition sense signal. Ignition is a digital input to the ESC. The ESC only cares to know if ignition is off or on, not the actual value of the ignition voltage. If the key switch is in the ignition position, the voltage at the ESC ignition input will be the same as ignition voltage (Figure 31). This is because the ESC microprocessor digital input for ignition is in parallel with the pull-down resistor. If the key switch is not in the ignition position (off), the voltage level at the ESC ignition input will be near 0V due to the pull-down resistor being connected to ZVR. The pull-down resistor drives the ESC input to ZVR thus guaranteeing a logic low level at the ESC microprocessor when there is no voltage at the ignition input (Figure 32).

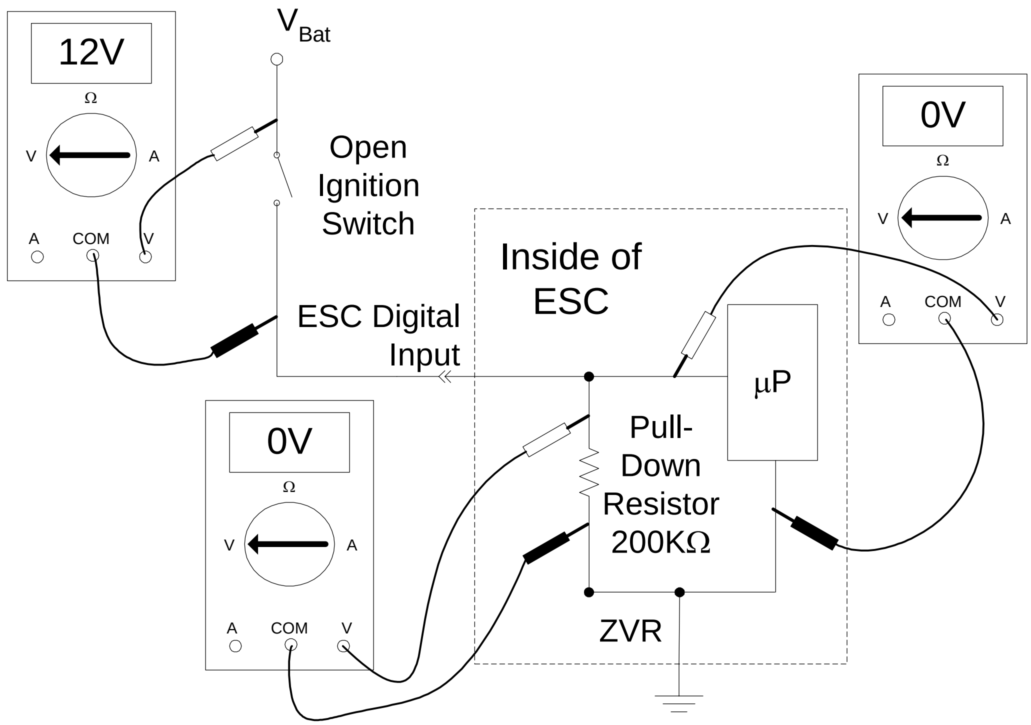

Figure 32 Biased Low Digital Input with Switch Open

Some ESC digital inputs are biased to accessory level voltage with ignition on and biased to 4.3V (5V minus a 0.7V diode drop) with ignition off. These inputs include the brake light switch*, dome light switch, and turn signal switches. All of these devices must function with the ignition off. Keep this dual bias level method in mind when troubleshooting. You can also have a lot of fun with this knowledge by asking your non-enlightened co-workers what they think is wrong when they see the voltage measured at an open turn signal input drop from 12V to 4.3V when the ignition is shut off.

(* Brake light switch is both a digital input and an analog input, more on this later.)

Analog Inputs

Several of the ESC inputs are analog inputs. An analog input differs from a digital input in that any voltage within a range can be resolved by the ESC microprocessor, not just on and off. The term *continuously variable* is often used when describing something that is analog. Analog inputs are usually used by the microprocessor to determine some physical quantity being measured by a transducer (sensor). An analog input you are probably familiar with on an engine controller is the engine coolant temperature sensor. An engine controller is able to determine the engine coolant temperature based on the voltage level at the coolant temperature analog input. From this voltage, the engine controller is able to cause a coolant temperature gauge to point at the appropriate coolant temperature (Figure 33). If a digital input were used for coolant temperature instead of an analog input, we could only have a coolant gauge point at two different values; hot and cold. Examples of ESC analog inputs include fuel level and air pressure.

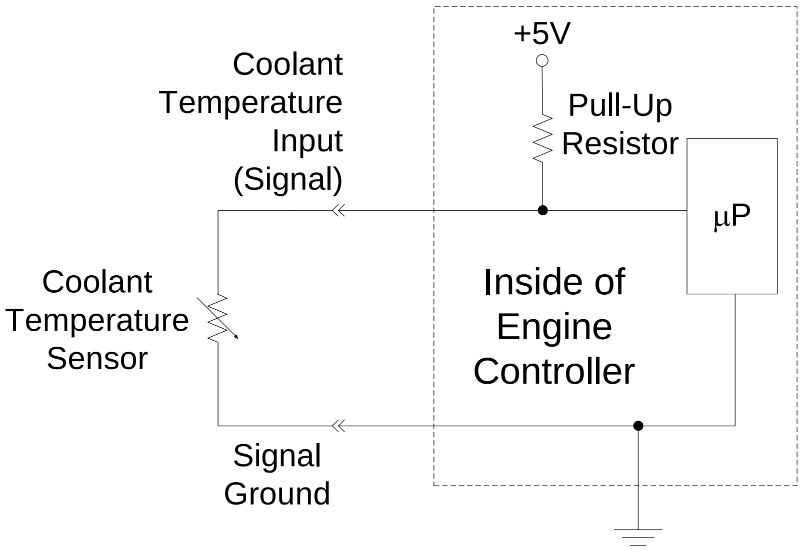

Figure 33 Engine Coolant Temperature Analog Input Example

Like digital inputs, ESC analog inputs may be biased high by some positive voltage level or biased low using ZVR. A biasing resistor is used to pull the input up to some voltage level or pull the input down to ZVR. The biasing resistor forms a series circuit with the sensor. In the example shown in Figure 34, the 1.2K-Ohm resistor represents a pull-up resistor in the ESC. The 800-Ohm resistance value is the resistance of a sensor under some certain physical conditions (temperature, fuel level, or what ever else the sensor is measuring). The voltage drop across the 800-Ohm sensor is 4.8V. This is the same voltage that the microprocessor would see at the input for this sensor as well since the sensor and microprocessor input are in parallel with each other. The high parallel resistance of the microprocessor input is negligible compared to the 800-Ohm sensor resistance. As the sensor resistance changes due to a change in whatever quantity the sensor is measuring, the voltage dropped across the sensor would change as well. For example, if the sensor resistance in Figure 34 became 1200 Ohms because of a change in the physical quantity being measured, the voltage dropped across the sensor would change to 6V.

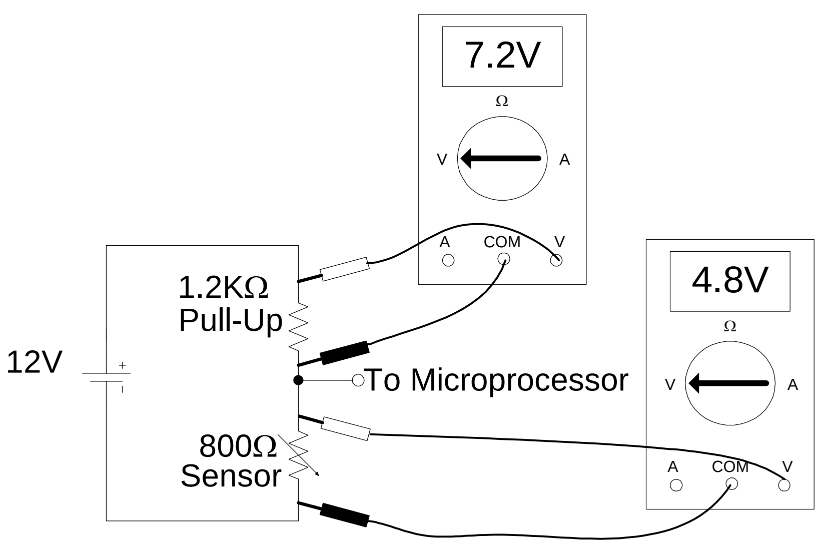

Figure 34 Analog Input Example

Generally speaking, the sensor type determines how the ESC input will be biased. If the sensor is a variable resistance device such as the fuel level sensor, the input will be biased high to some positive voltage level. One side of the variable resistance device is connected to the analog input; the other side is connected to ZVR. The variable resistance device and the pull-up resistor in the ESC form a voltage divider circuit. The ESC microprocessor input is in parallel with the sensor resistance so it sees the voltage dropped across the variable resistance device. The input resistance of the microprocessor is so high that we can ignore its affect on the circuit. The voltage level at the analog input usually represents some physical quantity. In the case of the fuel level sensor, the voltage at the analog input represents the fuel level in the tank. As the fuel level changes, the sensor resistance also changes as shown in Figure 35. The change in sensor resistance causes a change in the voltage level measured by the microprocessor at the fuel gauge input. Notice that the bias voltage is 80% of accessory voltage. This means that if the accessory voltage is 12.6V, the bias voltage is 80% of 12.6V or about 10V. This 80% of accessory voltage is a common bias voltage used in the ESC for analog inputs. Using 80% of accessory voltage as the bias voltage permits the ESC to detect a short to battery voltage on an analog input circuit. If the analog input circuit becomes shorted to battery, the voltage the ESC microprocessor input sees is battery voltage. The ESC will detect this condition and set a fault accordingly.

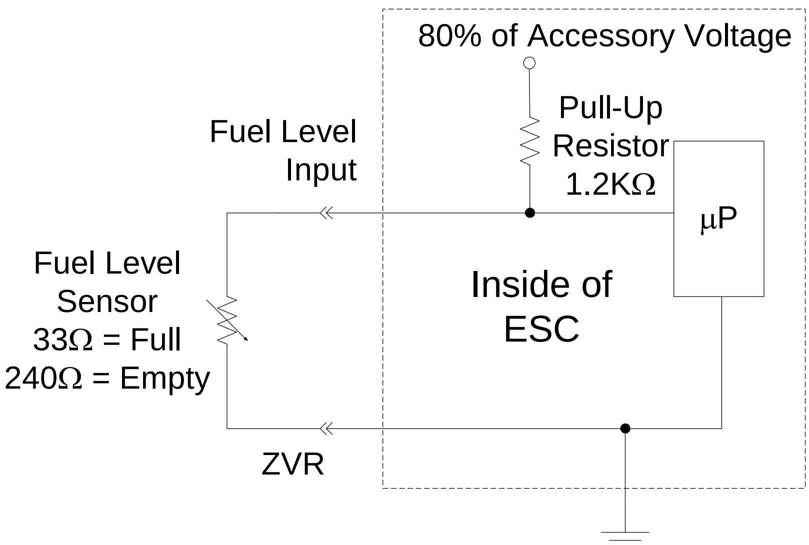

Figure 35 Biased High Analog Input

Now let’s calculate what the voltage reading at the fuel-sending unit would be with a full tank and with an empty tank. If we assume an accessory voltage of 12.6V, 80% of 12.6V is about 10V (12.6 x .8 = 10.08). We’ll calculate the full tank input voltage value first. If we ignore the high input resistance of the microprocessor, what we have is a series voltage divider circuit consisting of a 1200-Ohm resistor and a 33-Ohm resistor sourced by a supply voltage of 10V. The first step is to calculate the total circuit resistance. This is just the sum of 1200 Ohms and 33 Ohms. Next, we find the amount of current that will be flowing through the circuit. Ohm’s Law says that the current through the circuit is found by dividing the source voltage (10V) by the total circuit resistance (1200 + 33 = 1233 Ohms). Our equation for finding the circuit current with a full tank is as follows:

$$10V \div 1233\Omega = 0.008A \text{ or } 8mA$$

Now that we have the value of the current flowing through the sending unit resistance, we can easily calculate the value of the voltage dropped across the sending unit by multiplying the current by the resistance. This gives us the following equation:

$$8mA \times 33\Omega = 0.264V$$

The voltage dropped across the sending unit resistance with a full tank is 0.264V. This is only a little more than 1/4V. Since the microprocessor input is in parallel with the fuel-sending unit, the voltage at the microprocessor input would be practically the same as the level of the voltage dropped across the sending unit. A small amount of voltage is dropped on the connectors, wiring, and circuit board traces, but this should be negligible. Use the same method to calculate the voltage you would expect at the fuel sending unit input if the tank were empty. You should get an answer of about 1.67V.

If the sensor output is a variable positive voltage level, then the ESC analog input is biased to ZVR. An example of a ZVR biased analog input is primary air pressure. The air pressure sensor converts air pressure into a corresponding voltage between 0.5V and 4.5V. The ESC pull-down resistor is very large (81K Ohms) to prevent loading down the sensor. The sensor is designed to only supply a very small amount of current. If the sensor is forced to supply more current than it is designed for, the output voltage of the sensor will drop which would affect the accuracy of the sensor. The ESC microprocessor input is in parallel with the sensor output voltage and the ESC pull-down resistor. Therefore, the ESC microprocessor input sees the voltage supplied by the sensor (Figure 36). The microprocessor is then able to calculate the level of primary air pressure based on the voltage at the input. In the case of primary air pressure, as the air pressure increases the output voltage of the air pressure sensor increases as well.

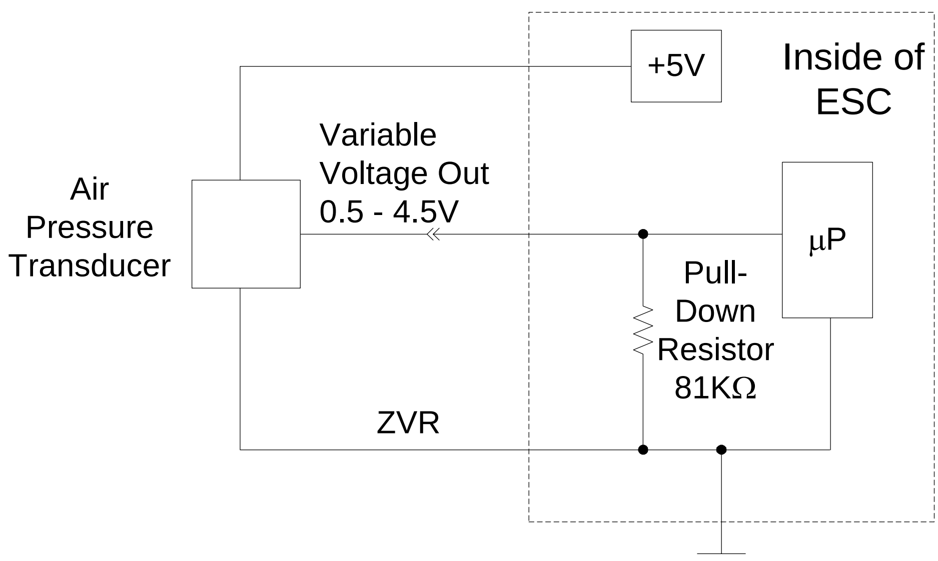

Figure 36 Biased Low Analog Input

Diagnosable Switches

Analog inputs are also used for diagnosable switches such as the brake and clutch switch. A diagnosable switch is a switch that the wiring between the switch and controller can be diagnosed for failures such as shorted to ground or open circuited. Let's look at an ordinary non-diagnosable switch connected to an accessory biased digital input first like those shown in Figure 29 and Figure 30. With the switch open, the voltage level at the input is accessory voltage. Closing the switch causes the input to pull down to 0V. Now suppose the wire between the input and the switch is cut or the connector to the switch becomes disconnected. Closing the switch does not change the voltage level at the input. The input voltage level always looks like an open switch, even if the switch is actually closed. Now suppose instead of an open circuit between the input and the switch, a short to ground exists. The voltage level at the input is now pulled down to 0V. This looks like a closed switch at the input, even if the switch is open.

If an analog input is used instead of a digital input along with a special diagnosable switch, the microprocessor can determine if the switch wiring is intact and if the switch is open or closed. A diagnosable switch differs from a standard switch in that it contains two resistors, one in series with the switch contact and another in parallel with the switch contact. An example of a diagnosable switch used on the High Performance Trucks is the upper clutch pedal position switch. The upper clutch pedal position switch is used to shut off cruise control if clutch pedal is depressed so this is an important input. The upper clutch switch contains two 1.2K-Ohm resistors. One of the resistors is in series with the switch contact, another is in parallel with the switch contact as shown in Figure 37. With the clutch pedal not depressed, the upper clutch switch contact is closed. The closed switch acts as a short circuit across the 1.2K-Ohm resistor that is parallel with the switch contact. If we disconnected the switch wiring and measured the resistance across the clutch switch we would find it to be 1.2K Ohms with the clutch not depressed. This 1.2K Ohms is the resistance of the series resistor only. If the clutch pedal is then depressed, the resistance of the switch increases to 2.4K Ohms since the switch contact is now open. Opening the switch contact removes the short circuit across the parallel resistor and places the two 1.2K-Ohm resistors in series for a combined resistance of 2.4K Ohms.

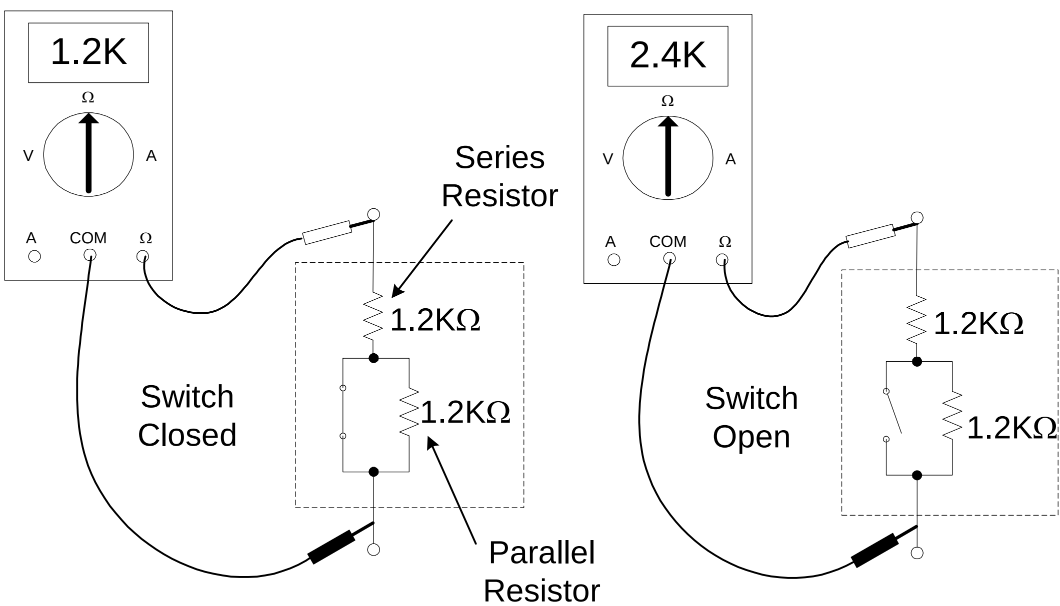

Figure 37 Diagnosable Switch

The clutch switch analog input is biased to accessory through a 2.4K-Ohm resistor. Assuming an accessory voltage of 12V, the voltage level at the clutch switch input with the clutch pedal not depressed is 4V as shown in Figure 38. You can use Ohm's law to verify this. Total circuit resistance is 3.6K Ohms; voltage is 12V so current is 3.33mA. 3.33mA of current through the 1.2K-Ohm series resistor in the clutch switch means the voltage drop across the switch assembly will be 4V. If the clutch pedal is depressed, the voltage at the clutch switch input will increase to 6V as shown in Figure 39. You may use Ohm's law to calculate the voltage at the input with the clutch switch contact open or just know that it will be ½ of the applied voltage since both resistances (clutch switch total resistance and pull-up resistor) are the same value (2.4K Ohms). The microprocessor knows that a voltage level of 4V means that the clutch pedal is not depressed and that a voltage level of 6V means that the clutch pedal is depressed.

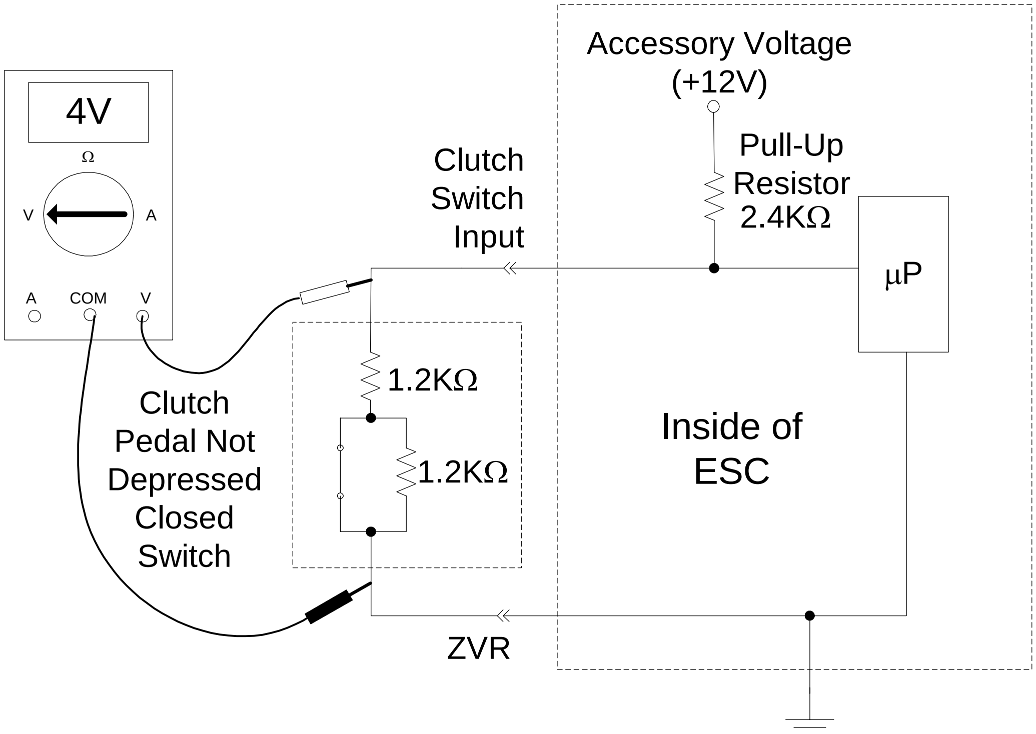

Figure 38 **Clutch Switch with Pedal Not Depressed**

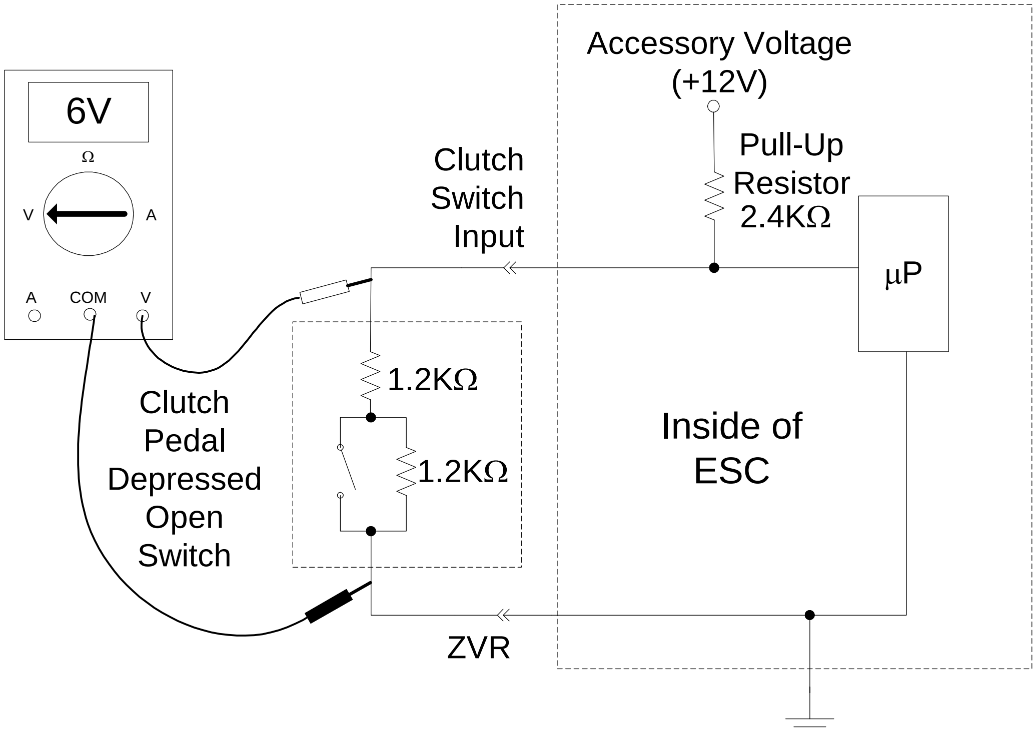

Figure 39 **Clutch Switch with Pedal Depressed**

Now let's look at the voltage level at the input with some failure modes introduced. If the clutch switch connector is disconnected from the clutch switch or the wiring between the ESC clutch switch input and the clutch switch is cut, the voltage at the clutch switch input will be near 12V (Figure 40). If the wire between the clutch switch and the ESC input is shorted to ground, the voltage level will be near 0V (Figure 41). The ESC microprocessor knows that a voltage of 12V at the clutch switch input is an open circuit and that a voltage level of 0V at the clutch switch input is a shorted to ground circuit. The ESC will set a fault for either of these conditions and disable cruise control since it is not possible to determine if the clutch pedal is depressed.

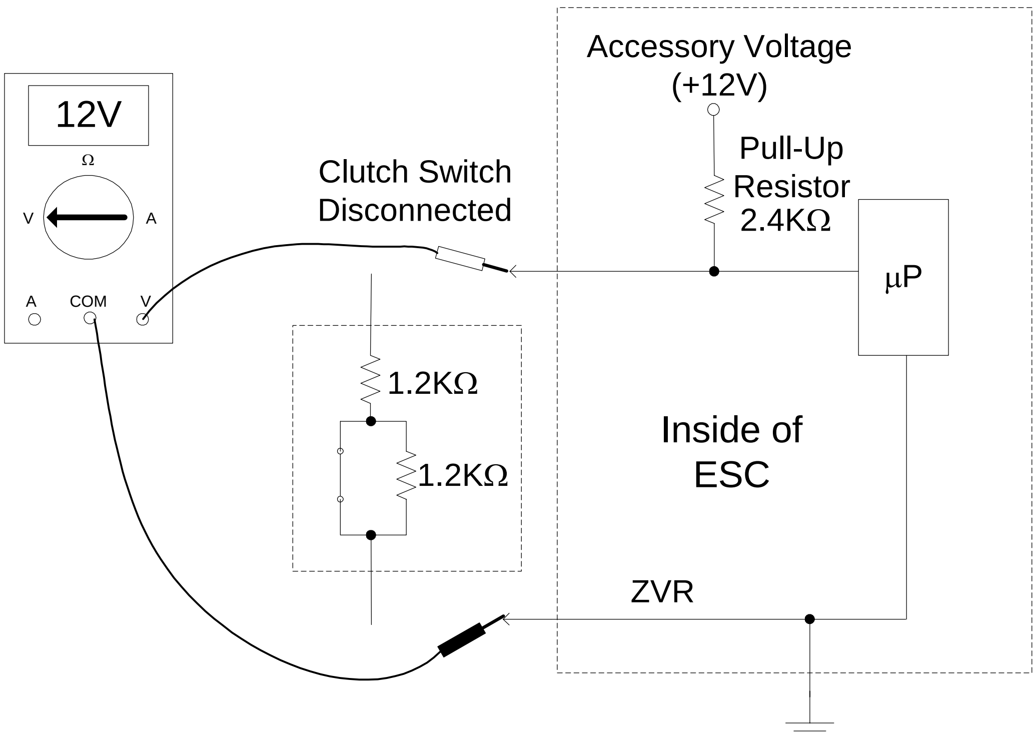

Figure 40 **Clutch Switch Disconnected**

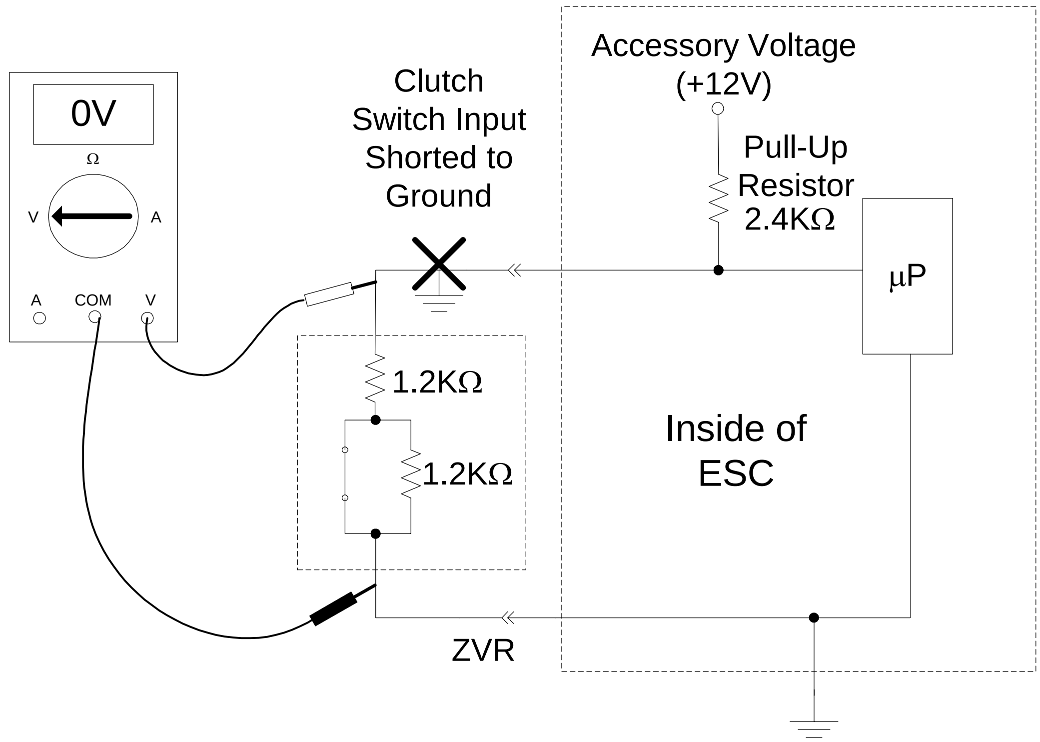

Figure 41 Clutch Switch Shorted to Ground

There is some tolerance in the acceptable 4V (clutch pedal not depressed) and 6V (clutch pedal depressed) values since most electronic components have an allowable tolerance. Additionally, accessory voltage itself is an ESC analog input so the ESC microprocessor knows the actual accessory voltage level. The ESC uses the actual accessory voltage level for calculations instead of a fixed 12V. As accessory voltage level changes such as when engine is running and alternator has raised system voltage to 14V, the voltage levels the ESC expects to see at all accessory biased inputs adjust accordingly.

A More Challenging Diagnosable Switch

The other diagnosable switch used in the High Performance Trucks is the brake light switch. This switch is a little more complicated since vehicle brake lights must function with the key switch in the off position. The downside of a standard diagnosable switch such as the upper clutch switch is that some current is always flowing through the switch anytime the biasing voltage is present regardless of switch contact state. A battery biased diagnosable switch will cause a key-off current draw. A special diagnosable switch that does not exhibit this key-off current draw was designed for the brake light circuit. The brake light switch uses a zener diode in place of the parallel resistor. A zener diode differs from the familiar rectifier diode that is normally used as an electrical one-way check valve. A zener diode is designed to be used in the backwards or reversed biased state. Like an ordinary rectifier diode, the zener diode will not conduct in the reverse direction. However, when the reversed voltage level exceeds a predetermined voltage (designated the breakdown voltage or V_Z), the diode switches on and conducts current. If the applied voltage continues to increase, the voltage level across the zener will remain at the predetermined voltage level (provided there is a series resistor in the circuit to drop the remainder of the voltage). Zener diodes are often used in voltage regulators for this reason. Figure 42 and Figure 43 illustrate a 6.8V_z zener diode with two different system voltages. Note that when the applied voltage is less than 6.8V, there is no current flow in the circuit.

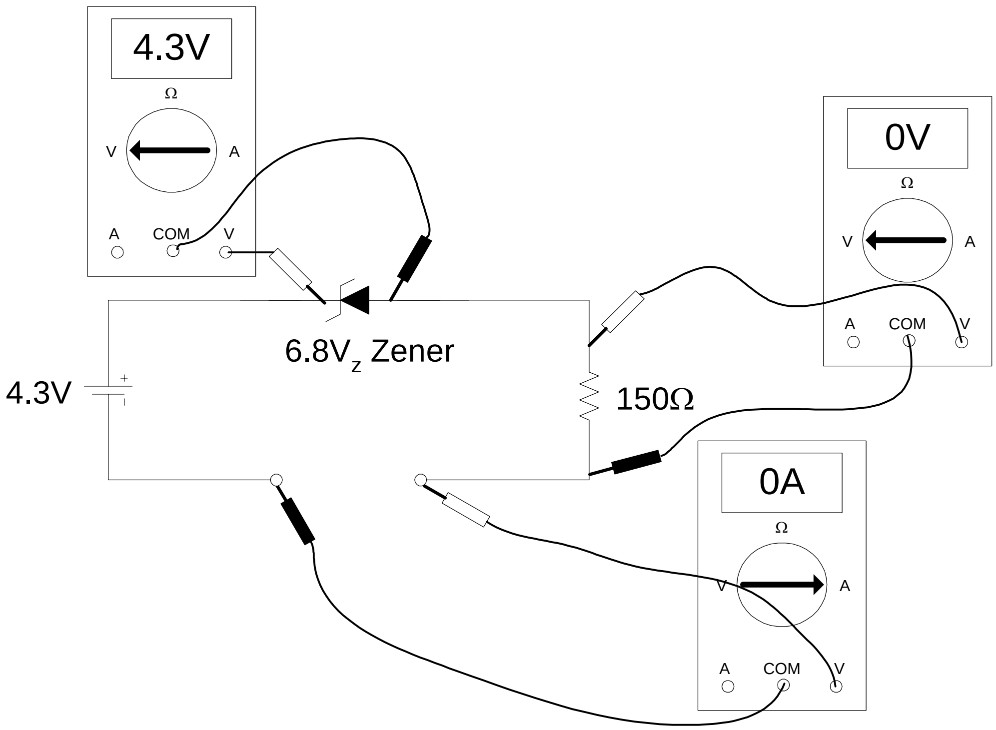

Figure 42 **Zener Diode below Breakdown Voltage**

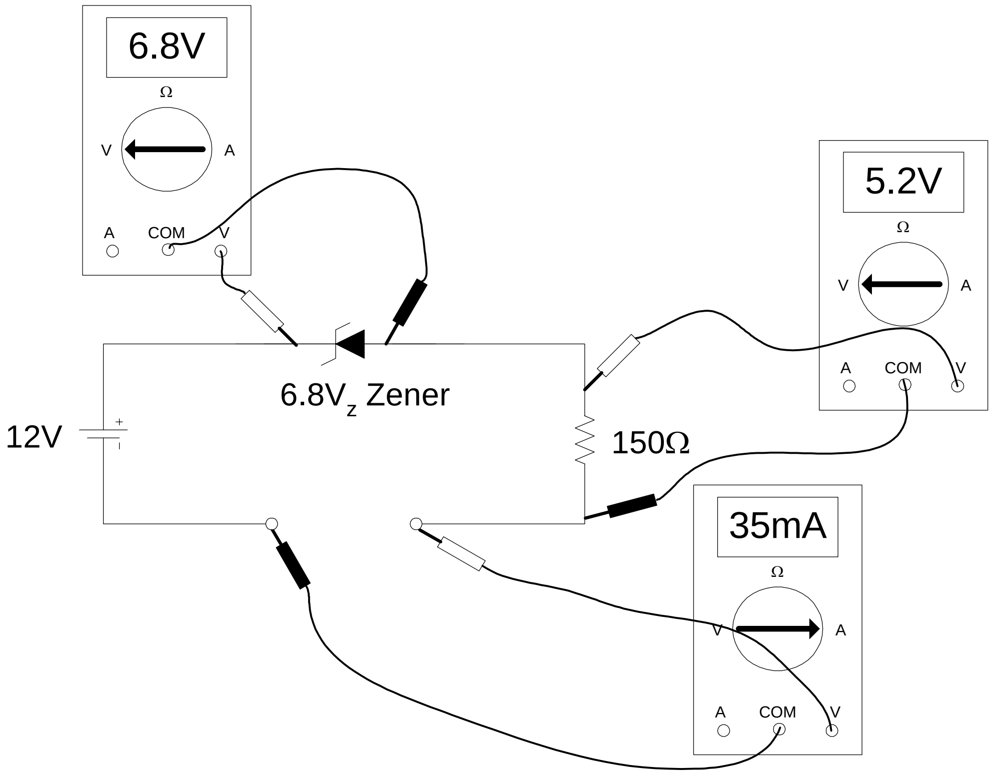

Figure 43 **Zener Diode With Supply Voltage Above Breakdown Voltage**

The zener diode used in the brake light switch has a breakdown voltage of 6.8V. The brake switch series resistor is 150 Ohms. The brake switch contact in parallel with the zener diode is closed when the brake pedal is depressed and open when the brake pedal is not depressed (Figure 44). With the key switch in the ignition or accessory position, the brake switch analog input is biased to accessory through a 1.2K-Ohm resistor as shown in Figure 44. Ignore the +5V and 10K-Ohm resistor for now. The blocking diode in series with the 10K-Ohm resistor isolates the +5V circuit with the key switch in the ignition or accessory positions. We'll look at the purpose of the +5V circuit later. The 12V accessory voltage (abbreviated as $V_{Acc)}$ less the 0.7V dropped on the series blocking diode is enough to cause the reverse biased 6.8V zener diode in the brake switch to conduct. When combined with the small voltage drop on the 150 Ohm resistor, the voltage level at the brake switch input with the brake pedal not depressed is about 7.3V as shown in Figure 44.

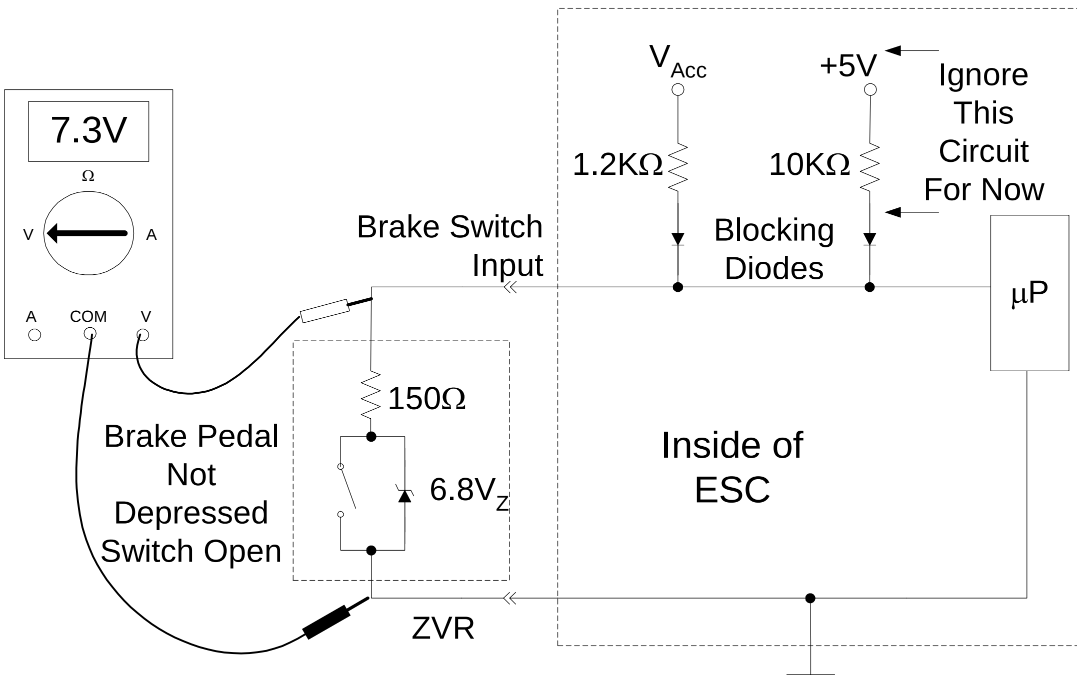

Figure 44 Brake Pedal Not Depressed Ignition On

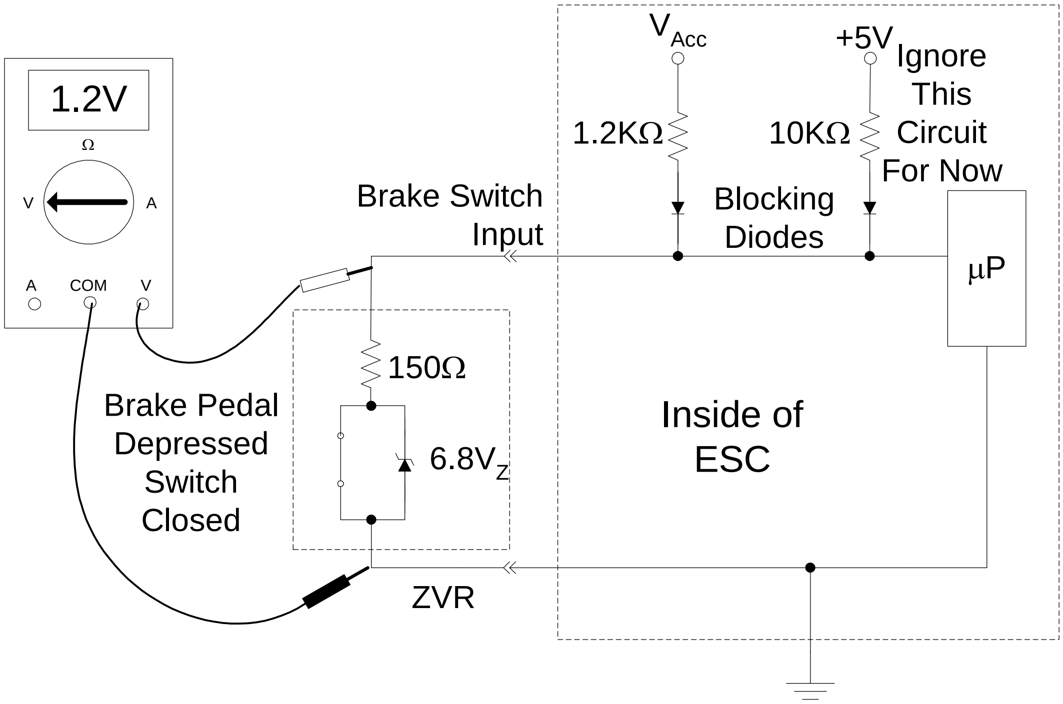

Figure 45　　Brake Pedal Depressed Ignition On

Depressing the brake pedal with the key switch in the ignition position causes the brake switch contact to close thereby shorting out the 6.8V zener diode. This causes the voltage at the brake switch input to drop to about 1.2V with the brake pedal depressed (Figure 45).

Now let's look at the brake switch circuit with some typical wire harness failure modes introduced. If the brake switch circuit is opened between the ESC brake switch input and the brake switch due to a cut wire or disconnected brake light switch, the voltage at the brake switch input would raise to about accessory voltage level less a diode voltage drop (Figure 46). An open in the ZVR circuit between the brake switch and ESC would also cause the voltage measured between the ESC brake switch input and ZVR to be about accessory voltage level less a diode voltage drop. Thus, the ESC can detect this failure mode and shut off and disable cruise control, and log a fault indicating the brake switch input voltage is out of range high.

If the brake switch circuit between the ESC brake switch input and brake switch were shorted to ground, the voltage level at the brake switch input would drop to about 0V (Figure 47). Thus, the ESC can detect this failure mode and shut off and disable cruise control, and log a fault indicating the brake switch input voltage is out of range low.

