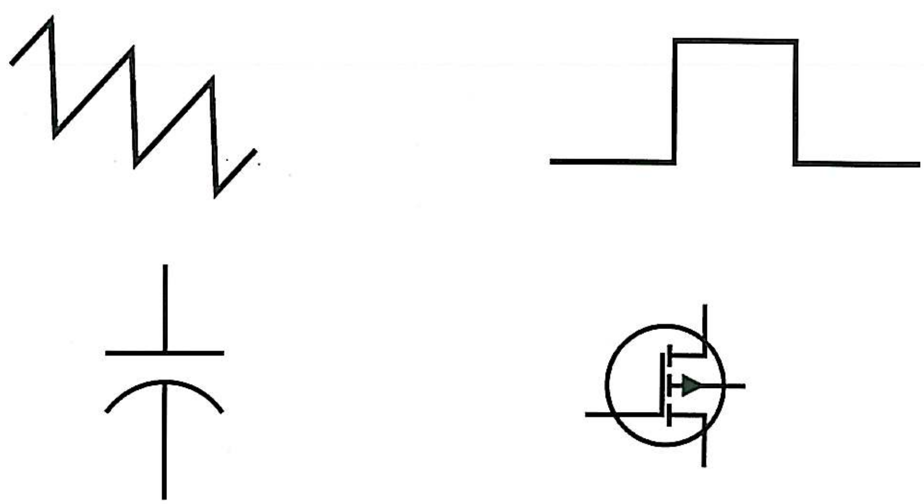
BASIC ELECTRONICS
And
TROUBLESHOOTING



PORTABLE POWER
INGERSOLL RAND
501 SANFORD AVE
MOCKSVILLE, N.C.

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CIRCUITS

Electric Current

An electric current is the flow of electrons from one point to another. This flow requires a pathway that is referred to as a ***conductor***. This conductor is most commonly a wire.

The flow of electric current is analogous to the flow of water through a pipe. The pipe is the conductor and the water is analogous to electric current. The water flow will have a pressure associated with it, which is analogous to voltage in the case of electric current. The unit of measurement of electric current is the ***ampere*** and the pressure associated with electric current is referred to as ***voltage.***

A fundamental law of electricity is that the **current is directly proportional to the applied voltage;** that is, if the voltage is increased, the current is increased. If the voltage is decreased, the current is decreased.

Currently, there are six methods of producing electricity:

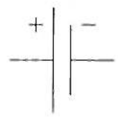
1. FRICTION – Voltage produced by rubbing two materials together.
2. PRESSURE – (Piezoelectricity) Voltage produced by squeezing crystals of certain substances.
3. HEAT – (Thermoelectricity) Voltage produced by heating the junction where two unlike metals are joined.
4. LIGHT – (Photoelectricity) Voltage produced by light striking photosensitive substances.
5. CHEMICAL ACTION – Voltage produced by chemical reaction in a battery cell.
6. MAGNETISM – Voltage produced in a conductor when the conductor moves through a magnetic field, or when a magnetic field moves through the conductor in such a manner as to cut the magnetic lines of force of the field.

For our purposes, we will be concerned with CHEMICAL ACTION and MAGNETISM. Most of our applications will be concerned with chemical action (Batteries).

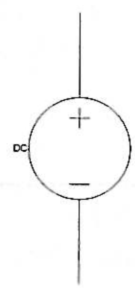
Electric current has two basic forms, Alternating Current or ***AC***, and Direct Current or ***DC*** , which is the topic of this text. AC current reverses direction periodically such as with 60 hertz. DC current is continuous and does not change direction.

A ***battery*** is a source of DC electrical power. It consists of a single or number of cells connected together to achieve a certain voltage level. The focus of this text will be on the lead acid battery.

The circuit symbol for a single cell battery is:

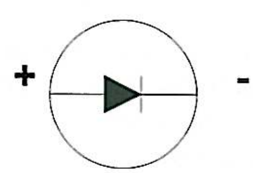


Another symbol that is used to designate a battery or power supply is:



In practice, most batteries consist of multiple cells. The number of cells depends on the voltage per cell. The lead acid battery is the most common battery used in off road equipment. The nominal cell voltage is 2.0 volts. This varies depending on the state of charge of the battery.

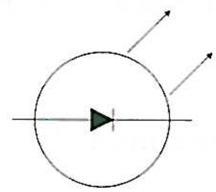
A ***diode*** is a semiconductor device that allows current flow in only one direction. The diode is formed using *P* type and *N* type semiconductor materials. The diode has froward resistance, reverse standoff voltage and current rating as important parameters. The symbol for a diode is:



The polarity + - indications of the diode are important. The + terminal is called the anode and the – terminal is the cathode. The diode will pass DC current when connected with the anode (+) to positive voltage and the cathode (-) to negative voltage.

Diodes have many uses such as rectification, steering, blocking and counter emf to name a few.

A ***LED*** is a special form of a diode that functions as a lamp when current is passed through it. It has light output in several colors and is used for indicator lamps. The symbol for an LED is:



What are the important parameters in a DC circuit ?

Voltage, Resistance **and** ***Current*** are the important parameters in a DC circuit. Measurement of these values will determine the health of the circuit.

These electrical parameters are analogous to parameters associated with a water system. Voltage is analogous to pressure in a water system, current to flow and resistance to pipe or fitting resistance to water flow.

In some cases, it is not easy to measure all parameters in a circuit. If two of the parameters can be measured, the third can be calculated. Ohm's law provides the basic formula for calculation.

Ohm's Law

V = I * R

Ohm's law is a basic electrical formula used to calculate voltage – current and resistance in an electrical circuit. **V** stands for voltage, **I** stands for current and **R** stands for resistance.

<u>Example:</u>

In a DC circuit, current equals 2 amps, resistance Is 1000 ohms.
What is the voltage ?

V = I * R

V = 2 * 1000 = 2000 Volts

The power consumption in DC circuits is an important parameter. This can be calculated using:

P = V * I

Where **P** is the power in watts, **V** is volts and **I** is the current.