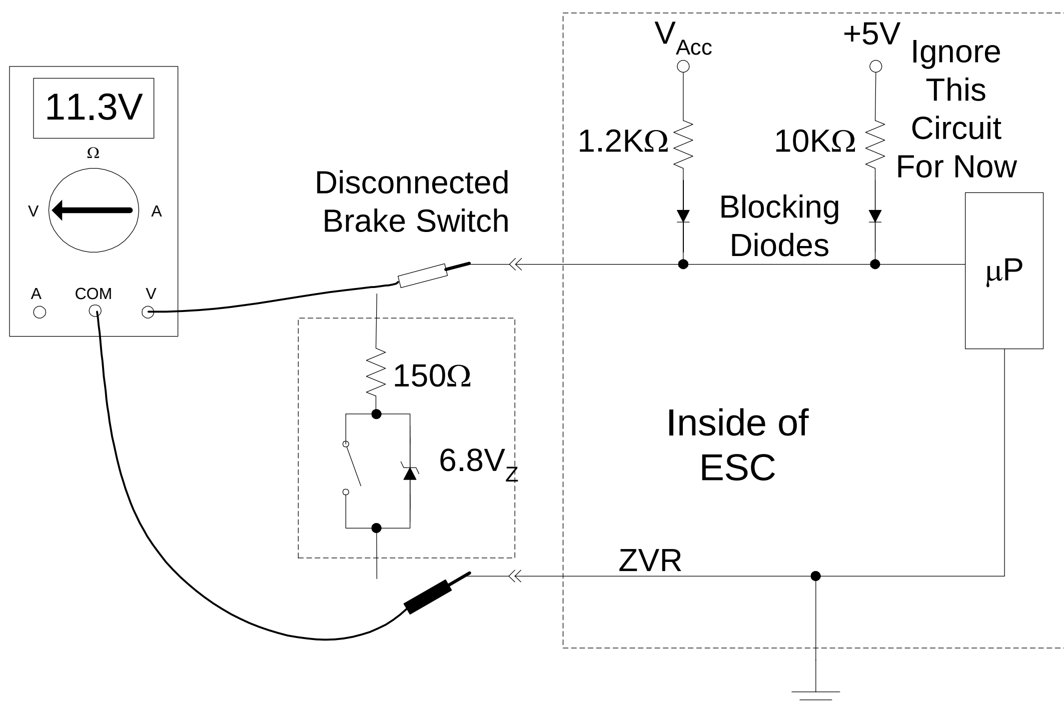

Figure 46 **Brake Switch Disconnected Ignition On**

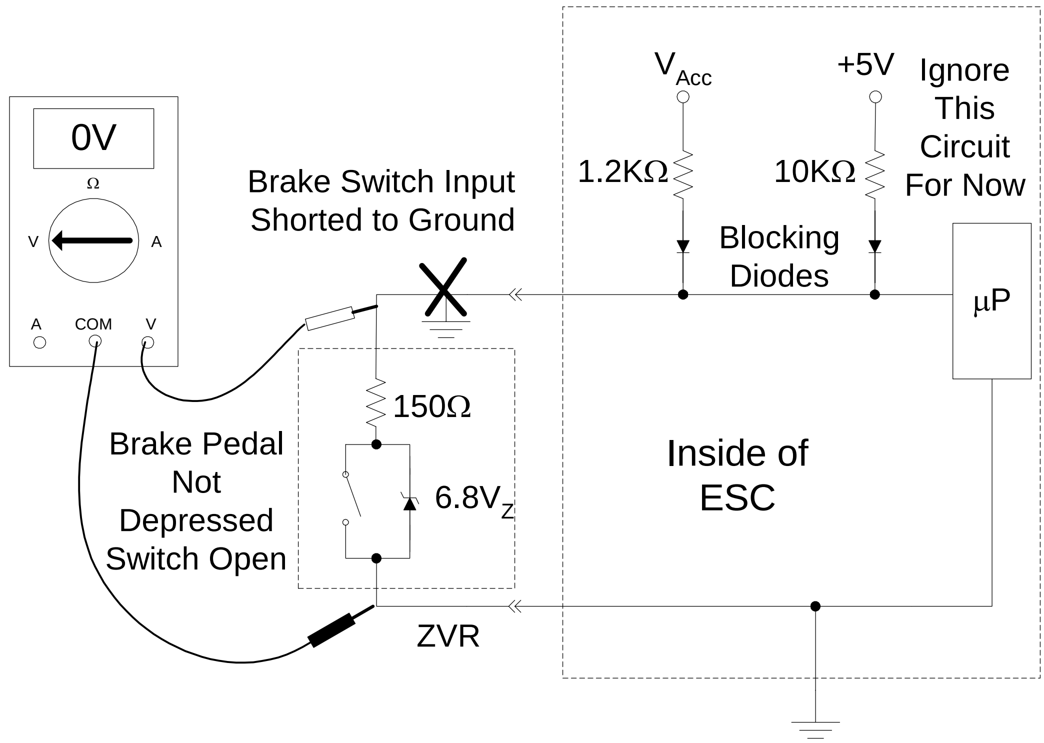

Figure 47 **Brake Switch Shorted to Ground Ignition On**

Now let's look at what happens at the brake switch input with the key switch in the off position. With the key switch in the off position, the brake switch input is biased to an ESC internal +5V through a 10K Ohm resistor and a standard diode (blocking diode). The standard diode in the +5V circuit prevents accessory voltage from backfeeding the 5V supply with the ignition on. Likewise, the standard diode in the accessory bias circuit prevents the +5V from backfeeding the accessory grid with the key switch off. The standard diode also drops about 0.7V so this causes the key-off bias voltage to drop to 4.3V instead of 5V. This 4.3V is not enough to switch on the 6.8V zener diode so almost no key-off current flows through the brake light switch. Voltage level at the ESC brake switch input with key switch off and brake pedal not depressed is about 4.3V as shown in Figure 48. If the brake pedal is depressed, the zener diode is shorted out and voltage level at the ESC drops to about 0.06V (60mV) as shown in Figure 49. Note that the ESC internal +5V is not the same +5V that acts as the supply voltage for sensors. The +5V supply used as the bias voltage for the brake switch input is present anytime the ESC is connected to battery voltage.

The ESC brake switch input is both an analog input and a digital input. The digital input is used to signal the microprocessor to switch on the brake lights. The analog input is used for brake switch diagnostics. The ESC does not perform switch diagnostics with the key switch off so no fault is set even though the input voltage is nearly 0V with ignition off and brake pedal depressed.

For tractor air brake applications and for trucks with trailer air brakes, only one brake switch is used. The single brake switch is located in the trailer brake feed line. Hydraulic brake vehicles also only use one mechanical brake light switch.

For truck air brake applications without trailer air brakes, two brake light switches are used. One switch is located in the primary air system; the other is located in the secondary air system. The two switches are wired in parallel, there is only one ESC input for brake switch. Because the two switches are in parallel, the voltages measured at the ESC input will decrease from a single brake switch application accordingly.

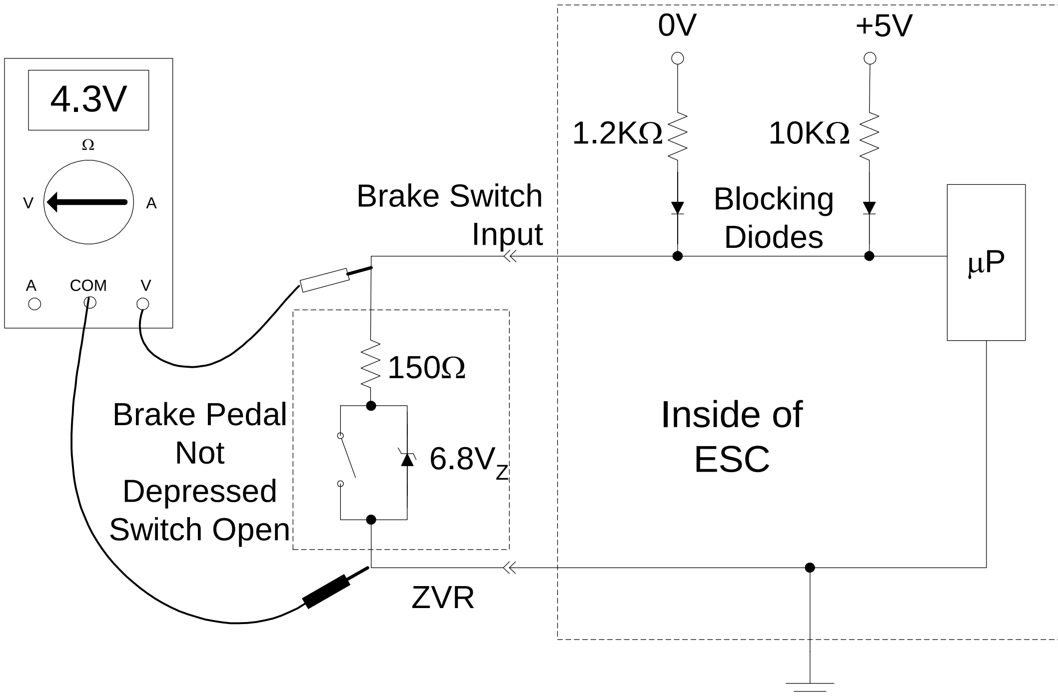

Figure 48 **Ignition Off, Brake Pedal Not Depressed**

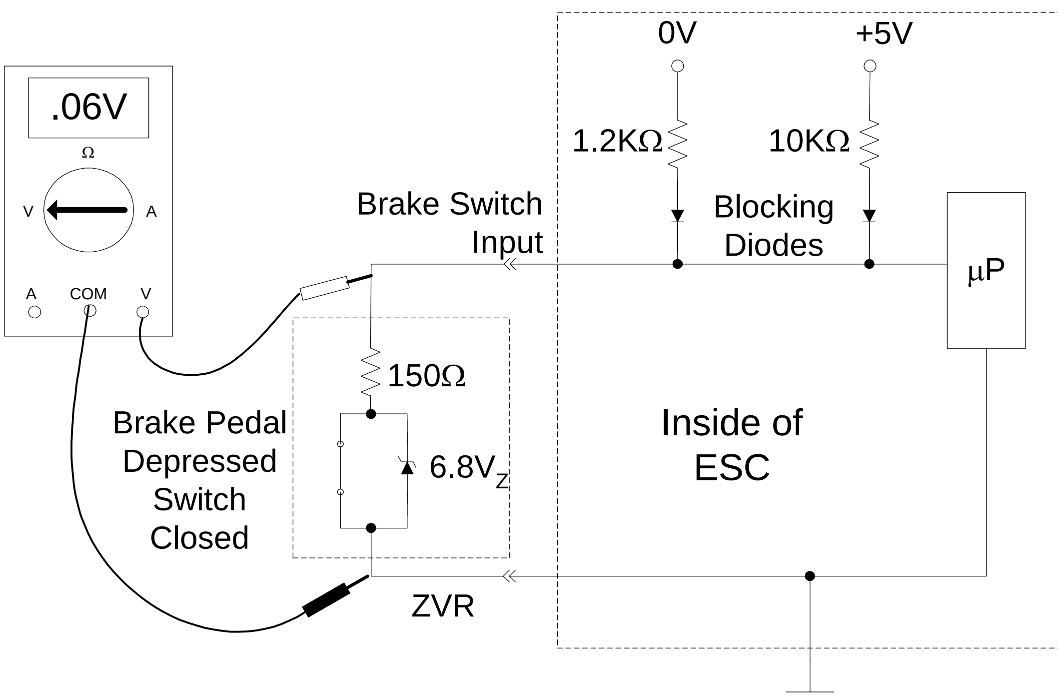

Figure 49 **Ignition Off, Brake Pedal Depressed**

Switch data link

A proprietary Switch data link provides communications between optional 6-switch and 12-switch pack switches located in the dash as well as power window/lock door pods. This private Switch data link permits data from up to 24 switches to be multiplexed down to 2 data wires. The Switch data link uses the specifications of J1708 and J1587. The wire colors of the twisted pair are dark blue for + and gray for -. Circuit ID number is also 3, like the J1708 ATA data link or J1708 Drivetrain data link as it is called. However, this private Switch data link is not a part of the familiar J1708 ATA data link. You cannot connect into this private data link and expect to see Drivetrain J1708 messages. Only the ESC, switch packs, and door pods communicate on the private Switch data link. If you connect some aftermarket J1708 device to the Switch data link, it will not work and will likely cause problems with the ESC and switch packs. Bottom line, don't do that. There is a splice pack in the dash harness near the wiper motor that you can connect to for J1708 Drivetrain data link. The ESC does not have any connection to the J1708 Drivetrain data link. J1708 Drivetrain data link is used on the High Performance Trucks primarily for engine, transmission, and ABS diagnostics only.

Switch Packs

Each truck may have up to two 6-switch packs and one 12-switch pack. Later-build trucks may also have a 3-switch pack, which has the same physical dimensions as a 6-switch pack. This special 3-switch pack will be discussed in greater detail later. Each 6 or 12 switch pack has two sets of wiring with opposite sex connectors. The switch packs are designed to be "daisy chained" together. That is, the first switch pack connects directly to the cab harness. Each remaining switch pack connects to the previous switch pack, etc as shown in Figure 50. The 6-switch packs fit into the DIN openings below the radio DIN opening. All 6-switch packs are identical except for the switch actuators. Each 6-switch pack knows which switch pack number it is based on addressing. The switch packs are addressed by a hardwired ground side address line. The first 6-switch pack is connected directly to the cab harness and is designated switch pack #1. There is no wire in cavity F of the cab harness switch pack connector. The 6-switch pack connected directly to the cab harness knows that it is switch pack #1 since cavity F has no ground wire. If another 6-switch pack is connected to switch pack #1, a wire in cavity F of switch pack #1 provides a ground on the second 6-switch pack address line. The switch pack knows that if cavity F of its connector is grounded, its address is switch pack #2.

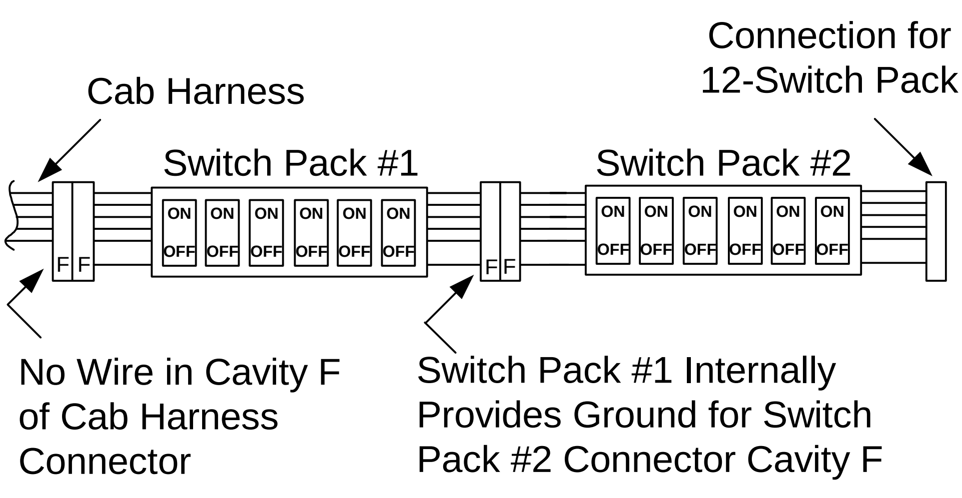

Figure 50 Switch Packs

The optional 12-switch pack is always assigned the unique address of switch pack #3 and switch pack #4 (like two separate 6-switch packs), regardless of how many other switch packs are on the vehicle. The unique software in the 12-switch pack causes it to always be addressed as switch pack #3 and #4, regardless if cavity F is grounded or not.

It is important to connect the switch packs in the correct order. Connecting the switch packs together and to the cab harness in the wrong order will cause switch pack addressing problems. The switch packs send a periodic message indicating the switch pack address. If a switch pack address that the ESC is expecting does not appear on the Switch data link, the ESC will set a fault indicating that switch pack x is missing. If two switch packs have the same address, they may send conflicting messages, which will really tick-off the ESC.

Switch packs are supplied with a chassis ground and accessory voltage feed. Therefore, features that are controlled by the switch packs cannot be operated unless the key switch is in the ignition or accessory positions. The switch packs are also supplied with a panel illumination feed from the electronic gauge cluster.

Two momentary-contact, circuit board mounted micro switches are located beneath each removable switch actuator as shown in Figure 51. The switch actuators are designed to depress either one or neither of the micro-switches. The state of the micro switches let the switch pack and ultimately the ESC know what position the switch actuator is in. Switch actuators may be two-position or three-position; and latch in one, two, or three positions. Switch actuators may also be momentary-contact type. The feature that the switch actuator is controlling dictates what type of actuator is used. For a feature such as fog lights, a two-position latching switch is used. With the fog light switch actuator in the off position (bottom of switch actuator depressed), the actuator depresses only the upper micro switch. With fog light switch actuator in the on position (top of switch actuator depressed), the actuator depresses only the lower micro switch. The switch actuator is two-position latching so it stays in the last position the operator has selected. A feature such as marker interrupt is also a two-position switch. However, the actuator is a momentary contact type. The switch actuator is spring loaded such that marker lights only change state when the actuator is depressed. The driver must hold down the actuator to momentarily change the state of the marker lights. Releasing the actuator returns the actuator to the non-interrupt position. An example of a three position latching actuator is the engine compression brake level actuator. With actuator in the 1 position, only the upper micro switch is depressed. With actuator in the 2 position, neither micro switch is depressed. With actuator in the 3 position, only the lower micro switch is depressed. Three-position actuators that are only latched in the center position (mono-stable) are also available and are used for remote power modules (RPMs) and some PTO features.

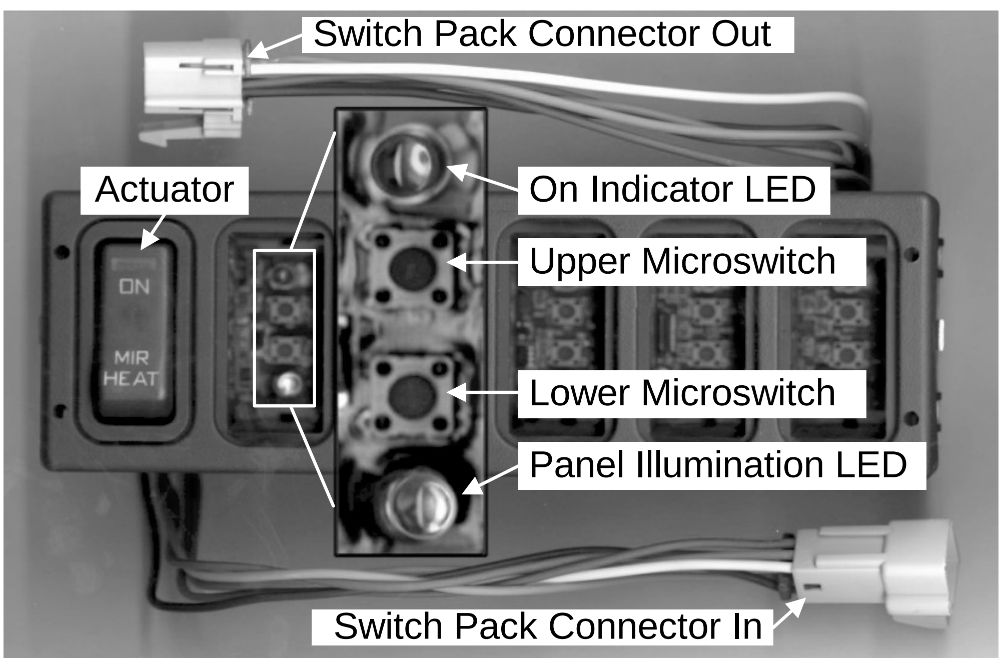

Figure 51 Switch Pack Micro Switches

The condition where both micro switches are depressed at the same time is an illegal state and will cause the ESC to set a fault. Additionally, if the ESC is expecting a 2-position switch actuator where a 3-position actuator has been installed, the condition where neither micro switch is depressed is also an illegal state and will set a fault.

The mounting holes for the LEDs in the switch pack are designed to accommodate either a green colored or amber colored LED. For most switch actuators, the upper LED emits a green colored light and only illuminates if the ESC is permitting the appropriate output to be switched on. The actual color of the LED lens when off may be green or clear. The lower LED is usually amber in color (lens appears clear when off) and is used for panel illumination. The base of the socket holding the LEDs is different for the two colors of LEDs. Green LEDs have a white colored base, amber LEDs have a black colored base. Other than color, the difference in the LED socket base is the location of one of the base contact wires. The switch pack circuit board LED mounting holes have three pads for the two LED base wires to contact. One pad is power for panel illumination feed, one pad is power for an indication of ON for that particular switch, and the other larger pad is a common LED ground. This permits an amber LED to always be panel illumination, regardless of which hole (top or bottom) in the switch pack circuit board the LED is placed into. Likewise, the green LED will always be the indication of ON regardless of which hole (top or bottom) the LED is placed into. Use care when installing these LEDs since they are keyed to ensure correct polarity. Unlike incandescent light bulbs, LEDs will not illuminate and may be damaged if reverse voltage polarity is applied.

The Switch data link is also used for communications between power window and lock door pods and the ESC. The power window and lock system is discussed in detail in the *How it All Works Together* section.

3-Switch Packs

Trucks built after late-2002 may have a 3-Switch pack if the vehicle is ordered with only 1 or 2 options that require a switch (not counting mirror heat which may be located in the EGC switch pack if the truck does not have a work light). The 3-Switch pack has the same physical dimensions as a 6-Switch pack. However, microswitches are only located in the first three switch actuator openings. Therefore, only three switch actuators may be installed in the 3-Switch pack assembly. The three remaining switch actuator locations have switch blanks installed. There is also only one electrical harness or pigtail on the 3-Switch pack assembly. This harness is designed to only be connected to the cab wiring harness. If additional features are added to the vehicle that requires more than three switches, the 3-Switch pack assembly must be removed and replaced with a 6-Switch pack assembly.

J1939 Drivetrain Data Link Inputs

The name assigned to the J1939 data link that connects the engine controller, ESC, electronic gauge cluster, automatic transmission controller, auxiliary gauge switch pack, and air ABS controller is the J1939 Drivetrain data link. Messages on the J1939 Drivetrain data link also act as inputs to the ESC. An example of such an input is vehicle speed. The engine controller transmits the vehicle speed over the J1939 Drivetrain data link. The ESC uses the vehicle speed information for several purposes such as inhibiting the operation of features such as power divider lock above a specific vehicle speed.

Body Builder Data Link Inputs

The name assigned to the proprietary J1939 data link that connects optional body builder electronic modules to the ESC is the Body Builder data link. Messages on the optional Body Builder data link act as inputs to the ESC. The Body Builder data link is discussed in the *Body Builder Applications* section.

ESC Outputs

ESC outputs are in the form of hardwired outputs or messages generated by the ESC over one of the data links. Hardwired outputs supply either high side (+12V) or sink low side (ground).

High Side Controlled Outputs

High side control is in the form of a direct high side feed. That is, the ESC provides the high side voltage for several relatively high-current loads such as headlights. The electronic devices inside the ESC that switch off and on the high current are called FETs. FET stands for Field Effect Transistor. You can think of these FETs as being the electronic equivalent of a relay. Like a relay, these particular FETs can only be either on or off, nothing in between. The FET is also like a relay in that a small signal is capable of controlling a large amount of current (Figure 52). Instead of the signal coming from a switch, the microprocessor provides a voltage signal to the FET causing the FET to switch on.

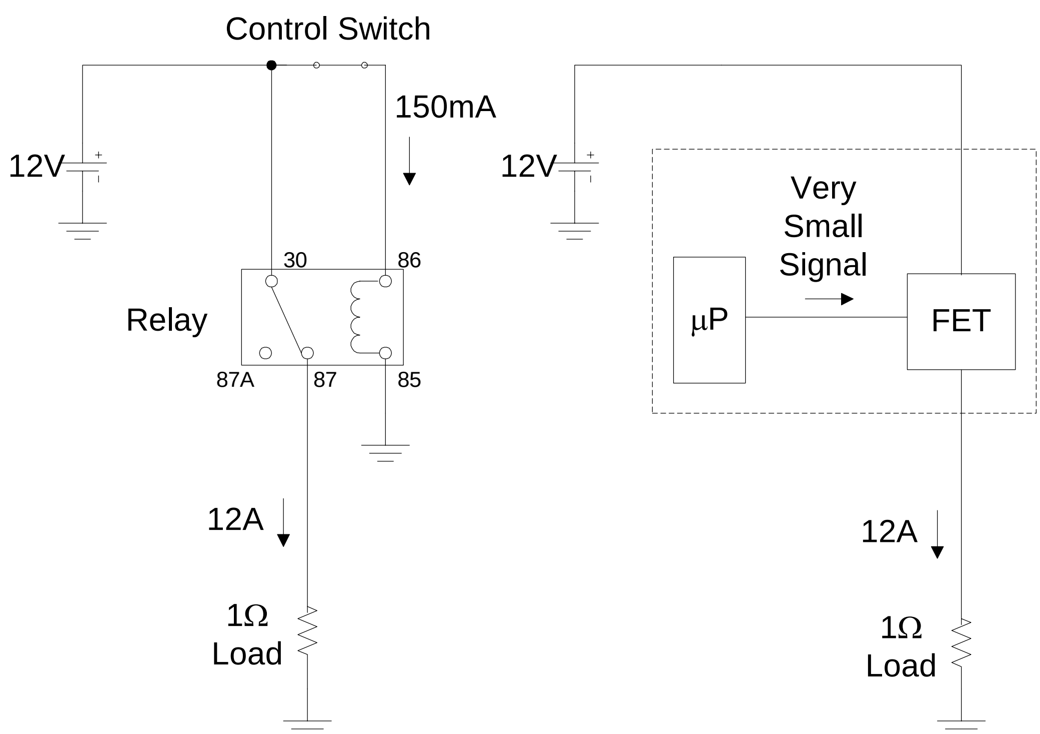

Figure 52 **FETs Compared to Relays**

The FETs used in the ESC have three different ratings, 1A, 10A and 20A. Standard devices use the following FETs:

1A FET Devices
Fuel Transfer Pump Enable (with 5-wire fuel transfer pump)
Hydro-Max Pump Motor Relay Coil

10A FET Devices
Turn signals (4 FETs, one for each corner)
Horn
A/C clutch

20A FET Devices
Low Beam Headlights
High Beam Headlights
Fog Lights
Tail, marker, clearance lights (all supplied by one FET)
Windshield wipers

Virtual Fusing (10A & 20A FETs)

The FETs used in the ESC are smarter than the average FET. The FETs are so smart that they are capable of measuring the amount of current being conducted by the FET. This information is sent back to the microprocessor so that the FET can be shut off if the FET is conducting too much current for its rating. This would be the case should a wire become shorted to ground or too many lights are installed on the vehicle. This "virtual fusing" as it is called eliminates the need for a fuse or circuit breaker in the individual high-side controlled circuits. Virtual fusing is designed to have the fusing characteristics of a circuit breaker. Virtual fusing for the FETs controlling the headlights and windshield wipers emulate an SAE Type I circuit breaker (automatic reset). Virtual fusing for all other FETs acts like an SAE Type II circuit breaker (resets with supply voltage cycled). For both types of virtual fusing, the ESC will permit currents of up to 110% of the rated output current (22A for 20A FETs, 11A for 10A FETs) indefinitely. As a circuit is overloaded more and more, the ESC uses a combination of time and current level to determine when to shut off the FET. If the ESC determines that the combination of time and current level is excessive, the overloaded FET is shut off and a diagnostic fault is set. Additionally, the FETs will also shut themselves off if the temperature of the FET reaches an unsafe value. The FET will cycle back on automatically when the FET temperature returns to a safe level. The ESC virtual fusing should shut the FET off before this temperature is reached.

Type I Virtual Fusing (Headlights and Wipers)

For the headlights and wiper FETs, the length of time before the ESC turns the FET back on to "retry" increases after each attempt. The first "retry" will occur at ½ second after FET was shut off due to the short or overload. If the short or overload no longer exists, the output will remain on indefinitely. However, if the circuit is still shorted or overloaded, the length of time will double between each "retry". The second retry will occur 1 second later, the third 2 seconds, etc. The maximum time the ESC will wait to retry a shorted or overloaded circuit is 512 seconds. After 512 seconds, the ESC will shut the FET off until the next key cycle. If the overload disappears at any time, the ESC will keep the output on indefinitely (as long as requested). The time between retries resets to ½ second if ignition is shut off and switched back on again.

Type II Virtual Fusing (All Others)

For all FETs except headlights and wipers, the ESC will retry the shorted or overloaded circuit ½ second after the FET has been shut off. If the short or overload still exists, the FET is shut off and not retried again until the next key cycle. After 3 successive key cycles with a shorted or overloaded circuit detected, the ESC will only permit the FET to switch on briefly (100ms) after each key cycle to test for the shorted or overload condition.

Low Side Controlled Outputs

Some ESC features are low side (ground) controlled. The ESC provides a switched path to ground for low current devices such as relay coils or small solenoids (Figure 53). These low side drivers as they are called are all relatively low current (0.5A or 1A) and are all contained in one chip. You can think of low side drivers as an electronically controlled switch to ground. Low side drivers are used for several optional vehicle features. This would include many compressed air powered options such as:

Air horn
Air suspension dump
Power Divider Lock
Differential Lock

The ESC provides control of these air-powered devices by providing a ground for individual air solenoids or for the optional air solenoid 4-pack. Low side drivers also control other optional relays such as trailer stop lamp relay and trailer turn signal relays. More on these systems later.

There are a total of 16 low side drivers in the ESC. Of these 16, four of them can also serve both as an input or output. This special type of low side driver output is used for the Wabco hydraulic brake warning lamp input as well as an output to the Wabco ABS controller as a request for diagnostic mode. More on the Wabco hydraulic ABS system later.

Low side drivers also have some diagnostic abilities. The example shown in Figure 53 shows that the low side driver chip contains a microprocessor (abbreviated μP). The low side driver chip is capable of detecting an open circuit or a shorted to ground circuit on each of the individual low side driver outputs. The chip is also able to detect that the driver is conducting too much current. If a driver is carrying too much current for its rating, the chip will protect itself by limiting current and by opening and closing the internal electronic switch (transistor) to prevent excessive temperatures which would otherwise damage the low side driver chip.

Let's first look at a normal low side driver circuit where everything is working properly. We'll use the trailer marker and tail lamp circuit as an example (Figure 53). Battery voltage (V_{Bat}) is connected to the high side of the relay. With the low side driver for the trailer marker relay switched off, we would expect to measure about +12V at the low side driver output for the trailer marker relay. When the park lights are switched on, the ESC switches on the trailer marker relay low side driver. This provides a low resistance path to ground for the trailer marker relay low side. The voltage level at the ESC trailer marker relay low side driver output drops from +12V to near 0V since the output has been switched to ground. This is normal operation for a low side driver; +12V at the output with the low side driver not switched on and near 0V with the low side driver switched on. Now what happens if the relay is removed from the circuit? The voltage level at an open circuited low side driver output is about +2.5V. This +2.5V comes from internal low side driver chip circuitry. The low side driver chip sees this +2.5V at any open circuited low side driver. This includes any unused low side drivers. The low side driver chip sees the +2.5V at the low side drivers and knows that the circuit is open. The ESC configuration programming also knows what low side drivers a particular vehicle uses. Any low side driver that is supposed to be used on a particular vehicle and has +2.5V at the output will set a diagnostic fault for an open low side driver circuit. The ESC ignores any unused low side drivers so faults are not set for these unused outputs, even though the voltage level is +2.5V.

The ESC also detects a low side driver that is shorted to ground. A short to ground causes the voltage at the low side driver output to drop to near 0V. Any voltage level less than 2V at a low side driver output <u>with the low side driver not switched on</u> causes the ESC to set a fault for that particular low side driver output shorted to ground. The ESC can also detect if loads are attached to unused outputs. If the voltage level on an unused low side driver output is greater than 3V, a fault is set indicating a load is connected to a low side driver that is supposed to be unused. This fault could be caused by a wire not being in the correct ESC connector cavity or by the ESC programming not being correct for the current vehicle configuration.

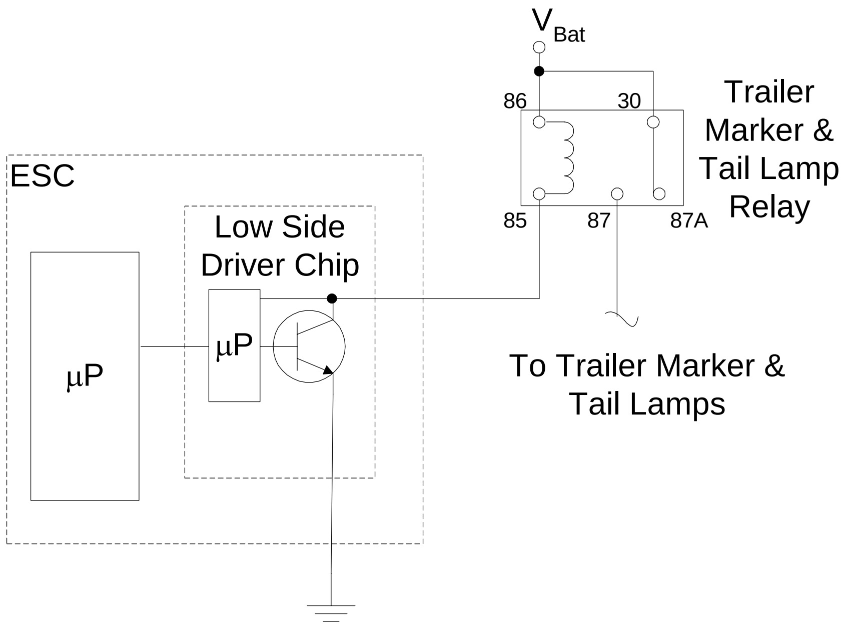

Figure 53 **Low Side Drivers**

Switch data link Control

The ESC is capable of control via the Switch data link. For example, the switch pack contains green on-indicator LEDs that are commanded to illuminate by the ESC over the Switch data link. The ESC switches on these LEDs when the corresponding output is switched on by the ESC. The ESC also commands these LEDs to flash under some circumstances such as when the driver has requested an action that is not permitted because of current vehicle speed, etc.

J1939 Drivetrain Data Link Control

Some features are controlled by messages transmitted onto the J1939 Drivetrain data link by the ESC. These features are then normally directly controlled by another electronic control module on the J1939 Drivetrain data link. Examples of features controlled by the ESC via J1939 Drivetrain data link messages include: cruise control, air pressure gauges, fuel gauge, and voltmeter. The hardwired input for each of these features is the ESC. The output is another device on the J1939 Drivetrain data link. For example, the fuel-sending unit is an analog input to the ESC. The ESC calculates the fuel level based on the voltage at the ESC fuel level sensor analog input and transmits a message containing fuel level information on the J1939 Drivetrain data link. The electronic gauge cluster (EGC) sees this message on the J1939 Drivetrain data link and drives the fuel gauge to the appropriate needle setting. This is similar to the way the engine controller drives some engine gauges over J1708 on previous truck models.

Body Builder Data Link Control

Some optional features are controlled by messages transmitted onto the optional Body Builder data link. Devices connected to the Body Builder data link respond to the messages and control their outputs accordingly. An example is the optional 7-pack air solenoid module, which is discussed in further detail in the *Air Controlled Optional Devices* section.

ESC Power Supply

The ESC has two separate 8 American Wire Gauge (AWG) sources or one single 4 AWG cable for battery power supply. On earlier models of High Performance Trucks, each of these cables is fused by a 60A Maxi fuse in the Power Distribution Center (PDC) located in the engine compartment near the dash panel. On later models, an integral fusible link protects each power supply input cable. Trucks built after mid-2003 have a single 4 AWG power supply cable. On ESCs with two power supply cables, half of the FETs are supplied battery power by one of the cables, the other half are supplied by the other cable. If one of the 60A ESC Maxi fuses or fusible link opens, features controlled by the FETs sourced from that fuse will not operate. This will cause the ESC to set a fault code for battery power supply open circuited. The ESC microprocessor power supply is sourced from either of the two battery power supplies (or the single battery power supply) or from the accessory input. The two or three sources of microprocessor power each pass through a diode to prevent the two or three supply sources from back feeding each other. The two or three separate sources provide redundancy for ESC microprocessor power.

ESC Ground

The ESC is grounded to the chassis through a 12 AWG wire located in the ESC cab side 8-way connector. The ESC ground wire is connected to chassis ground at the dash panel ground stud. ZVR is connected to the ESC ground at one location inside the ESC. The ESC exterior aluminum case is only grounded by its mounting to the dash panel. The ESC case may or may not be at the same potential as chassis ground, so don't use it for a voltage reference point. The paint on the dash panel may insulate the ESC case from ground. Don't worry about cleaning off the paint to ground the ESC case. It does not need to be grounded. Some mechanics have trouble understanding that two 8 AWG cables protected by 60A fuses (or fusible links) or one 4 AWG cable supply the high side to the ESC and yet the ESC ground is only a single 12 AWG wire. The amount of current flowing through the ESC ground wire is minimal. The ground wire must only carry the current of the relay drivers when they are switched on as well as the current drawn by the microprocessor and other "chips" in the ESC. This is an important concept to understand. The loads that the ESC supplies the high side power to are grounded at various locations throughout the vehicle.

ESC Memory

The memory used to hold the ESC programming is retained in what is called flash memory. The flash memory is non-volatile which means the memory is retained if the power is disconnected. Flash memory is similar to EPROM memory. The flash memory can be reprogrammed numerous times over the J1939 Drivetrain data link using a computer with International Configuration, AFC and Programming (ICAP) software.

Single Power Lead ESC Differences

The single-power lead ESC is similar to the previous versions of ESC. The power supply for the single-power lead ESC is a single 4 AWG cable instead of two separate cables. The single-power lead ESC housing is half aluminum and half plastic. The single-power lead ESC provides some additional functionality over the previous versions of ESC. Specifically, the single-power lead ESC contains the circuitry for the HydroMax monitoring module and the water in fuel (WIF) module. Both of these modules will be removed from the applicable wire harness on vehicles built with an single-power lead ESC (mid-2003). Additionally, the diode in the IP harness between the ignition and accessory relay coils will be integral to the ESC and will be removed from the IP harness on these vehicles. This means that accessory will drop out during engine crank on vehicles built with a single-power lead ESC.

The single-power lead ESC will also be a direct replacement for all ESCs without any modifications to the vehicle wiring. The revised ESC is designed to function both with and without a HydroMax monitoring module or WIF module. However, an earlier dual-power lead ESC cannot be installed in a truck designed for a single-power lead ESC.

Electronic Gauge Cluster (EGC)

The EGC, located in the instrument panel, includes: audible alarm, analog gauges, warning lamps, headlight switch, panel illumination level control, and an alpha-numeric Liquid Crystal Display (LCD) display. All gauges and most warning lamps in the EGC are controlled by J1939 Drivetrain data link messages. Direct sources of these messages are: engine controller, automatic transmission controller, pyrometer-ammeter module, and ESC.

Figure 54 Electronic Gauge Cluster (EGC)

The alphanumeric LCD display serves several purposes. Primarily, the LCD is used to display odometer information. A push-button next to the display permits changing the odometer to engine hours, trip hours, trip miles, and MPG. Later revisions of the EGC also have the ability to display accumulated PTO operational hours in the LCD. The push-button also permits changing the units between English and metric units by holding button down for several seconds.

The LCD also displays automatic transmission PRNDL (selected range) information directly above the odometer when applicable. A bar under the PRNDL display indicates which range position the shifter has been placed in. If the automatic transmission data is not available, the bar under the PRNDL display will not indicate any range information.

A second function of the LCD is to display diagnostic fault codes generated by the ESC, AGSP, and EGC. The EGC stores historic faults in non-volatile EEPROM memory (does not erase with battery disconnection). More information on diagnostic fault codes is in the troubleshooting section.

The EGC also houses the headlight switch and panel illumination control. The headlight switch is a 3-position latching rocker switch (off-park-on). The headlight switch position is transmitted on J1939 Drivetrain data link by the EGC. The ESC receives this data link message and controls headlights and park lights accordingly by switching on the appropriate FETs. In addition to the headlight switch and panel illumination control, a third switch may also be placed adjacent to the panel illumination control. This third switch can be either a work light switch or a mirror heat switch. In the case of this third switch, the EGC transmits the status of the mirror heat or work light switch to the ESC via J1939 Drivetrain data link.

In the area at the right side of the EGC opposite the headlight switch, an optional push-button start and ether start switch can be located. These switches are hardwired and have no connection to the EGC electronics. The EGC just provides the mounting platform for these optional switches.

The EGC controls panel illumination as well. With the headlight switch in park or on position, the EGC panel illumination is also switched on. The EGC also provides panel illumination for other interior devices such as radio and HVAC control. The panel illumination output from the EGC is high-side control (10A FET). The panel illumination level is obtained through duty-cycling the output. Duty cycling is also called pulse width modulation or PWM. This just means that the EGC switches the panel illumination FET off and on at a high rate (100Hz). The higher the panel illumination setting, the greater the percentage of time the EGC leaves the FET on for. At a 50% duty cycle, the FET is on ½ the time and off ½ the time as shown in Figure 55. This causes the panel illumination in the EGC, the radio, and the switch packs to appear at about half brightness. This is about as supplying the lighting with a continuous 6V. At 15% duty cycle (minimum level), the panel illumination appears to be barely on since voltage is only on and current only flowing through the panel illumination bulbs or LEDs 15% of the time. At 100% duty cycle, the panel illumination is on continuously so the bulbs or LEDs appear at full illumination.

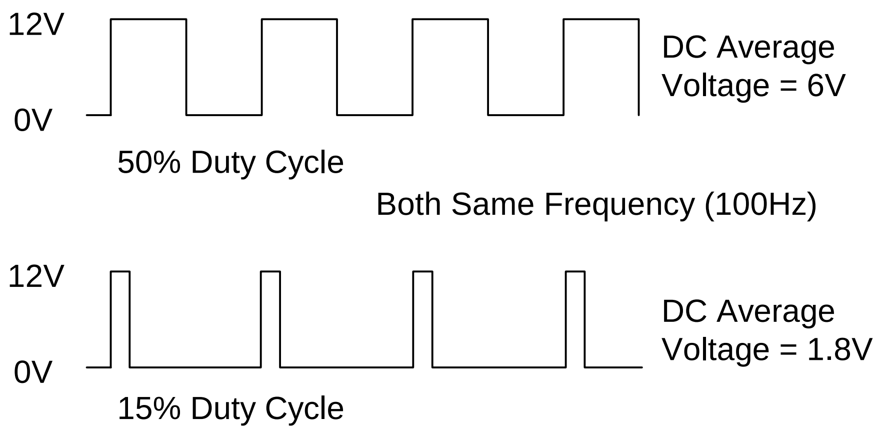

Figure 55 Panel Illumination PWM

The standard warning lamps in the EGC are not lamps at all, but rather LEDs. Service life of LEDs is much longer than conventional incandescent bulbs. Most of these LEDs are controlled by the ESC. That is, the ESC sends a J1939 Drivetrain data link message to the EGC. The EGC then commands the appropriate LED to illuminate. Some engine warning LEDs are directly controlled by the engine as well and do not depend on the ESC. Depending upon the ESC software revision level, the Check Electrical System (CES) LED may be directly controlled by the EGC. If the EGC does not detect ESC or engine messages on the J1939 Drivetrain data link, it will illuminate the CES warning lamp and log a fault.

The left-lower section of the EGC has four warning LEDs. Some truck equipment manufacturer (TEM) applications have special graphics for these four warning LEDs such as boom not stowed, outriggers not stowed, and PTO engaged.

The EGC also has provisions for some hard-wired incandescent warning lamps. These include differential lock indicator, auto-neutral, and others. Space for up to four incandescent lamp sockets are located in the right lower portion of the EGC. These optional warning lamps are not controlled by the EGC in any manner. The EGC just provides the socket to hold the hard-wired warning lamps.

The information for all gauges is obtained from J1939 Drivetrain data link messages. Sources of the J1939 data for the gauges include the engine controller, ESC, transmission controller, and pyrometer-ammeter module (PAM). Gauges controlled by the ESC or engine controller (other than speedometer and tachometer) will drive to 6 O'clock position should a sensor fault occur. For example, if the fuel sending unit circuit is opened, the fuel gauge will drive to the 6 O'clock position. Some gauges also contain a warning LED. These include the air pressure gauges, fuel gauge, voltmeter, oil pressure, coolant temperature, and transmission oil temperature. When the EGC sees the applicable data go above or below a predetermined level, the warning LED in the gauge illuminates. The warning LED also illuminates if the sensor associated with the gauge is faulted.

The analog gauges in the EGC are stepper motor driven gauges. A stepper motor is an electric motor that is capable of being driven in discrete increments of rotation. Each gauge has 3060 possible steps or positions between zero and full-scale deflection. This large number of steps makes the gauge appear to move in a smooth motion. The speed at which the gauge is driven to the desired needle setting is controlled by the EGC. A gauge such as the tachometer must respond quickly to commands from the engine controller since the actual engine RPM can change very quickly. It is desirable for some gauges to respond very slowly to changes. An example is the fuel gauge. By slowing the speed at which the fuel gauge moves to a new location, fuel sloshing caused by bumps, cornering, or rapid changes in vehicle speed will not cause the fuel gauge needle setting to oscillate.

The EGC also contains the audible alarm. The alarm provides a continuous cyclic beep for the low air pressure warning and Hydro-Max alarm. The alarm also beeps three times should the gauge warning LED illuminate indicating a gauge reading is out of the normal operating region (i.e. high engine coolant temperature). This three-beep cycle will only occur once per key cycle. The alarm will also beep five times per key cycle if the sensor associated with a gauge is out of range. Other features may cause the ESC to request the EGC to sound the alarm such as air suspension dump.