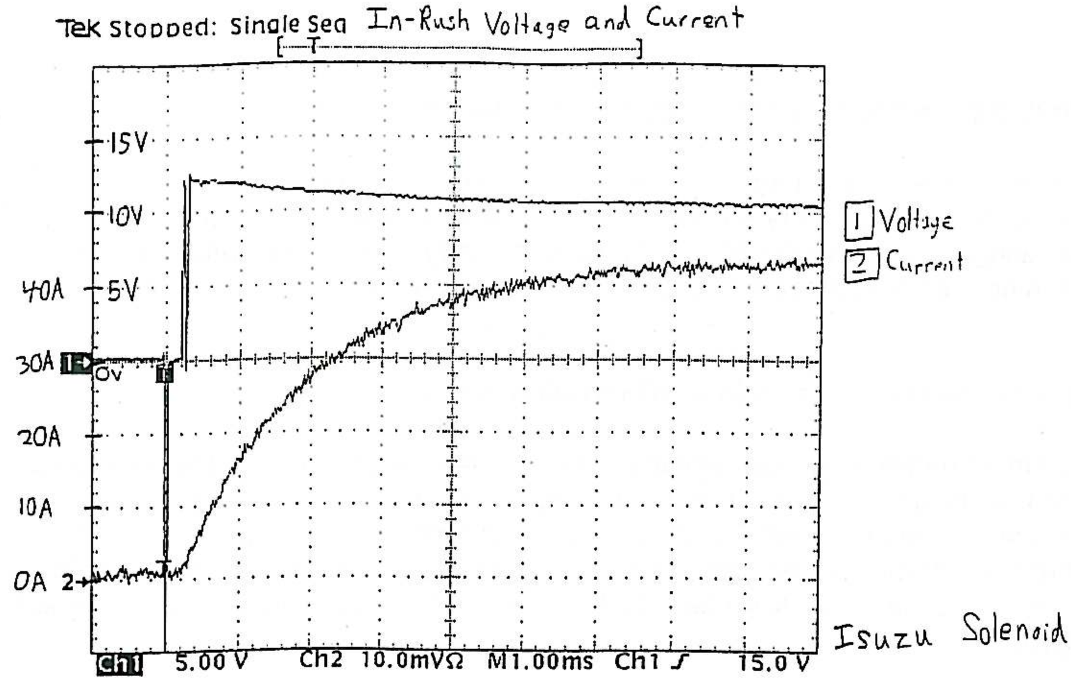
What is inrush current vs. continuous current ?

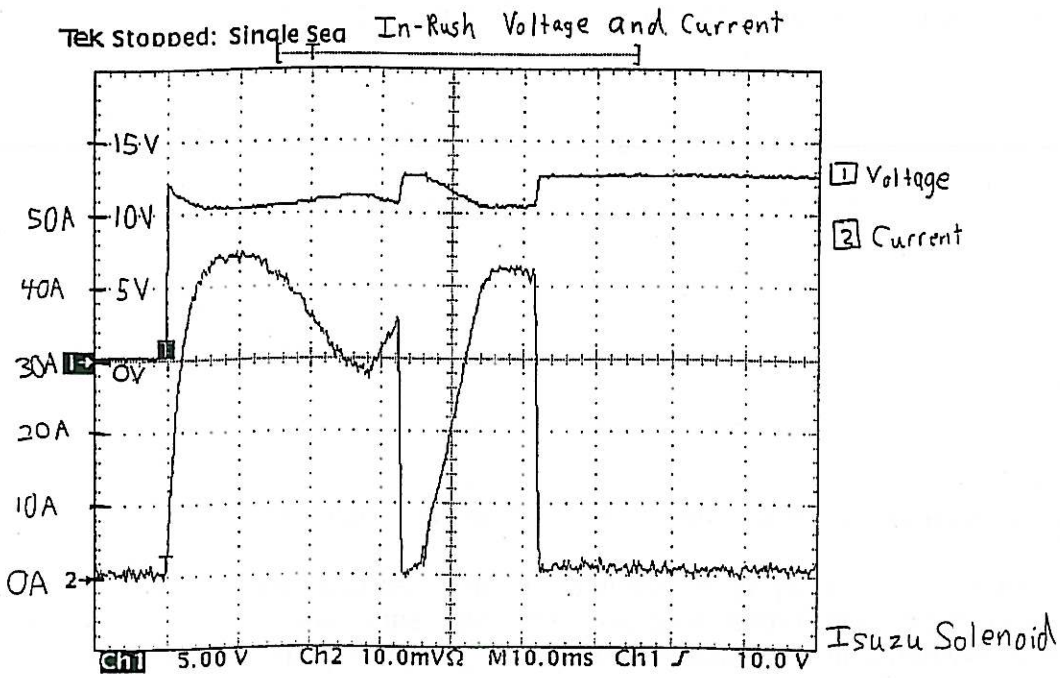
DC circuit can consume different levels of current depending on the operational state of the circuit. At the time power is applied to the DC circuit, an inrush or initial current may occur. This inrush current may be much large than the steady state or continuous operating current.

There can be a high inrush current in a circuit containing a capacitor as the capacitor charges. Once the capacitor charges, the continuous current is zero. There can be a high inrush current in a circuit containing an inductor. The continuous current will be less than the inrush current.

In most cases the inrush current only lasts for a few microseconds or milliseconds. Inrush current is important for fuse or circuit breaker sizing. Capacitors and inductors experience inrush current.

The following page shows a graph of inrush current from an inductor.


Tek Stopped: Single Seq In-Rush Voltage and Current
15V
10V
40A 5V
30A 1 0V
20A
10A
0A 2
1 Voltage
2 Current
Isuzu Solenoid
Ch1 5.00 V Ch2 10.0mVΩ M1.00ms Ch1 ∫ 15.0 V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20A
10A
0A 2
1 Voltage
2 Current
Isuzu Solenoid
Ch1 5.00 V Ch2 10.0mVΩ M10.0ms Ch1 ∫ 10.0 V

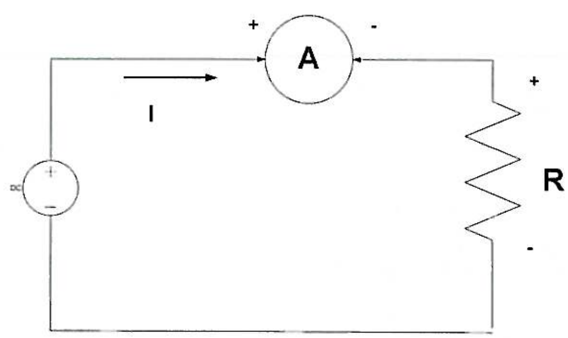
What are the sources of DC power on a machine ?

The battery is the primary DC power source on the machine. The engine alternator is a secondary source that is only available when the engine is operating. The alternator should be sized to carry all electrical loads on the machine plus additional capacity to charge the batteries.

How are the parameters in a DC circuit measured ?

DC circuit parameters are: voltage current resistance. These are measured using basic electrical instruments. Voltage is measured using a ***Voltmeter.*** Current is measured using an ***Ammeter.*** Resistance is measured using an ***Ohmeter.*** In most cases, these three instruments are combined into a single instrument called a ***Multimeter.*** Today, the most popular service instrument is a ***Digital Multimeter.***

An ammeter is inserted in series in the circuit to measure amps.

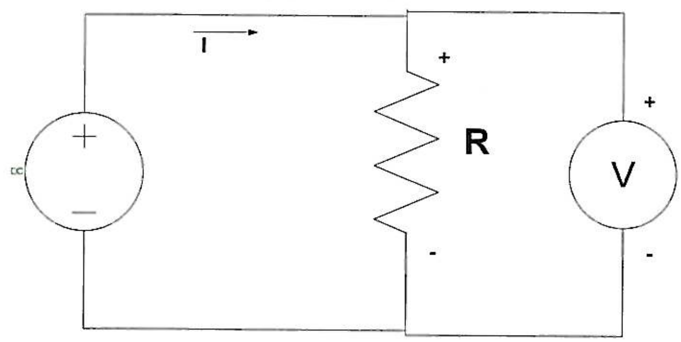


The ammeter measures the current supplied to the resistor, **R.**

Note the + and – polarity signs shown at the ammeter and resistor. These designate a ***polarity*** across these two circuit elements. There can be a voltage drop associated with this polarity. Measuring voltage drops is an important troubleshooting technique that will be explained in later sections.

The basic unit of current measurement is the ampere (amp) as defined earlier. In many cases the measured current will be less than one amp so two other terms are used to describe the current. ***Milliamps*** and ***Microamps*** are used to describe small values of current. One milliamp equals .001 amps. One microamp equals .000001 amps. The abbreviation for milliamps is Ma and for microamps, μa.

A voltmeter is placed in parallel with or across the resistor to measure volts.



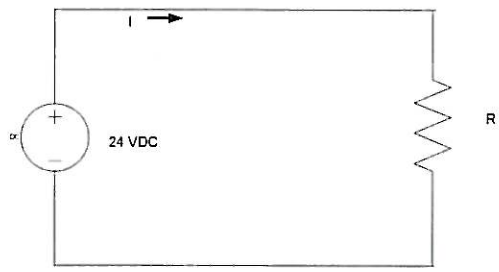
In this circuit, the volts read by the voltmeter is the same as the DC power volts. As defined by ohm's law: V = I * R

As described in the ammeter circuit, note the polarity across the resistor. Given the current direction shown, the voltage drop polarity is as shown. Any device placed in a DC circuit that has resistance associated with it will have a voltage drop across it.

The basic voltage measurement is volts. In many cases the voltage measured will be less than one volt so two additional terms are used to describe the voltage. ***Millivolts*** and ***microvolts*** are used to describe small values of voltage. One millivolt equals .001 volts. One microvolt equals .000001 volts. The abbreviation for millivolts is Mv and for microvolts it is μv.

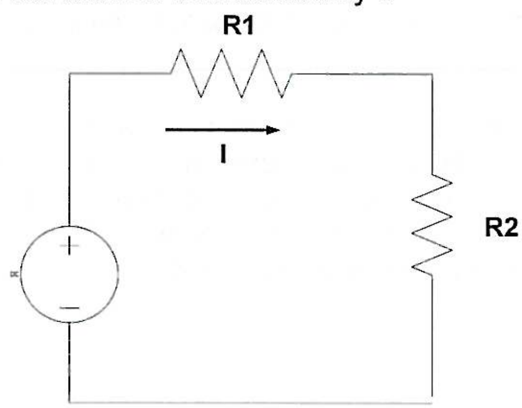
Series DC Circuits

A series DC circuit consists of the connection of circuit elements in series. For example, the simplest circuit would be a battery with another circuit element such as a resistor.

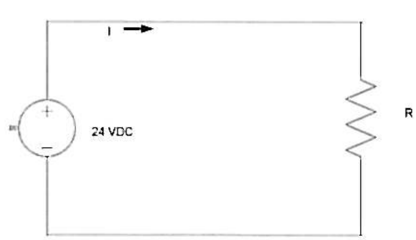


The battery supplies a source of DC current to the resistor.

A series circuit with three elements is shown below. It consists of two resistors and a battery. The current flow is indicated by I.

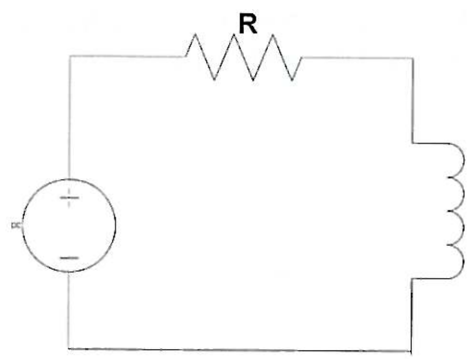


This circuit is equivalent to:



where R is equal to **R1 + R2**. For resistors in series, add the resistance values to get the equivalent resistance.