The EGC contains a microprocessor. The EGC microprocessor is taught what gauges and warning lights it contains and the ranges of normal operation for these gauges by the ESC. The EGC generates a check-sum number indicating how it has been taught and transmits this message periodically over Drivetrain data link. If the check-sum value does not agree with the ESC, the ESC will attempt to reteach the EGC. If new gauges are added to the EGC, the ESC programming must also be modified so the ESC can teach the EGC what the new gauges are. A gauge that is not taught will still sweep when the key switch is first turned on, but the data that the non-taught gauge displays is meaningless.

The program memory in the EGC microprocessor is also different than that used in the ESC. The program memory in the EGC cannot be reprogrammed. Replacement of the EGC microprocessor is necessary to change the EGC programming. The EGC microprocessor is soldered to the main circuit board so replacement of the main circuit board is necessary to upgrade the EGC programming. The EGC does contain some EEPROM memory for retaining previous faults logged by the ESC or EGC. This EEPROM memory is non-volatile so previously active faults remain in memory even if battery power is disconnected.

Gauge Cluster Revisions

The version of EGC main circuit board is shown briefly in the alphanumeric LCD display after cycling the ignition on. Main circuit boards prior to version 10 have minor programming changes to improve EGC functionality. Version 10 main circuit boards have introduced several changes to the EGC hardware and software. These hardware changes require a different headlight switch pack and audible alarm than those used on previous hardware revisions. If you replace a pre-version 10 circuit board with a post version 10 circuit board, you must also replace the headlight switch 3-pack and audible alarm. The audible alarm is a simple electronic beeper on EGC versions prior to version 10. Version 10 and later revisions use a speaker instead of a beeper for the audible alarm. The speaker is used to emit a "clicking" sound when the turn signal switch is on. The speaker type alarm should only be used on version 10 and later EGCs.

One change that you may notice with version 10 and later hardware is that the turn signal indicators in the EGC do not illuminate if the turn signal switch is on with the key switch off (although the turn signals on the truck still operate with the key switch off). However, with the flasher switch on and the key switch off, both turn signal indicators will illuminate. The cruise control LED has also been eliminated on Version 10 and later EGCs.

Version 11 main EGC circuit boards changed the manner in which the EGC handles odometer data. On versions prior to version 11, the EGC odometer simply displayed the current total vehicle miles data, which was transmitted over J1939 Drivetrain data link by the engine controller. Thus, the engine controller was responsible for accumulating and storing the total vehicle miles. If a version 10 or earlier EGC were removed from a vehicle with 100,000 miles and installed in another vehicle with 100 miles, the odometer in the version 10 EGC would display 100 miles since the engine controller is transmitting a J1939 Drivetrain data link message indicating the vehicle accumulated 100 miles.

With version 11 and later, the EGC accumulates and stores the total vehicle miles data in non-volatile memory. Thus if a version 11 EGC were removed from a vehicle with 100,000 miles and installed into a vehicle with 100 miles, the odometer would display 100,000 miles even though the engine controller indicated that accumulated miles were only 100 miles. If the vehicle were then driven, the odometer would begin accumulating miles from 100,000 miles, not 100 miles. For example, if the vehicle were driven 10 miles the odometer would display 100,010 miles. If we returned the version 11 EGC to the original vehicle, the odometer would still indicate 100,010 miles and would increment future miles to that value. This is similar to the functionality of a mechanical odometer. Note that the version 11 and later EGC's only write the total miles data to non-volatile memory every five miles of vehicle travel or when the key switch is turned to the OFF position, even though the displayed value changes with every 1 mile of distance traveled. If battery power to the EGC were lost before the EGC has written the total miles data to non-volatile memory, the odometer would display the previously stored value when battery power was restored. This means that the most the odometer can be off due to an inadvertent loss of EGC battery power is 5 miles.

Pyrometer Ammeter Module (PAM)

The Pyrometer Ammeter Module or PAM is used to convert the output of the pyrometer thermocouple and/or ammeter shunt to a value that is transmitted over the Drivetrain J1939 data link. The PAM is located in the engine compartment in a small plastic package with a sealed connector and is mounted to the back of the air cleaner housing on International engines.

Auxiliary Gauge-Switch Pack (AGSP)

The Auxiliary Gauge-Switch Pack (AGSP) is a hybrid device that communicates on the J1939 Drivetrain data link. As its name implies, the AGSP has provisions for both gauges and switches (Figure 56). Up to three gauges and six switches may be installed in the AGSP. The design of the switch portion of the AGSP is very similar to a 6-Switch pack and uses the same switch actuators and LEDs. The AGSP has the same dimensions as a 12-Switch pack and is designed to fit into the double DIN slot in the IP. The AGSP is supplied with accessory voltage, ground, and panel illumination from either the last 6-Switch pack or the cab harness connector for the 6-Switch pack if the truck has no other switch packs. A separate fuse in the IP fuseblock supplies battery power to the AGSP. The AGSP is connected to the Drivetrain J1939 data link in the cab through a 2-wire connector. The AGSP has no Switch data link connection. The AGSP transmits information on the status of its switches over the J1939 Drivetrain data link. The AGSP also drives its gauges based on information received on the J1939 Drivetrain data link similar to the EGC.

The AGSP is only available on 7000 and 8000 series High Performance Trucks. The gauges available for the AGSP include: air application, axle temperatures (FR & RR), fuel pressure, boost pressure, pyrometer, and ammeter.

Figure 56 Auxiliary Gauge Switch Pack (AGSP)

How It All Works Together

In this section, we'll take a detailed look at how several of the electrically controlled features work. The electric horn is an easy system so we'll start with it.

Horns

Electric (city) Horn

The ESC horn input is a digital input that is biased to battery positive (V_{Bat}) through a 1.2K-Ohm resistor. Pressing the horn pad causes a low current switch to close and provide a path to ZVR. This path to ZVR pulls the input voltage down to near 0V. To sound impressive, we'll say that closing the horn switch pulls the ESC horn input low. The ESC microprocessor detects this logic low level and commands the 10A horn FET to switch on. Switching the horn FET on provides +12V to the horn. The other side of the horn is hardwired to chassis ground. Therefore, current flows from the FET through the horn to chassis ground, ultimately causing the horn to honk. When the operator is no longer depressing the horn pad, the horn switch opens and the ESC input pulls back to a high logic level again because the input is biased to battery positive. The ESC micro sees this high level at the horn input and commands the horn FET to shut off. The high side (+12V) is no longer supplied to the horn so the horn stops honking. Many other features operate in a similar manner. A hardwired switch input causes an ESC digital input to go low (0V), the ESC responds by turning on a high current FET to provide the high side for the device being controlled. The complete circuit is illustrated in Figure 57.

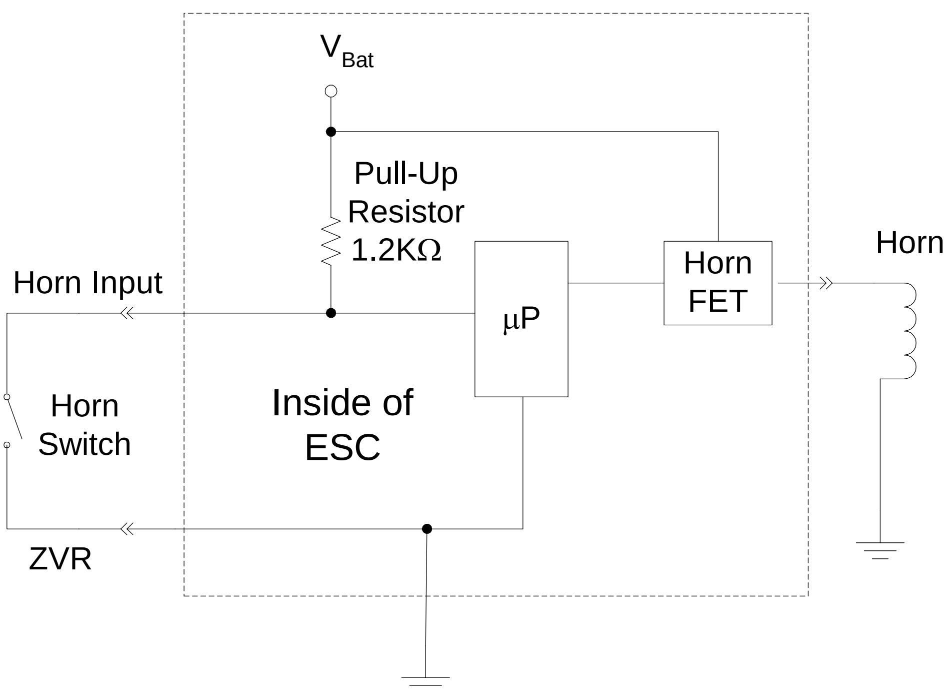

Figure 57 Complete Electric Horn Circuit

Air Horn

The air horn functionality is described in the Air Controlled Features section.

Vehicle Lighting

Dome Light

The dome light is another easy circuit as shown in Figure 58. The low current proximity switches or push-button switches in the B-pillar of each door are all wired in parallel. With the door closed, the switch is open and the voltage level at the dome light digital input is near accessory voltage level or 4.3V depending if key switch is on or off. The dome light switch input is biased to accessory with ignition on and biased to 5V less a diode voltage drop (4.3V) if ignition is off. Opening the door causes the voltage level at the dome light digital input to drop to near 0V. When the ESC sees indication of an open door, the ESC switches on the 10A dome light FET. The low side of the dome light is hardwired to ground so the dome light illuminates. When the door is closed, the ESC will turn the dome light FET off immediately if ignition is on or wait 20 seconds before turning off dome light FET if ignition is off. If the dome light is in 20-second delay mode, the level of the dome light illumination will drop by 10% when the door is first closed. This reduction in illumination level provides a confirmation that the ESC will turn off the dome light in 20 seconds. The dome light can also be supplied with battery voltage by pressing up on the dome light lens. If the dome switch is in this ON position, the dome light will remain on continuously. Therefore, if you close the door with ignition off and do not see the 10% drop in dome light illumination, the dome light switch is probably in the on position. The time (20 seconds) and duty cycle (10%) are both programmable parameters that can be modified. The ESC dome light FET also supplies the current for optional courtesy lamps.

Earlier models of High Performance Trucks also had a diode in the dome lamp assembly. The diode has been removed and the dome light switch has been reconfigured to source the bulbs with current from either a battery fuse or from the ESC dome light FET. Therefore, the optional courtesy lamps will not illuminate on later models with the dome lamp switch in the ON position unlike the operation with earlier models.

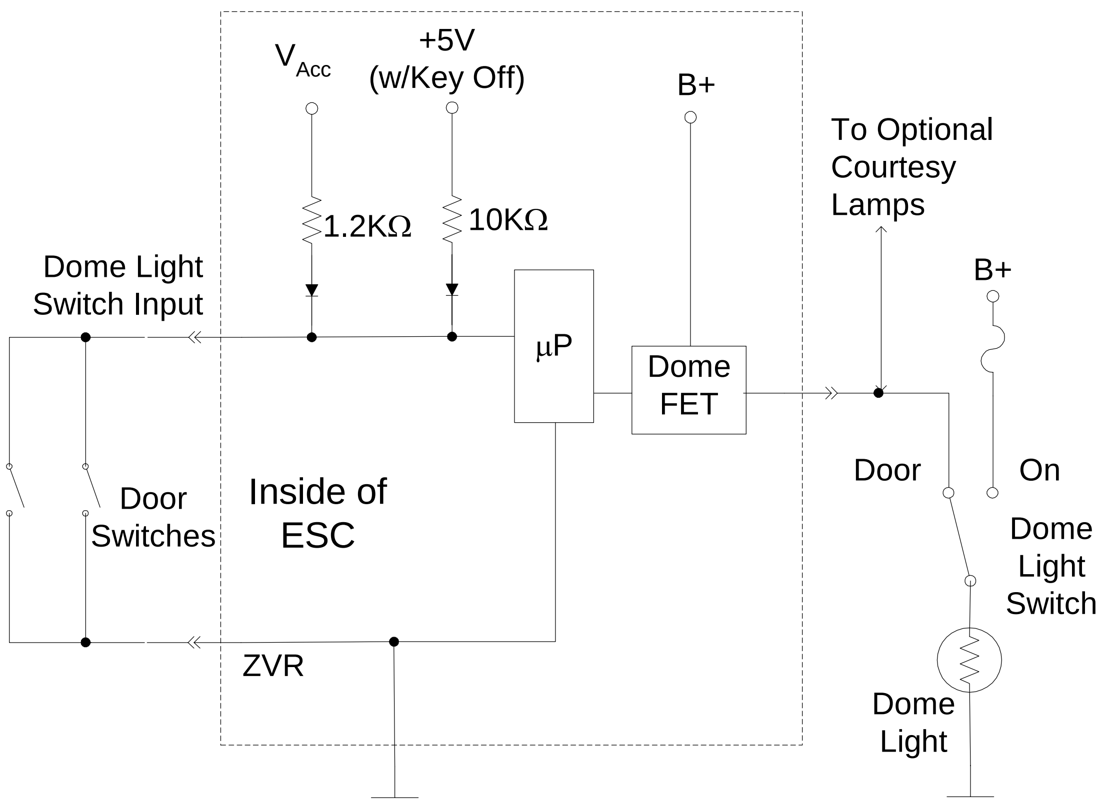

Figure 58 Dome Light Circuit

Turn Signals and Hazard Flashers

You won't find a conventional flasher on these trucks. The ESC performs the function of the turn signal and hazard flasher. The turn signal and hazard input consists of two biased high digital inputs (Figure 59). The left and right turn signal digital inputs are each biased to +5V less a diode drop (4.3V) through a 10K Ohm resistor with the key switch in the off position. Both turn signal digital inputs are biased to accessory through a 1.2K-Ohm resistor with the key switch in the accessory or ignition positions. Closing the left or right turn switch contact pulls down the appropriate ESC digital input. Since there are several differences between vehicles with combination rear stop-turn lights and separate rear stop-turn lights, we'll look at each system separately.

Turn Signals With Combination Rear Stop-Turn Lights

The ESC contains four 10A FETs for the turn signals, one for each corner of the vehicle. The two FETs for the rear combination stop-turn lights will also perform the function of brake lights. If the left turn switch contact is closed, the ESC responds by cycling the left front and left rear FETs on and off at a predetermined rate for as long as the left turn signal switch is closed. The right turn contact does the same thing for the right turn FETs. Depressing the hazard switch causes both left and right turn signal inputs to pull down to ZVR. This activates all four turn signal FETs.

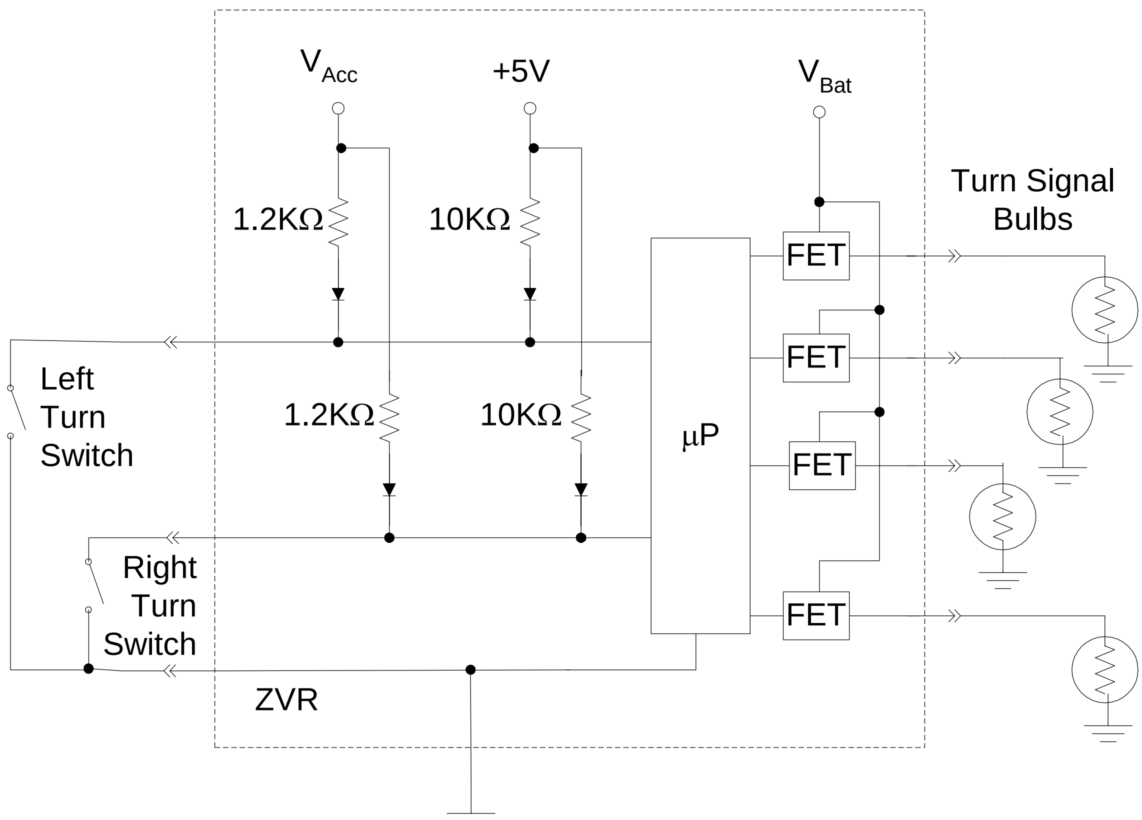

Figure 59 Turn Signal and Hazard Flasher Circuit

Turn Signals With Separate Rear Stop-Turn Lights

If the vehicle has separate rear stop-turn lights, then the front turn signal FETs also act as the high side for the rear turn signal bulbs as well as the front turn signal bulbs. A front turn signal splice pack in the dash wiring harness provides a connection point for the rear turn lights. The rear turn signal FETs are not used.

Trailer Turn Lights

On vehicles with a trailer socket, turn signal FETs also supply the high side to the trailer left turn and trailer right turn relay coils located in the PDC. Depending on how the trailer is wired, the front turn FETs or rear turn FETs are used to provide the high side to the trailer turn relays. If the trailer lights have combination stop-turn lights then the combination stop-turn splice pack is used to supply the trailer turn relay coil high side. If the trailer lights have separate stop-turn lights, then the front turn signal spice pack is used to supply the trailer turn relay coil high side. The output of the trailer turn signal relays supply battery voltage to the trailer socket turn signal terminals when the relay is energized.

Brake Lights

Depressing the brake pedal closes a special diagnosable brake switch contact. Details on the operation of this special switch were discussed in the section on analog inputs.

Brake Lights With Combination Rear Stop-Turn Lights

On vehicles equipped with combination rear stop-turn lamps, the rear turn signal FETs are also the brake light FETs. If neither turn signal switch is closed, the ESC switches on both rear turn signal FETs when it detects that the brake pedal is depressed. If a turn signal switch is also closed with brake pedal depressed, the ESC switches on the rear turn FET for the side opposite the turn continuously and cycles the rear turn FET for the side of turn. Hazard flashers on with brake pedal depressed is a programmable parameter in the ESC software. The default parameter setting is that brake lights will override hazard lights. That is, the rear turn lights will illuminate continuously if brake pedal is depressed with hazards on. The ESC software may be modified so that hazard lights will override brake lights.

Brake Lights With Separate Rear Stop-Turn Lights

Vehicles with separate stop and turn lamps utilize a body and trailer stop lamp relay to supply voltage to the rear stoplights. The high side of the relay coil is supplied with battery voltage. The low side of the relay coil is connected to an ESC low side driver output. The ESC switches on the low side driver when the microprocessor determines that the brake pedal is depressed. When the relay is energized, battery voltage is supplied to the rear stop lamps as well as the trailer 7-way socket, if applicable.

Headlights

The headlight switch is a part of the EGC. Beneath the 3-position headlight switch actuator are two micro switches mounted to a small circuit board. This arrangement is very similar to the switch packs shown in Figure 51. The switch actuator causes either one or neither of the micro switches to be depressed. With headlight switch in the off position, the upper micro switch is depressed. With headlight switch in the park position, neither micro switch is depressed. Finally, with headlight switch in the headlight position, the lower micro switch is depressed. The microprocessor in the EGC detects the status of the micro switches. From the status of the micro switches, the EGC generates a J1939 Drivetrain data link message indicating the requested headlight state (on, off, or park).

The ESC contains two 20A FETs that are used for headlights as shown in Figure 60. One 20A FET is used for both low beam headlights; another 20A FET is used for both high beam headlights. The ESC has accessory biased digital inputs for dimmer switch and flash-to-pass (FTP). If the EGC sends a J1939 Drivetrain data link message requesting headlights, the ESC switches on the low beam FET. If the ESC then sees a change in the dimmer switch input, the low beam FET will be switched off and the high beam FET switched on. The dimmer switch is a simple momentary contact switch. The ESC keeps track of which headlights are currently on, high beam or low beam. If the dimmer switch is toggled again, the ESC will switch off the high beam FET and switch on the low beam FET. The dimmer switch is activated by pulling the multifunction switch (turn signal stalk) all the way back to an internal stop.

The FTP switch contact is closed when the multifunction switch stalk is pulled back about ½ way between relaxed position and dimmer position. The FTP input is used to temporarily change the state of the headlights. If headlights are off and the FTP switch is closed, the ESC switches on the high beam FET for as long as the FTP switch is closed. If headlights are on, the high and low beams will toggle. That is, if low beams are on, the high beams will illuminate for as long as FTP switch is closed. Conversely, if high beams are on, the low beams will illuminate for as long as FTP switch is closed (both high and low beam are never on at the same time). Releasing the multifunction switch will return the headlights to the last state.

Since the FTP and dimmer switches are both biased to accessory voltage, neither will function with the key switch in the off position. Only low beam headlights will illuminate if the headlights are switched on with the key switch in the off position. High beam headlights will remain on however if the high beam FET is switched on before switching off the key switch.

Besides just transmitting a J1939 Drivetrain data link message when headlight switch in on, a failsafe headlight enable hardwired line runs between the EGC and ESC. If headlights are on, the ZVR biased headlight enable (HLE) digital input is pulled high. The HLE circuitry in the ESC is a microprocessor input and also runs directly to the low beam headlight FET and the park light FET signal lines as shown in Figure 60. This failsafe permits low beam vehicle headlights to function if J1939 Drivetrain data link communication between EGC and ESC is lost or if a problem with EGC or ESC microprocessor exists. One important note, if the EGC does not have battery power (fuse blown, etc), the headlights cannot be switched on since the headlight micro-switch is supplied with battery power and the ESC HLE digital input is biased low. The EGC panel illumination will also not operate with the EGC battery power missing.

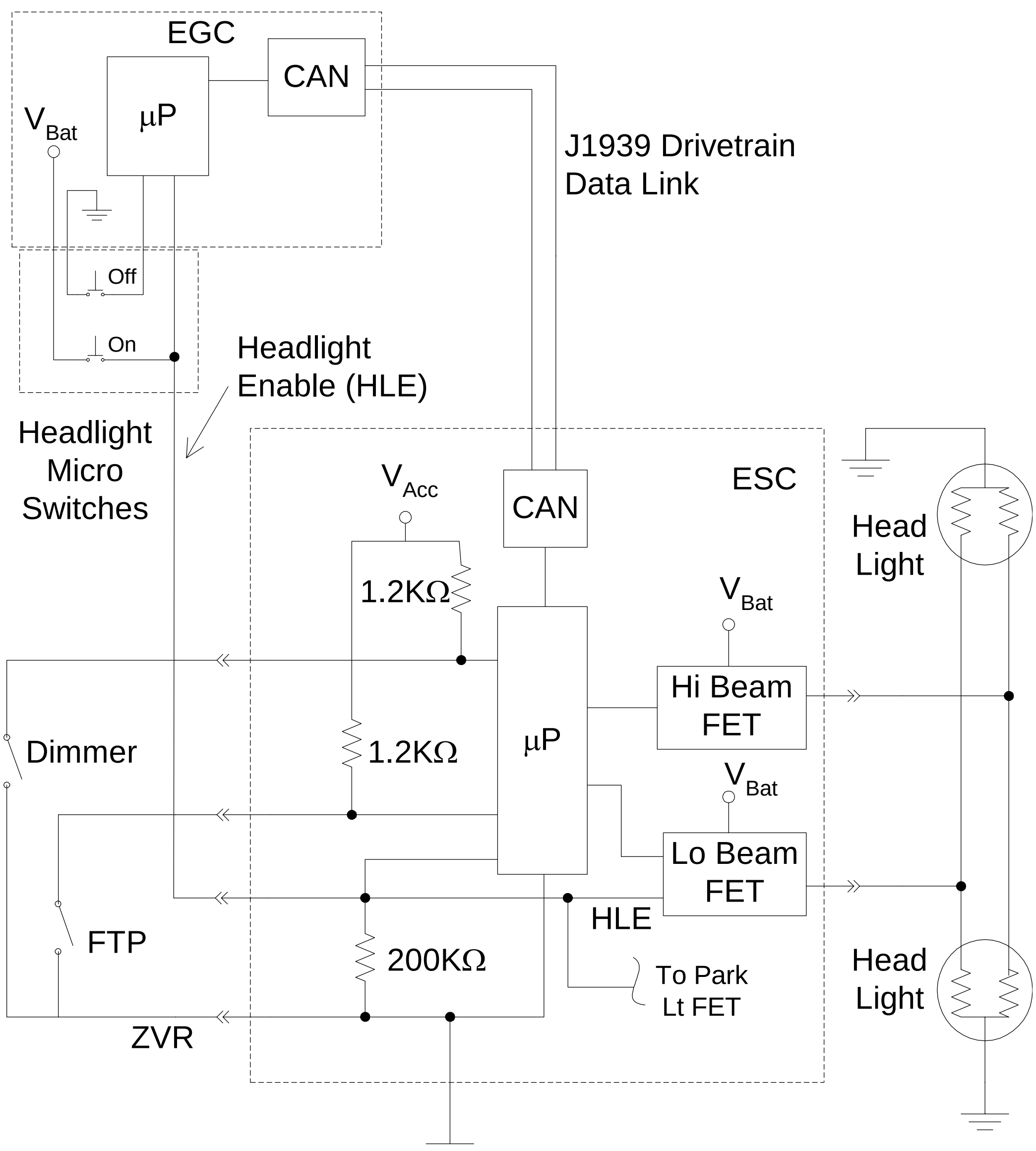

Figure 60 **Headlight Circuit**

Tail, Marker, Clearance Lights

A 20A FET also supplies all marker, clearance, identification, and tail lights and is switched on any time the EGC is transmitting a request for headlights or park lights. The output is a little different than all others because it consists of two separate output pins at the ESC (Figure 61). One output is located in the 8-way brown connector outside of the cab. This output supplies the taillights, front side marker, and clearance lights. Another output is located in the ESC 8-way brown connector inside the cab. This output supplies the front cab identification lights and back of mirror lights, if applicable. One FET sources both outputs.

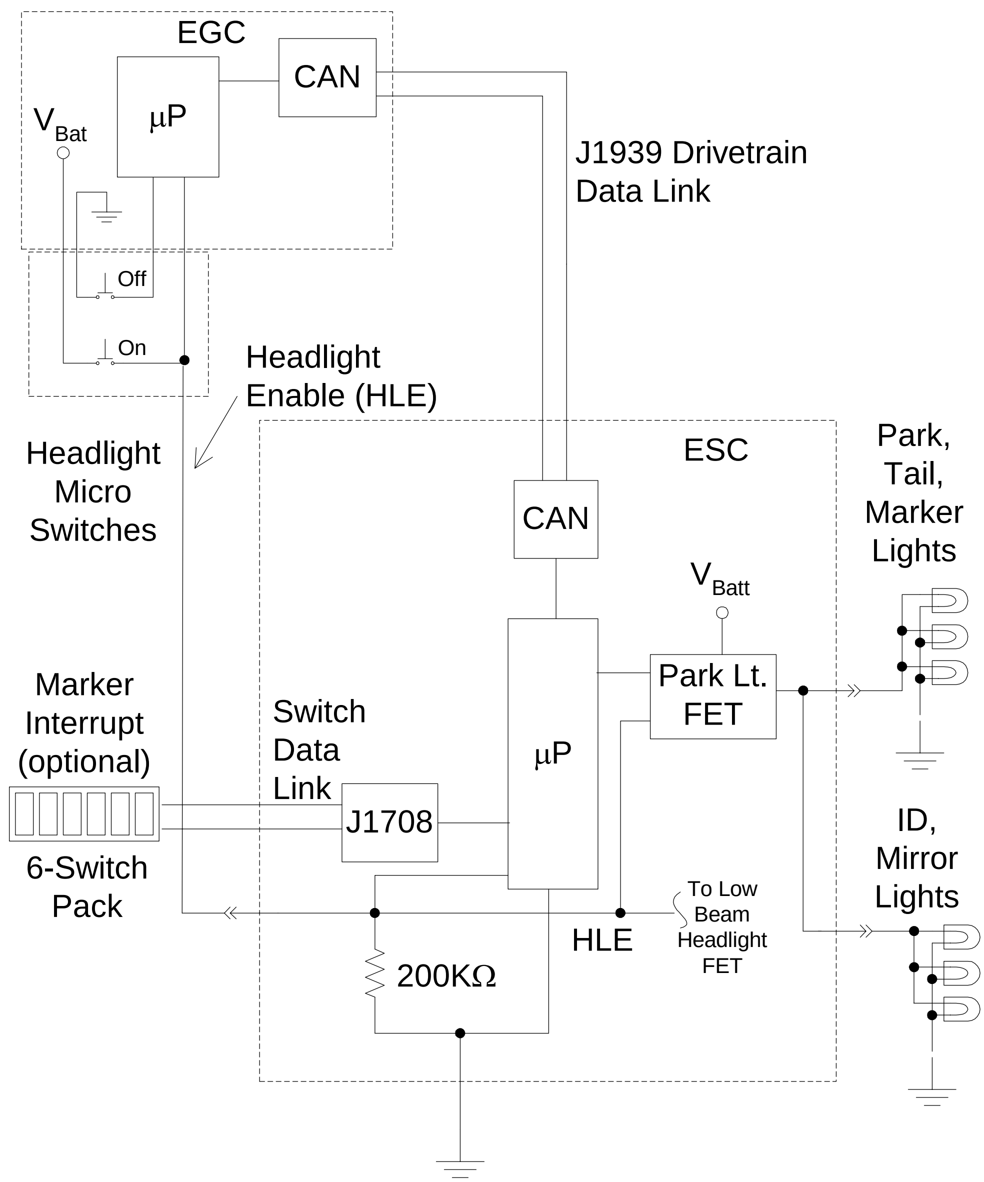

Figure 61 Tail, Marker, And Clearance Light Circuit

Marker Interrupt

An optional marker interrupt switch is located in a switch pack. Operating the marker interrupt switch causes the switch pack to transmit a message over the Switch data link to the ESC. The ESC responds by toggling the state of the 20A park light FET. If the park light FET is off when the marker interrupt switch is activated, the park light FET is switched on for as long as the marker interrupt switch is activated. If the 20A park light FET is on when the marker interrupt switch is activated, the 20A park light FET is switched off for as long as the marker interrupt switch is activated. Since the 20A park light FET controls all tail, marker, and clearance lights; the marker interrupt switch affects all tail, marker, and clearance lights. Marker interrupt will not function if the key switch is in the off position.

Daytime Running Lights

Optional daytime running lights (DRL) can be ordered or programmed into the ESC. DRL is obtained by duty-cycling the low beam headlight FET. The frequency is 70 Hz with a duty cycle of 75%. The ESC switches on DRL anytime the ignition is on, headlights are off, and park brake is released.

Fog Lights

The optional fog lights are controlled by the ESC. The fog light switch is located in a switch pack. Switching on the fog light switch actuator causes a message to be transmitted over the Switch data link. The ESC receives this Switch data link message and checks for two other conditions before switching on the 20A fog light FET. The first condition is that the low beam headlights must be on (not just DRL). The fog lights are not permitted to operate with headlights in high beam. Secondly, the key switch must be in the ignition position. If both conditions are met, the ESC will switch on the 20A fog light FET. The FET then supplies the high side for the fog lights. The fog lights are grounded through hardwire to chassis ground. If the fog lights are illuminated and the headlights are switched to high beam, the fog lights will go out until the headlights are returned to low beam. If the ESC has turned on the fog lights, a Switch data link message is transmitted back to the 6-switch pack fog light switch to illuminate the green LED in the upper switch window. The green LED indicates that the ESC fog light output is switched on.

Work Light

The work light is also controlled by the ESC. The work light switch is located in the EGC three-switch module next to the panel illumination level control. Depressing the work light switch causes a J1939 Drivetrain data link message to be generated by the EGC. The ESC receives this J1939 Drivetrain data link message and switches on the 10A work light FET. The FET supplies the high side for the work light. The time that the work light will remain on with the key switch in the off position is programmable in ESC software. The indicator in the work light actuator will flash if the work light is left on and vehicle speed above some value is detected.

HVAC System

A/C Clutch Control System

The A/C system is a cycling clutch orifice tube (CCOT) system. The mechanical components of the system are similar to that used by many automotive manufacturers. A fixed orifice (.062”) near the evaporator inlet separates the high side from the low side to provide the pressure drop necessary for refrigeration. Since the restrictive device at the evaporator inlet is a fixed orifice tube and not a variable expansion valve, the means to control the evaporator temperature is to cycle the compressor off. Unlike most other CCOT systems, there is no low side cycling switch in the system. Instead, a 10A FET in the ESC directly controls the A/C clutch. The ESC microprocessor uses seven inputs to determine when the A/C clutch should be cycled off or cycled on. These inputs are as follows:

1. *A/C Request* is an accessory biased ESC digital input. The HVAC control head in the center of the instrument panel provides a chassis ground (not ZVR) at the ESC A/C request digital input when the control head is in any A/C or defrost position with the fan switch not in the off position.

2. *HVAC Control Head Diagnostic* is an accessory biased ESC digital input. The HVAC control head pulls this input to chassis ground every 5 seconds for 2.5 seconds (.2 Hz, 50% duty cycle) if the HVAC control head has not detected any faults. If this signal is not present, the ESC will not engage the A/C clutch and will log a fault for the missing signal. Some other HVAC control head faults will also cause the ESC to disable the A/C clutch as described in the *HVAC Control System* section.

3. *Engine RPM* is a J1939 Drivetrain data link message used by the ESC for A/C clutch control. The engine RPM must be greater than 300 RPM for the compressor to be engaged. If the J1939 Drivetrain data link engine RPM message is not present, the A/C clutch is disabled.

4. *High Side Pressure* is a ZVR biased ESC analog input. The high side pressure information is used by the ESC to disable the A/C clutch if high side pressure is too high or too low for safe compressor operation. The high side pressure information is also used by the ESC to control an optional on-off cooling fan drive. The high side pressure input is similar in functionality to a high-pressure cut-off switch, a low-pressure cut-off switch, and a cooling fan switch on a conventional A/C system. A pressure transducer in the liquid line near the condenser outlet provides a variable voltage output indicative of high side pressure. The transducer is supplied with 5V and ZVR from the ESC. The output of the pressure transducer is approximately 0.25V to 4.75V (Figure 62).

5. *Vehicle Speed* is a J1939 Drivetrain data link message used by the ESC in conjunction with high side pressure to determine if a fault for excessive high side pressure should be logged. This fault will cause the ESC to disable the A/C clutch.

6. *Evaporator Inlet Refrigerant Temperature* is an 80% of accessory voltage biased ESC analog input. Evaporator inlet refrigerant temperature is used by the ESC to determine when to cycle the A/C clutch under normal operating conditions. The evaporator inlet refrigerant temperature input is similar in functionality to a cycling switch on a conventional CCOT system. The device used to measure the evaporator inlet temperature is a thermistor, a variable resistance device. These particular thermistors have a negative temperature coefficient (NTC). This means that is as temperature increases, the resistance decreases. The thermistors are also non-linear. Non-linear means that if you looked at a graph with thermistor resistance on one axis and temperature on the other axis, the line connecting the data points would be curved, not straight (Figure 63). The inlet thermistor is located in the evaporator inlet line immediately after the orifice tube.

7. *Evaporator Outlet Refrigerant Temperature* is an 80% of accessory voltage biased ESC analog input. The evaporator outlet refrigerant temperature is used by the ESC to cycle the A/C clutch off under light heat load conditions to prevent evaporator freeze-up (ice forming on exterior of evaporator core). The evaporator outlet refrigerant temperature is also used by the ESC in conjunction with the high side pressure transducer to determine if ambient temperature is too low for safe compressor operation. The evaporator outlet refrigerant temperature is also measured by a thermistor, which is identical to the evaporator inlet thermistor. The outlet thermistor is located in the accumulator.

The complete A/C system circuit is shown in Figure 64.

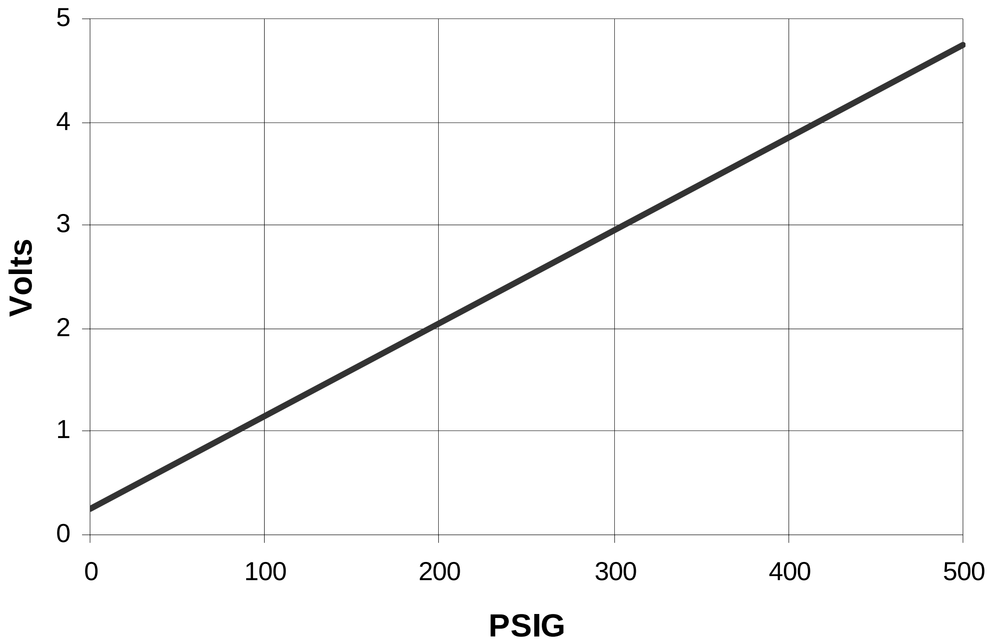

Figure 62 High Side Pressure Transducer Output

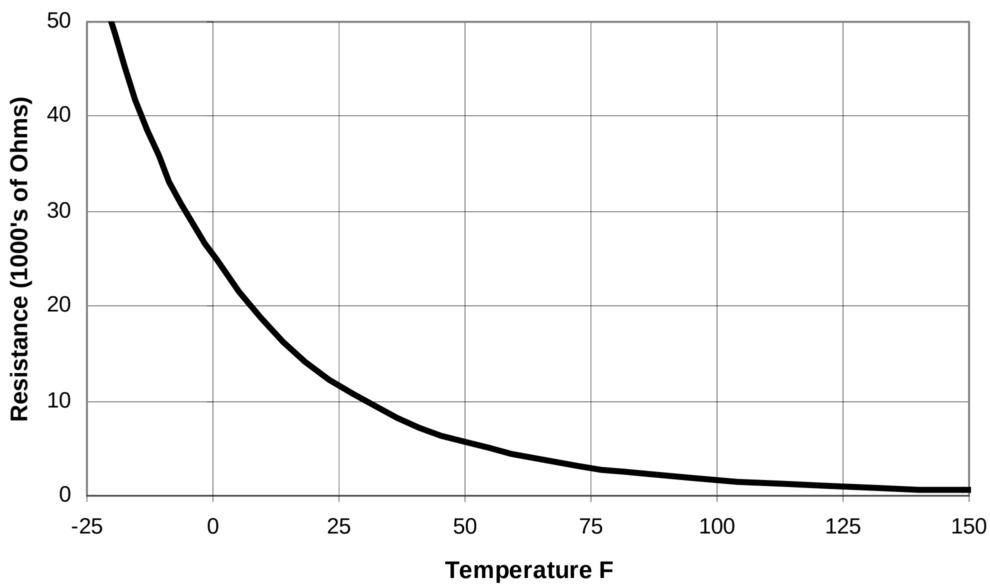

Figure 63 Thermistor Resistance vs. Temperature

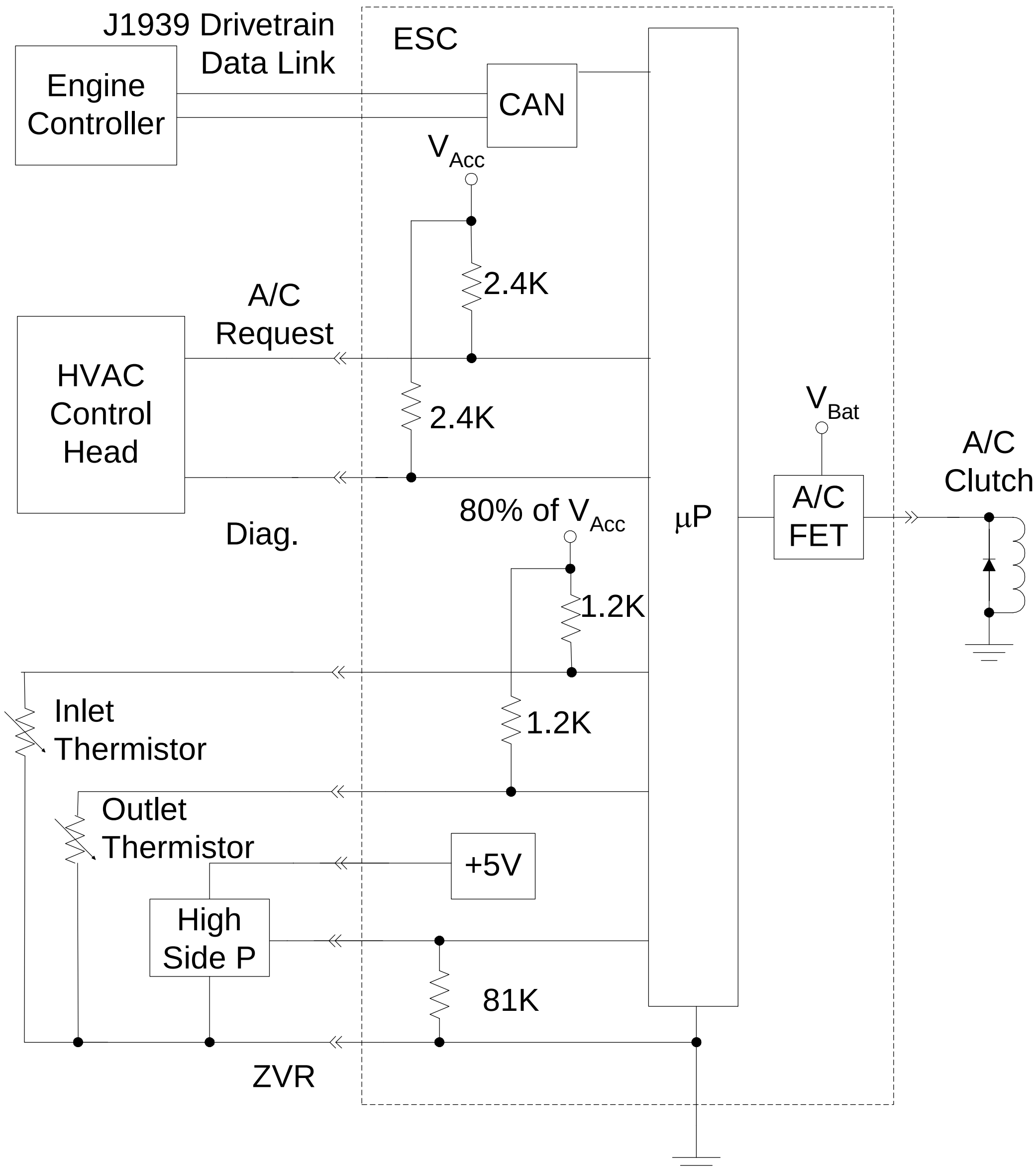

Figure 64 **A/C System Circuit**

Normal A/C Operation

The portion of software in the ESC that controls the A/C clutch is called RCD, which stands for refrigerant control and diagnostics. There are several requirements necessary before the A/C clutch may be cycled on. First, the engine must have been running for at least eight seconds and the HVAC control head must be in an A/C or defrost position with the fan switch not in the off position (ESC A/C request digital input is pulled low by the HVAC control head). RCD then uses data from the evaporator outlet thermistor and high side pressure transducer to determine if system temperature is too low (cold ambient) for safe A/C clutch engagement. Low system temperature is defined as high side pressure below 40 psi and outlet temperature below 33° F. This is similar in functionality to the operation of the low-pressure cut-off switch found on previous models. If the system temperature is not too low, RCD then examines the value of evaporator inlet refrigerant temperature. Evaporator inlet refrigerant temperature must be greater than 43° F for the A/C clutch to be cycled on. Additionally, RCD will not permit the A/C clutch to cycle on if high side pressure exceeds 250 psi. This level of high side pressure would not normally be expected on a static A/C system, but may be seen if the system has just been operated in very high ambient temperatures. RCD also checks to make sure that several HVAC related faults are not detected by the ESC. If all conditions required by RCD for A/C clutch operation are met, the microprocessor switches on the 10A A/C clutch FET. To simplify the requirements for A/C clutch activation, **ALL** of the following statements must all be true: (> means greater than, < means less than)

1. Engine has been running for at least eight seconds OR a missing engine RPM J1939 message has returned for at least eight seconds
2. A/C request active (A/C request line at ESC less than 1.2V)
3. High side pressure > 40 psi AND outlet temperature > 33° F
4. Inlet temperature > 43° F AND A/C clutch has been off for at least 8 seconds
5. High side pressure < 250 psi
6. Pressure transducer AND thermistor circuits not faulted
7. HVAC control head does not have multiple faults AND HVAC control head diagnostic signal is present at ESC input
8. A/C clutch virtual fusing is not active
9. ESC ignition AND accessory inputs are logic high

After the ESC cycles on the A/C clutch, the evaporator inlet refrigerant temperature is then used to determine when to cycle off the A/C clutch. Too low of an evaporator temperature will cause moisture condensed on the evaporator to turn to ice and block airflow through the evaporator (evaporator freeze-up). When evaporator inlet refrigerant temperature drops to 30° F and the compressor has been on for at least 7 seconds, the A/C clutch is cycled off. It is important to understand that both of these conditions (time since clutch was cycled on and temperature) must be met before the clutch may be cycled off. The A/C clutch will cycle back on again after evaporator inlet refrigerant temperature reaches 43° F and at least eight seconds have elapsed since the A/C clutch was cycled off. Under light heat load conditions, the A/C clutch might cycle on and off no more than once every 15 seconds (seven seconds on, eight seconds off). Under high heat load conditions, the A/C clutch might cycle on and not cycle back off again until the engine or A/C is shut off because evaporator inlet refrigerant temperature might not drop below 30° F.