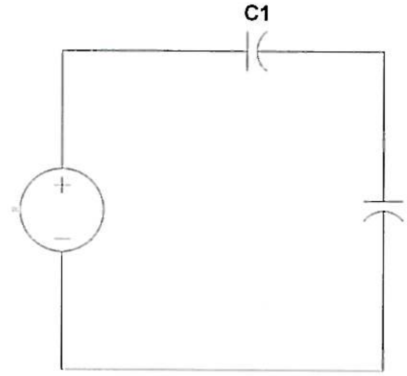
Another example:



For the case of non-time varying DC current, the inductor has a DC resistance value. The equivalent resistance:

R = equivalent resistance $R = R + R_L$

For the case of capacitors:

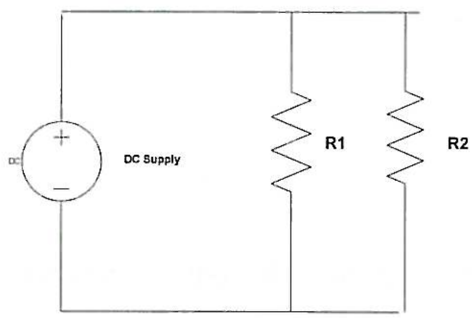


To find the equivalent capacitance, C_E -

$$\frac{1}{C_E} = \frac{1}{C1} + \frac{1}{C2}$$

Parallel DC Circuits

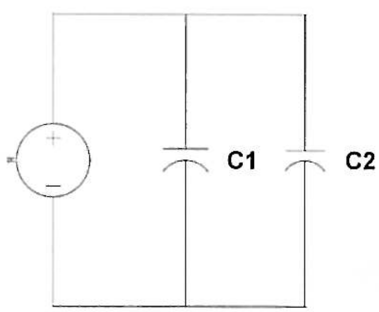
A parallel DC circuit consists of the connection of circuit elements in parallel. For example, the simplest circuit would be a battery with two resistors connected in parallel:



To find the equivalent resistance, **R_E :**

$$\frac{1}{R_E} = \frac{1}{R1} + \frac{1}{R2}$$

For capacitors in parallel:

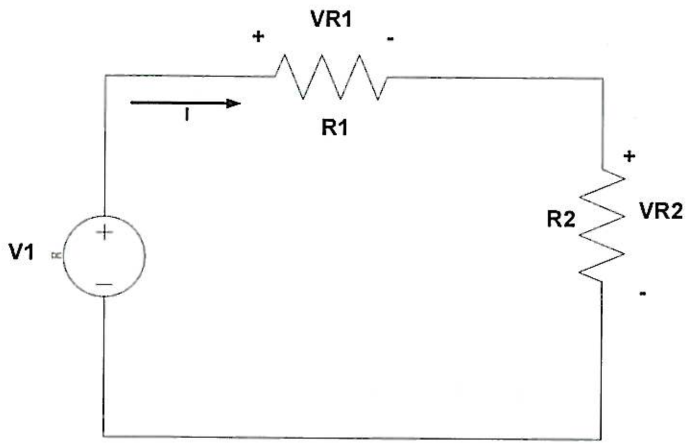


To find the equivalent capacitance, **C_E,**

$$C_E = C1 + C2$$

Kirchhoff's Law

Kirchhoff's voltage law states that the algebraic sum of the voltages around any closed path in a circuit is zero. Refer to the circuit below.

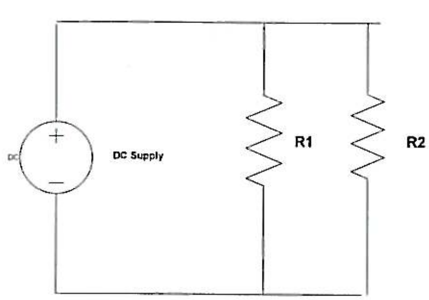


$$-V1 + V_{R1} + V_{R2} = 0$$

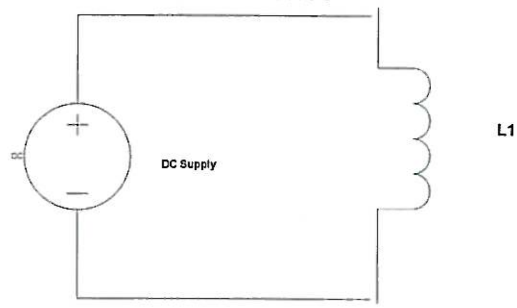
This can also be stated as the sum of the voltage drops around a circuit must equal to the source voltage. This concept is the basis of a very useful troubleshooting technique, which will be explained in a later section.

What are some of the basic DC circuits used in off road equipment ?

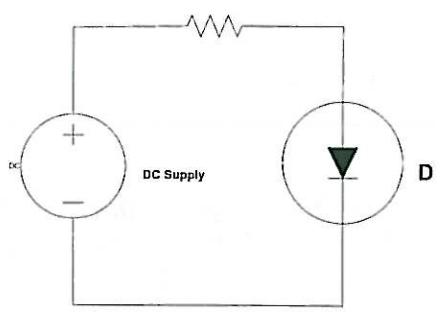
Resistors in parallel



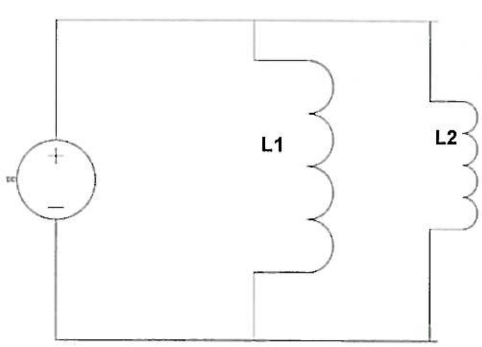
Inductor in series



Diode is series

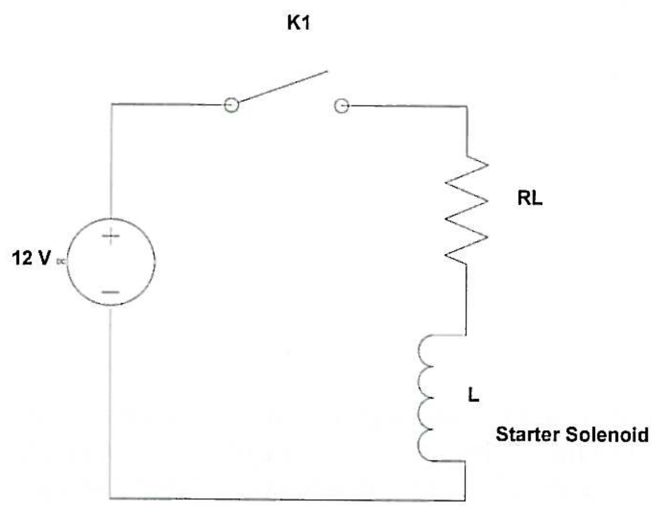


Inductors in parallel.



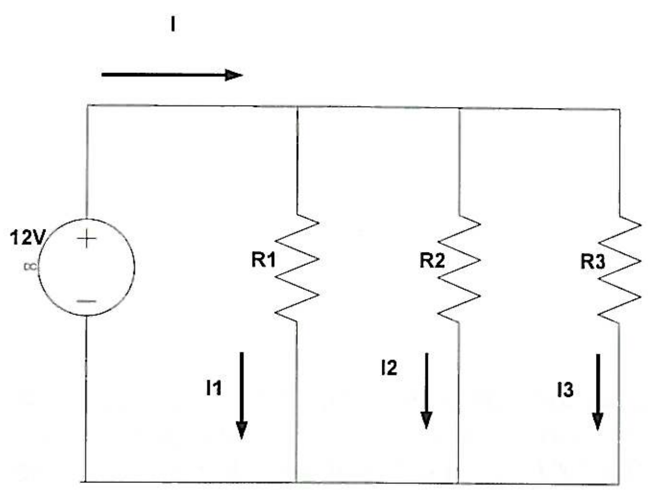
Typical Machine Circuits

Engine Starter Solenoid Circuit:



The **RL** represents the inductor DC resistance. **K1** is the auxiliary start relay contact.

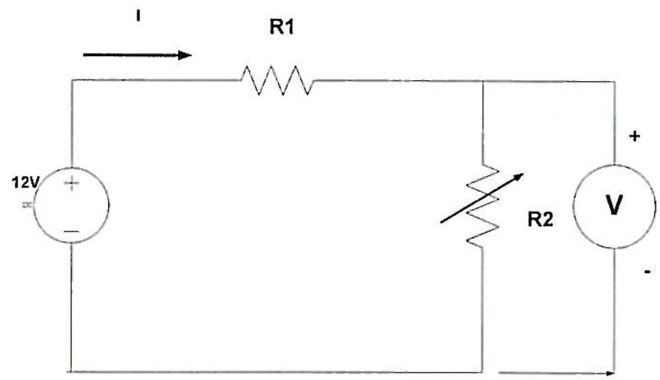
Orifice Heater Circuit:



R1, R2, R3 are the heater elements. The total circuit current, **I**:

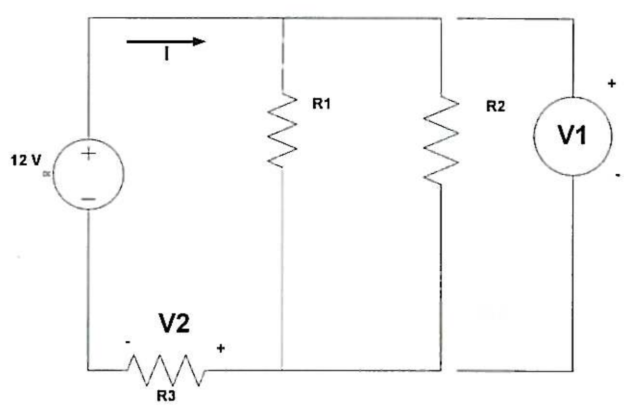
I = I1 + I2 + I3

Fuel Level Circuit:



The **R2** with the arrow through it refers to a variable resistor. The fuel level gauge is a variable resistance device. The voltage, **V,** will vary as the fuel level changes. In practice, R2 is referred to as a sender and is used to drive a gauge or is the input to a computer system.

Lighting Circuit:

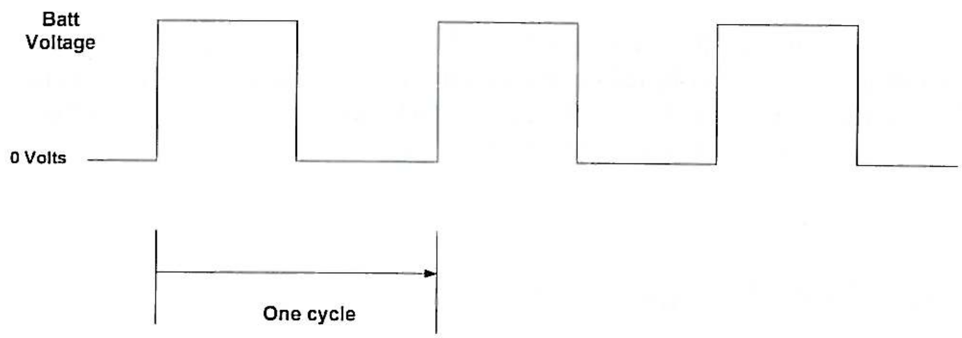


R1 and **R2** are the lamps, **R3** is the ground circuit resistance as would appear if the machine frame or structure is used for ground return. The voltage drops in the circuit are V1 and V2. V1 + V2 = 12V. If the value of R3 is large, V2 will be large which will reduce V1 which means the lights will be dim. Therefore, it is important to have good ground connections so R3 will be small.

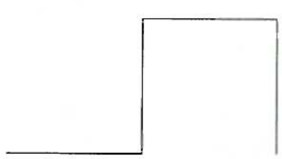
DC Pulse Circuits

Some applications require a solenoid to be driven at a variable duty cycle. This is usually associated with proportional valves, such as those used in hydraulic applications. In these cases, a ***pulse width modulated*** (PWM) DC signal is used to drive the solenoid.