Under some light heat load conditions, the evaporator outlet refrigerant temperature may be several degrees lower than the evaporator inlet refrigerant temperature. If the value of the evaporator outlet refrigerant temperature drops below 24° F and at least seven seconds has elapsed since the A/C clutch was cycled on, the ESC will shut off the A/C clutch to help prevent evaporator freeze-up.

Moisture condensed on the accumulator and suction hose may freeze during operation. The pressure of refrigerant in the accumulator and suction line continues to decrease (flash off) as refrigerant is pulled into the compressor. The presence of ice on the accumulator and suction line should be considered normal, provided that moisture condensed on the evaporator core does not freeze and restrict airflow through the evaporator.

The ESC will also cycle off the A/C clutch if the high side pressure exceeds 420 psi. This is similar in functionality to the operation of the high-pressure cut-off switch found on previous models. The high side pressure transducer information is also used to by the ESC to request the engine controller to switch on the engine fan for vehicles equipped with on-off fan drives. If applicable, the ESC sends a message over J1939 Drivetrain data link requesting the engine fan be switched on by the engine controller if high side pressure exceeds 285 psi. The engine fan will remain on for one-minute intervals until the high side pressure drops below 185 psi. This means that after high side pressure drops below 185 psi, the fan will stay on until the next full minute has elapsed since fan was first commanded on. The ESC will only transmit this fan request message if the ESC is programmed for on-off engine fan drive. If an on-off engine fan drive is added to a truck equipped with air conditioning, the ESC programming must also be modified using ICAP.

To simplify the requirements for A/C clutch de-activation, if **ANY** of the following statements are true the ESC will de-activate the A/C clutch: (> means greater than, < means less than)

1. Engine is not running OR the engine RPM J1939 message is missing
2. Evaporator inlet refrigerant temperature is < 30° F AND A/C clutch has been on for at least 7 seconds
3. Evaporator outlet refrigerant temperature is < 24° F AND A/C clutch has been on for at least 7 seconds
4. High side pressure > 420 psi
5. A/C request no longer active (ESC A/C request line is above 4V)
6. Pressure transducer OR thermistor circuits are reported as faulted
7. HVAC control head has multiple faults AND the A/C clutch has been on at least 7 seconds
8. The diagnostic signal from HVAC control head is no longer present at the ESC input AND the A/C clutch has been on at least 7 seconds
9. A/C clutch virtual fusing is active
10. ESC ignition OR accessory inputs are logic low

Abnormal A/C System Operation and Diagnostics

One of the benefits of using the ESC to control the A/C clutch is that the ESC can also help protect the A/C system and alert the driver that the level of refrigerant is low before all cooling ability is lost.

The temperature difference between the evaporator inlet refrigerant temperature and evaporator outlet refrigerant temperature with the A/C clutch engaged is used for low refrigerant diagnostics. The evaporator inlet and outlet refrigerant temperature difference with A/C clutch on is minimal on a fully charged system after the cab temperature has stabilized. Depending on heat load, the evaporator inlet refrigerant temperature will be slightly lower or slightly higher than the evaporator outlet refrigerant temperature on a fully charged system. If some refrigerant should leak out of the system, the evaporator inlet refrigerant temperature will be much lower than the evaporator outlet refrigerant temperature after the cab temperature stabilizes. This is because there is an insufficient quantity of refrigerant moving through the evaporator to absorb any more heat. The greater this temperature difference, the lower the level of charge in the system. The algorithm that RCD uses to calculate the charge level in the system is fairly complicated. A combination of time, heat load, and evaporator inlet and outlet refrigerant temperature differential are used to calculate the charge level. If the RCD determines that the charge level is marginal, a fault will be set by the ESC indicating a medium charge level exists. Like all other ESC faults, this fault is stored in the Electronic Gauge Cluster (EGC). This fault will illuminate the Check A/C warning LED in the EGC. The A/C system will still operate normally in this mode but with decreased cooling capacity due to the marginal refrigerant charge level. If RCD determines that the charge level has become too low for safe compressor operation, the ESC will shut off the A/C clutch to prevent compressor damage. In addition to setting a low charge fault, the ESC will command the EGC to illuminate the Check A/C warning LED. The ESC will then inhibit A/C clutch operation until the low charge problem is fixed and the faults are cleared.

The high side pressure transducer is also used to shut off A/C clutch if high side pressure is greater than 420 psi. If the vehicle speed is less than 20 MPH, the ESC will permit the high side pressure to increase up to 420 psi without setting any faults. At 420 psi, the ESC shuts off the A/C clutch until the high side pressure drops to 250 psi and the clutch has been off for at least 8 seconds. The ESC will permit this cycle to occur three successive times, after which time the compressor is disabled for 5 minutes or until vehicle speed exceeds 20 MPH. These three tries with 5 minutes between retries cycle will repeat as long as the vehicle speed is below 20 MPH. However, if vehicle speed is at least 20 MPH and the high side pressure reaches 420 psi on three successive clutch cycles, the ESC will illuminate the Check A/C warning lamp and set a diagnostic fault indicating the high side pressure is excessive. The ESC will then not permit A/C clutch operation until the problem is fixed and the faults are cleared.

The thermistor circuits are checked for faults by the ESC. As indicated by Figure 63, the resistance of the thermistors decreases as temperature increases. The maximum temperature the ESC will equate to a given thermistor resistance is 240° F. Therefore, a thermistor circuit that is shorted to chassis ground or ZVR will look like 240° F to the ESC. If a thermistor resistance equating to 240° F is seen at the ESC, the ESC will set a fault for that particular thermistor circuit shorted to ground. The ESC will then inhibit A/C clutch operation until the thermistor circuit is no longer shorted to ground and at least 8 seconds have transpired since the A/C clutch was shut off. This 8-second time delay prevents an intermittent thermistor circuit short to ground from causing the ESC to rapidly cycle the A/C clutch. The ESC will set a fault for a shorted thermistor circuit, and illuminate the Check A/C warning LED.

The minimum temperature the ESC will equate for a given thermistor value is 0° F. Therefore, a thermistor circuit that is open-circuited will look like 0° F to the ESC. Unlike a value of 240° F, a value of 0° F is an acceptable value for low-side refrigerant temperature (i.e. sub-zero ambient temperature). Because of this, some additional checks must be made to determine if a thermistor circuit is open, or if the refrigerant is just really cold. First, the thermistors are only checked for an open circuit with the A/C clutch not activated. Next, the high side pressure must be greater than 20 psi. This helps the ESC ascertain that the ambient temperature is above 0° F. Next, the temperatures of the evaporator outlet and inlet thermistors are compared. If one thermistor is exactly 0° F and the other thermistor is greater than 30° F, the thermistor that is indicating 0° F is determined to be open circuited. The ESC will inhibit A/C compressor operation until the thermistor circuit is no longer open and at least 8 seconds have transpired since the A/C clutch was shut off. The ESC will set a fault for the appropriate thermistor out of range high and illuminate the Check A/C warning LED.

The high side pressure transducer circuit is also checked for faults by the ESC. If a voltage equating to a pressure greater than 500 psi is detected at the ESC high side pressure input, the A/C clutch operation is inhibited and a fault is set indicating that the high side pressure transducer circuit is above normal operating voltage. This fault could be caused by a transducer circuit shorted to the 5V sensor supply circuit or a defective high side pressure transducer. Since the ESC high side pressure input is biased to ZVR, an open circuit in the pressure transducer signal line between the ESC and the transducer will cause the voltage at the ESC high side pressure input to drop to near 0V. A value of 0V also equates to a high side pressure of 0 psi or less (vacuum). Therefore, the ESC cannot discern the difference between an open high side pressure transducer signal circuit, a shorted to ground high side pressure transducer signal circuit, or a fully discharged A/C system. On some earlier versions of ESC software, any of these problems will cause the ESC to log a fault for high side pressure transducer circuit out of range low and illuminate the Check A/C warning LED. However in extreme cold ambient temperature conditions, the pressure of the refrigerant can drop to near 0 psi even though the system may be fully charged. This caused a problem of the ESC falsely reporting a fault in extremely cold weather when none existed. Therefore, the pressure transducer out of range low fault was removed from ESC logic. Unfortunately, this also prevents the ESC from being able to detect that the A/C system is fully discharged. The low pressure will inhibit the A/C clutch though to protect the compressor.

HVAC Control System

The HVAC control head controls the blower motor speed, mode doors, and temperature doors. The control head also provides the request to the ESC for A/C clutch operation.

Blower motor

Variable blower motor speed is obtained through a device called the linear power module (LPM). The blower motor is provided with a constant battery feed via a 30A fuse or breaker in the cab fuse block (Figure 65). The LPM controls the blower motor ground by adding an electronically controlled series resistance. The more series resistance that is added, the slower the blower motor will operate. A resistor block performed this speed control function on previous models. The LPM is supplied with a 0 to 4.8V control signal from the HVAC control head corresponding to the desired blower motor speed. The higher the control signal voltage level, the lower the value of series resistance the LPM will add. This results in the motor operating faster as control voltage is increased. With the HVAC control head motor speed selector in the off position, the control voltage is 0V. This results in the LPM opening the blower motor ground and stopping the blower motor. The LPM is also supplied with an ignition signal. This ignition signal controls the logic of the LPM. The LPM will not operate the blower motor without this ignition signal. The LPM wire harness also contains a 1K-Ohm resistor, which is connected between the motor speed control signal line and ground. This resistor prevents the blower motor from operating at low speed with the ignition on and the blower speed setting in the off position. Note that there is no mention of the ESC with regards to blower motor. The ESC has no control over blower motor.

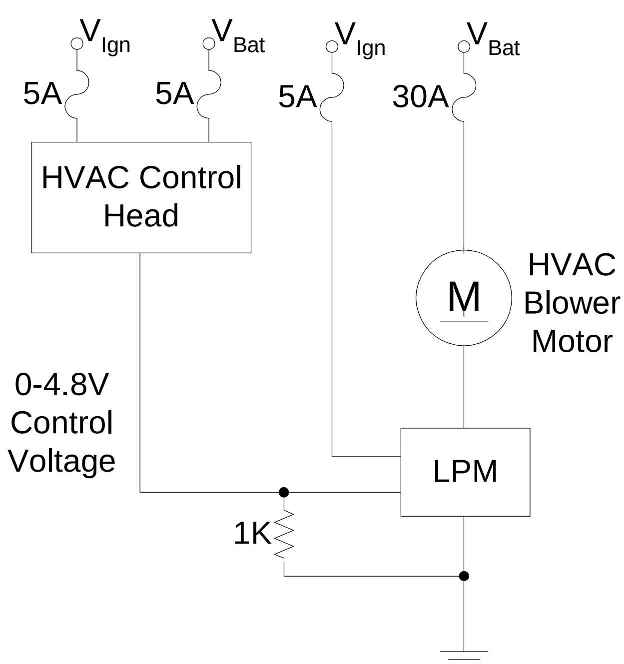

Figure 65 Blower Motor Circuit

HVAC Air Control Doors

The HVAC control head controls three 7V motor-driven doors (two on vehicles without A/C). These doors control the mode (defrost, panel, floor), temperature blend, and inlet air (with A/C only). The circuit is illustrated in Figure 66. The HVAC control head is capable of driving each motor in both directions of rotation by reversing motor polarity. The motors are designed to operate at a supply voltage of 7V. The HVAC control head knows the position of the doors even though there is no position sensor and the motors are just typical brush-type DC motors. The HVAC control head watches for the spikes (noise) caused by commutation as a motor “step” count as shown in Figure 67. Upon initialization (reconnection of battery power), the HVAC control head drives each motor to one extreme of travel until the motor stalls when the door is fully closed. From this point, the HVAC control head drives the motor the other direction by reversing polarity. The HVAC control head then counts the number of commutator segments necessary to make the motor stall in the other direction. From this point, the motor is zeroed. The HVAC control head is now capable of driving a door motor to any desired position corresponding to an HVAC control head setting. The HVAC control head remembers where each motor is positioned from the previous use even if key switch is shut off. Removing the battery connection or HVAC control head battery fuse with key switch off causes the control head to perform a recalibration since motor position information is lost. The HVAC control head also performs a recalibration after every 20 ignition cycles to eliminate any error that has accumulated in resolving motor position.

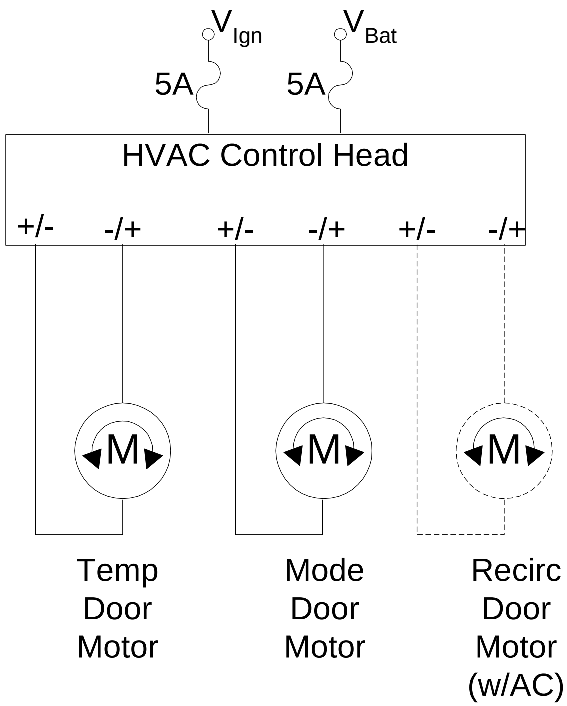

Figure 66 HVAC Air Control Doors

If something prevents a door from reaching full travel (not enough pulses), the door travels too far (too many pulses), or if the pulses due to commutation are not seen by the HVAC control head, a fault will be set in the ESC. The ESC uses an accessory biased digital input as the means of determining what faults the HVAC control head has detected. The HVAC control head pulls the ESC digital input to ground at a specific frequency with a duty-cycle of 50%. If no faults are detected, the HVAC control head provides a ground every 5 seconds for 2.5 seconds as shown in Figure 68. The HVAC control head is capable of detecting five different faults or operating conditions. Each of these faults or conditions alter the frequency at which the ESC digital input is pulled to ground (duty cycle remains at 50%). If the ESC does detect any change in the diagnostic digital input (remains at 0V or 12V), the ESC will also set a fault indicating a loss of communication with the HVAC control head. If a fault is active for multiple HVAC control head faults or if the control head signal is not detected, the ESC will inhibit A/C clutch operation as well.

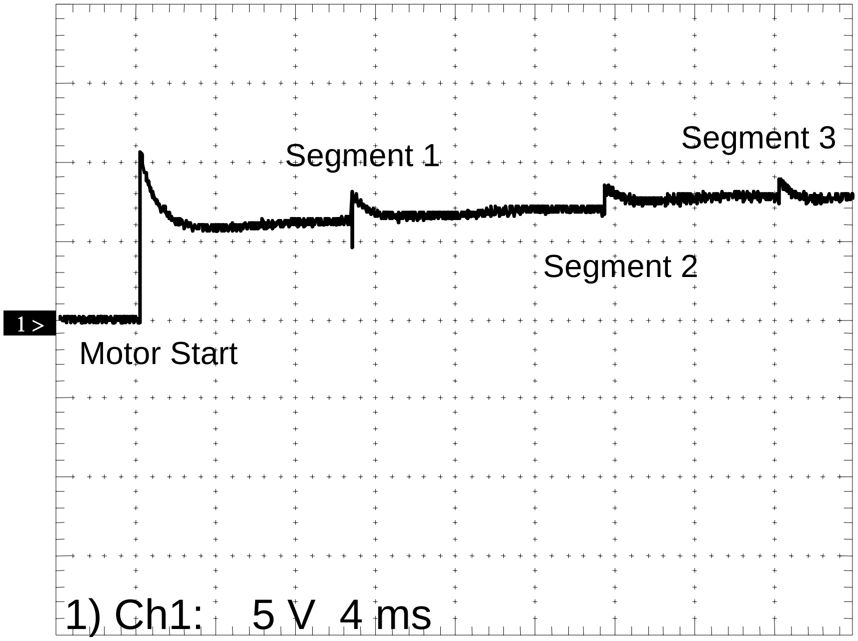

Figure 67 **Motor Commutator Segments Used to Resolve Door Position**

Fault	**A/C Clutch Inhibited**	**Total Time (Sec)**	**Time High (Sec)**	**Time Low (Sec)**	**Waveform**
No Fault	No	5	2.5	2.5	2.5 2.5
Recirculating Air Door	No	4	2	2	2 2
Temperature Door Fault	No	3	1.5	1.5	1.5 1.5
Mode Door Fault	No	2	1	1	1 1
Multiple Fault	Yes	1	0.5	0.5	.5 .5
Control Head Fault	Yes	N/A	N/A	N/A	0V or 12V Continuous

Figure 68 **HVAC Control Head Faults**

Engine Related Systems

Cruise Control

Cruise control has several changes for the High Performance Trucks. The cruise control switches located in the steering wheel are 2-position momentary contact switches wired in parallel. The switches are connected to the ESC instead of the engine controller, as was the case with previous models. The ESC generates J1939 Drivetrain data link messages containing cruise switch status destined for the engine controller. The engine controller uses the J1939 Drivetrain data link messages to actuate cruise control. Clutch and brake switch are also used for cruise control status. These switches are ESC inputs and are transmitted over the J1939 Drivetrain data link instead of being hardwired to the engine controller as was done in the past. The cruise control system is illustrated in Figure 69. Note that the Cruise LED in the EGC only applies to versions prior to version 10.

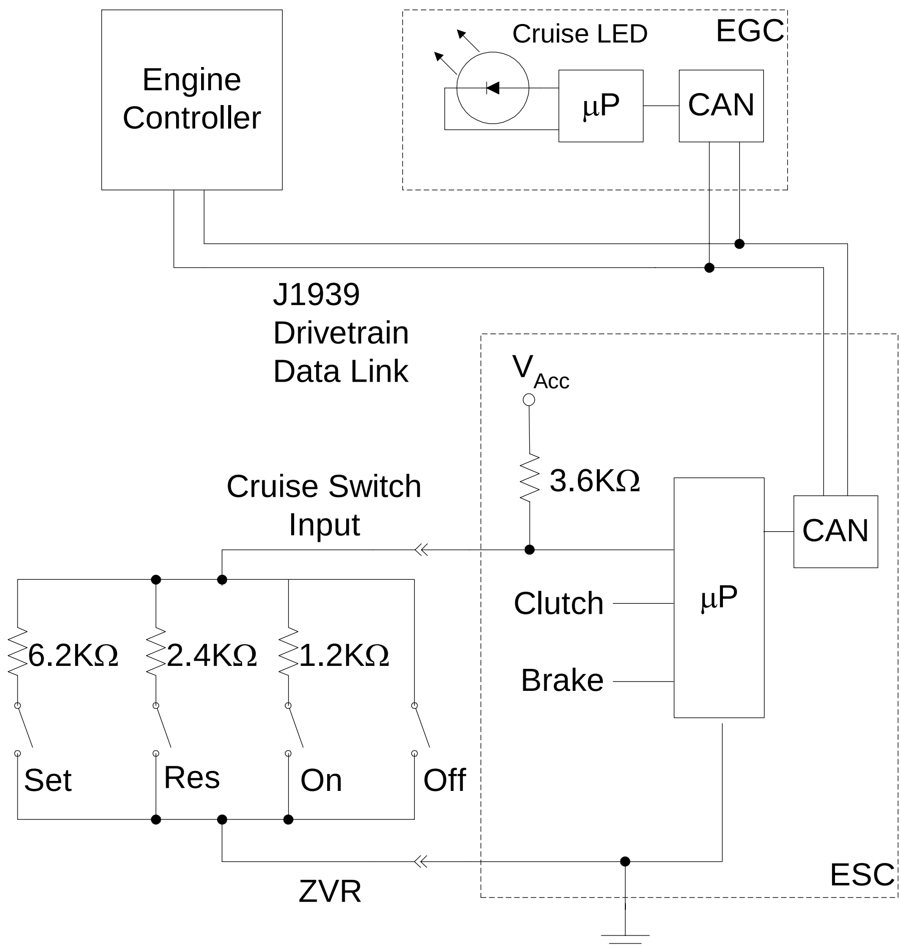

Figure 69 Cruise Control System

The ESC input for cruise control consists of one accessory biased analog input. The pull-up resistor is 3.6K Ohms. The four switch contacts (two per switch) provide a varying resistance path to ZVR. If the ON switch is closed, a 1.2K-Ohm resistor in series with the switch provides a path to ZVR (Figure 70). A voltage divider between the pull-up resistor and 1.2K-Ohm cruise-on resistor causes input voltage to go to 3V (assuming 12V accessory voltage for all examples). If the SET switch is closed, a 6.2K-Ohm resistor in series with the switch provides a path to ZVR as shown in Figure 71. A voltage divider between the pull-up resistor and 6.2K-Ohm resistor causes input voltage to go to 7.6V. If the RESUME switch is closed, a 2.4K-Ohm resistor in series with the switch provides a path to ZVR (Figure 72). A voltage divider between the pull-up resistor and 2.4K-Ohm resistor causes input voltage to go to 4.8V. Finally, if the OFF switch is depressed, a straight shot to ZVR is completed (Figure 73). The OFF switch contains no series resistor. This causes input voltage to drop to near 0V. Remember that these voltages were all calculated using an accessory voltage of 12V. The ESC adjusts cruise control input voltages accordingly as the accessory voltage changes.

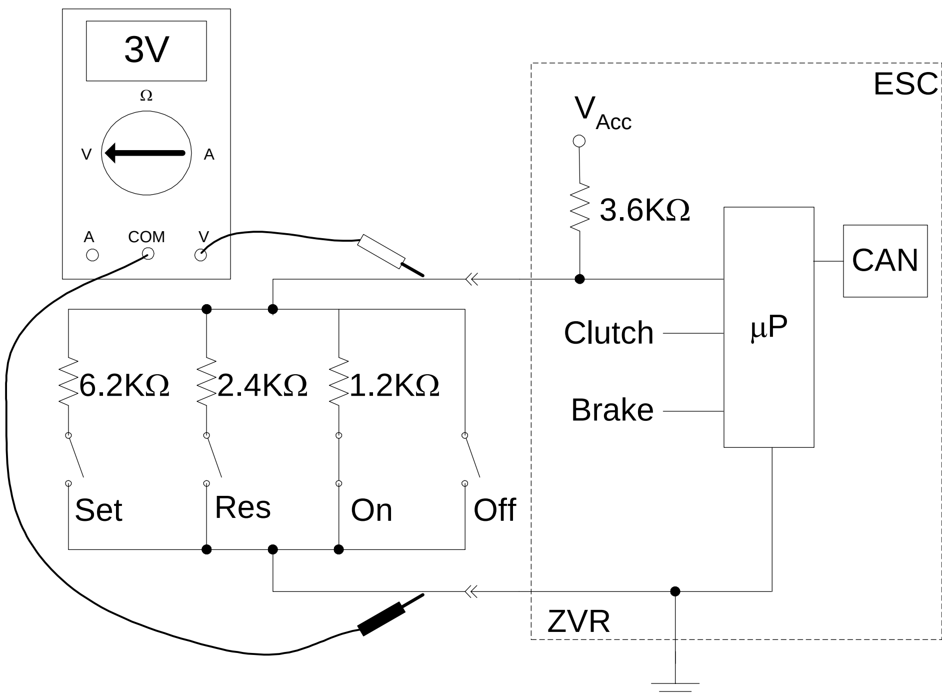

Figure 70 Cruise On Switch Depressed

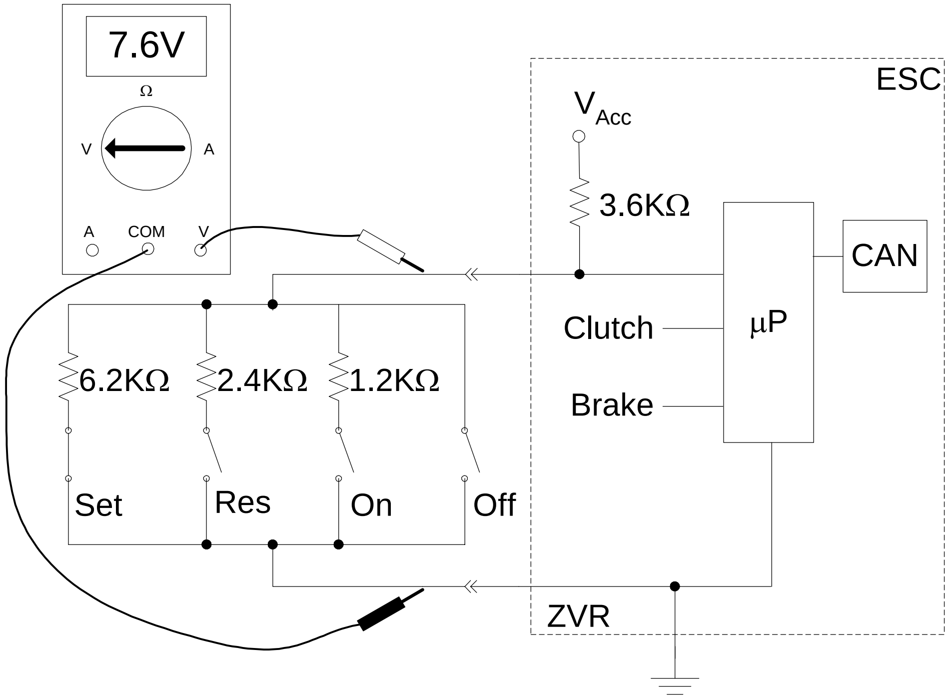

Figure 71 **Cruise Set Switch Depressed**

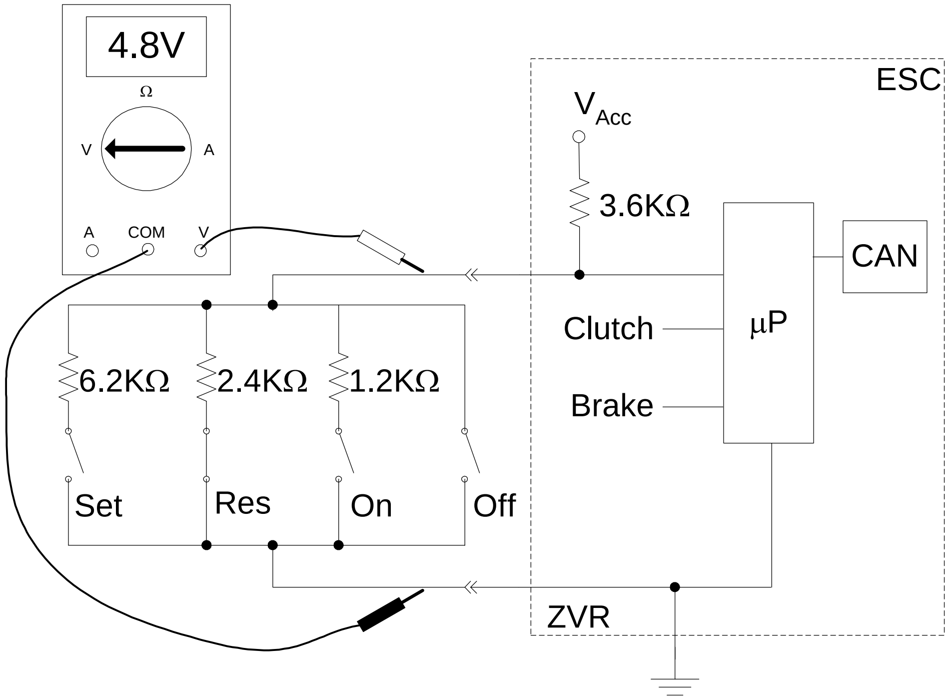

Figure 72 **Cruise Resume Switch Depressed**

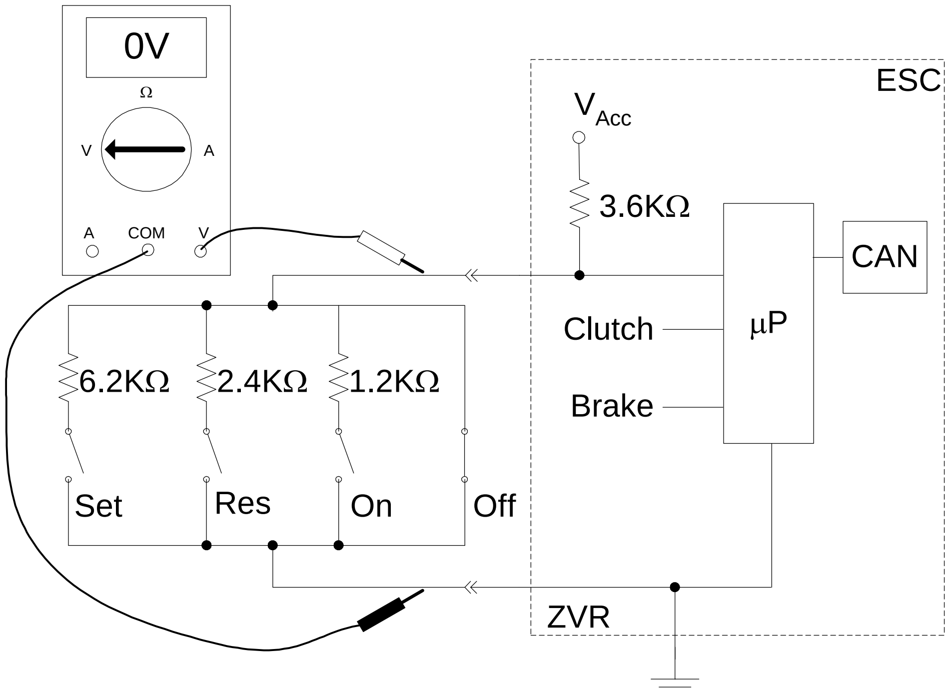

Figure 73 Cruise Off Switch Depressed

If the cruise ON switch is depressed, the ESC detects the appropriate voltage level at the cruise analog input and generates a J1939 Drivetrain data link message indicating that the cruise ON switch is active (depressed). The ESC continues to transmit the status of the cruise ON switch as active (depressed) even after the momentary contact cruise ON switch is released. The ESC will transmit the status of the cruise ON switch as active until the cruise OFF switch is depressed or ignition is cycled. The engine controller sees this J1939 Drivetrain data link message and knows that the cruise ON switch is active. If the cruise SET switch is then depressed, the ESC again detects this by the voltage level at the cruise analog input and transmits a J1939 Drivetrain data link message to this effect for as long as the momentary contact cruise SET switch is depressed. The engine controller sees that the SET switch has been depressed by the J1939 Drivetrain data link message and will maintain the requested vehicle speed if all other conditions are correct for cruise activation. Once the engine controller is actively controlling vehicle speed, the engine controller will transmit a J1939 Drivetrain data link message indicating that cruise control is active. The ESC receives this message and responds by sending a message to the EGC over J1939 to illuminate the cruise control indicator light (EGC revisions prior to version 10 only). This indicator light is on any time the engine is actively controlling vehicle speed. Pressing the cruise SET switch with the engine controller actively controlling vehicle speed causes the ESC to transmit a J1939 message indicating the cruise SET switch is depressed. The engine controller sees the cruise set message and puts vehicle into cruise control coast mode until the cruise SET switch is no longer depressed. If the cruise RESUME switch is depressed, the ESC transmits a message indicating cruise resume for as long as the momentary contact cruise RESUME switch is depressed. If engine is actively controlling vehicle speed, the engine controller will accelerate the vehicle to a new cruise set speed for as long as the ESC is transmitting the RESUME switch depressed message.

Other ESC inputs for cruise control include the clutch switch and the brake light switch. Pressing the clutch or brake pedal causes the ESC to transmit a J1939 Drivetrain data link message indicating that the brake or clutch is depressed. The engine responds by deactivating cruise, just like with a hardwired brake or clutch switch. If the cruise OFF switch has not been depressed, pressing the RESUME switch after pressing brake or clutch causes the cruise to resume to the last set speed. Once again, the resume J1939 Drivetrain data link message is generated by the ESC and acted upon by the engine controller.

Pressing the cruise OFF switch causes the ESC to transmit a J1939 Drivetrain data link message indicating that the cruise switch is in the OFF position. The engine controller responds by deactivating cruise control. The ESC will transmit this cruise switch off message continually after the momentary contact OFF switch is released. If cruise control is desired again, the cruise ON and SET switches must be depressed again. The cruise switch functionality from an operator’s perspective is the same as previous models except the cruise switches are mounted in the steering wheel and the cruise ON and OFF switches are momentary contact switches instead of latching rocker switches.

The ESC will also set the cruise ON message to cruise OFF if the ESC detects that an ABS event is occurring (based on the hardwired input with Wabco hydraulic ABS or the J1939 message from Bendix or Wabco air ABS). Therefore, a false detection of an ABS event will inhibit cruise control.

If a problem occurs with J1939 Drivetrain data link after cruise control is activated, the engine controller will shut off cruise control if five successive ESC messages regarding cruise control are not received. The cruise control status message is exchanged between the engine controller and ESC at a rate of ten times per second so if the engine does not see cruise control messages from the ESC for ½ second, cruise is shut off.

Pressing combinations of the cruise control switches is also detected by the ESC and is used for diagnostics. If the ON and RESUME switch are both depressed at the same time, the 1200-Ohm ON resistor and 2400-Ohm RESUME resistor are placed in parallel resulting in a combined series resistance of 800 Ohms. This drops the voltage at the ESC cruise control input to 2.2V. This switch combination is used to place ESC in the diagnostic mode (provided park brake is set). If the ON and SET switches are both depressed at the same time, the 1200-Ohm ON resistor and 6200-Ohm SET resistors are placed in parallel resulting in a combined series resistance of 1005 Ohms. This drops the voltage at the ESC cruise control input to 2.7V. This switch combination is used to clear ESC and EGC faults (provided left turn signal is on and park brake is set).

The cruise control switches are also used for engine speed control (PTO speed control) in the same manner as previous models. The J1939 Drivetrain data link messages for PTO engine speed control are identical to those for cruise control.

Engine Crank (with International Engines)

There are several changes in engine crank from previous models. Most importantly, keep in mind that the ESC has no affect on engine crank. The ESC cannot keep the engine from cranking or starting. The ESC microprocessor is not designed to operate at the low voltages seen when the starter motor is first engaged. Therefore, there is a good chance that the ESC microprocessor will reset during engine crank due to the voltage dip. The engine crank circuit differs depending on what transmission the vehicle has. Let's look at what all vehicles with International engines (except those with factory auto neutral), regardless of transmission type, have in common first. The crank circuit for vehicles with factory auto neutral is unique and is shown in the circuit diagram book.

The key switch is supplied with one battery feed. The key switch supplies the high side to the in cab and chassis ignition relay coils when in the ignition or start positions. The low side of both relay coils is grounded so the relays both energize with key switch in ignition or start positions. With the key switch in the start position, the high side of the starter relay coil located in the power distribution center (PDC) is supplied with battery voltage. The low side of the starter relay is connected to the engine controller engine crank inhibit (ECI) pin. When the engine controller determines that the driveline is disengaged, it will provide a ground for the starter relay coil low side. With the starter relay energized, battery voltage is switched to the starter solenoid (the big one on the starter). With the starter solenoid energized, battery voltage is switched to the starter motor causing the starter motor to rotate. If the vehicle has thermal overcrank protection, the normally closed thermal switch is in series with the starter relay coil low side and the engine controller ECI pin. If starter motor is overheated, the thermal switch opens which de-energized the starter relay and prevents starter motor operation until the thermal switch cools.

The manner that the engine controller determines that the driveline is disengaged is where the automatic transmission and manual transmission vehicles differ. On vehicles with Allison MD transmissions, the WTEC controller provides a direct 12V feed to the engine controller driveline disengage pin (DDS) when the transmission is in neutral as shown in Figure 74. This is similar to previous models except there is no longer a neutral relay between the transmission controller and engine controller.

On vehicles with LCT transmissions, the Neutral Start/Back Up (NSBU) switch directs 12V from the chassis ignition relay to the engine controller DDS pin when the transmission is in neutral or park (if applicable) as shown in Figure 75.

Vehicles with manual transmissions are where the big changes are as illustrated in Figure 76. A two-level clutch switch is used. The upper clutch switch is used by the ESC for cruise control dropout. The normally open lower clutch switch is used for driveline disengage information. The lower clutch switch is supplied with ignition voltage from the in-cab ignition relay. Both the upper and lower clutch switches are proximity switches and both switches are contained in one package. The metal clutch pedal arm passes in front of the clutch switch when the pedal is depressed. The metal clutch pedal arm causes the proximity switch to change states. The lower clutch switch closes when the pedal is fully depressed. With the lower clutch switch closed, 12V from the cab ignition relay is directed to the engine controller driveline disengaged (DDS) input pin.

An important change in International engine controller software between the High Performance Trucks and the previous models is the logic for DDS. The logic for crank inhibit with manual transmissions has been swapped. On previous models, with the clutch depressed the normally closed clutch switch was opened. This had the affect of "floating" the engine controller DDS pin with the clutch depressed. The engine controller DDS input is biased to ground so on previous models, the engine controller considered a low logic level (0V) with manual transmission as OK to crank. With the High Performance Trucks, a low logic level with manual transmissions at the DDS input is considered <u>not</u> OK to crank. Like automatic transmission vehicles, a vehicle with a manual transmission now requires a logic high level (12V) at the engine controller DDS input to permit the engine to crank. The change in the logic is accomplished through a new programmable parameter in the engine controller. This parameter is the vehicle type parameter. Choices for this parameter are NGV and NOT NGV. NGV (Next Generation Vehicle) is the new model, previous models are NOT NGV. If the parameter is set to NGV, the crank inhibit logic for vehicles with transmission type set to manual will be opposite that of previous models (NOT NGV). This parameter is not changeable in the field so provided the engine controller was originally programmed correctly (or reprogrammed), this should never present a problem. However, this does cause a problem if an engine controller from a previous model and a new model are swapped. The crank inhibit will function backwards on both vehicles. The engine will crank only if the clutch is not depressed. Obviously, this is not a desirable condition.

Note that each of the following three drawings illustrates a 40A Maxi Fuse as the circuit protection device for the starter solenoid circuit. All models other than 8600's built after late-2002 use a fusible link as the circuit protection device instead of a 40A Maxi Fuse.