A basic pulse waveform is:

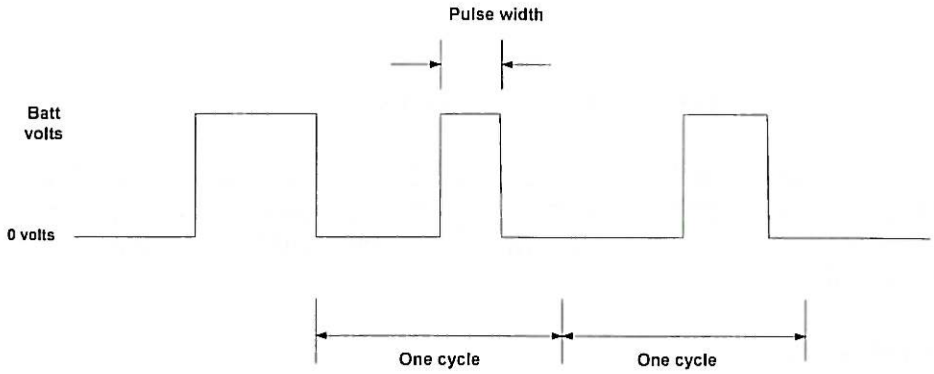


This is a 50% duty cycle waveform. This means the signal is high 50% of the total waveform time or one cycle and low 50% of the cycle. One cycle would appear as:



The waveform is symmetrical, 50% off and 50% on. This basic waveform is the basis for a pulse width modulated waveform.

A basic PWM waveform:



As can be seen here, the on time pulse width varies. By changing the pulse width, the current through the solenoid is changed. The average current through the solenoid is varied by the pulse on time of the PWM waveform. This provides an easy method of current control through a solenoid.

DC Circuit Protection

There are two basic circuit protection devices: ***fuses*** and ***circuit breakers***. Fuses are a single event device. If a short circuit occurs, the fuse element will melt open, to disconnect the circuit from the power source. The fuse must be replaced.

Most of the fuses encountered in off road equipment will be of the ***ATC*** type or ***AGC*** type. The ATC is the blade type fuse with ¼" blades that are rated at 32 volts. The AGC is the circular glass type fuse with metal end caps that are rated at 32 to 250 volts. The ATC types are more widely used the AGC.

ATC type fuses are available in three types, ATC, ATM and Max physical sizes. The ATC type has amperage ratings from 1 to 40 amps, the ATM from 2 to 30 amps, and the Max from 20 to 80 amps.

AGC fuses are available in a variety of physical sizes, the ¼" X 1 ¼" and 5mm X 20mm being the more common ones. These have current ratings of 1 to 30 amps. Since their voltage rating goes to 250 volts, they can be found in AC circuits on off road equipment.

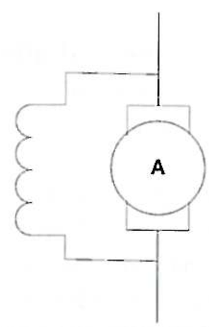
Circuit breakers are another form of circuit protection that have the feature of reset. Once they open the circuit due to an excessive current, they can be manually reset or some units automatically reset. Circuit breakers used in off road equipment are typically thermal or magnetic types.

DC Motors

A DC motor converts electrical energy into mechanical energy. Its operation is based on the principle that a current carrying conductor placed in, and at right angles to, a magnetic field tends to move at right angles to the direction of the field.

The DC motor consists of two components, the armature and the field. In most cases the field is the stationary set of coils located in the motor case and the armature is the set of coils attached to the rotor or rotating part of the motor. There are three basic types of DC motors, based on the way the field coils are connected. Each has certain advantages under various loading conditions.

The ***shunt wound*** is as follows:

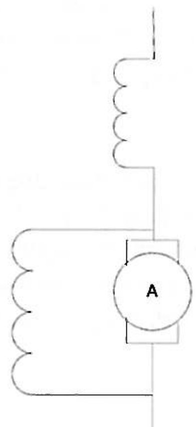


In this case the field coil connects in parallel with the armature. This type of motor develops constant speed and variable torque with constant voltage applied and does this under changing load conditions. This motor is used in shop equipment such as lathes, milling machines, planners and shapers.

The ***series wound*** is as follows:

The field coil is in series with the armature. This type of motor develops variable torque under constant voltage, but the speed varies widely under changing load conditions. The motor is used to drive cranes, hoists, winches and as a starter motor for engines.

The ***compound wound*** is a follows:



One set of field coils is in series with the armature and another set of field coils is in series. This motor has increased starting torque over that of the shunt motor, and has less speed variation than the series motor.

DC motors provide armature connections using a commutator-brush assembly or are brush less. The brush less variety generally applies to high speed, high performance applications that can bear the cost of this configuration. Most of the basic work horse motors are of the brush-commutator configuration. The commutator is a copper bar assembly attached to one end of the armature (rotor). The armature coils connect to the commutator segments. The brushes, usually two, are mounted in the motor housing and ride on the commutator bars. This provides a method of connecting the armature to a source of power.

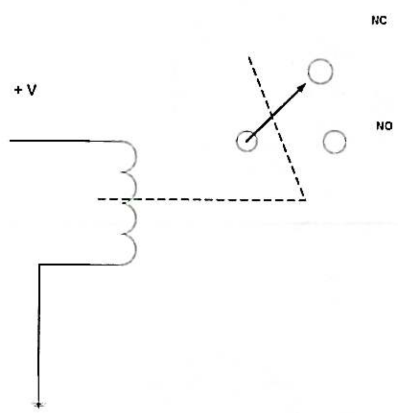
Many DC motors have a permanent magnet instead of the field coil. This is especially true in small DC motors and is seeing more wide spread use in larger motors. Permanent magnet motors tend to be more expensive than motors with field coils.

DC motors can have a small armature resistance. Due to this fact, the motor can draw a large current at startup. In the case of industrial applications, a motor starter would be used which would limit the inrush current. For off road equipment, a starter in seldom used so sizing of circuit protection is important. The fuse or circuit breaker used must take into account the inrush current at startup.

Relays

Relays are electrically operated switches. They are classified according to their uses such as: control relays, power relays, or sensing relays. The function of a relay is to take a small amount of electrical power and control a larger amount of electrical power. In many cases relays are used for isolation of two circuits. Computer controllers use relays to connect to various loads as an isolation element to isolate the controller from the particular load.