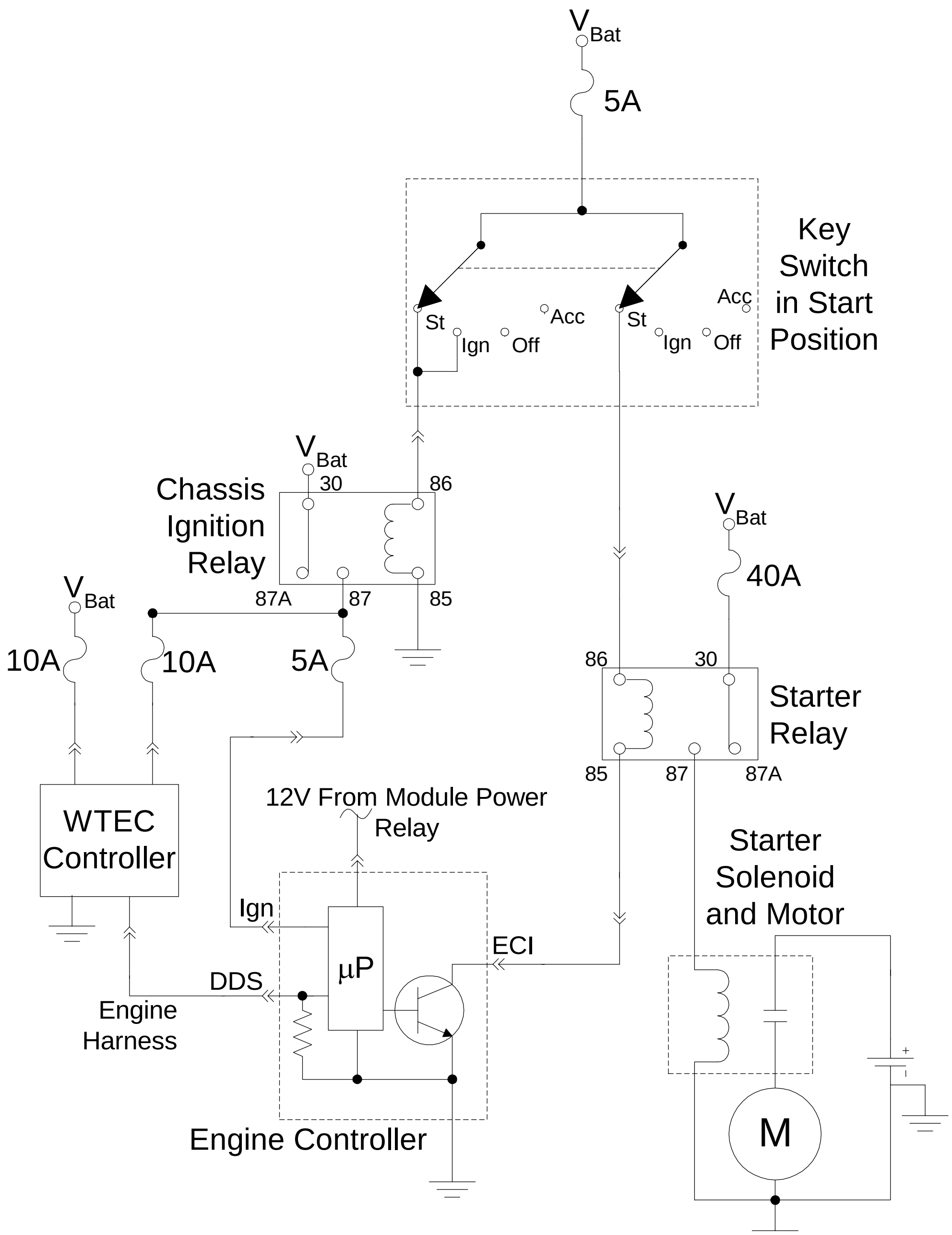

Figure 74 **International Engine Crank Circuit with Allison MD Transmission**

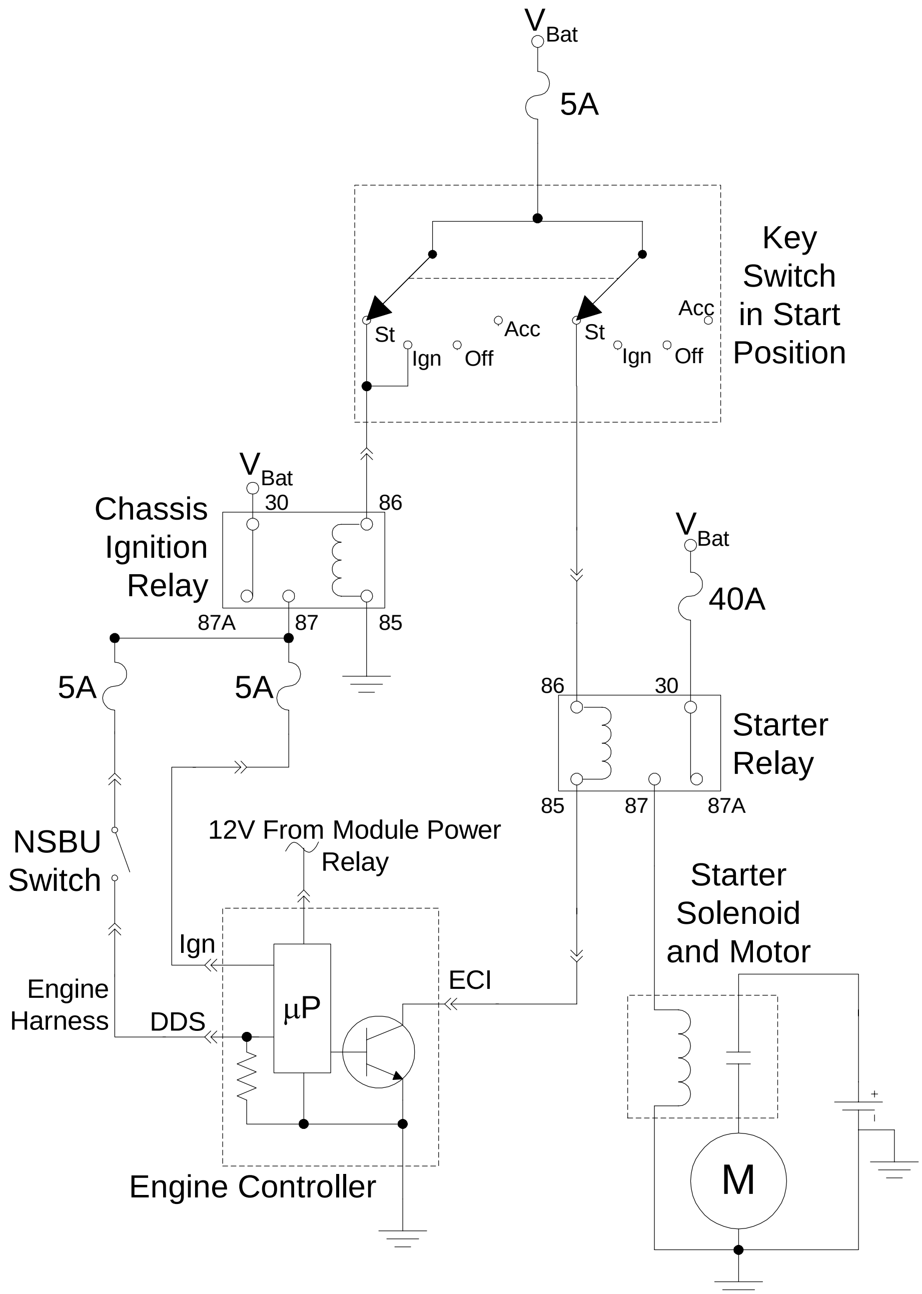

Figure 75 International Engine Crank Circuit with Allison LCT Transmission

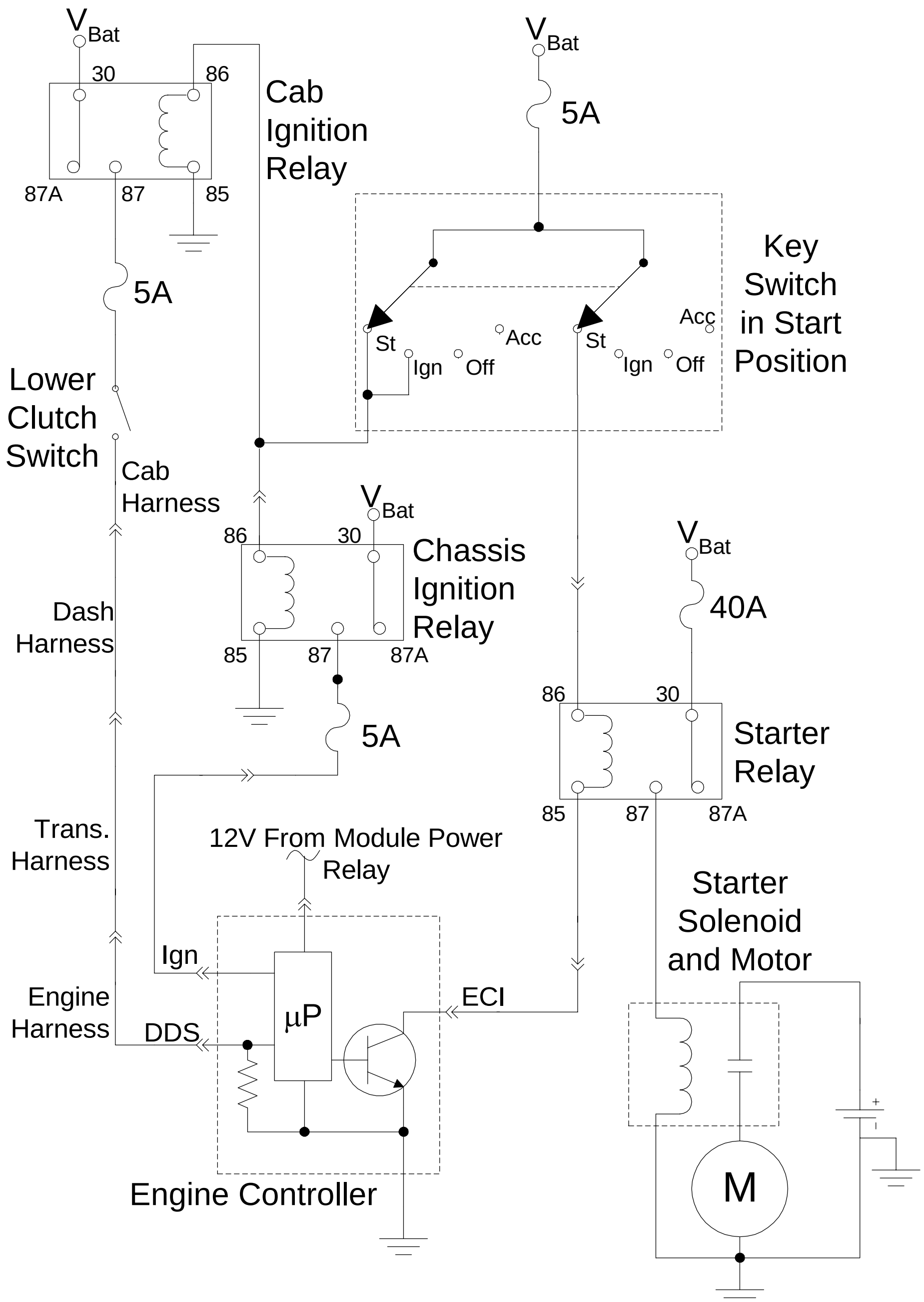

Figure 76 **International Engine Crank Circuit with Manual Transmission**

Engine Crank (Caterpillar and Cummins)

Engine crank on trucks with Caterpillar or Cummins engines do not utilize the engine controller to inhibit crank. The engine crank circuit for a manual transmission is shown in Figure 77. The lower clutch switch provides a ground for the starter relay to permit engine crank only when the clutch is depressed. Vehicles with automatic transmissions utilize a crank inhibit relay to permit engine crank only when the transmission is in neutral as shown in Figure 78.

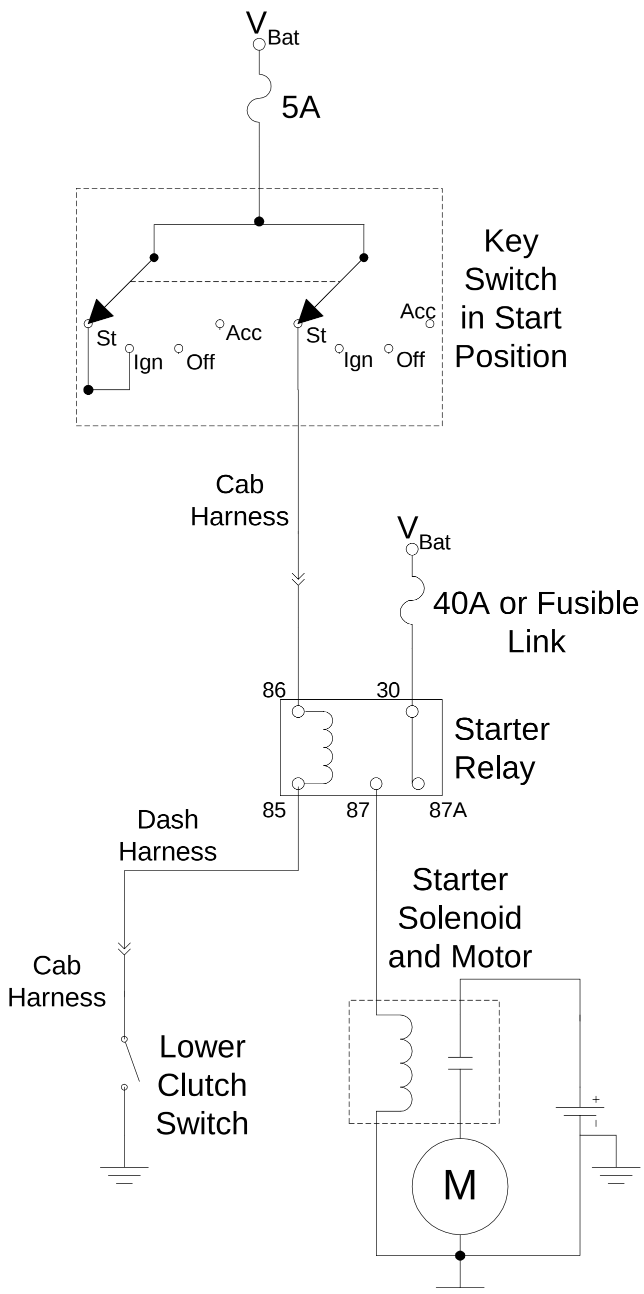

Figure 77 Big Bore Engine Crank with Manual Transmission

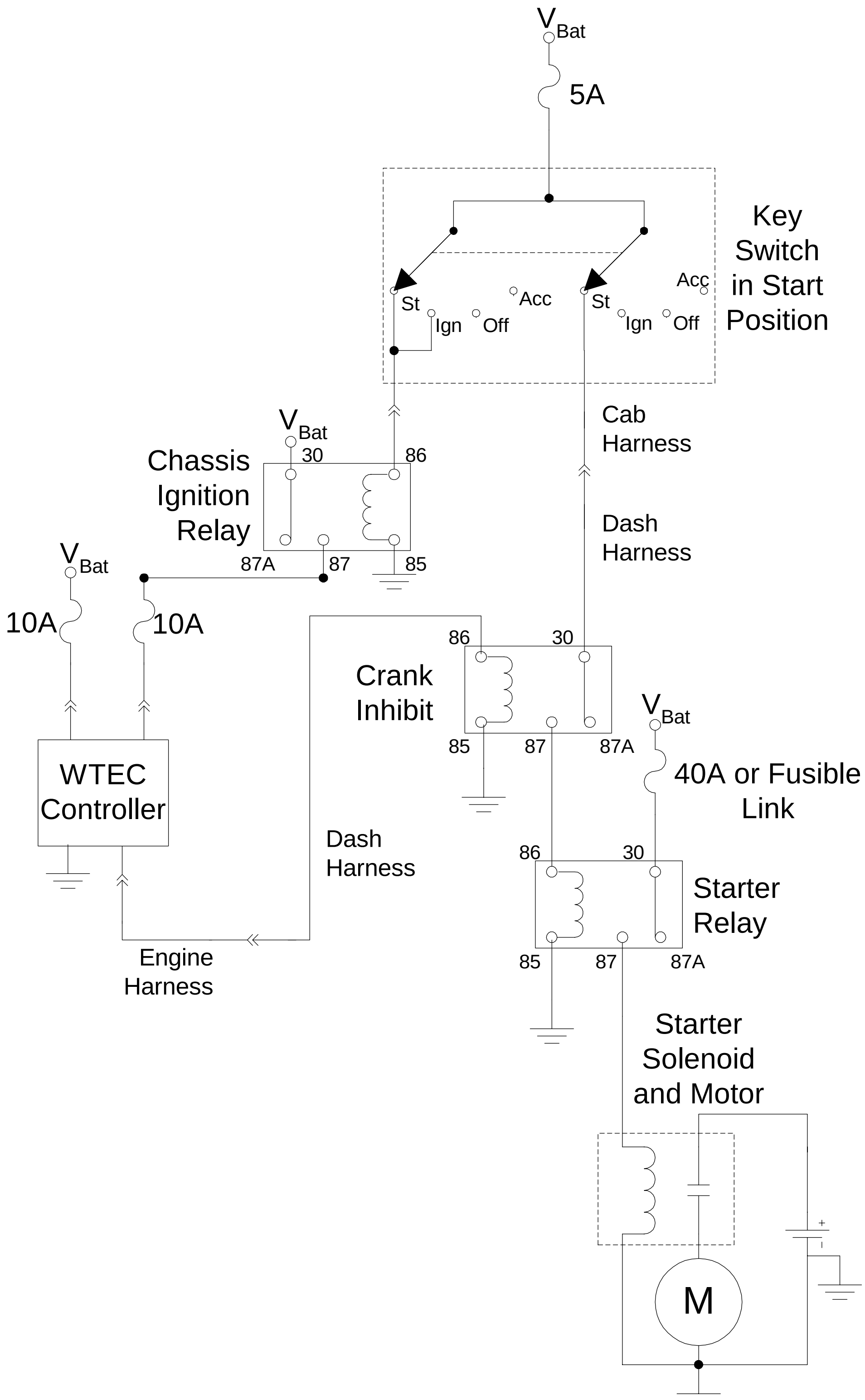

Figure 78 **Big Bore Engine Crank with Automatic Transmission**

Ether Start

Ether start is controlled the same as previous models. The ESC has no control over ether start. A hardwired switch located in EGC right side switch panel provides 12V to the high side of the ether start solenoid. The low side of the solenoid is in series with a thermal switch to chassis ground.

On-Off Engine Fan Drive

An optional air or electrically controlled engine fan is available. The engine controller controls the ground side of the fan air solenoid or relay as with previous models. An optional fan override switch permits the fan to be switched on by the operator as well. The fan override switch actuator is located in a switch pack. Switching on the fan over ride causes the ESC to transmit a J1939 Drivetrain data link message requesting the engine fan. The engine controller responds by opening the ground for the low side of the fan solenoid (air fan clutch) or relay (electric fan clutch). This causes the fan to run at all times with the fan override switch in the on position. The ESC will also request the engine controller to switch on the fan via a J1939 Drivetrain data link message if A/C high side pressure exceeds 285 psi. The engine controller responds to the J1939 Drivetrain message by opening the ground circuit for the fan solenoid or relay. Note that the engine controller parameter for A/C fan activation must be set to off on all High Performance Truck models with International engines. Otherwise, the engine fan will be engaged at all times since there is no normally-closed hardwired high side pressure switch in the system.

Compression Brake (Caterpillar and Cummins Engines)

The compression brake on big bore engines is controlled by the engine controller. The compression brake on/off switch and level switch actuators are located in a switch pack. The switch pack transmits a message over the Switch data link to the ESC indicating the status of the compression brake switches. The ESC then requests compression brake by transmitting the status of the compression brake switches to the engine controller over the J1939 Drivetrain data link. The engine controller responds to the request for compression brake and enables the brake when conditions for operation are met.

Exhaust Brake (International I6)

The optional exhaust brake switch actuator is located in a switch pack. The circuit is shown in Figure 79. Switching on the exhaust brake actuator causes the switch pack to generate a Switch data link message. The ESC sees this message and transmits a message over J1939 Drivetrain data link requesting the engine controller switch on the exhaust brake. If conditions are correct for exhaust brake, the engine controller provides the low side for the exhaust brake relay coil. An ignition fuse in the PDC provides the high side for the exhaust brake relay coil. With the exhaust brake relay energized, the exhaust brake solenoid is supplied with 12V. The low side of the exhaust brake solenoid is hardwired to chassis ground. The exhaust brake solenoid permits air to pass to the exhaust brake air cylinder when energized. The cylinder closes the exhaust brake valve when air is applied. If the engine controller determines that exhaust brake is no longer requested or conditions are no longer correct for exhaust brake, the engine controller opens the ground being provided to the exhaust brake solenoid. The air holding the exhaust brake cylinder is dumped when the exhaust brake solenoid is switched off. Additionally, if the ABS controller senses the drive wheels on the vehicle are nearing lock-up, a J1939 Drivetrain data link message is generated by the air ABS controller or ESC (with hydraulic ABS). The engine controller opens the ground circuit for the exhaust brake relay if a drive axle ABS event is occurring. This is because the exhaust brake may be the cause of the drive axle ABS event. The engine will re-engage the exhaust brake when the ABS event message is no longer present. Additionally, the ESC will not transmit the exhaust brake message if an ABS fault is present. This is because the ABS controller may not be able to detect that a drive axle ABS event is occurring with an ABS fault present.

The exhaust brake is a good example of a system that uses several concepts. The Switch data link message is converted by the ESC into a J1939 Drivetrain data link message. The engine controller converts the J1939 Drivetrain data link message into a ground for the exhaust brake relay. The exhaust brake relay switches on a solenoid that the engine controller could not directly control due to high current requirements. The exhaust brake solenoid permits air to pass to the exhaust brake cylinder to perform the heavy task of restricting the exhaust. The engine controller transmits a J1939 Drivetrain data link message indicating that the exhaust brake is active. The ESC responds to this message by transmitting a message over the Switch data link commanding the switch pack to illuminate the appropriate green switch LED.

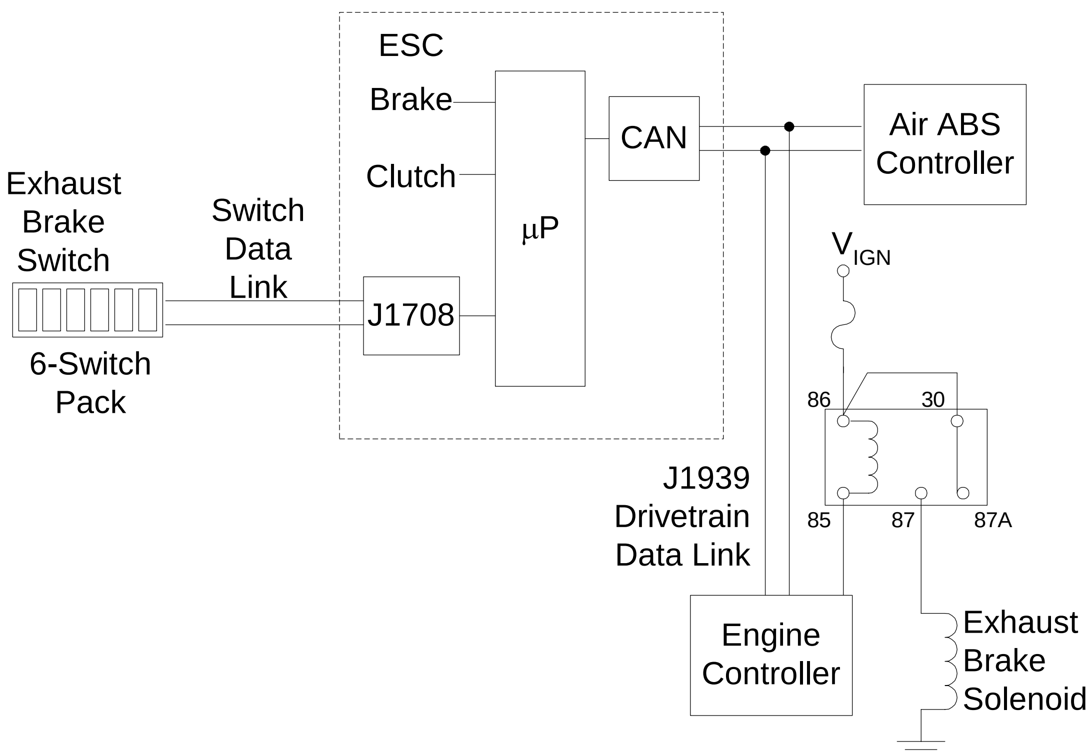

Figure 79 Exhaust Brake

Warning Lights, Gauges and Messages

When the key switch is switched to the ignition position, the EGC receives a J1939 Drivetrain data link message from the ESC indicating ignition is on. The EGC also has a hardwired ignition feed. When the EGC senses ignition has been switched on, the EGC responds by driving each gauge counterclockwise to the peg and then clockwise to the full sweep position (end of gauge marking) and then back to the zero position. This action eliminates any error that may have accumulated in gauge needle position. Each gauge will then drive to the appropriate position such as ½ tank, 60 psi, etc. During the gauge sweep, the EGC also illuminates all applicable warning LEDs for several seconds as a bulb check. After the bulb check the LEDs all go out and the appropriate LEDs switch back on such as brake pressure warning, etc. The gauge sweep process also occurs anytime battery power to the EGC has been cycled with the key switch in the off or accessory positions. After the gauge sweep and warning LED check, the EGC just does what it is told regarding all gauges and warning lights via J1939 Drivetrain data link messages. The only exception to this is the check electrical system warning lamp as described below.

Check Electrical System LED

Earlier ESC Software Revisions

The check electrical system (CES) warning LED is controlled by both the ESC and the EGC. If the ESC has detected specific faults, the ESC will transmit a J1939 data link message requesting the EGC illuminate the CES LED. The ESC will keep the CES on for one minute following detection of an active fault. The EGC will also illuminate the CES if the EGC is not able to communicate with the ESC over J1939 Drivetrain data link. The EGC will keep the CES illuminated until communication with the ESC is restored. The CES will also illuminate if the cluster ignition feed is high and the EGC microprocessor is not responding.

Later ESC Software Revisions

The CES will only illuminate if the EGC or Auxiliary Gauge Switch Pack (AGSP) detects a fault. Faults logged by any other module will not cause the CES to illuminate.

Seat Belt Reminder LED

The seat belt reminder LED is controlled by the ESC. When the ESC sees the ignition digital input go high, the ESC transmits a J1939 Drivetrain data link message to the EGC requesting that the seat belt reminder LED be illuminated. The ESC sends this message for several seconds after ignition is first switched on. There is no seat belt switch, so the LED is illuminated even if the seat belt is fastened.

Low Washer Fluid Level LED

A float in the washer bottle opens a switch connected to ZVR when the washer level is low. This switch is connected to ESC digital input that is biased to accessory voltage through a 1.2K-Ohm pull-up resistor. With the low washer switch closed (fluid not low), the voltage at the ESC digital input is near 0V. With the low washer switch opened (fluid low), the voltage at the digital input raises to near 12V. This causes the ESC to transmit a J1939 Drivetrain data link message indicating the low washer fluid warning LED should be illuminated. The EGC responds by illuminating the low washer fluid warning LED.

Water in Fuel LED

The same water in fuel (WIF) light module (cube) used in previous models is also used on the High Performance Trucks built with a dual-power lead ESC (mid-2003). The output of the WIF module is connected to an ESC ground biased digital input. The WIF module provides a high level signal when water is sensed in the fuel filter. The ESC responds to the high level signal at the input by transmitting a J1939 Drivetrain data link message indicating the WIF LED should be illuminated. The EGC responds by illuminating the WIF LED. The single-power lead ESC contains the circuitry for monitoring the water in fuel sensor directly. Trucks built after mid-2003 which were originally equipped with the single-power lead ESC do not have a WIF module. The output of the WIF sensor is connected to an ESC analog input. The voltage at the analog input is used to determine if water is present in the fuel. The single power lead ESC is also capable of interfacing with a WIF module so a single-power lead ESC can be installed as a service part on trucks equipped with a WIF module. However, a truck originally equipped with a single-power lead ESC cannot be retrofitted with an earlier revision dual-power lead ESC.

Park Brake Warning Light

The park brake switch provides a path to ZVR for the accessory biased ESC park brake switch digital input. On air brake vehicles, applying the park brake permits the normally closed park brake pressure switch to return its normal state. On vehicles with hydraulic brakes, lifting the park brake lever causes the normally open proximity switch to close. Regardless of brake type, the ESC digital input is pulled low when the park brake is applied. The ESC transmits a J1939 Drivetrain data link message requesting the park brake warning light be illuminated. The ESC also shuts off DRL with the park brake set if the vehicle is so equipped. The status of the park brake switch is also used in several ESC algorithms to inhibit or enable a particular feature.

ABS Warning LED

The air ABS controller transmits a J1939 Drivetrain data link message when an ABS fault has been detected by the ABS. The ESC detects this message and transmits a J1939 Drivetrain data link message to the EGC requesting the EGC to illuminate the ABS warning LED. For hydraulic ABS, the ESC transmits a J1939 Drivetrain data link message requesting ABS warning LED when a hydraulic ABS fault is detected. For more information on ABS warning lamp, see the appropriate ABS section.

Traction Control Warning LED

The air ABS controller transmits a J1939 Drivetrain data link message when the traction control switch is in the disable position. The ABS controller will also transmit this message if traction control switch is in the enable position and traction control event (wheel spin) is occurring. The ESC detects this message and transmits a J1939 Drivetrain data link message to the EGC requesting the EGC to illuminate the traction control warning LED.

Check A/C LED

The ESC transmits a J1939 Drivetrain data link message when certain A/C system faults are detected requesting the Check A/C LED as described in the HVAC section.

Engine Warning LEDs

The engine controller transmits the appropriate J1939 Drivetrain data link message requesting the amber ENGINE, red ENGINE, or Wait to Start (V8) warning LED be illuminated. Unlike most other warning LEDs, the EGC looks for these engine controller messages directly from the engine controller instead of a retransmitted message from the ESC.

Automatic Transmission Warning LEDs

The automatic transmission controller transmits the appropriate J1939 Drivetrain data link message indicating a condition that requires the range inhibit or check transmission warning LED be illuminated. The ESC detects this message and transmits a J1939 Drivetrain data link message to the EGC requesting the EGC to illuminate the range inhibit or check transmission warning LED.

Axle Oil Temperature

Optional axle oil temperature gauges (one or two) are available. Each rear axle (one or two) contains a variable resistance sensor. The sensor is a variable resistance device with a negative temperature coefficient. This means that as the sensor gets warmer, the sensor resistance decreases. The ESC analog inputs are biased to 80% of accessory voltage. The ESC converts the variable voltage level at the analog inputs to a J1939 Drivetrain data link message. The EGC or AGSP responds to the J1939 Drivetrain data link message by driving the appropriate rear axle oil temperature gauge to the corresponding value.

Voltmeter

The voltmeter is controlled by the ESC. Accessory voltage is an analog input to the ESC. The ESC microprocessor measures the accessory voltage level and transmits a J1939 Drivetrain data link message indicating voltage level. The EGC receives this Drivetrain data link message and drives the voltmeter to the appropriate voltage. If the voltage is less than 12V or greater than 15V and engine RPM is at least 325 RPM, the red warning LED in the gauge will illuminate. The EGC will also sound the audible alarm for five short beeps if the LED is illuminated.

Engine Messages (International Engines)

The LCD display is also used to display engine controller generated messages. If the amber ENGINE LED is illuminated, the LCD display will toggle between the words WARN ENGINE and the odometer value. If the red ENGINE LED is illuminate, the LCD display will toggle between the words OIL/WATER and the odometer value. The audible alarm will also sound continuously if red ENGINE LED is illuminated. The LCD display is also used to display a change oil maintenance reminder, if enabled in engine software. The LCD display will toggle between the words CHANGE OIL and the odometer value if the programmed maintenance interval is exceeded. The maintenance reminder may be reset using Master Diagnostics or a Pro-Link scan tool. The reminder may also be reset using the cruise control switches on later models.

Fuel Gauge (single tank)

The fuel gauge is controlled by the ESC. The fuel-sending unit is similar to previous models in that a float attached to a potentiometer provides a variable resistance as the float follows the fuel level in the tank. The resistance range of the potentiometer is about 33 Ohms with tank full and about 240 Ohms with tank empty. One end of the potentiometer is connected to ZVR through the ZVR splice in the dash wiring harness. The other end of the potentiometer is connected to an ESC analog input. The potentiometer is isolated from the sending unit mounting flange by a plastic material. Otherwise, the ZVR side of the potentiometer may become shorted to chassis ground through the fuel tank since the fuel tank may be grounded through its mounting. Remember that we don't want ZVR connected to chassis ground at more than one location.

The ESC analog input for the fuel gauge is biased to 80% of accessory voltage as shown in Figure 80. This means that with battery voltage at 12V, the open circuit voltage at the ESC fuel gauge input would be about 9.6V. The ESC converts the voltage level at the analog input to a J1939 Drivetrain data link message indicating the percentage of fuel in the tank. The EGC uses the fuel level information to then drive the fuel gauge to the correct position. If the wiring between the fuel gauge and the ESC become open circuited, or if the ZVR at the fuel-sending unit is open circuited, the voltage level at the analog input will raise to 80% of battery voltage. If the wiring between the analog input side of the potentiometer is shorted to ground, the voltage at the ESC fuel gauge analog input will drop to near 0V. Either of these conditions will set the appropriate fault in the ESC. Because of the open or short condition, the level of fuel in the tank is now unknown. The ESC transmits a message to the EGC to drive the fuel gauge to the 6 O'clock position, sound the alarm 3 beeps, and illuminate the low fuel warning LED in the gauge.

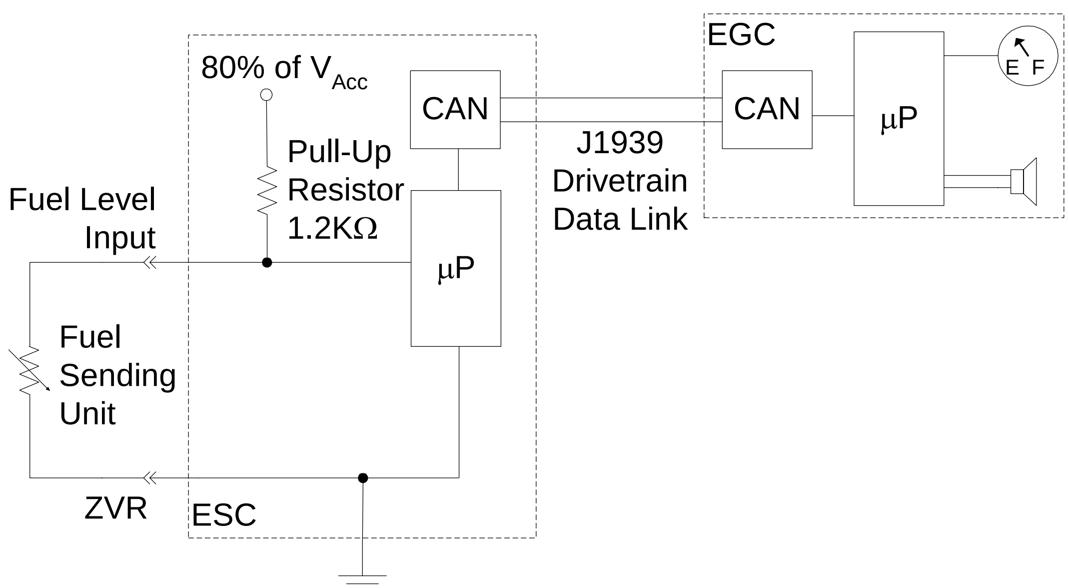

Figure 80 Fuel Gauge Circuit

Dual Fuel Tank System (Earlier 5-Wire Transfer Pump)

All High Performance Trucks, except 8600 models, with dual fuel tanks do not utilize the dual draw, dual return system used on previous models. Instead, the fuel is drawn from and returned to the right side fuel tank only*. A fuel transfer pump located on top of the right side tank draws fuel from the left side tank and pumps fuel into the right side tank. A fuel-sending unit in each tank is used by the fuel transfer pump to determine when to operate. The logic to control the fuel transfer pump is contained within the pump assembly. If the fuel level in the left tank is greater than the fuel level in the right side tank, the fuel transfer pump will operate until the levels in the left and right side tank are equal. The fuel transfer pump can only operate in the one direction. That is, fuel can only be transferred from the left tank to the right tank. If the fuel level in the right tank is greater than the level in the left tank, no action will occur until the right tank level drops below the left tank level. The power supply for the fuel transfer pump is supplied by an ignition-fused circuit. The ESC switches on a 1A high side driver if the engine is running. The 1A high side driver output acts as an enable signal for the fuel transfer pump. If this signal is not present, the fuel transfer pump will not operate regardless of fuel levels. Therefore, the fuel transfer pump only operates if the engine is running. On later versions of ESC software, the ESC will also shut off the 1A FET if either fuel sensor circuit is faulted or the draw tank is more than 85% full.

The output of both sending units is also monitored by the ESC. Only the right side sending unit value is displayed by the fuel gauge since this is the “useable” fuel level. This is done in the same manner as described previously for single fuel tank vehicles. Additionally, the left fuel tank is monitored by the ESC for faults (short to ground, open). If a left or right fuel sending unit circuit fault is detected, the ESC sends a J1939 Drivetrain data link message to the EGC to drive the fuel gauge to 6 O’clock, sound alarm 3 beeps, illuminate gauge LED, and shut off the fuel transfer pump enable signal.

Note that the input impedance of the fuel transfer pump causes the voltage measured at the ESC input with a disconnected fuel sending unit to be about 50% of accessory voltage. This differs from the single fuel tank system, which pulls the input voltage with a disconnected sensor up to about 80% of accessory voltage.

The dual fuel tank system for models with International engines built prior to mid-2002 with a 5-wire transfer pump is shown in Figure 81.

* 7600 Models with dual fuel tanks are an exception and use the left side tank as the draw tank and the right side tank as the storage tank. The exhaust routing requires this change.

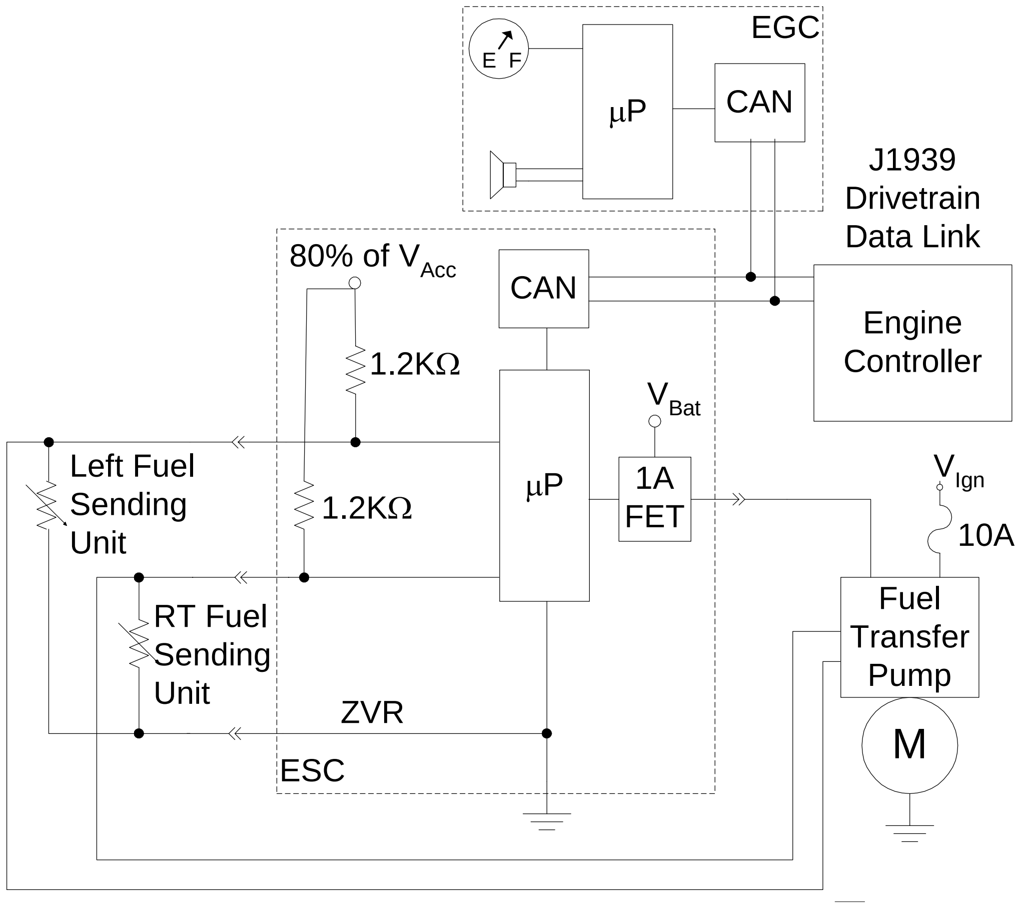

Figure 81 **Dual Fuel Tank System With 5-Wire Transfer Pump**

Dual Fuel Tank System (2-Wire Transfer Pump)

The fuel transfer pump on models built mid-2002 and later is a simple 2-wire “dumb” pump as shown in Figure 82. The ESC provides the control logic for these models. The pump is supplied with chassis ground. An ESC low side driver controls the transfer pump relay located in the PDC. The relay provides +12V to the transfer pump when energized. The ESC evaluates the difference between the left side sending unit and the right side sending unit and energizes the fuel transfer pump relay when conditions for fuel transfer are correct. These conditions are similar to those described above for the 5-wire fuel transfer pump system.

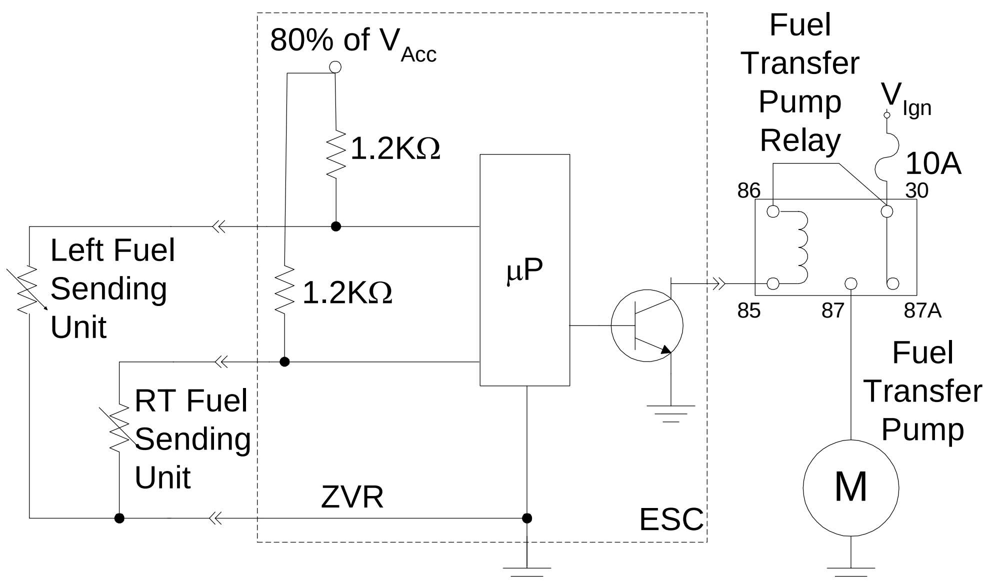

Figure 82 Fuel Transfer Pump System With 2-Wire Transfer Pump

Hydro-Max (Built Prior to Mid-2003)

The Hydro-Max hydraulic brake power assist system used on previous models is also used on the High Performance Trucks with some changes. The brake monitor module is carry-over (trucks originally built with a dual-power lead ESC). However, one difference between the system on previous models and High Performance Trucks is that the ESC supplies the high side control of the Hydro-Max pump relay. A 1A high side driver in the ESC supplies 12V to the high side of the Hydro-Max pump relay when the key switch is in the ignition position or anytime the service brake is depressed as shown in Figure 83.

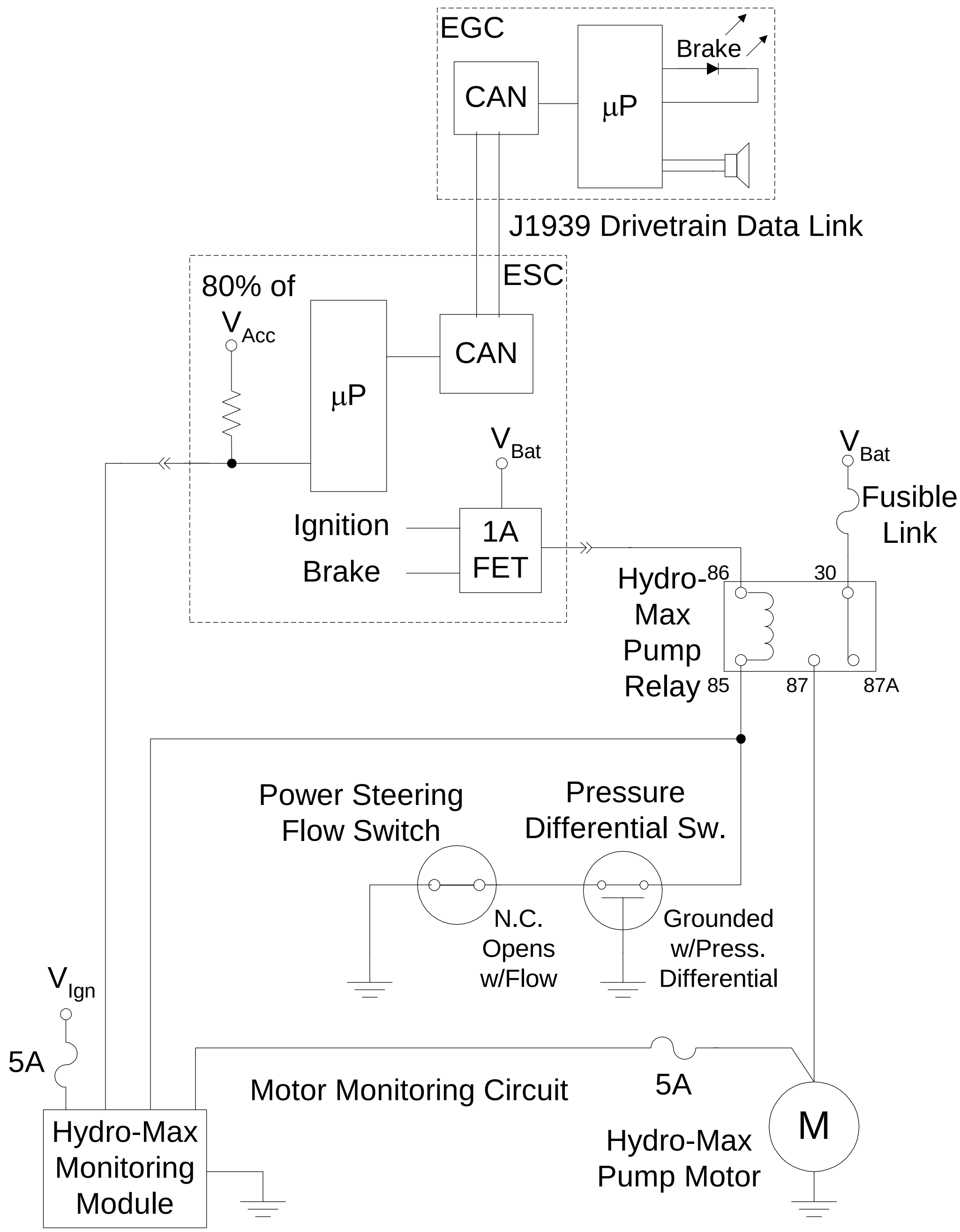

Figure 83 Hydro-Max System (w/Dual Power Lead ESC Built Prior to Mid-2003)

With the Hydro-Max pump relay energized, the pump motor will operate if the flow switch or pressure differential switch is closed. The flow switch is normally closed and requires power steering pressure to open the switch.

The brake monitor module watches for problems with the Hydro-Max system. If any fault is detected, the brake monitor module outputs a ground level signal to an ESC accessory biased analog input. If the key switch is in the ignition position, the ESC will transmit a J1939 Drivetrain data link message to the EGC requesting the audible alarm be sounded and the brake pressure warning lamp be illuminated.

System problems that will cause the brake monitor module to detect a fault are as follows (all with key switch in the ignition position):

- If the power steering flow switch is closed at any time. This may indicate that the engine has stalled or power steering pressure was lost for some reason.
- If the power steering flow switch is open when the key switch is first switched on. The module must see a transition from flow switch closed to flow switch open after key switch is first switched on. Otherwise, the flow switch may be disconnected or an open circuit exists.
- If the pressure differential switch closes indicating an imbalance in the split hydraulic system.
- If the brake monitor module cannot find a ground through the pump motor monitoring circuit. This may indicate a worn motor, missing ground, etc. Note that a 5A fuse in the PDC is in this circuit. If the fuse is missing or blown, the monitor module will fault.

Note: Since the EGC contains the audible alarm, the old method of removing the alarm so you could work on vehicle with ignition on and engine off without going crazy will not work. To disable the alarm while servicing the vehicle, press and hold the panel illumination button up or down while simultaneously pressing and holding the trip reset button on EGC for five seconds. The alarm will stay off until the next ignition cycle or until engine RPM is seen by the EGC.

Hydro-Max (w/Single-Power Lead ESC Built After Mid-2003)

The Hydro-Max monitoring module is removed from the vehicle wiring harness on trucks originally equipped with a single-power lead ESC. The single-power lead ESC contains the circuitry to permit the ESC to monitor the Hydro-Max system without the need for the monitoring module (Figure 84). An electronic circuit called a flip-flop permits the ESC to determine if the Hydro-Max flow switch has transitioned after the engine starts. Remember that the ESC microprocessor may reset due to the low voltages associated with engine crank. The flip-flop circuit acts as a memory for the ESC. This permits the ESC to “remember” if the flow switch was closed prior to engine crank even if the ESC resets during engine crank. The positive side of the Hydro-Max motor is the input to the ESC flip-flop circuit. The operation of the system is identical to the previous monitoring module version.

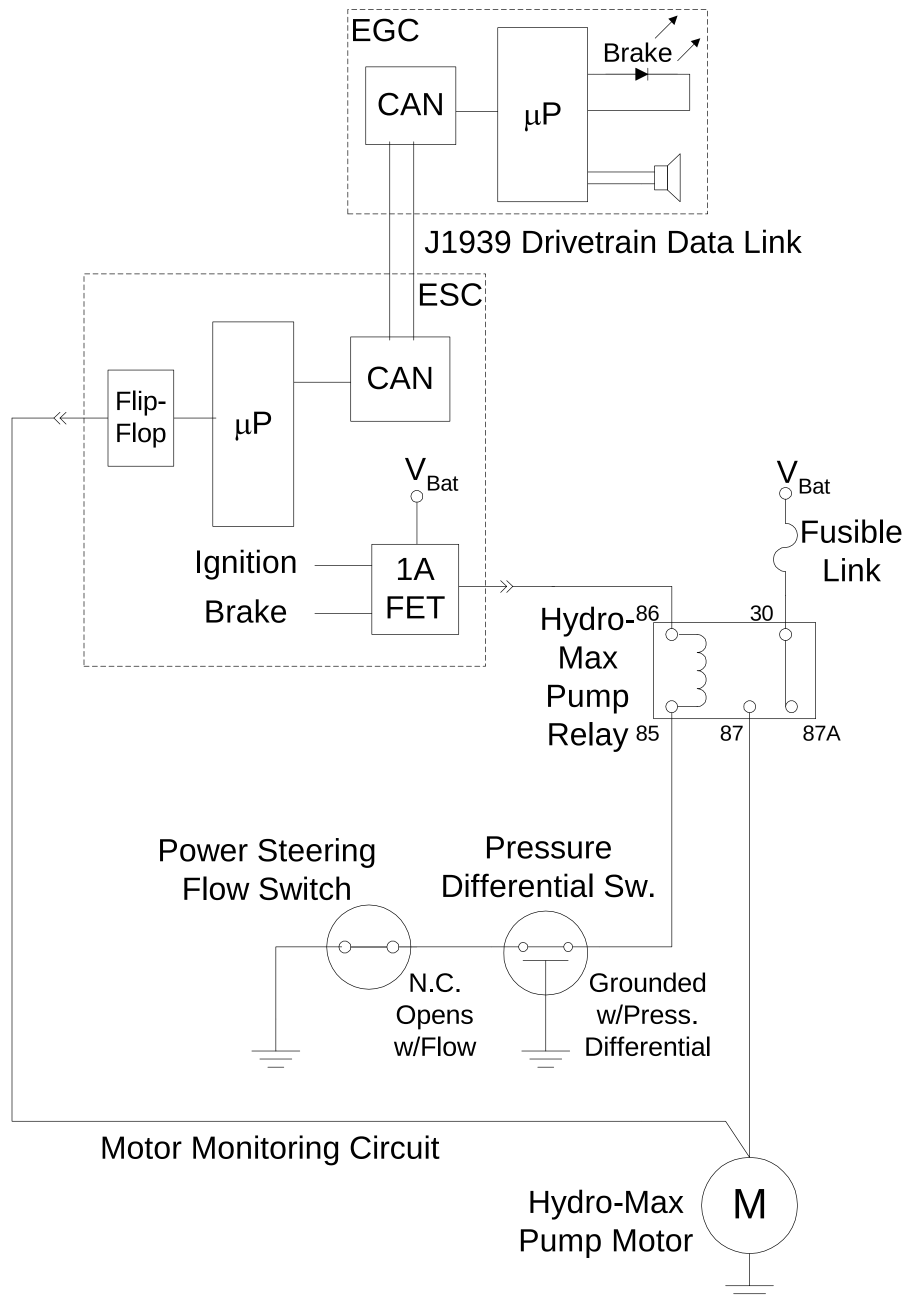

Figure 84 Hydro-Max Monitoring System (w/Single Power Lead ESC After Mid-2003)

Air Pressure Gauges

There are no air hoses connected to the EGC. Instead, the pressure in the primary and secondary air systems are monitored by the ESC. Two pressure transducers (sensors) are located inside the cab in the foot valve feed air lines. These transducers convert air pressure into a variable voltage level. The transducers are atmospheric pressure compensated. This means that the pressure transducer references the pressure it measures in the air system to barometric pressure. A small hole in the connector end of the sensor permits atmospheric pressure to enter the transducer to act as a reference pressure. The sensors output an increasing voltage level as pressure in air system increases as shown in Figure 85. The sensors have three wires: a +5V sensor supply voltage, ZVR, and an output. The sensor output acts as an analog input to the ESC. This input is biased low through an 81K Ohm pull-down resistor (Figure 86).

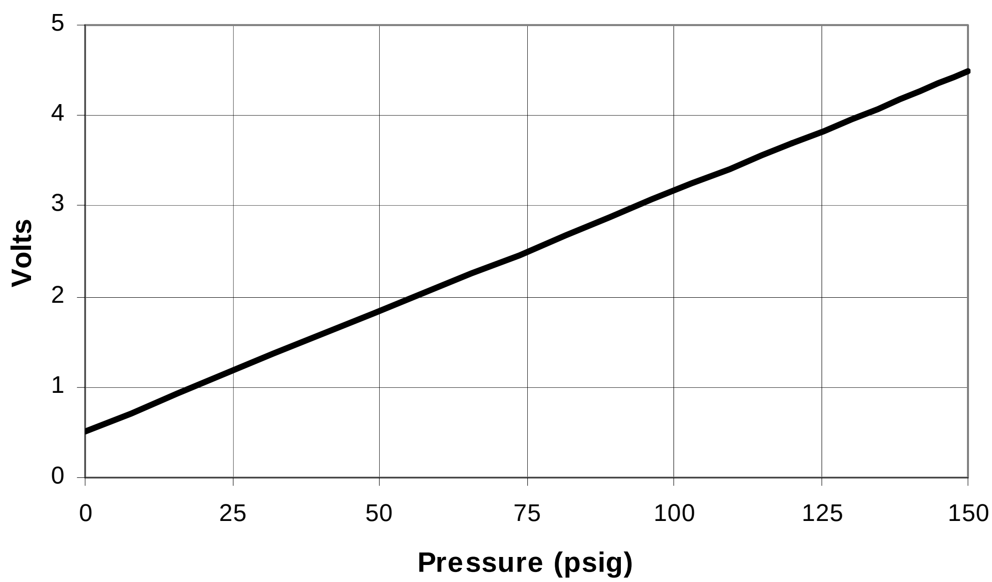

Figure 85 Air Pressure Transducers Output

If the electrical connector is not connected to the sensor, the ESC will detect a voltage near 0V and set a fault for the appropriate air pressure transducer. The ESC will send a J1939 message indicating a pressure sensor fault. The EGC responds by driving the appropriate air pressure gauge pointer to the 6 O’clock position, turns on the gauge warning LED, and sounds the alarm continuously.

If input voltage is within the range of .5V to 4.5V, the ESC will convert the input voltage to a J1939 message corresponding to the system pressure. The EGC sees the J1939 message and drives the gauge pointer to the appropriate step. If the pressure is determined to be less than 72 psi, the EGC also illuminates the gauge warning LED in the appropriate air pressure gauge and sounds the alarm until pressure exceeds 72 psi for both primary and secondary systems.

If voltage is greater than 4.5V, the ESC logs a fault for the appropriate air pressure transducer shorted to battery voltage and sends a message on J1939 indicating a sensor fault for appropriate sensor. The EGC responds by driving the appropriate air pressure gauge pointer to the 6 O’clock position, turns on the gauge warning LED, and sounds the alarm continuously.

Vehicles without air brakes may also have an air compressor for air-powered accessories. In this case, a single air pressure sensor is located in the engine compartment near the air compressor. This sensor is identical to that used for air brake systems. The ESC input is the same as that used for the primary air pressure sensor. The auxiliary air pressure gauge is located in the same EGC location as the primary air pressure gauge. The sensor diagnostics for the auxiliary air pressure system are the same as the primary and secondary air pressure system.

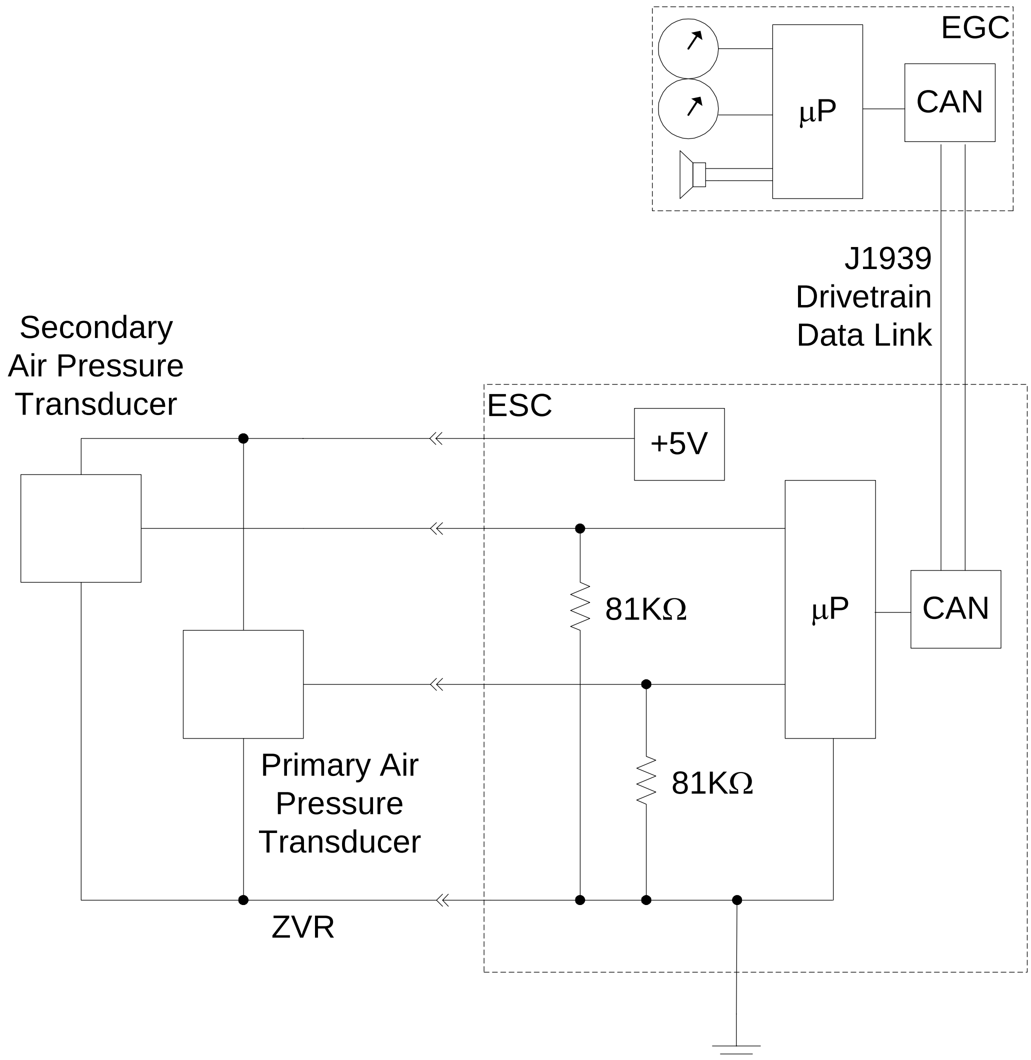

Figure 86 **Air Pressure Gauge Circuit**

Power Windows and Locks

Power door "pods" are located in each door. The driver's door pod contains switches for each window, a window lockout switch, and a power door lock switch for all doors. The other door pods contain a switch for that door's power window and a lock switch for all doors. The input connector of each door pod consists of +12V power feed (fused at 30A), a 12 AWG ground wire, and the Switch data link wiring. The Switch data link permits all pods to communicate with each other and with the ESC. The output of each door pod is connected to the respective door's power lock and power window motor as shown in Figure 87.

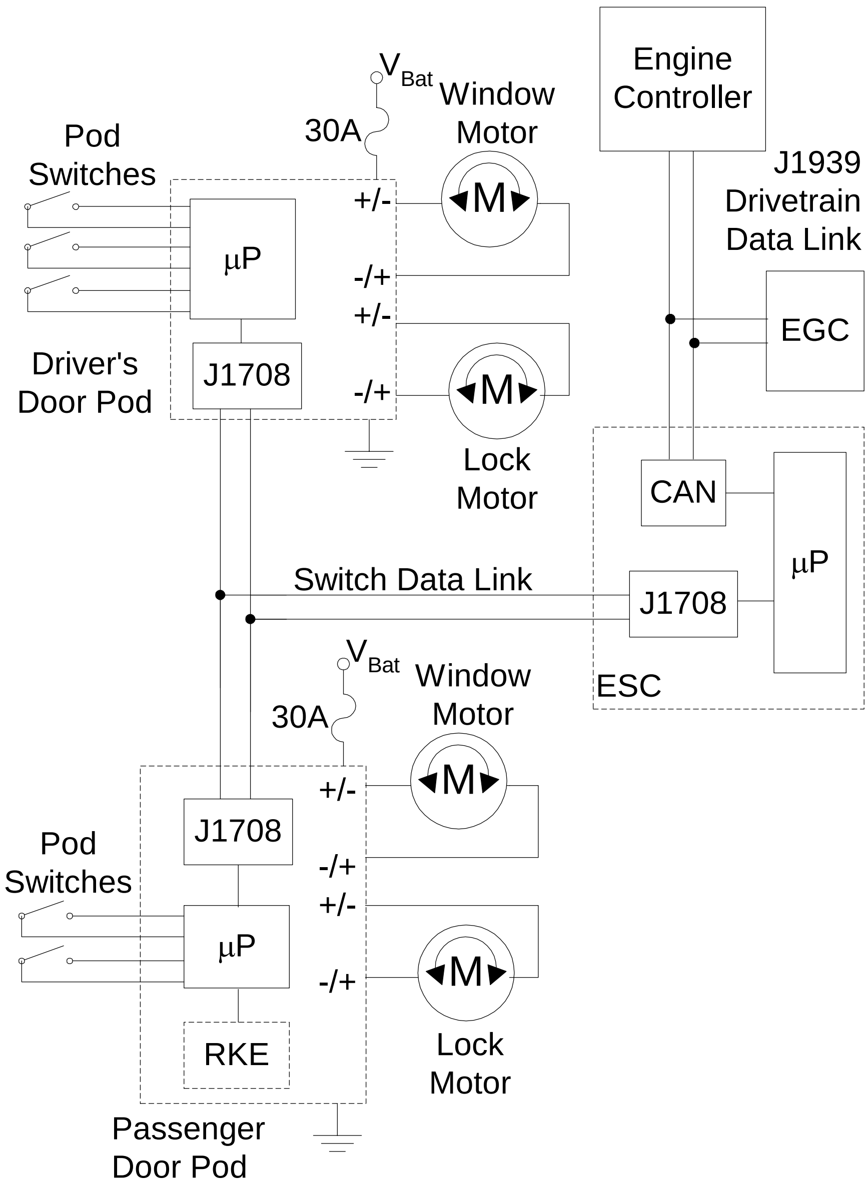

Figure 87 Power Window and Lock Circuit

The lock button on each pod causes the lock motor directly connected to the pod to operate. A message is also transmitted to the other pod instructing it to operate its lock motor as well. For example, if the lock button is depressed on the driver side door pod, the driver's door pod powers its own door lock motor to operate in the lock direction. This also causes the driver's door pod to transmit a request for the other door pod to power its door lock motor in the lock direction as well. This works the same for any door. Pressing the lock or unlock button causes that pod to power its own lock motor and transmit a request for the other pod to power its lock motors as well. The door locks will operate with key switch in any position including off.

The power windows work the same as the power locks except the ESC must transmit an "accessory on" message over the Switch data link before power window motors will operate. The power windows are not permitted to function with key switch in the off position, but may operate with key in the accessory or ignition positions. If key switch is not in the off position, the door pods control the power window motors in the same manner as described above for the power door locks. The driver side pod has a switch for the passenger window as well. Pressing the passenger window switch on the driver side pod causes a message to be transmitted over the Switch data link instructing the passenger side pod to raise or lower the passenger side window.

The panel illumination level for the door pods is transmitted over the Switch data link as well. The ESC transmits a Switch data link message to the door pods indicating the level of illumination the pod should set its internal panel illumination to. The pod then PWMs its internal illumination LEDs to the appropriate level of panel illumination. The ESC receives the panel illumination level information from the EGC via the J1939 Drivetrain data link.

An available option is remote keyless entry (RKE). If the vehicle has RKE, the front passenger door pod contains the RKE receiver. Pressing the lock or unlock button causes the front passenger door pod to command all other pods to lock or unlock their doors. Additionally, the ESC can be programmed to chirp the horn when the doors are locked using the RKE.

The ESC on a vehicle with power door locks can also be programmed using ICAP so that the ESC will issue a global door lock command the first time vehicle speed is greater than 5 MPH each key cycle. The vehicle speed at which the doors lock may be changed using ICAP.

Crew-Cab (4-door) models are also available with power locks and windows. The driver's door pod with crew cab has an additional switch to select the front or rear windows. This permits the driver to control each window independently. The rear door pods are identical to the front passenger door pod (without RKE). The rear door pods are distinguished from the front passenger door pod and from each other by means of an address line. There are two address lines in the 7-way connector on the passenger door pods. The wire harness provides the ground to the appropriate address line. Address line #1 is grounded for the left rear door pod. Address line #2 is grounded for the right rear door pod. Neither address line is grounded for the front passenger door pod.

ABS Brakes

Wabco Hydraulic ABS

High Performance Trucks with hydraulic brakes are equipped with Meritor-Wabco ABS. The system consists of wheel speed sensors, an electronic control module and a hydraulic valve unit. Details on the basic system are available from Meritor-Wabco so let's just look at the differences when applied to International High Performance Trucks. The hydraulic ABS system does not presently have J1939 capabilities. Therefore, the ESC takes on the responsibility of generating J1939 messages for the hydraulic ABS controller. The ESC generates J1939 messages with a source identification of an ABS controller.

ABS Warning Lamp

An ABS related message transmitted by the ESC is ABS warning lamp request. Wabco hydraulic ABS circuit with no faults present is shown in Figure 88. Current flow is indicated by the darker lines.

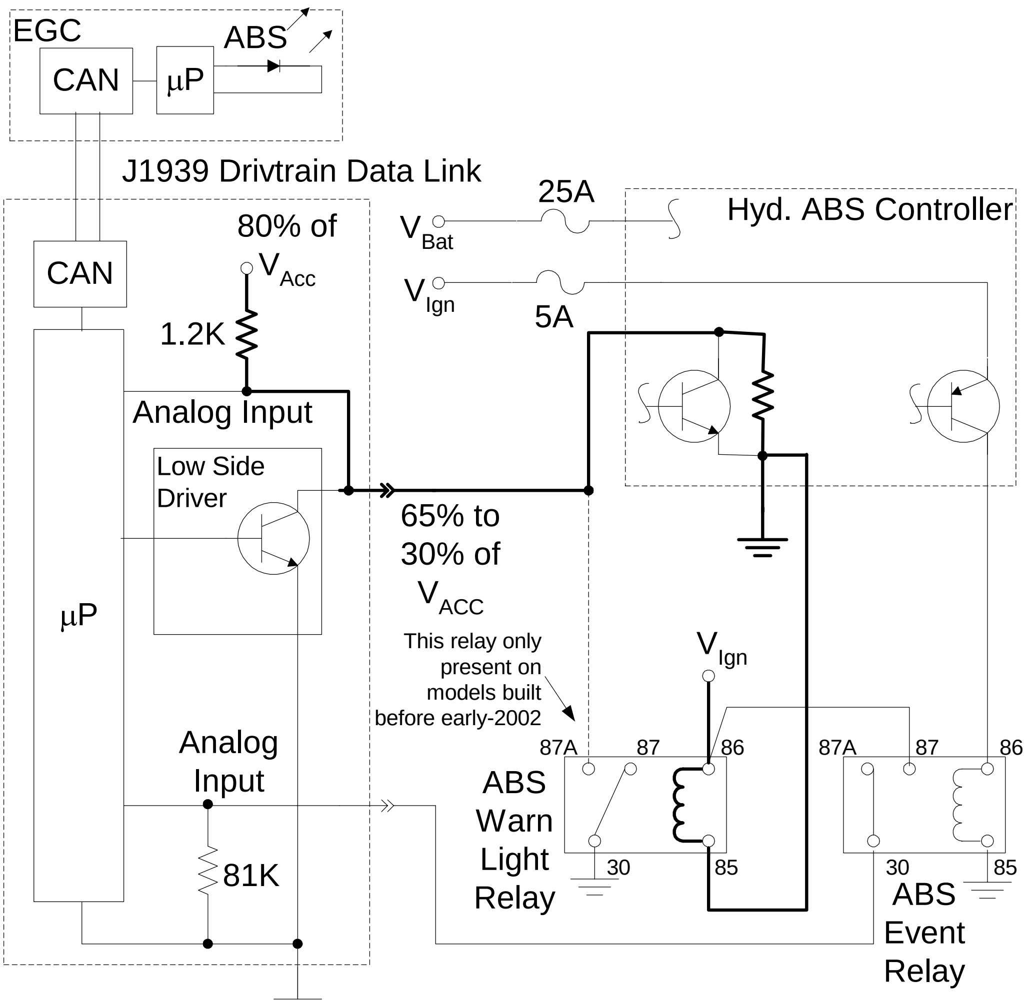

Figure 88 **Wabco Hydraulic ABS Circuit with No Faults Present**

Figure 89 illustrates the circuit when an ABS fault is present. A low side driver in the ABS controller switches on which provides a ground for the ESC analog input. The low side driver in the ABS controller pulls the ESC analog input voltage down to about .5V. The ESC responds by generating a J1939 message requesting that the EGC illuminate the ABS warning LED.

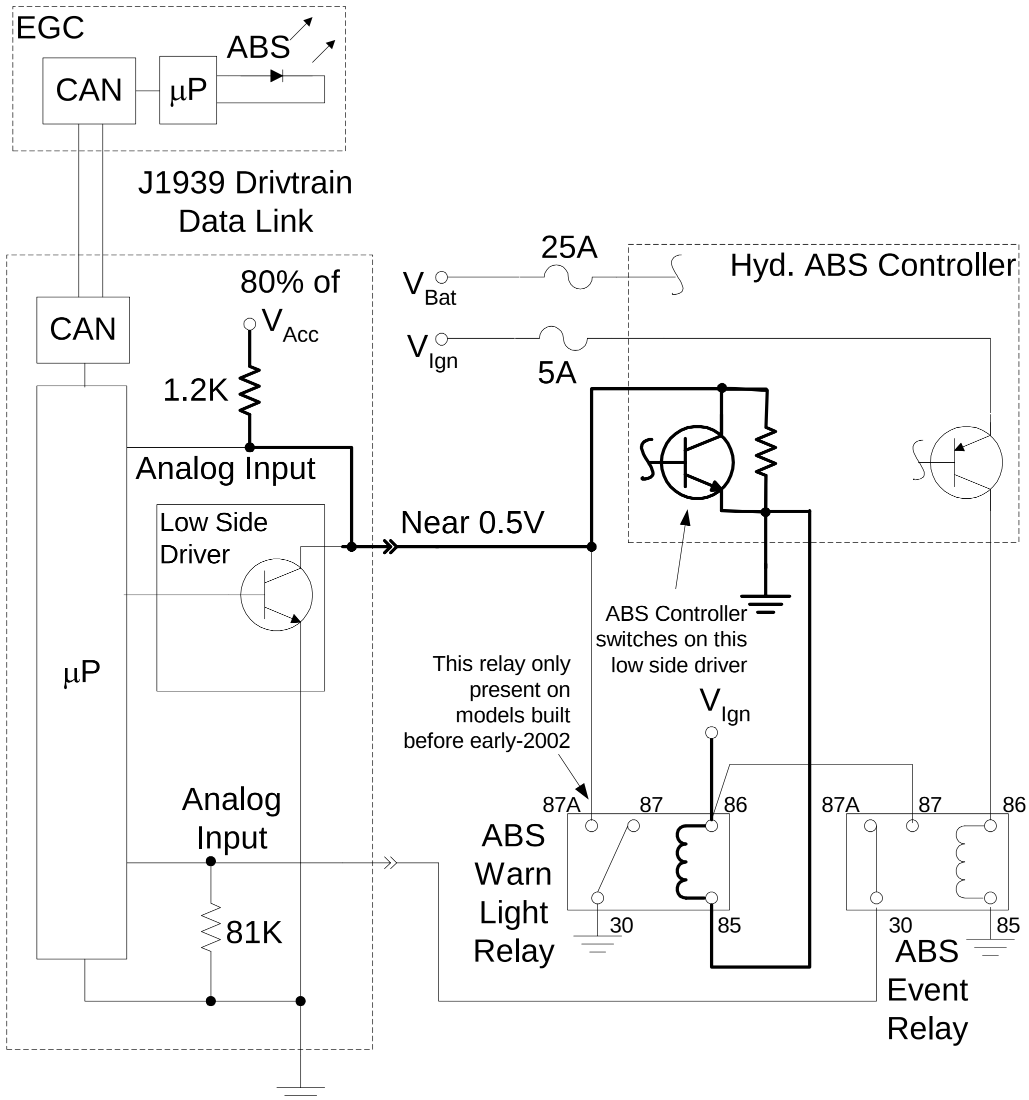

Figure 89 **Hydraulic ABS Controller with Faults Present**

An ABS warning light relay is located in the PDC on early models of High Performance Trucks built before January 2002. The high side of the relay coil is supplied with ignition voltage. The low side of the relay coil is provided by the ABS controller. The normally closed contact of the relay is connected to an ESC combination analog input/low side driver output pin and the ABS controller. Terminal 30 of the relay is connected to chassis ground. If the ABS controller is connected to the wiring harness, the warning light relay coil is provided with a ground. This causes the ABS warning light relay to switch open the path to ground that the ESC input/output would otherwise see through the normally closed relay contacts.

If the ABS controller is not connected to the vehicle harness for some reason, the ABS warning light relay will not be energized. The normally closed relay contacts then provide a path to ground at the ESC analog input. This causes the voltage at the ESC analog input to pull down to near 0V. The ESC will then transmit a message to the EGC requesting the ABS warning lamp be illuminated. The circuit is shown in Figure 90.

On models of High Performance Trucks built after January 2002, the ABS warning light relay has been eliminated. The relay was removed because the ESC is capable of detecting that the black ABS connector is not mated to the ABS module without the relay. This is because the ESC hydraulic ABS warning lamp input is an analog input. If the black ABS connector is not mated to the ABS module, the ESC microprocessor will see about 80% of the accessory voltage level at hydraulic ABS warning lamp input. This is above the 30% to 65% level seen at the input when there are no faults present. The ESC responds to the 80% accessory voltage level at the input by transmitting a J1939 message to the EGC requesting the ABS warning lamp be illuminated.

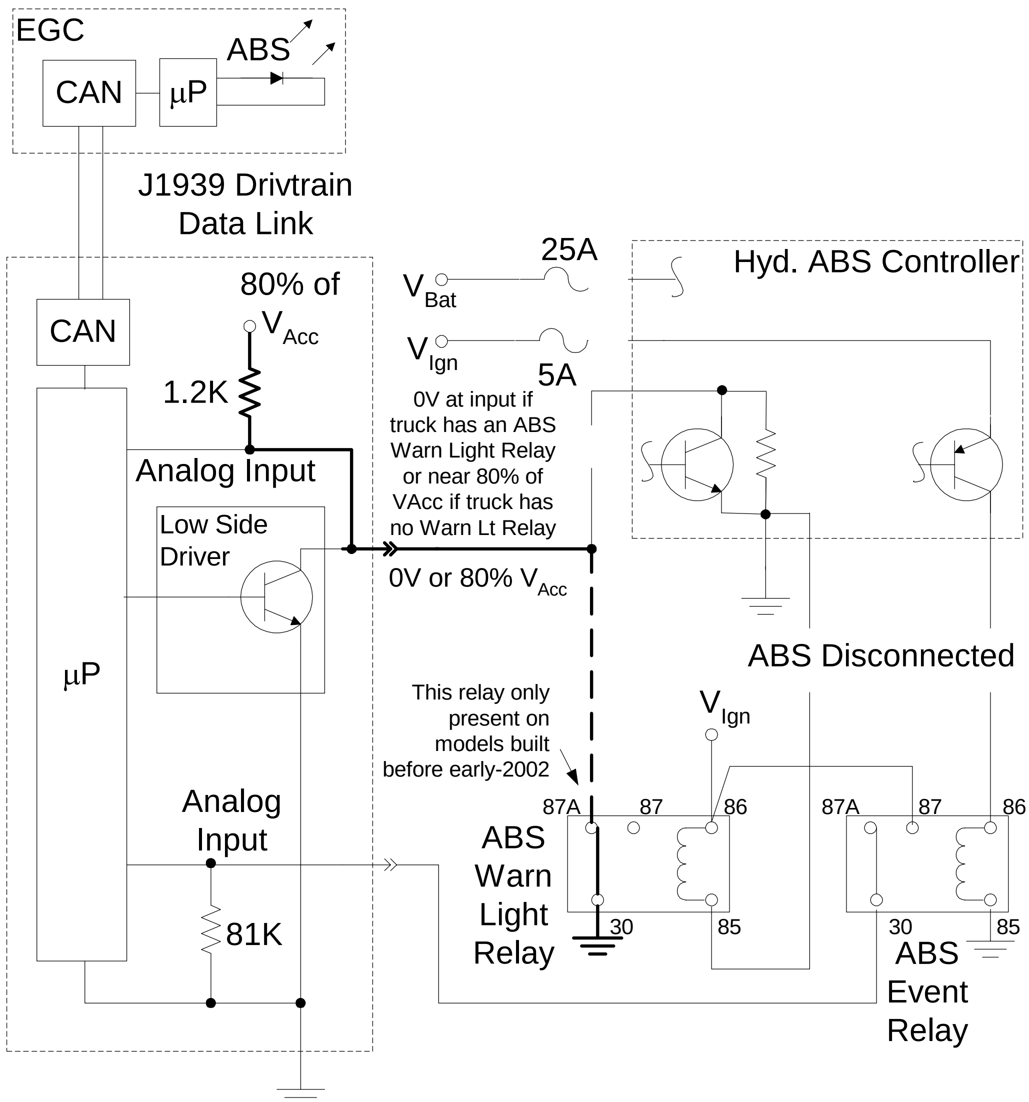

Figure 90 Hydraulic ABS Controller Not Connected to Wire Harness

Drive Axle ABS Event

Another hydraulic ABS message generated by the ESC indicates that a drive axle ABS event is occurring. This means that the rear wheels are locked up or nearing lock up. This information is used by Allison automatic transmission controller to unlock the torque converter to prevent stalling the engine. The drive axle ABS event message is also used by the engine controller to disengage the engine brake, if applicable. This is necessary because the engine brake could be responsible for the drive axle ABS event, not the service brakes. The Wabco ABS controller provides the high side for the ABS event relay coil located in the PDC should a drive axle ABS event occur. The low side of the relay coil is hardwired to chassis ground. When the ABS event relay is energized, ignition voltage is switched to the ESC ABS event input. This input is biased to ZVR through an 81K-Ohm resistor. With the ABS event relay not energized, the voltage at the ABS event input will be about 0V. When the ABS controller energizes the ABS event relay, the voltage at the ESC ABS event input will raise to near ignition voltage. The ESC responds by transmitting a J1939 Drivetrain data link message indicating an ABS drive axle event is occurring. This message is disguised to look like the ABS controller is sending the message (message source ID number is ABS controller). The engine controller responds to the message by disengaging the exhaust brake or engine brake, if applicable. The automatic transmission controller also responds to the message by unlocking the torque converter, if applicable. Additionally, the ESC sets the cruise ON message to cruise OFF. The circuit is illustrated in Figure 91. On trucks built after late-2002, the ABS Event Relay is only present on hydraulic brake vehicles with an auto trans. or an exhaust brake.

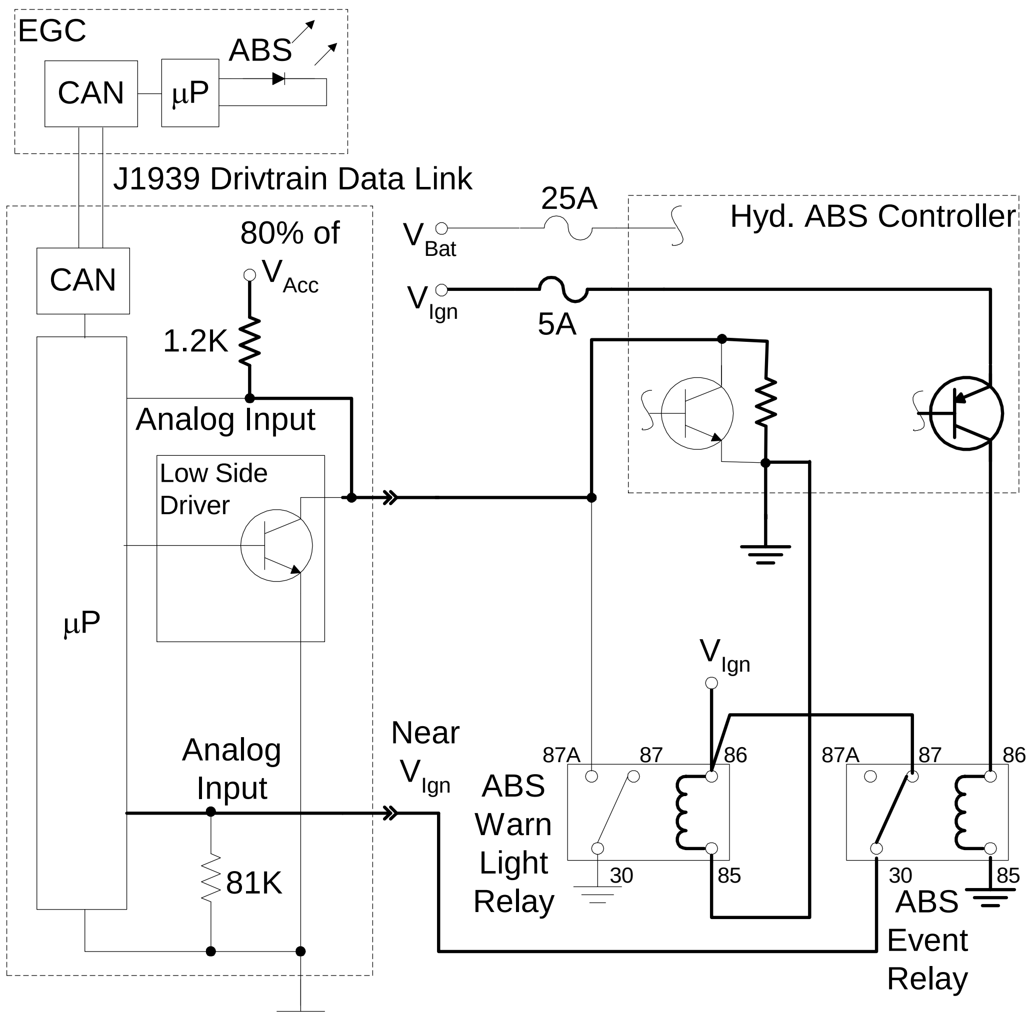

Figure 91 **Hydraulic ABS Drive Axle Event Occurring**

Hydraulic ABS Fault Codes

The ABS warning light on vehicles with Wabco hydraulic ABS can also flash out fault codes stored in the ABS controller. This is done by placing the vehicle into diagnostic mode using the standard ignition on, park brake set, press cruise on and resume buttons simultaneously. The Wabco ABS controller is placed into the diagnostic mode by providing a ground to its ABS warning light output. The ABS controller warning light output is both an input and an output. This is the reason the ESC also uses a combination analog input / low side driver output pin for this circuit. When the ESC is placed into diagnostic mode, the low side driver for the combination input/output is switched on for the length of time that the cruise switches are depressed. Provided that the cruise on and resume witches are simultaneously depressed for at least one second, the ground provided by the ESC at the combination input/output pin will cause the ABS controller to go into diagnostic mode. After the cruise switches are released, the ABS controller will begin pulling the ESC input/output to ground and then opening the circuit in a timed pattern to cause the ESC to flash out two-digit fault codes stored in the ABS controller.

Miscellaneous Hydraulic ABS Information

If the cruise on and resume switches are simultaneously depressed for longer than 30 seconds, the ABS controller will set a fault for ABS warning light circuit shorted to ground. The ABS controller will then not attempt to flash out fault codes.

If the ABS diagnostic circuit is open between the ABS controller and the ESC, the ABS will set a fault for warning light circuit open. The Wabco ABS controller sees the impedance of the accessory biased ESC input/output as a conventional hardwired ABS warning lamp bulb.

The Wabco ABS controller will keep the ABS warning lamp illuminated even after a fault is no longer present until all wheel speed sensors provide a valid signal. This is true even if the fault was not for a wheel speed sensor. The ABS controller will also keep warning light illuminated until all wheel speed sensors provide a valid signal if faults are cleared, even if no faults were in memory. Turning the warning light out requires that the vehicle move at several MPH to validate all the wheel speed signals are present.

On trucks built with a dual-power lead ESC, a diode is placed between the ignition and accessory relay coils to keep the accessory relay active during engine crank. The ignition switch is designed to drop out accessory in the crank position. However, if the accessory relay drops out during crank, the accessory circuit pulls down near ground level. This causes the accessory biased ESC input to look like a request for diagnostics to the ABS controller. If the ABS warning lamp flashes out fault codes after cranking engine, check for a missing or backwards ignition to accessory diode. Note: trucks built after mid-2003 with the single-power lead ESC no longer require the ignition to accessory diode in the wire harness. The diode is contained within the single-power lead ESC circuitry so the accessory relay is permitted to drop out with the key switch in the crank position.

Wabco ABS uses J1708 for diagnostics. The Wabco diagnostic software utilizes a standard J1708 to serial communications adaptor.

Bendix Air ABS

Compared to hydraulic ABS, air ABS is fairly simple. The main reason for this is that the new Bendix EC30 air ABS controller is J1939 compatible. The basic ABS is very similar to the EC17 system used on previous International models. One difference is the ability of the EC30 ABS controller to transmit ABS warning light and drive axle ABS event information over J1939 Drivetrain data link. This simplifies the system as shown in Figure 92.

Drive Axle ABS Event

If the ABS controller detects the wheels on the drive axle are nearing lock-up, the ABS controller transmits a J1939 Drivetrain data link message indicating this. The engine controller and automatic transmission controller see this information on the J1939 Drivetrain data link and act accordingly. The engine controller will release any engine brake that may be causing the drive axle wheel lock-up, if applicable. The automatic transmission controller will unlock the torque converter if necessary. The ESC will also set the cruise control on J1939 Drivetrain data link message to cruise control off status

Air ABS Warning Lamp

The ABS warning lamp information is also transmitted by the ABS controller. If an ABS fault condition is detected, the ABS controller will transmit a message over J1939 Drivetrain data link. The ESC detects this message and sends a message to the EGC requesting that the ABS warning lamp be illuminated. The EGC does not look for the ABS warning lamp message directly from the ABS controller. A single message containing all warning lamp information (except engine warning lamps) is sent to the EGC over J1939 Drivetrain data link from the ESC. The ABS controller sends out a periodic "heartbeat" message indicating everything is OK. If this message is missing for five successive heartbeats, the ESC will request the EGC illuminate the ABS warning lamp since the ABS status is not known. Therefore, an open J1939 connection between the ESC and ABS controller will cause the ABS warning lamp to be illuminated.

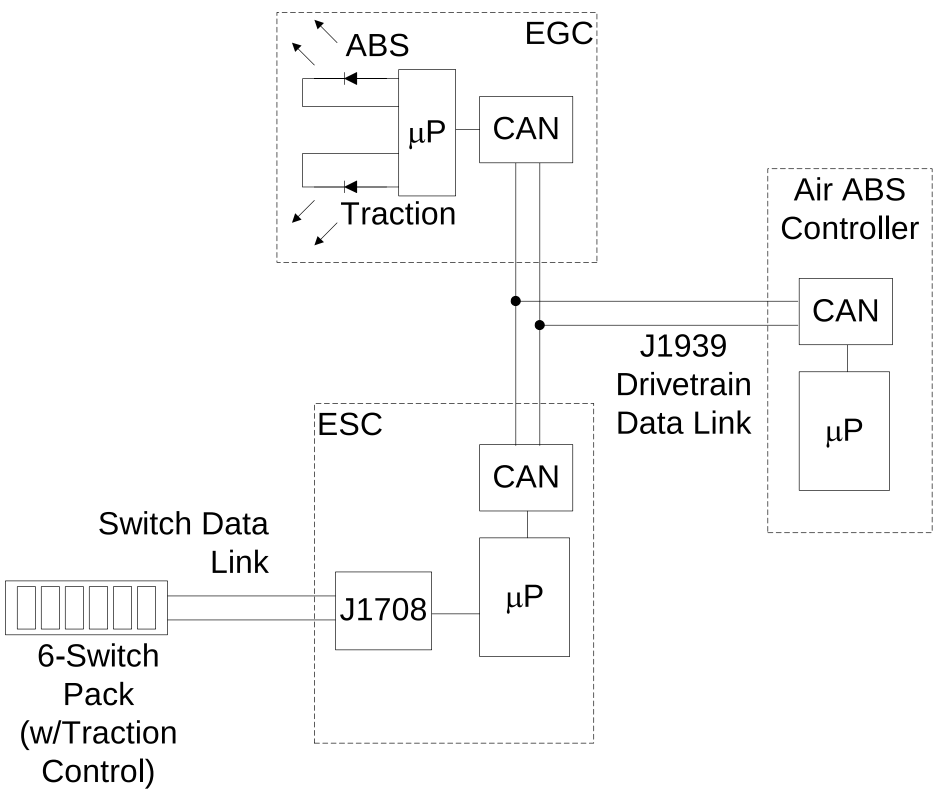

Figure 92 Bendix Air ABS Circuit w/Optional Traction Control

Traction Control
Traction control is also available with Bendix air ABS. A switch pack actuator permits disabling traction control. The switch pack communicates the status of the traction control switch to the ESC over the Switch data link. The ESC transmits a message to the ABS controller indicating the status of the traction control switch over J1939 Drivetrain data link. If the traction control switch is in the enabled position, the ABS controller will perform traction control when necessary. If the traction control switch is in the disable position, the ABS controller will disable traction control and transmit a message over J1939 Drivetrain data link indicating that traction control is disabled. The ESC receives this message and transmits a message to the EGC over J1939 Drivetrain data link requesting illumination of the traction control warning LED. The EGC responds by illuminating the green traction control warning LED. If the traction control LED is on continuous (not flashing), traction control is disabled. Additionally, if the traction control switch actuator is in the enable position and a traction control event is occurring (the ABS controller is actively performing traction control), the traction control warning LED will flash for the duration of a traction control event.

Two levels of traction control are performed on vehicles with traction control and International engines depending on vehicle speed. If the drive axle wheel speed sensors detect a traction control event (drive wheel slip), the ABS controller will first respond by transmitting a request over J1939 Drivetrain data link for the engine controller to reduce torque (cut fuel). If the traction control event is still occurring, then the ABS controller will perform differential braking provided vehicle speed is below 25 MPH. Differential braking involves applying the brake of the wheel that is spinning. The traction control solenoid located on top of the rear relay valve applies air to the relay valve just as though the brake pedal had been depressed. The modulators are then used to block air to the brake of the wheel that is not spinning and pass air through to the brake of the wheel that is spinning. This action will slow the spinning wheel and transmit torque to the wheel that is not spinning.

Trailer ABS Warning Light
If the vehicle has trailer air brake provisions, the ABS controller will be equipped for trailer ABS warning light. The ABS controller detects a trailer ABS fault through a signal transmitted by the trailer ABS controller. The trailer ABS controller transmits a high frequency signal onto its power supply feed (center pin of the 7-way trailer connector). This is called Power Line Carrier or PLC. The truck ABS controller detects this high frequency signal in its own power supply feed. If the signal indicates that there is a problem with the trailer ABS controller, the truck ABS controller generates the appropriate J1939 Drivetrain data link message requesting the EGC illuminate the Trailer ABS warning LED.