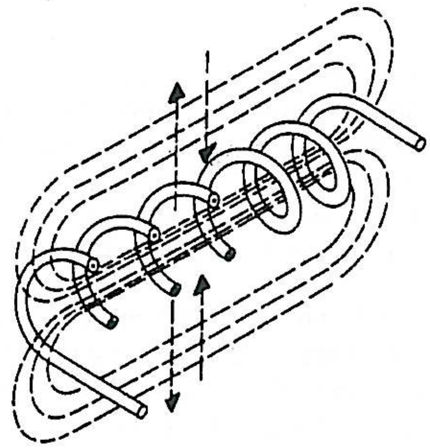
A relay consist of a coil or solenoid and the fixed and moveable contact sets. The solenoid and the moveable contacts form the magnetic circuit. When voltage is applied to the coil the magnetic field pulls in the moveable contact set. This activates or "makes" these contacts. At the same time, the fixed contacts are broken or de-activated. A basic relay configuration is shown below.

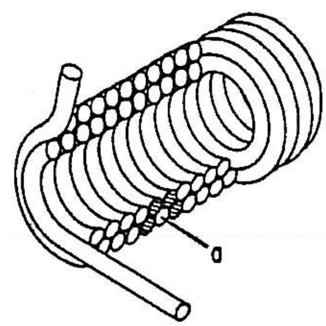


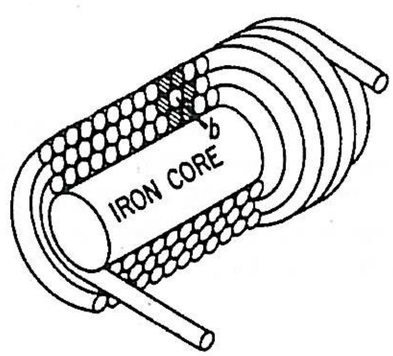
Relays are specified according to contact current rating and coil voltage rating. The contact current ratings go from milliamps at 5-12 volts DC to 10-30 amps at 250 volts AC. The coils have both AC and DC ratings from 5 volts to 600 volts. Relays are also specified as to the number of poles or contact sets. The contacts can be normally open or normally closed.

Solenoids

A solenoid is a basic magnetic circuit. Sometimes these are called "coils" which is not exactly true. It is more than just a coil. The solenoid is made up of an inductor with an iron core material. The coil of wire is wound around the iron core. When a current is passed through the coil, a magnetic field is generated around the coil. This field will attract other ferrous metal devices. The diagram below shows solenoid coil construction.



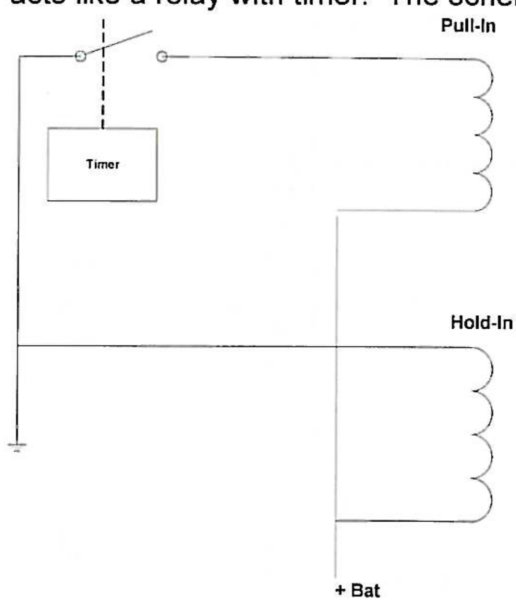




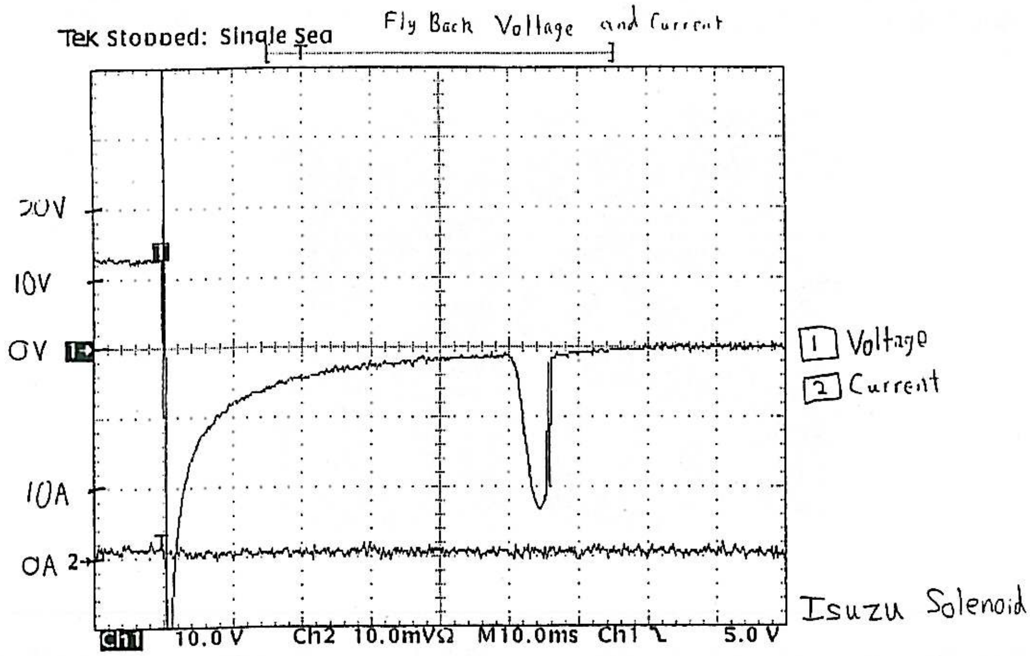
If the iron core is designed so it can be moved in and out of the coil, mechanical work can be performed. This is the basis of a solenoid. One common application of solenoids is a fuel solenoid on an engine. A solenoid is used to move the fuel pump lever to turn the fuel ON or OFF.