Air ABS Diagnostics
Air ABS diagnostics are still performed over J1708. The ABS warning lamp will not flash out fault codes. An enhanced version of Bendix ACom diagnostic software is available. LEDs on the ABS controller will indicate a single fault as in previous models and a magnet may be used to clear faults or reset controller as in the past.

Wabco Air ABS
The Wabco Air ABS is an optional system available on 8600 models. This system also has J1939 capabilities like the Bendix system. The functionality of the system as it pertains to International High Performance Trucks is nearly the same as the Bendix system described above. Some minor differences are as follows: The traction control warning LED in the EGC flashes if traction control is disabled instead of illuminating steadily like the Bendix system. The traction control LED with the Wabco system will also illuminate steadily for several seconds if the ABS controller detects a traction control event is occurring instead of flashing like the Bendix system.

Allison Automatic Transmissions

Two families of Allison automatic transmissions are available on the High Performance Trucks: the World Transmission MD or HD series (WTEC) and the Light Commercial Transmission (LCT) 2000 series.

World Transmission Series

The WTEC transmission controller remains mostly unchanged from previous models. Changes include some enhanced J1939 capabilities. The range inhibited and check transmission warning light information is now transmitted over J1939 Drivetrain data link. If the Allison controller transmits a request for range inhibited or check transmission warning lamps, the ESC detects the message and transmits another message to the EGC requesting range inhibited or check transmission warning lights. The Allison controller also transmits the requested range the operator has selected (gear selector position). The EGC receives this message directly from the Allison controller (ESC does not reprocess this message) and changes the PRNDL display accordingly. If transmission PRNDL message is not detected by the EGC, the EGC will not indicate (underline) any selected range.

The engine load information is transmitted between the Allison controller and engine controller over J1708 as with previous models. If J1939 were not connected to the Allison controller, no degradation in shift performance would be noted. Vehicle speed is still a hardwired variable frequency pulse signal hardwired from the transmission controller directly to the engine controller like previous models*. The engine controller converts the variable frequency speed signal to a J1939 Drivetrain data link message indicating vehicle speed. The EGC responds by setting speedometer to the value indicated by the engine controller. The pulses per mile programmable parameter in the engine controller is used to convert the hardwired transmission speed signal to a vehicle speed.

Driveline disengaged (neutral) is also still a hardwired signal from the Allison controller to the engine controller. If the transmission is in neutral, the driveline-disengaged signal from the Allison controller will be near 12V. If transmission is not in neutral, the driveline-disengaged signal will be near 0V. This is unchanged from previous models as well.

The WTEC controller switches on back-up lights by supplying a hardwired signal to the low side of the back-up light relay coil in the PDC. The ESC has no control over back-up lights regardless of transmission type.

An optional transmission oil temperature gauge is available. The WTEC controller uses an internal sensor to measure transmission sump oil temperature. This information is transmitted on Drivetrain data link. The EGC receives this Drivetrain data link message directly and drives the transmission oil temperature gauge to the corresponding location.

Auto neutral is also available as an option. The auto neutral switch is located in a six-pack or 12-switch pack. Switching on the auto neutral switch causes a Switch data link message to be generated. The ESC receives this Switch data link message. If the park brake is set and vehicle speed is near 0 MPH, the ESC then switches on a low side driver. The output of the low side driver is connected to the Allison WTEC controller terminals for auto neutral and park brake status. This causes the transmission to shift into auto neutral. A hard-wired incandescent warning light in the EGC will also illuminate when auto neutral is active. A relay in the PDC is used to control this warning light. Additionally, an auto neutral relay and crank inhibit relay are also located in the PDC to modify the engine crank circuit. These prevent cranking the engine with the shifter not in true neutral position.

** Vehicles with a transfer case and an Allison automatic transmission utilize a conventional VSS located in the transfer case. The engine controller is hardwired to this VSS in this special case instead of the transmission controller.*

LCT 2000 Series

The LCT uses a cable-operated shifter and has a mechanical neutral start and back-up light switch (NSBU switch) mounted on the side of the transmission. The vehicle back-up lights are in series with the NSBU switch back-up contacts. When shifter is in reverse position, the back-up lamp contacts are closed and pass current through to the back-up lights. The NSBU switch also provides the LCT controller with information on what position the shifter is in. The LCT does not have J1708 capabilities. All information is exchanged over J1939 Drivetrain data link including engine load information. If J1939 were not connected to the LCT controller, the transmission would shift in the default mode. This would mean up shifts would only occur at rated RPM and would be very harsh.

Like the World Transmission series, range inhibited, check transmission warning light, and PRNDL information is transmitted by the LCT controller over J1939 Drivetrain data link. The ESC and EGC respond accordingly to J1939 transmission messages.

The vehicle speed variable frequency pulse is also hardwired to the engine controller like the MD 3000 series. The engine controller converts the variable frequency speed signal to a J1939 Drivetrain data link message indicating vehicle speed. The EGC responds by setting speedometer to the value indicated by the engine controller. The engine programmable parameter for transmission type with International engines is Allison MD. No separate parameter in the International engine controller for LCT has been established at this time.

For engine crank, the driveline disengage information (neutral or park positions if applicable) is also a hardwired input to the engine controller. Like the MD series, 12V is driveline disengaged; 0V is transmission not in park or neutral.

A switch on the side of the shifter permits modifying the shift schedule for performance or economy. Depressing the switch toggles an ignition signal to the LCT controller requesting transmission utilize performance or economy shift schedules. On some early build High Performance trucks, an indicator light in the shifter handle illuminates when the transmission is in the performance mode. On later models of High Performance Trucks, the indicator light is a green or amber ECON LED in the EGC. The ESC receives the J1939 Drivetrain data link message from the LCT controller indicating that the transmission is in the economy mode. The ESC then transmits a J1939 Drivetrain message requesting that the EGC illuminate the ECON LED.

On LCT 2400 transmissions with a park position, the shifter is locked into park position until the service brake is depressed and ignition is on. A normally closed locking solenoid in the shifter handle is supplied with ignition voltage when the ignition is on. The low side of the locking solenoid is connected to an ESC low side driver. The ESC switches on the low side driver when the service brake is depressed and the transmission is in the park position. This permits the shifter to only be moved from park position when the service brake is depressed.

An optional transmission oil temperature gauge is available. The LCT controller uses an internal sensor to measure transmission sump oil temperature. This information is transmitted on Drivetrain data link. The EGC receives this Drivetrain data link message directly and drives the transmission oil temperature gauge to the corresponding location.

LCT diagnostics are only performed over J1939 Drivetrain data link. Allison TransPro software with a J1939 to parallel port interface (MagiKey) is used to obtain fault codes and will display several transmission parameters.

Driver Visibility Features

Mirror Heat

The optional mirror heat switch is located in an IP mounted switch pack. On models built after late-2002, the mirror heat switch may also be located in the EGC 3-pack switch pack if the truck does not have a work light. The mirror heat switch actuator on trucks built before late-2002 is a two-position latching switch. The mirror heat switch actuator was changed to a three-position mono-stable switch after late-2002. This is because the actuator may be located in the EGC 3-pack switch pack on these trucks. If the mirror heat switch actuator was the latching type and was latched in the on position in the EGC 3-pack, the EGC would not go into the low power consumption mode (sleep mode) with the key switch in the off position.

If the mirror heat switch is located in an IP mounted switch pack and the switch is turned on, data is transmitted from the switch pack to the ESC via the Switch data link. If the mirror heat switch is located in the EGC 3-pack switch pack, the EGC transmits a J1939 Drivetrain message to the ESC with the status of the switch. Either way, this data tells the ESC that the mirror heat switch has been switched on. The ESC responds by switching on a 20A FET. Two 10A fuses in the cab fuse block divide the single ESC output into an output for each mirror (Figure 93). This is one of the few instances where wiring that is protected by virtual fusing is also protected by a smaller conventional fuse or breaker located in the cab fuse block. The 10A fuses permit the use of 18 AWG wiring in the mirror harness.

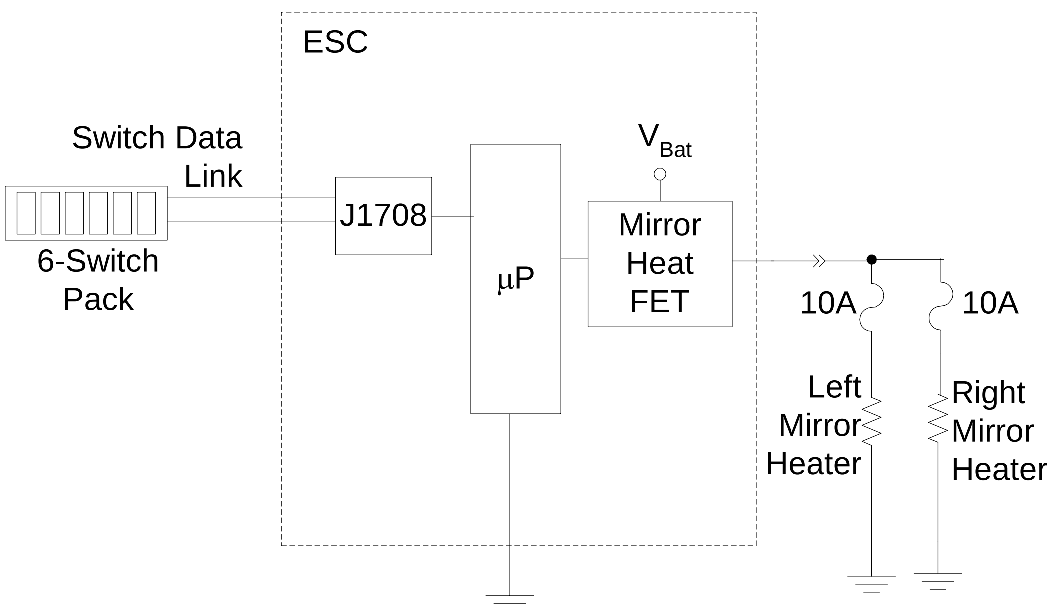

Figure 93 Mirror Heat Circuit

Windshield Wipers

The wiper system consists of a multifunction wiper switch, a two-speed permanent magnet wiper motor, and two wiper control relays. The ESC supplies the high side for the wiper motor and provides low-side control of the two wiper relays. The ESC is also responsible for intermittent wiper dwell timing.

ESC Wiper Inputs

The windshield wiper switch has a total of eight positions: off, five intermittent wipe settings, low speed, and high speed. The wiper switch is actually three separate switches. Each of the three switches is connected to an accessory biased ESC digital input. Closing a switch provides a path to ZVR, which pulls the digital input to near 0V. Each of the eight possible wiper switch settings causes a different combination of open and closed switches. The combination of open or closed switches is used by the ESC to determine which switch position the driver has selected as illustrated in Figure 94. Note that if the wiper switch is disconnected, the inputs will all pull up to accessory voltage level. This will cause the ESC to operate the wiper motor at high speed. Other wiper inputs include ESC ignition and ESC accessory inputs.

	Sw 2	*Sw 1*	*Sw 0*
Off	Closed	Closed	Closed
Int 1	Closed	Closed	Open
Int 2	Closed	Open	Closed
Int 3	Closed	Open	Open
Int 4	Open	Closed	Closed
Int 5	Open	Closed	Open
Low	Open	Open	Closed
High	Open	Open	Open

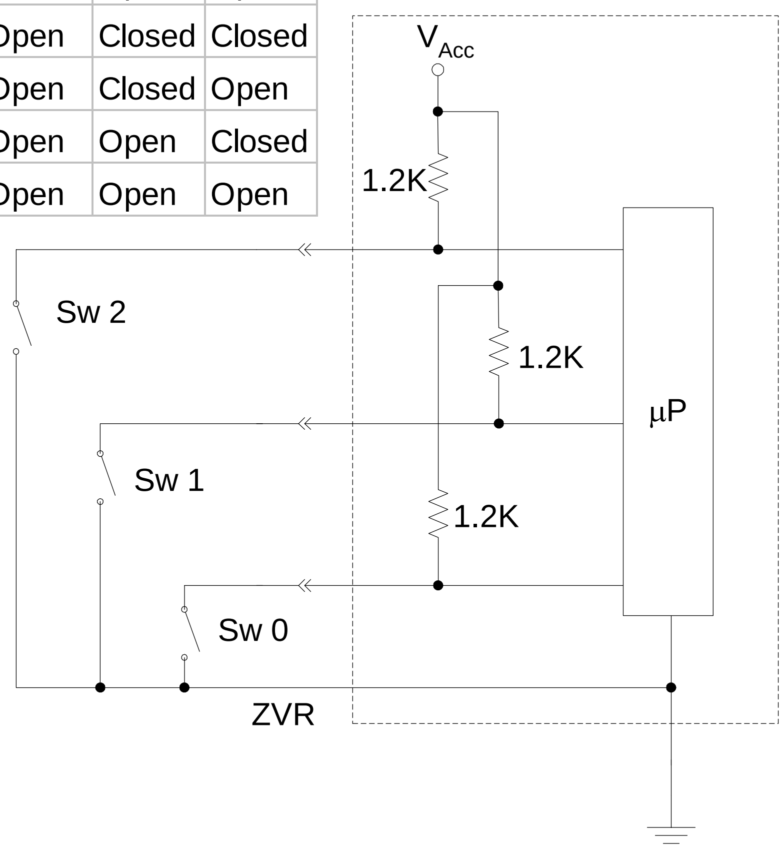

Figure 94 ESC Wiper Inputs

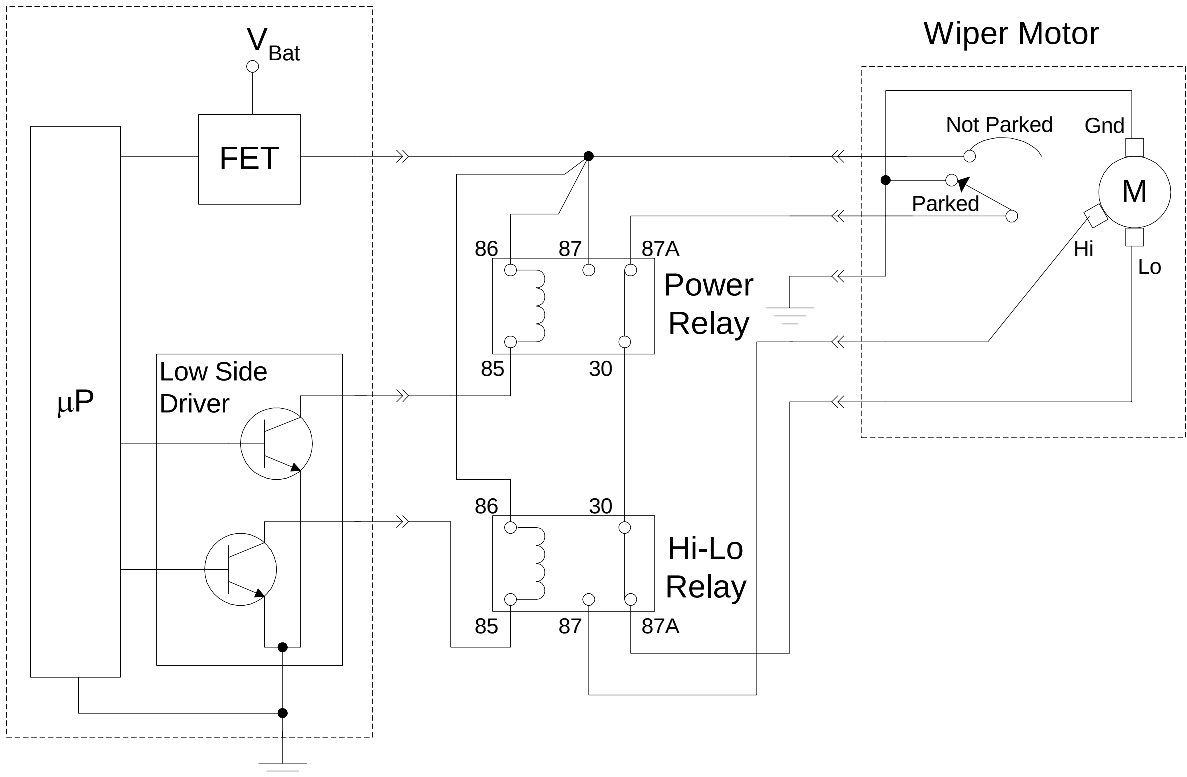

Figure 95 ESC Wiper Outputs

ESC Wiper Outputs

Three ESC outputs control the wiper motor. These outputs consist of a 20A high side FET and two low side drivers. The 20A FET provides +12V to the wiper motor park terminal, the high side of both control relay coils, and the normally open terminal (87) of the wiper power relay. The 20A FET is switched on any time the key switch is in the ignition position, regardless of wiper switch position. The two low side drivers permit the ESC to control the two relays. The ESC will only permit the wiper motor to operate if both ignition and accessory voltage are present at the ESC ignition and accessory inputs. The wiper outputs circuit is shown in Figure 95.

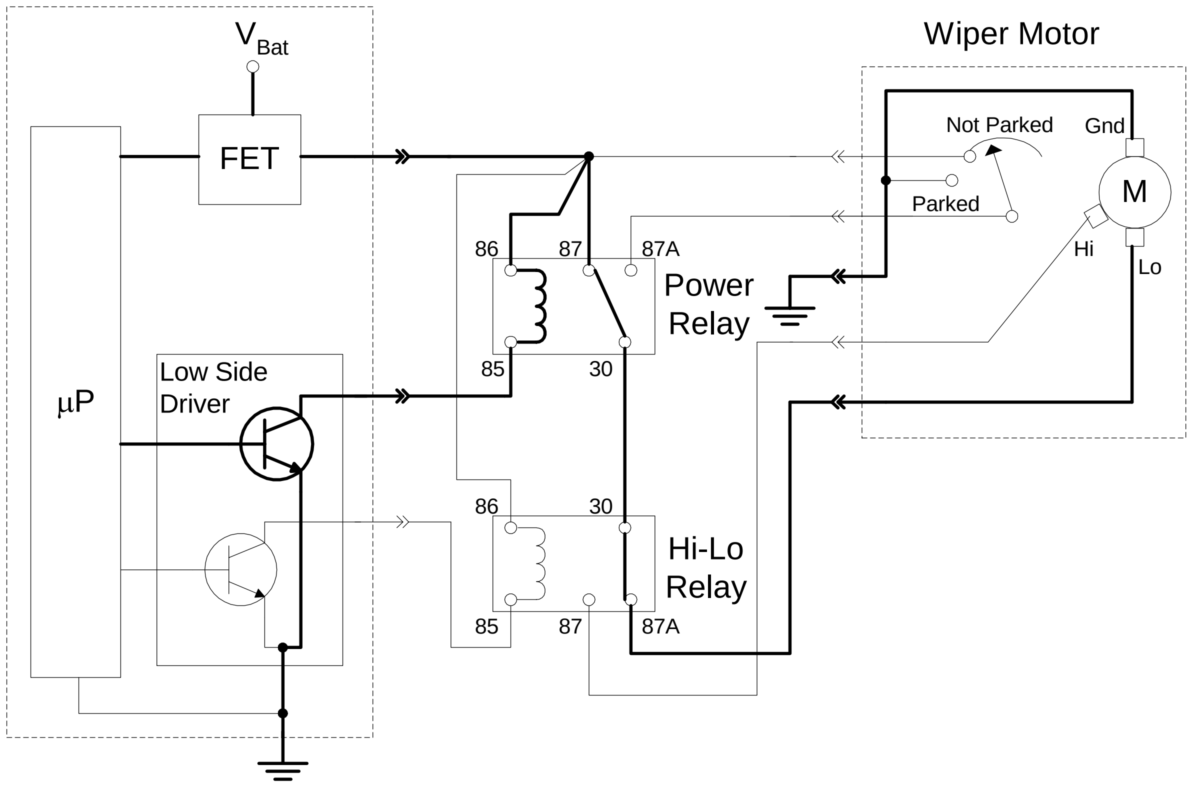

Figure 96 Wiper Low Speed Operation

Wiper Low Speed Operation

Assuming the key switch is not in the off position, the 20A FET is on so +12V is supplied to the wiper power relay normally open terminal and relay coil high side. The ESC detects that the wiper switch is in the low speed position through the combination of digital inputs. The ESC then switches on the wiper power low side driver, which causes the wiper power relay to energize. With the wiper power relay energized, current flows through the wiper power relay normally open contact to the hi-low relay. Since the wiper switch is in the low speed position, the ESC does not have the hi-low relay low side driver switched on so the hi-low relay is not energized. Therefore, current flows through the normally closed contact of the hi-low relay to the low speed terminal of the wiper motor. From the low speed terminal, current flows through the wiper motor low speed brush through the armature and returns to ground. This current flow causes the wiper motor to operate in low speed as indicated by the heavier circuit lines in Figure 96.

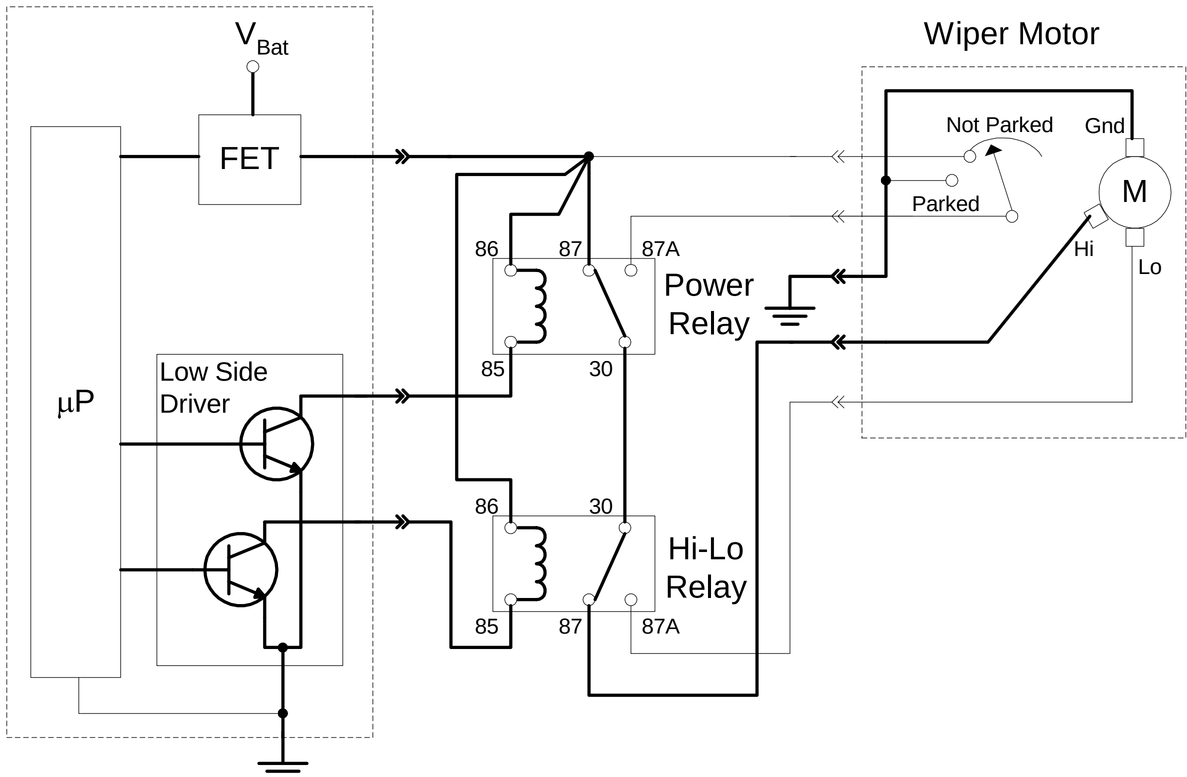

Figure 97 Wiper Motor High Speed Operation

Wiper High Speed Operation

Assuming the key switch is not in the off position, the 20A FET is switched on so +12V is supplied to the wiper power relay normally open terminal and power relay coil high side. +12V is also supplied to the high side of the wiper hi-low relay coil. The ESC detects that the wiper switch is in the high-speed position through the combination of digital inputs. The ESC then switches on the low side drivers for the wiper power relay and the wiper hi-low relay. With the wiper power relay energized, current flows through the wiper power relay normally open contact to the hi-low relay. Since the wiper switch is in the high-speed position, the hi-low relay is also energized. Therefore, current flows through the normally open contact of the hi-low relay to the high-speed terminal of the wiper motor. From the high speed terminal, current flows through the wiper motor high-speed brush through the armature and returns to ground. This current flow causes the wiper motor to operate in high speed as illustrated in Figure 97.

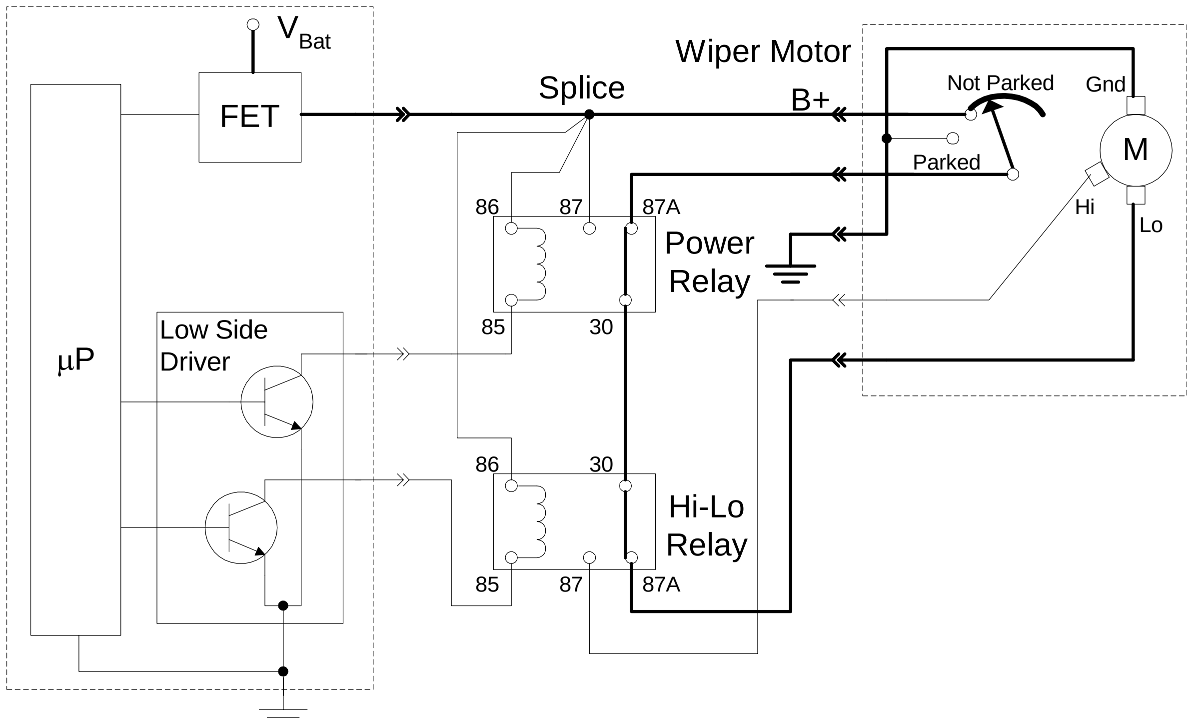

Figure 98 **Wipers Off, Not Yet Parked**

Wiper Park

If the wipers are switched to off, the ESC shuts off both low side drivers. This causes both wiper relays to de-energize and the contacts return to normally closed state as shown in Figure 98. Assuming the key switch is not in the off position, the 20A FET is still providing +12V to the wiper park terminal. If the wipers are not parked, the wiper park switch (internal to wiper motor) will be contacting the B+ terminal. Current flows from the B+ terminal, through the park switch, to the normally closed contact of the wiper power relay. Since the ESC has de-energized both relays, current flows through the normally closed contact of the wiper power relay and through the normally closed contact of the hi-low relay to the low speed terminal of the wiper motor. Current then flows through the low speed brush and armature to ground. This causes wiper motor to operate at low speed. Once the wipers are parked, the contact between the wiper park switch and B+ terminal is opened. This interrupts current flow through the motor and causes the motor to stop in the parked position (Figure 99).

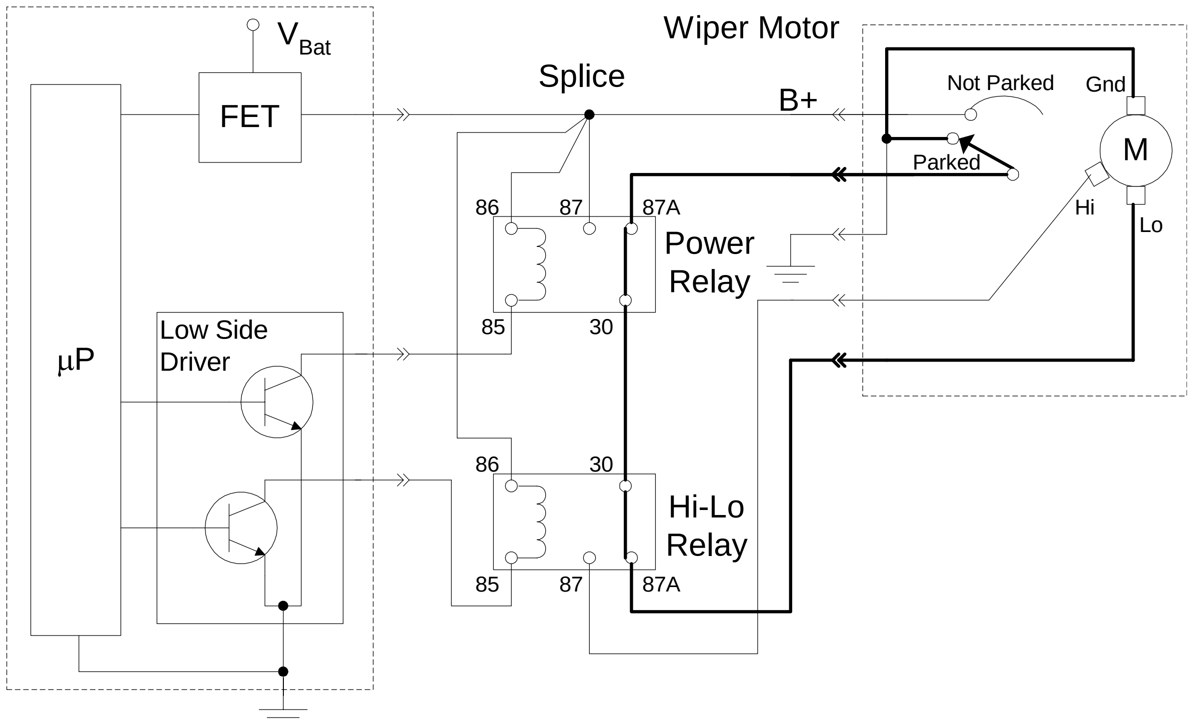

Figure 99 Dynamic Motor Braking

To prevent the inertia of the wiper system from allowing the now de-energized motor to coast through the park position and start the park process all over again, dynamic motor braking is used. A DC motor is also a generator. You know that the more load current a generator is forced to supply, the harder it is to turn the generator (think of a loose squealing alternator belt when lights are switched on, etc). Imagine how hard it would be to make a generator turn if the generator output were shorted to ground (not to mention the sparks and smoke). That is what dynamic motor braking is, a shorted generator. When the rotating wiper park switch is in the park position, a short circuit is placed between the wiper motor low speed brush and ground brush. Trace back through the circuit shown in Figure 99 and you will see the short circuit between the low speed brush and ground brush. The short circuit causes the coasting non-powered wiper motor (now a generator) to stop abruptly in the park position. When the motor stops, the current produced by the coasting motor (generator) also ceases so we don't get a lot of sparks and smoke like we would from a shorted generator.

Intermittent Operation

With the wiper switch in any of the five intermittent positions, the ESC provides a .75 second pulse of the wiper power relay. This pulse causes the wiper motor to move off the park position. From there, normal wiper park occurs. Intermittent wipe is like moving wiper switch from off to low speed just long enough to get wiper motor off the park position and returning wiper switch to the off position. The ESC controls when the next wiper power relay pulse will occur based on the intermittent switch position selected. This delay or dwell is between 2 seconds and 14 seconds depending on which intermittent position is selected.

Washer Operation

The washer pump is not controlled by the ESC. However, the ESC does use the washer pump switch status as a digital input so that the wipers will operate for several cycles if washer switch is depressed. When the ESC detects the washer switch is depressed, the wiper power relay is energized by the ESC through the low side driver. The ESC will leave the wiper power relay energized for 4 seconds after the washer switch is released. This permits excess washer solvent to be wiped off.

Air Controlled Optional Devices

An optional 4-pack or 7-pack remote air solenoid module is available to control several types of compressed air powered devices (Figure 100). Each module uses modular air solenoid valves, which may be normally open or normally closed type. A normally open air solenoid will permit air to pass to the device when the solenoid is not energized and blocks the flow of air with the solenoid energized. A normally closed air solenoid blocks the flow of air when the solenoid is not energized and permits air to pass to the device when the solenoid is energized.

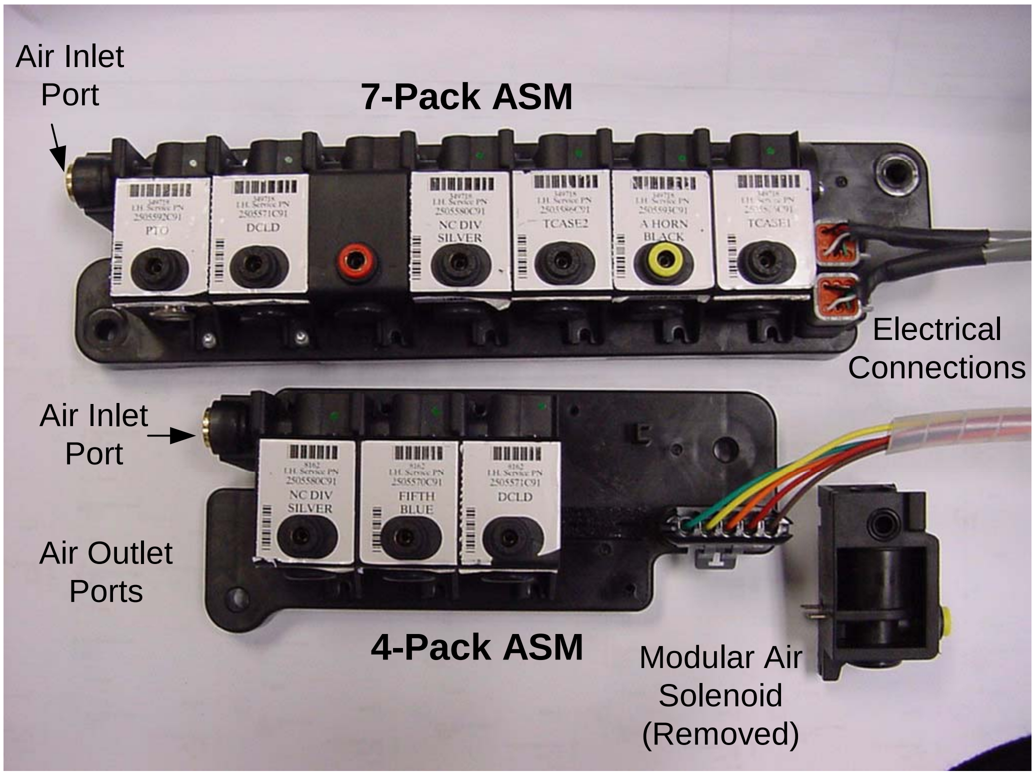

Figure 100 **Air Solenoid Modules**

<u>4-Pack Air Solenoid Module</u>

The 4-pack remote air solenoid module (ASM) may contain between one and four air solenoids. The ESC supplies a common high side feed for the air solenoids through a 10A FET. The 10A FET is switched on anytime the key switch is in the ignition or accessory positions. Each of the modular air solenoids is individually controlled by an ESC low side driver. The ESC provides a hardwired ground for each of the air solenoids. If the ESC detects that a low side driver for any solenoid in a 4-pack is shorted to ground, the ESC will shut off the air solenoid high side 10A FET. This will prevent uncontrolled activation of the solenoid that is shorted to ground. This also has the side effect of disabling any other solenoid in the 4-pack until repairs are made.

<u>7-Pack Air Solenoid Module</u>

The 7-pack remote air solenoid module (ASM) may contain between one and seven air solenoids. The 7-pack ASM is a J1939 Body Builder data link device. Details on Body Builder data link devices are discussed in the *Body Builder Applications* section. Power for the 7-pack ASM is provided by the ESC 10A solenoid power FET. The ESC transmits messages over the Body Builder data link to command the 7-pack ASM to switch on the appropriate solenoid. A truck may be equipped with up to two 7-pack air solenoid modules for a total of 14 optional air solenoids. There are two different part numbers for 7-pack ASM's. If a vehicle has two 7-pack ASM's, the modules must be different part numbers. The difference between the two part numbers is the internal J1939 identification or address of the module. This address is integral to the hardware (circuitry) and cannot be changed in the field. The address difference permits the ESC to distinguish between the two otherwise identical modules.

The number of air-controlled features ordered determines if the vehicle will get a 4-pack ASM, one 7-pack ASM or two 7-pack ASMs. Some features that utilize either of the remote air solenoid modules are described in detail below.

Each of the following features may be powered by a 7-Pack or 4-Pack Air Solenoid Module:

Power Divider Lock (PDL)

The 2-position latching PDL switch is located in a switch pack. When the actuator is switched on, the switch pack generates a Switch data link message. If the PDL solenoid is located in a 4-pack ASM, the ESC then switches on the appropriate low side driver if the vehicle speed is below the maximum PDL engagement speed (programmable). If the PDL solenoid is located in a 7-pack ASM, the ESC will transmit a message over the Body Builder data link commanding the 7-pack ASM to switch on the appropriate solenoid if the vehicle speed is below the maximum PDL engagement speed. If the ESC has switched on the PDL solenoid, the ESC then generates a message over Switch data link to command the PDL switch green indicator LED to illuminate when the PDL is activated. The ESC will flash the green indicator LED in the switch pack and beep the alarm five times if the vehicle speed is greater than the maximum PDL engagement speed with the PDL switch actuator in the on position. The ESC does not disengage the PDL if maximum PDL set speed is exceeded. The ESC can also be programmed to beep the alarm continuously anytime that the PDL switch actuator is in the on position.

Differential Lock

The 2-position latching differential lock switch is located in a switch pack. When the actuator is switched on, the switch pack generates a Switch data link message. If the differential lock solenoid is located in a 4-pack ASM, the ESC then switches on the appropriate low side driver if vehicle speed is less than the maximum differential lock speed (default of 25 MPH). If the differential lock solenoid is located in a 7-pack ASM, the ESC will transmit a message over the Body Builder data link commanding the 7-pack ASM to switch on the appropriate solenoid if vehicle speed is less than the maximum differential lock speed. If the ESC has switched on the differential lock solenoid, the ESC then generates a message over Switch data link to command the differential lock switch green indicator LED to illuminate when the differential lock is activated. The ESC will disengage the differential lock solenoid, flash the green indicator LED, and beep alarm five times if the vehicle speed is greater than the maximum differential lock speed with switch actuator in the on position. The switch actuator must be cycled off and back on again to re-engage the differential lock once vehicle speed is below the maximum differential lock speed. Additionally, a hardwired incandescent bulb in the EGC will illuminate when the differential lock is engaged. A switch in the differential housing completes a ground circuit for this warning lamp when the differential lock is engaged. Trucks with 6X4 and differential lock have two separate hardwired switches and warning lights in the EGC (FR &RR axle).

Sliding Fifth Wheel Lock Release

The 2-position momentary contact sliding fifth wheel lock release switch is located in a switch pack. When the actuator is switched on, the switch pack generates a Switch data link message. If the sliding fifth wheel lock solenoid is located in a 4-pack ASM, the ESC then switches on the appropriate low side driver if vehicle speed is below the maximum sliding fifth wheel lock release speed (default of 2 MPH). If the sliding fifth wheel lock solenoid is located in a 7-pack ASM, the ESC will transmit a message over the Body Builder data link commanding the 7-pack ASM to switch on the appropriate solenoid if vehicle speed is below the maximum sliding fifth wheel lock release speed. If the ESC has switched on the sliding fifth wheel lock solenoid, the ESC then generates a message over Switch data link to command the sliding fifth wheel lock switch green indicator LED to illuminate. The ESC will disengage the sliding fifth wheel lock release and flash the green indicator LED if the vehicle speed is greater than the maximum sliding fifth wheel lock release speed with the sliding fifth wheel lock switch actuator in the on position.

Air Suspension Dump (prior to Late-2003)

The air suspension dump system (built prior to late-2003) consists of one 4-pack or 7-pack normally closed air solenoid and a standard air switching solenoid like that used for engine air fan clutch control. The standard air switching solenoid is switched on any time the key switch is in the ignition position. The 4-pack or 7-pack air solenoid is controlled by the ESC. A 2-position latching air suspension dump switch actuator is located in a switch pack. Setting the switch actuator to the dump position causes the switch pack to transmit a message over Switch data link. If the air suspension dump solenoid is located in a 4-pack ASM, the ESC then switches on the appropriate low side driver if vehicle speed is below the maximum air suspension dump speed (default of 5 MPH). If the air suspension dump solenoid is located in a 7-pack ASM, the ESC will transmit a message over the Body Builder data link commanding the 7-pack ASM to switch on the appropriate solenoid if vehicle speed is below the maximum air suspension dump speed. If the ESC has switched on the air suspension dump solenoid, the ESC then generates a message over Switch data link to command the air suspension dump switch green indicator LED to illuminate when the air suspension dump is activated. The ESC will switch off the air suspension dump solenoid (re-inflate air bags), flash the green indicator LED, and beep the alarm five times if the vehicle speed is greater than the maximum air suspension dump speed with the air suspension dump switch actuator in the on position. The air suspension dump switch must then be cycled off and back on again to dump air suspension once vehicle speed is below the maximum air suspension dump speed.

Air Suspension Dump (after Late-2003)

The air suspension dump system (built after late-2003) consists of two adjacent 4-pack or 7-pack normally open (air passes with solenoid NOT energized) air solenoids and a modular shuttle valve assembly. The ESC controls the two normally open air solenoids. The modular shuttle valve installs directly into the two adjacent air solenoids. The pneumatics for this system are greatly simplified when compared to the previous system. The shuttle valve maintains the Hadley valve in the last state when the key switch is in the OFF position. The shuttle valve traps air pressure in the air line to the Hadley valve to keep the suspension dumped. The shuttle valve blocks air pressure in the air line to the Hadley valve to keep the suspension inflated.

Air Horn

The air horn switch is located in the steering wheel. The switch may also be located on the passenger side in the dash panel for fire truck applications. The switch provides a path to ZVR for an ESC accessory biased digital input. If the air horn solenoid is located in a 4-pack ASM, the ESC then switches on the appropriate low side driver when the air horn switch is depressed. If the air horn solenoid is located in a 7-pack ASM, the ESC will transmit a message over the Body Builder data link commanding the 7-pack ASM to switch on the appropriate solenoid. The key switch must be in the ignition or accessory positions for the air horn to operate.

Other Air Operated Features

Several other air-operated features are controlled in a similar manner to those described above. These features include: two speed rear axle, front air suspension dump, PTO, transfer case (uses two or three solenoids), and many others. Each of these solenoids may be located in a 4-pack air solenoid or a 7-pack air solenoid. Switches are located in one of the switch packs. ESC logic inhibits solenoid operation based on park brake status, vehicle speed, and other parameters. Some of these parameters may be programmable at the dealership level.

Body Builder Applications

Body Builder Data Link

The Body Builder data link is a private serial data link meeting the specifications of SAE J1939/11 or SAE J1939/15. The Body Builder data link provides an easy way for truck equipment manufacturers (TEMs) to add various electrical devices and controls. The Body Builder data link is connected to the ESC and possibly several optional modules. These modules include the 7-pack remote air solenoid module discussed in the *Air Controlled Optional Devices* section. Other modules available include Remote Power Modules (RPMs) and Remote Engine Speed Control Module (RESCM). These modules are illustrated in Figure 101. A possible vehicle configuration with all of these body builder features present is shown in Figure 102. Note that the engine controller is not connected to the Body Builder data link. The ESC acts as a "bridge" between the J1939 Drivetrain data link, the Switch data link, and the Body Builder data link.

Body Builder data link devices have two identical 6-way connectors as shown in Figure 101. These connectors are internally wired together. Pin 1 of one connector is internally wired to Pin 1 of the other connector and so on. The two connectors provide a means to "daisy-chain" Body Builder data link devices together. Since a CAN network uses a bus topology, the actual physical order in which devices are connected to the data link is really unimportant. However, terminating resistors must be present at both ends of the Body Builder data link. The last Body Builder data link device connected to the Body Builder data link must have a terminating resistor installed in the unused 6-way connector. Normally, the ESC is the most forward device on the Body Builder data link. A terminating resistor is located in a "Y" splice near the ESC outside 36-way connector if the truck has shielded cable. If the truck has non-shielded cable then the terminating resistor is identical to that installed in the last Body Builder data link device and is located in a connector near the ESC. If the vehicle has Body Builder data link devices both forward and rearward of the ESC, this terminating resistor can be removed to provide a means to connect devices forward of the ESC to the Body Builder data link. A terminating resistor must then also be installed in the unused 6-way connector of the Body Builder data link device located forward of the ESC.

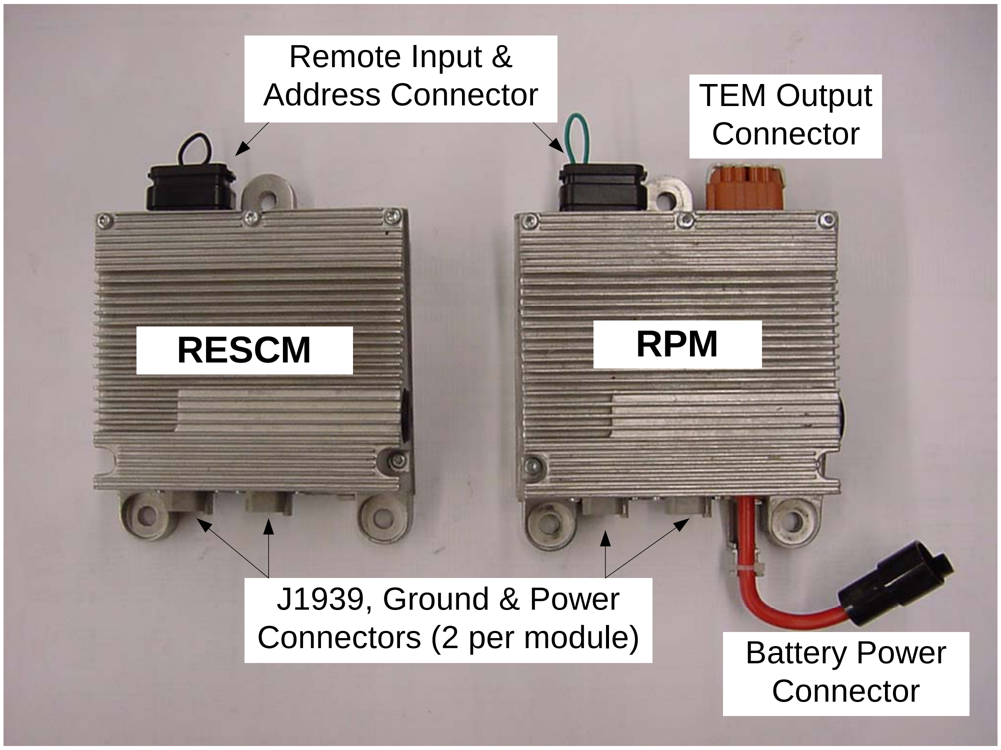

Figure 101 Remote Engine Speed Control and Remote Power Modules

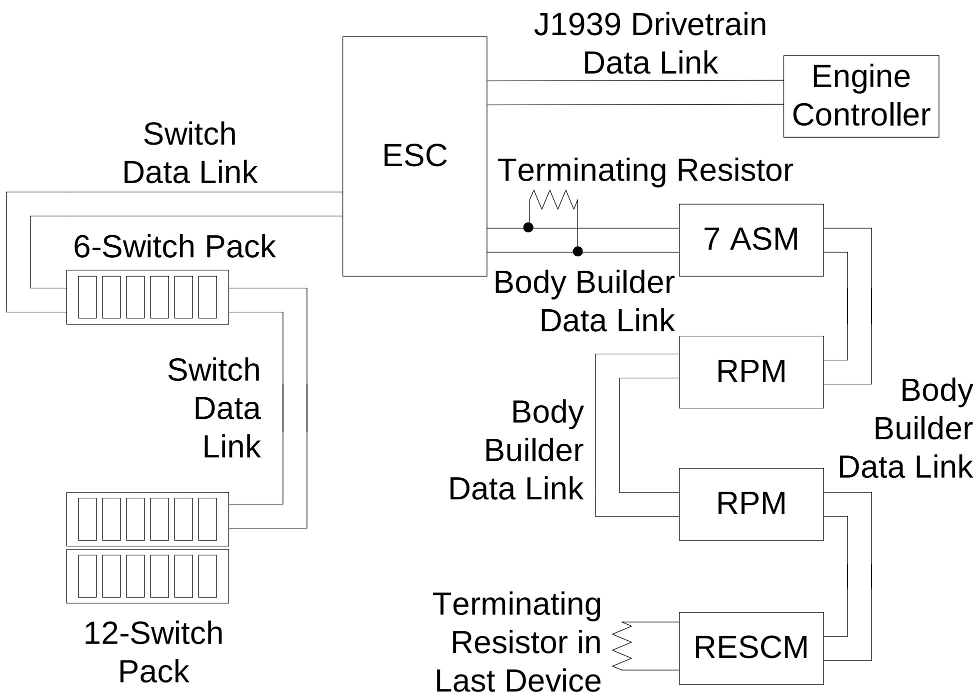

Figure 102 Body Builder Applications

Remote Power Modules

Remote Power Modules (RPM) are designed to supply the high side power for up to 6 devices. Each high side output is a 20A FET, the same as those used in the ESC. The maximum total current that each RPM can source is limited to 80A. The RPM high current power supply fusible link may open if the 80A total is exceeded. This is similar to the wiring for most houses. Even though there may be ten or more 20A circuit breakers for the various outlets throughout the house, the main circuit breaker may be 100A. If you plugged in ten 15A toasters throughout the house, the 100A circuit breaker will open even though none of the 20A breakers have opened.

The battery power and ground for the RPM microprocessor is supplied via a 6-way connector from the vehicle wire harness. The RPM high current power supply lead does not supply the RPM microprocessor battery power nor does the RPM case mounting provide a ground for the microprocessor. If the battery power and ground are not present at the 6-way connector, the RPM will not operate. This 6-way connector may also contain an ignition feed (solenoid power) but ignition power is not used by the RPM. The ignition power is only used by an optional 7-pack air solenoid module. The 6-way connector also contains the Body Builder data link wiring (CAN_H and CAN_L). Two identical 6-way connector mates are located on the RPM. It does not matter which of these connectors the vehicle wire harness is mated with. If there are other Body Builder data link devices on the vehicle, the unused RPM 6-way connector is used to “daisy-chain” the Body Builder data link, power, ground, and ignition to the next device. If the RPM is the last device on the Body Builder data link, a terminating resistor located inside a sealed connector mate is plugged into the unused RPM 6-way connector.

A vehicle may have up to three RPMs for a total of 18 high side outputs. Each RPM is assigned a unique address based on the location of a jumper wire in the 23-way RPM remote input and address connector. The address is assigned based on where the RPM is physically located on the vehicle. All RPMs are identical parts. The address jumper makes the RPM unique. Each RPM will communicate with the ESC over the Body Builder data using a source address corresponding to the address jumper location. If the address jumper is not present or is located in the wrong cavities, the ESC will log a fault indicating RPM #n is not communicating with the ESC.

Control of each FET is via the Body Builder data link or hardwired switches that the TEM would connect to the RPM remote inputs (Figure 103). Let's look at control via the Body Builder data link first. Each RPM has six switches in one or more 6-switch packs in the IP that are connected to the Switch data link or J1939 Drivetrain data link (AGSP). The switch actuators may be three position actuators, which are latched in the center position. The ON and OFF positions are momentary contact (spring loaded centered). The switch actuators may also be the two-position latching type. The switch actuators have blank windows. Several stickers are provided with the switch pack that may be applied to the blank switches so that the vehicle operator knows what each switch controls.

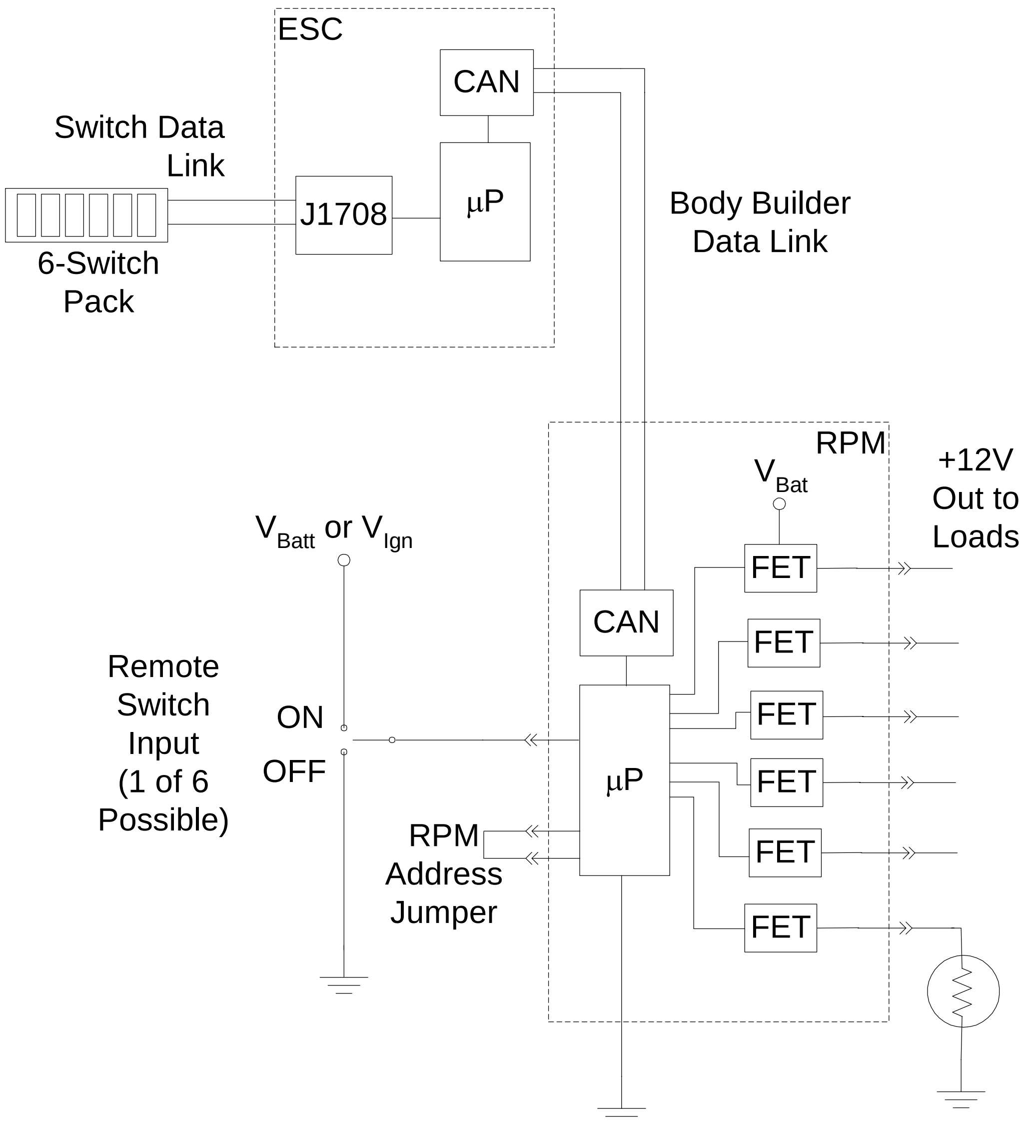

Figure 103 Remote Power Module

If the RPM switch actuator is the momentary type, pressing the appropriate switch actuator ON (pressing top of actuator) causes a Switch data link message to be generated. The ESC sees this message and responds by sending a message over the Body Builder data link. The Body Builder data link message contains information regarding which RPM the message is for and which of the 6 outputs the RPM should switch on. This message is received by the appropriate RPM, which then switches on the FET connected to output #1. Whatever device the body builder has connected to output #1 will then be supplied with +12V. This device could be a light, a siren, or a missile launcher, anything that does not draw more than 20A continuously. The FET will continue to remain on after the operator releases the momentary contact ON switch and the actuator returns to the center position.

Pressing the same switch actuator OFF (pressing bottom of actuator) causes a Switch data link message to be generated. The ESC sees this message and responds by sending a message over the Body Builder data link directing the appropriate RPM to switch off output #1. This message is received by the appropriate RPM, which then switches off the FET connected to output #1. The device connected to output #1 is no longer supplied with +12V.

Latching type switch actuators act in the same manner as momentary switch actuators with a few exceptions. If the key switch is cycled off with a momentary actuator controlled RPM output energized, the output will not switch back on when the key switch is placed in the ignition or accessory positions. Remember that switch packs are supplied with accessory power, not battery power. A latching type actuator in the on position with the key switch in the off position will cause the ESC to enable the corresponding RPM output to energize when the key switch is placed in the ignition or accessory positions. Another difference is the manner in which recovery from overcurrent faults is handled. A RPM output controlled by a momentary type switch will not re-attempt to energize an output if an overcurrent (i.e. short to ground) condition is detected by the RPM. However, a RPM output controlled by a latching type switch actuator will attempt to energize an output up to ten times if an overcurrent fault is detected.

These differences in behavior should be considered when choosing the type of switch actuator for a RPM output. Since the ESC may reset during engine crank due to the battery voltage dip, any output that had previously been switched on by a momentary contact switch actuator will be switched back off if the ESC resets. If an output must be switched on prior to engine crank and remain on after engine crank, a latching switch actuator must be used for the switch actuator corresponding to that particular output. The difference in how an overcurrent fault is handled by the two different switch actuators should also be considered when choosing the actuator type.

Remote switch inputs may also be used to control each RPM output. The RPM has a remote switch input connector. Each RPM output may be switched on or off using a TEM installed hardwired switch. These remote inputs, which are located in the 23-way RPM remote input and address connector, are biased to 50% of battery voltage. The remote switch provided by the TEM is a momentary contact switch, which is latched in the center position (similar to the 6-pack switch actuator). ON and OFF positions are momentary contact. The ON switch contact is wired to battery or ignition voltage. The OFF switch contact is wired to chassis ground. Pressing the remote wired switch ON causes the voltage at the RPM remote input to rise to battery voltage level. This causes the ESC to command the RPM to switch on the output associated with that particular hardwired remote input. Pressing the switch OFF causes the voltage at the RPM remote input to drop to 0V. This causes the ESC to command the RPM to switch off the output associated with that particular hardwired remote input. The reason for using momentary contact switches throughout is that an output may be switched on from inside the cab using the 6-pack switch actuator and then switched off using a hardwired remote input from outside the vehicle or vice-versa. The ESC sees the 50% of battery voltage at the RPM remote input (center latched position) and a centered 6-pack switch actuator as a "maintain present output state" command for that particular RPM output. It is important to note that the RPM outputs can only be commanded on by the ESC. Even though a RPM remote input may be switched ON, the ESC must command the RPM to switch on the appropriate output via the Body Builder data link.

Each FET is protected by virtual fusing which is discussed in the ESC section. The fusing level of each output may be modified by reconfiguring the ESC software using ICAP. Default fusing level for each FET is 20A. This value may be decreased to whatever value the TEM requires to protect their wiring. There is no need to change RPM virtual fusing level if the wiring used by the TEM is of adequate gauge for a 20A circuit breaker.

In addition to the basic Remote Power Module software, there are several specific TEM applications that have been developed. These use the RPM to control a PTO, provide remote engine speed control through the RPM inputs, and several similar applications. Many of these features have programmable parameters that can be changed by the TEM or dealership to customize the operation of the vehicle. Additionally, TEMs and dealerships will soon be able to write custom software for the ESC to control RPMs and air solenoid modules using a software development tool called Diamond Logic Builder.

Remote Engine Speed Control Module

The Remote Engine Speed Control Module (RESCM) is another Body Builder data link device, due for release in late-2003. The RESCM permits TEMs to easily install wiring for remote engine speed control. The RESCM also provides variable frequency outputs representing vehicle speed and engine speed. This provides a means for easy installation of a remote mounted speedometer or tachometer. Stop engine and warn engine outputs are also provided, which can be hardwired to remote engine warning lamps. A vehicle may only have one RESCM. The RESCM is always addressed as RESCM #1 via a jumper wire between terminals 1 and 2 of the 23-way RESCM address and remote input connector.

The RESCM is very similar in appearance to the RPM, except there is no large battery power feed and no 8-way TEM output connector. Remote PTO engine speed control switches are hardwired to the RESCM. The RESCM has provisions for engine speed control (PTO) preset or variable. Additionally, a remote accelerator position sensor (APS) may be connected to the RESCM. A remote APS provides a remote variable engine speed control accelerator pedal. Remote switches and a remote accelerator position sensor are installed by the TEM using the 23-way RESCM address and remote input connector. The RESCM supplies the +5V and signal ground for a remote APS.

The operation of remote PTO is very similar to the operation of the steering wheel-mounted vehicle cruise control switches. The RESCM transmits messages over the Body Builder data link indicating the status of its hardwired inputs. The engine controller is not connected to the Body Builder data link, so the ESC performs the task of transmitting the requests for engine speed control over the J1939 Drivetrain data link. The ESC acts as a “bridge” between the Body Builder data link and the J1939 Drivetrain data link. The engine controller responds to the J1939 Drivetrain data link message by controlling engine speed accordingly. The engine controller also transmits vehicle speed, engine speed, and warning lamp information over the J1939 Drivetrain data link periodically. The ESC rebroadcasts this information over the Body Builder data link. The RESCM receives this engine information and drives the remote warning lights, remote tachometer, and remote speedometer accordingly. These devices are also installed by the TEM using the 23-way RESCM address and remote input connector. The remote tachometer output supplies 12 pulses per revolution, the remote speedometer output supplies 30K pulses per mile.

The battery power and ground for the RESCM microprocessor is supplied via a 6-way connector from the vehicle wire harness. The RESCM case mounting does not provide a ground for the microprocessor. Battery power and ground must be present at the 6-way connector for the RESCM to operate. This 6-way connector may also contain an ignition feed (solenoid power) but ignition power is not used by the RESCM. The ignition power is only used by an optional 7-pack air solenoid module. The 6-way connector also contains the Body Builder data link wiring (CAN_H and CAN_L). Two identical 6-way connector mates are located on the RESCM. It does not matter which of these connectors the vehicle wire harness is mated with. If there are other Body Builder data link devices on the vehicle, the unused RESCM 6-way connector is used to “daisy-chain” the Body Builder data link, power, ground, and ignition to the next device. If the RESCM is the last device on the Body Builder data link, a terminating resistor located inside a sealed connector mate is plugged into the unused RESCM 6-way connector.

Electrical Troubleshooting

There are lots of new things to learn on these new High Performance Trucks to become an effective electrical system troubleshooter. Until you get some experience, here are some pointers.

High Impedance Voltmeters

The 20A FETs and the 10A FETs are manufactured by the same supplier, but the FETs have some important differences other than the current rating. The 20A FETs may cause some confusion when testing an open circuit with a high-impedance voltmeter. First, let's take a look at a model of a FET. A model is a representation of a complicated device. The model of a 20A FET is shown in Figure 104. The switch is the transistor, the resistor in series with the switch is the FET on resistance and is a very small value, the 1 Mega Ohm (1M Ohm) resistor in parallel is the FET leakage resistance, and the diode is the PN junction formed in the manufacturing process of the FET. The model for a switched on FET has the switch closed, the model for a switched off FET has the switch open. The switched off FET is the model we are concerned with. The 1 Mega Ohm leakage resistance is very large so leakage current through a switched off FET is very small. By comparison, the leakage resistance of the 10A FET is much less than that of the 20A FET (K-Ohm range).

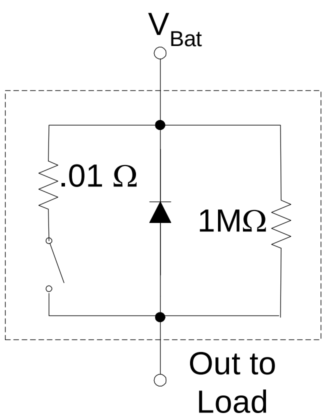

Figure 104 20A FET Model

Leakage current can cause confusion when a high impedance voltmeter is used for troubleshooting electrical problems. The internal impedance (resistance) of a Fluke 88 meter is 10 Mega Ohms (10 Million Ohms). This means that the meter looks like a 10 Mega Ohm resistor to the circuit that is being tested. This high impedance of digital meters usually makes them ideal for measuring voltage levels in circuits containing electronics. The voltmeter resistance is so high that it does not normally affect the circuit that is being tested provided it is placed in parallel with the load, source, etc. for voltage measurements. This makes a high impedance meter ideal for measuring input voltages. However, the high impedance of the voltmeter becomes a problem when testing open circuits with leakage current present. If a high impedance voltmeter is used to measure the open circuit voltage between a switched off FET output and ground, the voltmeter will read almost battery voltage even though the FET is switched off. The reason for this erroneous reading is simple. Since the circuit is open, the meter is not being placed in parallel with a load but rather in series. Since the resistance of the meter is much greater than the resistance of the switched off FET, a simple series voltage divider circuit is formed with one resistor being the FET and the other the voltmeter. The voltage dropped across the meter when testing an open circuit with the FET switched off will be about 90% of battery voltage as shown in Figure 105.

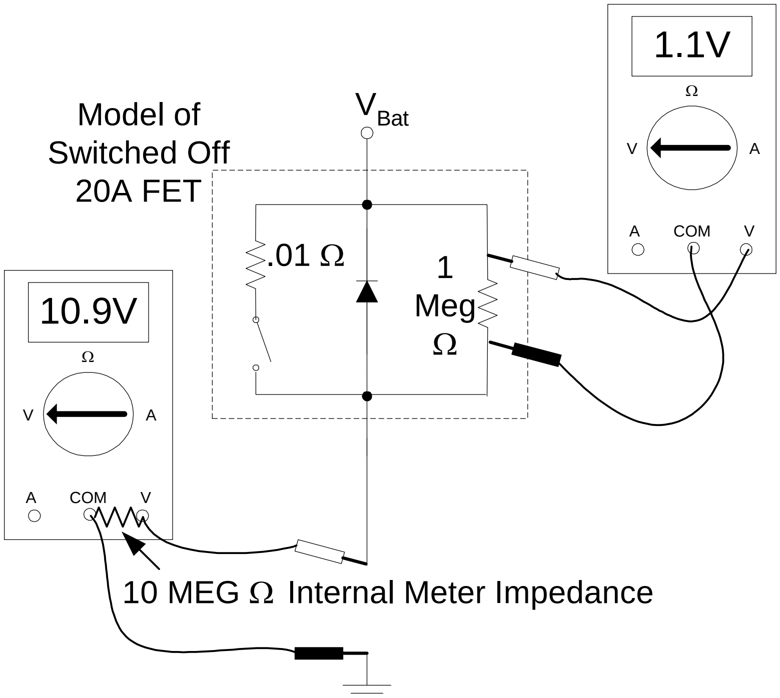

Figure 105 Leakage Current and High Impedance Multimeter

Leakage current does not normally present a problem since the resistance of any load (lights, wiper motor, etc) is miniscule compared to the 1 Mega Ohm of FET resistance. If you tried to measure the voltage caused by leakage current across (in parallel with) the headlights, your meter will not even register unless your meter can measure microvolts (millionths of volts).

As an example of the problems leakage current can cause, let's look at a complaint of inoperative fog lights. Let's also say that the actual cause of the inoperative fog lights is that the switch actuators in the 6-switch pack were not installed in the correct order. The actuator that says fog lights actually powers the heated mirrors and vice-versa. This means that when we switch on what we think is the fog lights; we are really turning on the mirror heat. When we switch on what looks like the mirror heat actuator, we are actually telling the ESC that we want fog lights. Since the fog lights require us to have on low beam headlights, we'll assume that no one has ever tried turning on the mirror heat with the low beam headlights on, so it just looks like the fog lights will not work. Since we don't have the luxury of knowing what the real problem is, we need to troubleshoot the fog light system. Since neither fog light works, it is probably safe to assume that both bulbs are not burned out. A quick look at the wiring diagrams indicates that the fog light ground and headlight ground share a common ground splice. Since the headlights work, the problem does not appear to be the ground. We go ahead and verify that the ground at one of the fog lights is ok. The likely cause appears to be with the high side of the fog lights. With the supposed fog light switch actuator turned on, the low beam headlights on, and the ignition on, we check for voltage at one of the fog light connectors (other fog light connector is still connected) and verify that there is 0V on the high side. Since the ESC controls the fog lights and the brown ESC output connector is very accessible, that looks like a good place to check for fog light high side power. Disconnecting the ESC outside 8-way brown wire harness connector and installing the breakout box without connecting the vehicle wire harness to the breakout box, we use a digital voltmeter to measure the voltage between pin A of the brown connector and ground. The digital voltmeter indicates 11V between pin A of the breakout box and chassis ground. Although the fog light FET is not switched on, we still measure 11V at the ESC fog light output. The problem now looks like there is an open circuit in the wire harness between the ESC and fog light splice. A continuity check of the wiring harness between the ESC brown output connector and one of the fog light connectors shows nearly 0 Ohms of resistance. Now it appears that everything should work, perhaps we might think that there is an intermittent open circuit and the process of moving the wiring harness has temporarily fixed the open circuit. Reconnecting the ESC brown output connector to the ESC, we see that the fog lights still do not work. This is now not making any sense. We have voltage at the ESC output, continuity in the wire harness between the ESC and fog lights, but no voltage at the fog light connector.

You may have encountered a similar situation in the past where your digital meter appeared to be giving you incorrect information. The high impedance of a digital meter coupled with an open circuit causes leakage current to look like "real" voltage.

Reverse Battery Operation

The diode in parallel with the FET shown in Figure 104 can cause some unexpected operation if the vehicle batteries are connected backwards. Besides destroying the alternator rectifier bridge, connecting the batteries backwards causes all devices controlled by a FET to be supplied with voltage, regardless if the FET is switched on or not. This means the horn honks, all lights come on, and wipers operate. If you connect batteries backwards, you immediately know something is wrong. It looks really neat to hook up batteries backwards but causes some expensive repairs. Some of the most damaging results of connecting batteries backwards are that the A/C clutch is supplied with reverse voltage. This causes the diode across the A/C clutch to be forward biased resulting in a direct short to ground. The short to ground through the diode will cause the A/C clutch diode to be destroyed as well as possibly damaging the 10A A/C clutch FET. This means a you'll have to replace the A/C clutch and possibly replace the ESC. If you find a damaged ESC A/C clutch FET and a damaged A/C clutch suppression diode, suspect that the vehicle batteries have been connected backwards or jump-started backwards at some point.

Fault Codes

The ESC and EGC are capable of logging fault codes when certain faults are detected. Fault codes for these devices are stored in EEPROM memory in the EGC. Fault codes may be retrieved on the vehicle by switching on ignition, setting the park brake, and depressing the cruise ON and RESUME switches at the same time. The EGC alphanumeric display will indicate a series of numbers in the format shown in Figure 106, which indicate the fault code stored in memory.

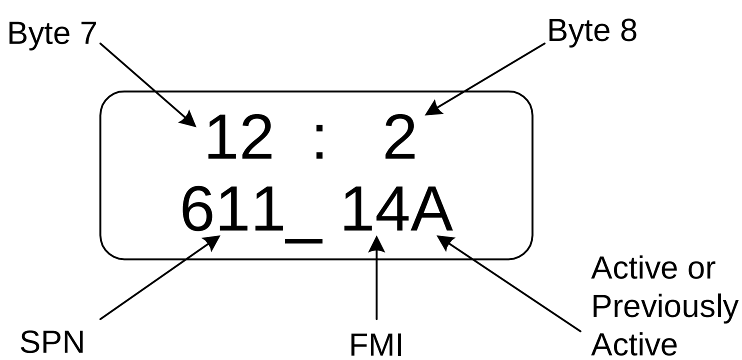

Figure 106 EGC Display Fault Messages

Fault messages transmitted over J1939 are similar to those used in J1708. The Suspect Parameter Number (SPN) used in J1939 is similar to the Parameter Identifier (PID) used in J1708. The SPN identifies which subsystem has failed. An example of an SPN used by the ESC is 611. SPN 611 indicates that a high-side FET amperage fault has occurred or is occurring. Next, a Failure Mode Indicator (FMI) is used to indicate the type of failure that has been detected. At the present time, all FMIs are assigned the value of 14. SAE defines FMI 14 as manufacturer defined special instructions. After the FMI, an A or P denotes if the fault is active (A) or previously active (P).

Each J1939 fault message generated by the ESC or EGC is one 8-Byte message in length. The fault message contains the SPN, FMI, and an indication if the fault is active or previously active. Additionally, byte 7 and byte 8 of the fault message indicate more specific information on the failure. These two bytes of data are used to indicate information such as which output or input has failed and the type of failure such as out of range high, etc. For example, a fault message with SPN 611, FMI 14, Active = yes, Byte 7 = 12, Byte 8 = 2 indicates that the ESC is detecting an open circuit on output #12 (electric horn). This fault is displayed in Figure 106.

ESC and EGC active fault messages are broadcast at the rate of once per second. Each fault message contains data for only one fault. The maximum number of active or inactive ESC and EGC faults that the EGC can store is 31.

Faults are generally logged when the input voltage from a sensor is out of range (OOR) high or OOR low. Depending on how the input is biased, an open circuited analog input will appear OOR high or OOR low. If the analog input is biased high, an open circuited analog input will be OOR high. If the input is biased low, an open circuited analog input will be OOR low.

Low side drivers may log several faults. As explained in the section on low side drivers, the ESC holds an open circuited low side driver at 2.5V. If the voltage drops below 2V, a fault is set indicating the low side driver is shorted to ground. If the voltage on an unused output is greater than 3V, a fault is set indicating a load is present on an unused output. This is normally the case when the ESC software is not correct for the vehicle or the wiring has been mispinned.

Faults for missing J1939 messages may also be logged. Devices such as the ABS controller, automatic transmission controller, and engine controller have specific J1939 messages that are transmitted periodically. For example, the Bendix air ABS controller transmits a message at least every 100 milliseconds indicating the status of the ABS controller even if nothing is wrong. This lets all other devices know that the ABS controller is alive and well. If the ABS controller lost power, it would not be able to transmit any messages. If the ESC does not see this “heartbeat” message from the ABS controller for five successive message cycles (500 milliseconds), the ESC will log a fault indicating that the ABS controller was not heard from. These message time-out faults are normally set by poor electrical connections in the data link wiring. By knowing the topology of the data link, which faults are set, and what does not work, locating a problem caused by an intermittent J1939 connection is not usually as difficult as it may first appear.

It is important to remember that the EGC display will only show faults generated by the ESC and EGC. Engine, transmission, ABS (other than Wabco hydraulic), and all other devices require other methods to retrieve the respective fault codes. Just because the EGC display says NO FAULTS does not mean that the transmission controller may not have a fault stored in it.

Vehicles with International engines will also flash out fault codes using the red and amber engine warning LEDs similar to previous models. To place the International engine in diagnostic mode, with key on, engine off, park brake set; depress the cruise ON and RESUME switches simultaneously within three seconds of key on. The engine controller will then cause the red and amber engine warning LEDs to flash out fault codes, if present.

Troubleshooting the J1939 Drivetrain Data Link

There are some quick checks you can make on the J1939 Drivetrain data link to determine if wiring is causing your problem. As indicted in the section on the J1939 data link, each end of the backbone has a 120-Ohm resistor across the two conductors. The two resistors of the J1939 Drivetrain data link are in parallel with each other, which makes the DC resistance between the two conductors look like 60 Ohms if measured between terminals C and D of the diagnostic connector. You should only make this resistance measurement with the battery disconnected so that you can be sure that no device is transmitting on the data link. If the resistance of the data link is 120 Ohms, then there is an open circuit somewhere or there is a terminating resistor missing. By knowing the topology of the system and by any fault codes indicating a missing J1939 message, you should be able to narrow down the location of the open circuit fairly quickly. If the resistance between the conductors is near 0 Ohms, then the two conductors are shorted together at some point. Open the data link at the various harness connectors to locate the source of the shorted conductors.

Depending on where an open circuit in the data link is located, the way the vehicle will respond will differ. A CAN system is designed to have no controller in charge. Therefore, devices on either side of the open circuit will act as though there are two separate data links. For example, if the data link connection at the pass-through connector is opened, the engine controller, air ABS controller, and transmission controller will still be able to communicate with each other. Likewise, the ESC and EGC will also be able to communicate with each other. However, the ESC and EGC cannot communicate with the ABS, engine, or transmission controller with the open circuit present. You can also use INTUNEs sniffer function (nose icon) to determine which devices are communicating on the J1939 Drivetrain data link as seen from the diagnostic connector.

Other problems with data link wiring that can cause problems are shorts to ground or shorts to battery voltage. Use a high impedance voltmeter to measure voltage between CAN_H to ground and CAN_L to ground. The normal voltage between either CAN_H or CAN_L and ground is about 2.5V measured with a DVOM set to DC volts <u>with data traffic on the link</u>. If you read 12V or so, the conductor you are measuring is likely shorted to B+ at some point. If you read 0V between either conductor and ground <u>with data traffic on the link</u>, the conductor you are measuring is shorted to ground at some point. Open the data link at various locations to find the source of the shorted condition. In general, if CAN_H is shorted to ground or if CAN_L is shorted to B+, all data link communications cease. A short to ground of CAN_L does not have much impact on the system. You may not detect any abnormalities if only CAN_L is shorted to ground. The number of error messages generated on the data link is likely to increase if CAN_L is shorted to ground though. A short to B+ of CAN_H may or may not cause detectable problems on the data link.

You can also look for intermittent data link problems by using a meter with peak Ohms hold such as a Fluke 88. With batteries disconnected, clip onto CAN_H and CAN_L at the diagnostic connector and set meter for peak hold Ohms. Wiggle the data connections through the entire backbone while watching for a change in maximum or minimum resistance. Remember that an open circuit in either data link conductor will cause the data link DC resistance to increase from near 60 Ohms to near 120 Ohms (provided both resistors are present). A CAN_H to CAN_L short will drop the resistance measured across the conductors to near 0 Ohms.

Moisture in data link connectors can also present a communications problem that is difficult to diagnose. Moisture can cause terminals to corrode and also changes the characteristic impedance of the data link.

You may also troubleshoot the Body Builder data link in a similar manner. However, the Body Builder data link is not connected to the diagnostic connector. You will need to use the breakout box at the outside ESC 36-way connector to test the Body Builder data link. The terminating resistors are located in a connector cap in the last device connected to the backbone and near the ESC outside 36-way connector. The resistance measured across the Body Builder data link should be 60 Ohms.

Some Quick Tests

Several seemingly difficult problems have been traced back to a loss of ignition or a loss of accessory voltage to the ESC. One of the first things to check when you have a weird problem is to determine if the windshield wipers operate. With the key switch in the ignition position, the wipers should operate. If the ESC does not have both ignition and accessory voltage, the wipers will not operate. If the wipers do not work, does the voltmeter display battery voltage? If the voltmeter works, then the ESC has accessory and a possible problem is a loss of ignition to the ESC. The loss of ESC ignition can cause a list of problems. If the voltmeter does not work and all the other gauges are functional, then a possible problem is a loss of accessory to the ESC. A loss of ESC accessory also causes a list of problems. The ESC may or may not set faults for the loss of ignition or accessory, so a lack of faults is really not a good indicator of the status of ESC ignition or accessory.

The four gauges on the right side of the EGC are all supplied J1939 Drivetrain data from the ESC. If all other gauges are functional, a possible problem is a loss of J1939 communications between the ESC and the EGC. This could be due to a number of ESC problems. If the speedometer and tachometer and other engine gauges do not work and the four right side gauges are functional, a possible problem is a loss of J1939 communications between the EGC and the engine. If the cruise control also does not work, this may indicate that the ESC also cannot communicate with the engine.

A loss of battery feed to the EGC will cause inoperative headlights and inoperative panel illumination. All the gauges will still function though since they are powered by either ignition or battery feeds. A quick check for a loss of battery feed to the EGC is remove and replace the EGC battery fuse with the key switch in the OFF position. The gauges should sweep when the EGC battery fuse is re-installed if the EGC battery feed circuit is intact. If the gauges do not sweep under these conditions, check for an open EGC battery feed circuit.

INTUNE

The INTUNE diagnostic software is a very useful tool. INTUNE can be used to look at values of ESC inputs and the state of ESC outputs. Most ESC outputs can also be forced-on using INTUNE. This force-on feature is great for making a quick check to determine if something is not working because of a wiring problem or because the ESC is not switching on the output. This force-on feature is also convenient when looking for wiring problems on devices that would normally only be switched on by the ESC with the engine running such as the A/C clutch. The software is easy to use, especially if you are familiar with Master Diagnostics.

Assessment

1. Technician A says that J1939 cable has a characteristic impedance of 120 Ohms, which cannot be measured with an Ohmmeter. Technician B says that if both terminating resistors were present on a functional J1939 data link network, an Ohmmeter connected across the J1939 data link conductors with vehicle batteries disconnected should measure about 60 Ohms. Who is correct?

   A. A only
   B. B only
   C. Both A and B
   D. Neither A nor B

2. The ESC is not communicating on the J1939 Drivetrain data link because the CAN_H terminal is pushed out of the ESC connector containing the J1939 Drivetrain data link. Which one of the following electrical features would not operate?

   A. Electric horn
   B. Windshield wipers
   C. Brake lights
   D. Voltmeter

3. The ESC on a vehicle with a single fuel tank logs a fault indicating the fuel level sensor is out of range high. Which is the most likely cause?

   A. The fuel tank is not properly grounded
   B. The ESC fuel level sensor circuit is open between the sensor and the ESC fuel level input
   C. The ESC fuel level sensor circuit is shorted to ground between the sensor and ESC fuel level input
   D. The fuel tank has been overfilled

4. The DT466 engine will not crank on a 4300 with a manual transmission. Battery voltage is 12.6V. Technician A says that an open circuit in the J1939 Drivetrain data link could be the cause of the no-crank. Technician B says that the voltage level at the ESC clutch switch input should be measured using the breakout box, or by using INTUNE, to determine if the upper clutch switch circuit is the cause of the no-crank. Who is correct?

   A. A only
   B. B only
   C. Both A and B
   D. Neither A nor B

5. The ESC logs a fault indicating that one of the low side driver outputs has a load present on an unused output. Which of these problems could cause the ESC to log this fault?

   A. A feature that uses a low side driver has been removed from the ESC programming and the associated vehicle wiring and load device (relay or solenoid) has not been removed from the vehicle
   B. The faulted low side driver circuit is shorted to ground
   C. The faulted low side driver circuit is open
   D. Both B and C

6. The dome light could not be shut off on a 4400. The technician discovered a short to ground in the wiring between the driver side door switch and the ESC dome light input. Repairing the shorted wire restored proper dome light operation. The technician who made the repair tells his co-workers about the problem while waiting at the parts counter. Technician A says that ESC virtual fusing protected the shorted wiring in this instance. Technician B says that before the repair was made (circuit was still shorted to ground), the voltage between the ESC dome light input and ZVR would have been about 12V with the ignition on and about 4.3V with the ignition off. Who is correct?

   A. A only
   B. B only
   C. Both A and B
   D. Neither A nor B

7. The A/C clutch will not engage on a 4400. The ESC is not logging any faults. The high side and low side pressures are both about 75 psi as indicated by A/C pressure gauges. INTUNE indicates the following readings:

Evaporator inlet temperature	40 degrees F
Evaporator outlet temperature	74 degrees F
High side pressure	73 psi

   What could be the cause for the inoperative A/C clutch on this vehicle based on these readings?

   A. Evaporator inlet thermistor is defective (not indicating correct temperature)
   B. High resistance in the wiring connections between the evaporator inlet thermistor and the ESC
   C. The orifice tube is plugged
   D. Both A and B

8. The cruise control and PTO engine speed control will not function on a 4400. The ESC also cannot be placed into the diagnostic mode using the cruise control switches. What could be the possible cause(s) of both problems?

   A. One of the cruise control switches is defective
   B. The ESC cruise control input circuit is open between the cruise switches and the ESC cruise control input
   C. The ESC cruise control input circuit is shorted to ground between the cruise switches and the ESC cruise control input
   D. All of the above

9. The HVAC blower motor will not operate on a 4300. Technician A says that the linear power module ground circuit may be open. Technician B says that the 1K-Ohm resistor between the LPM control line and ground may be open. Who is correct?

   A. A only
   B. B only
   C. Both A and B
   D. Neither A nor B

10. Neither power window motor will function on a 4300. The door locks both work correctly though. Pressing either door lock switch (driver or passenger) causes all door locks to operate. The panel illumination in the door pods also illuminate when the park lights are switched on. What could be the possible cause(s) of the power window motors not functioning?

    A. The Switch data link conductors are shorted together
    B. The Switch data link between the ESC and door pods is open
    C. The key switch is in the off position
    D. All of the above

11. The windshield wipers cannot be completely shut off on a 4300 regardless of wiper switch position anytime the key switch is in the ignition position. With the wiper switch in the off position, the wipers sweep once every 14 seconds. There is also no difference in wiper motor speed between high speed and low speed wiper switch positions. The time delay between intermittent positions Int 2 and Int 3 is the same. The time delay between intermittent positions Int 4 and Int 5 is also the same. What could be the possible cause of all of these problems?

    A. ESC wiper switch input SW0 circuit is shorted to ground between switch and ESC input
    B. ESC wiper switch input SW0 circuit is open circuited between switch and ESC input
    C. ESC wiper switch input SW2 circuit is open circuited between switch and ESC input
    D. The wiper hi-low relay normally open contacts are fused together (relay acts as though the coil is always energized)

12. The wiper motor stops immediately without parking when the wiper switch is placed in the off position. Technician A says that the wiper power relay coil low side circuit may be shorted to ground between the relay and ESC low side driver output. Technician B says that the wiper motor B+ feed circuit may be open between the splice and wiper motor B+ terminal. Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B

13. The driver side mirror heater does not heat the mirror. The passenger side mirror heater functions correctly. Which of these could <u>NOT</u> be the problem?

    A. Blown driver side mirror heat fuse
    B. ESC mirror heat FET has detected an overcurrent and is virtually fused
    C. Open ground circuit for driver side mirror heater
    D. Open circuit between driver side mirror heat fuse and driver side mirror heater

14. The driver of a 4300 indicates that the A/C does not cool at all. There are no faults logged in the system (previous or active). A quick check reveals that the A/C clutch is not cycling on. Technician A says that the A/C request circuit between the ESC A/C request input and HVAC control head may be open circuited. Technician B says that the A/C clutch circuit may be shorted to ground between the ESC A/C clutch output and A/C clutch (virtual fusing is active). Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B

15. The on/off air powered engine fan drive on a 4400 does not engage the engine fan clutch even though an A/C high side pressure gauge shows that the A/C high side pressure is 325 psi. The A/C system functions normally other than the fan problem. The engine fan clutch does cycle on though when engine coolant temperature reaches 212° F (the programmed fan on temperature). Technician A says that the J1939 Drivetrain data link between the ESC and engine controller may be open circuited. Technician B says that the normally closed A/C pressure switch in the A/C system high side may not be opening (switch is defective). Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B

16. The exhaust brake does not operate on a 4300 with a DT466 and Wabco hydraulic ABS brakes. Technician A says that the ABS event normally open relay contacts may be fused together (relay acts as though the coil is always energized). Technician B says that the ESC ABS event input circuit may be open between the ABS event relay and ESC ABS event input. Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B

17. A 4400 has two remote power modules. The remote power module located behind the battery box does not operate. A wire harness is connected to both of the 6-way connectors of the remote power module located behind the battery box. The remote power module at the end of the frame rail has a terminating resistor in one of the 6-way connectors and is functioning correctly. What could be the cause of the inoperative remote power module?

    A. The remote power module behind the battery box is addressed incorrectly
    B. The Body Builder data link is open between the ESC and the inoperative remote power module
    C. There is no ignition power at the 6-way connector for the inoperative remote power module
    D. All of the above

18. A 4400 is equipped with Bendix air ABS with traction control. Technician A says that the traction control warning LED in the EGC should be illuminated continuously when the traction control switch actuator is placed in the disable position and key switch is in the ignition position. Technician B says that the traction control warning LED in the EGC will flash if the traction control switch actuator is in the enable position and a traction control event is occurring (ABS controller is actively controlling wheel slip). Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B

19. A 4200 with an Allison 2000 LCT automatic transmission does not shift correctly. The PRNDL display in the EGC also does not indicate what gear position has been selected. All other gauges work correctly. Which of these is the most likely cause of the problem?

    A. The J1939 Drivetrain data link CAN_H and CAN_L are shorted together in the transmission wire harness
    B. The J1939 Drivetrain data link CAN_H terminal or CAN_L terminal is pushed out of the 44-way pass-through connector (dash harness to cab harness connector)
    C. The J1939 Drivetrain data link is not connected to the Allison LCT transmission controller
    D. The Allison LCT transmission controller has not been programmed correctly and is communicating on the J1708 Drivetrain data link instead of the J1939 Drivetrain data link

20. The fog lights will not illuminate when the fog light switch actuator is set to the ON position. The ESC does not log any faults when the fog light switch actuator is switched on. Technician A says that the switch pack containing the fog light switch actuator may not be connected to the Switch data link. Technician B says that the fog lights will not operate if the key switch is in the off position. Who is correct?

    A. A only
    B. B only
    C. Both A and B
    D. Neither A nor B