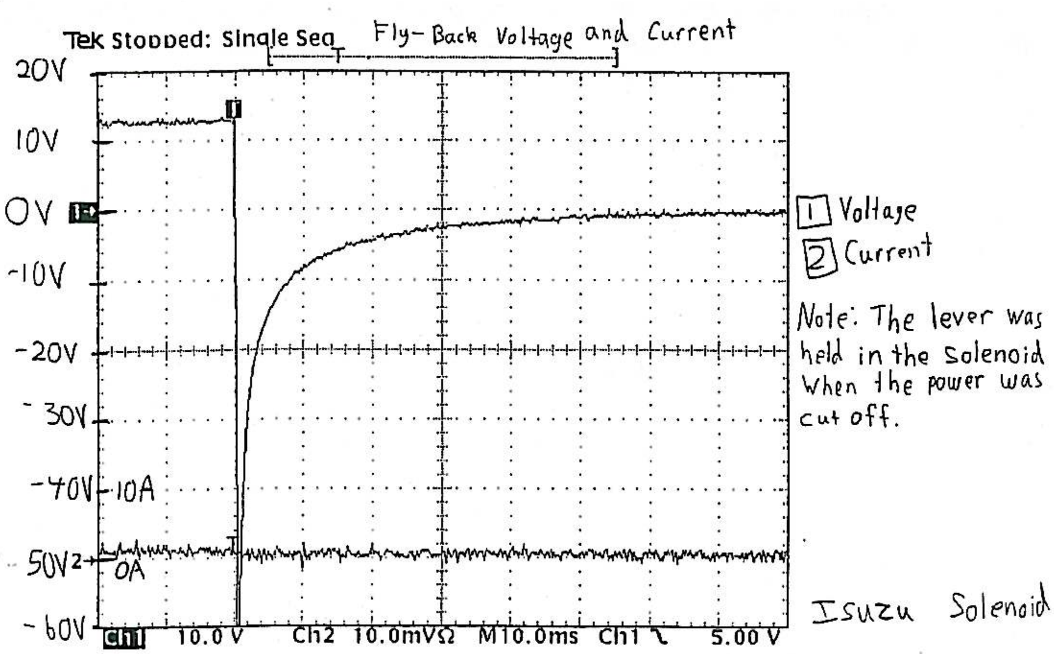
Many of these fuel solenoids have dual coils, one for pull-in and one for hold-in. The hold-in coil is always energized when the machine is operating and the pull-in coil is used to give the extra magnetic field to pull the solenoid plunger into the coil assembly. Once the plunger is pulled in the hold-in coil has a strong enough magnetic field to hold the plunger in. The picture below shows a Syncro Start solenoid.

These types of two coil solenoids usually have a timer control module associated with them. The purpose of the timer unit is to activate the pull-in coil for only a short period, usually one second or less. The timers are an electronic device that acts like a relay with timer. The schematic below shows this configuration.

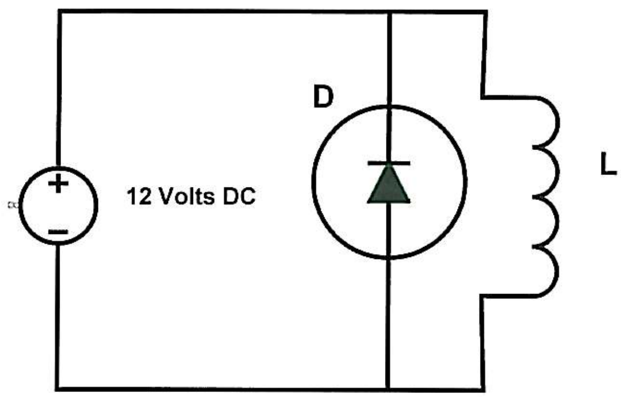


Inductors (solenoids) experience another electrical condition called inductive "Kick". Once power is removed from an inductor, it will produce a negative spike or Kick as it discharges. This kick comes from the magnetic field produced while the inductor is powered. The following diagram shows an inductive kick from a solenoid.





This inductive kick can induce noise into other sensitive circuits. One of the methods employed to reduce this noise is to install a diode at the coil. The diode will conduct due to the inductive kick energy and the diode and coil will become a circuit. The inductive kick energy will be dissipated in the resistance of the coil as heat. The diagram below shows this circuit.



Device Resistances

Listed below is a table of typical resistance values found for various devices used on off road equipment.

Device	Resistance
Solenoid Valve	30 – 50 Ω
Pump Motor	
Engine Starter Motor	
Hella DC Relay	75 – 100 Ω

SECTION 2
DIGITAL MULTIMETER

What is a digital multimeter ?

There are two basic types of multimeters, analog and digital.
A multimeter is the combination of a voltmeter, ammeter and ohmeter. A digital multimeter uses an LED or LCD display. The analog meter uses a meter scale as the display device. Some multimeters also measure frequency, duty cycle and capacitance.

This text will focus on digital multimeters. They are available in two varieties, manual and auto ranging. The manual multimeter requires the user select the measurement range using the selector switch. The auto ranging multimeter automatically selects the range.

What are some of the features of a digital multimeter ?

The basic digital multimeter has a selector switch used to select the type of measurement desired and the maximum range of that measurement. The more advanced meters have and auto range feature. With this meter, the type of measurement is selected and the meter automatically set the range for the measurement.

The Fluke 80 series meters are an example of an auto ranging multimeter. A picture of the model 80 appears in the following pages. Also shown is an example of a manual multimeter. The user must select the measurement range for the manual multimeter.

Analog Voltmeters

The digital multimeter has all but taken the market from the analog multimeter. There are many more models of digital multimeters with more features than those of analog meters. Analog multimeters can be used to make measurements and perform troubleshooting described in this text. If an analog meter is to be used, it should be one of the high quality units such as a Simpson 260, Triplette 610 or Triplette 310. These multimeters have higher accuracy units available and have higher input impedances, which will lower circuit loading during measurements.

The Test Light

The coventional test light used for many years as the measurement tool is not suited for testing the type of circuits and components described in this text. Measurements such as voltage drops and resistance checks are crucial in electronics equipment and the test light cannot accommodate these measurements.

How is DC voltage measured ?

Refer to the picture below. The selector switch is set to the "V" selection with the straight bar over the "V". This refers to the constant voltage or DC volts position. The black test lead plugs into the "COM" jack and the red lead into the "V Ω" jack. The meter will read DC volts values from 0 to 1000 volts.

Fluke 87 Configured For DC Volts

The manual multimeter is configured as shown to read DC volts:

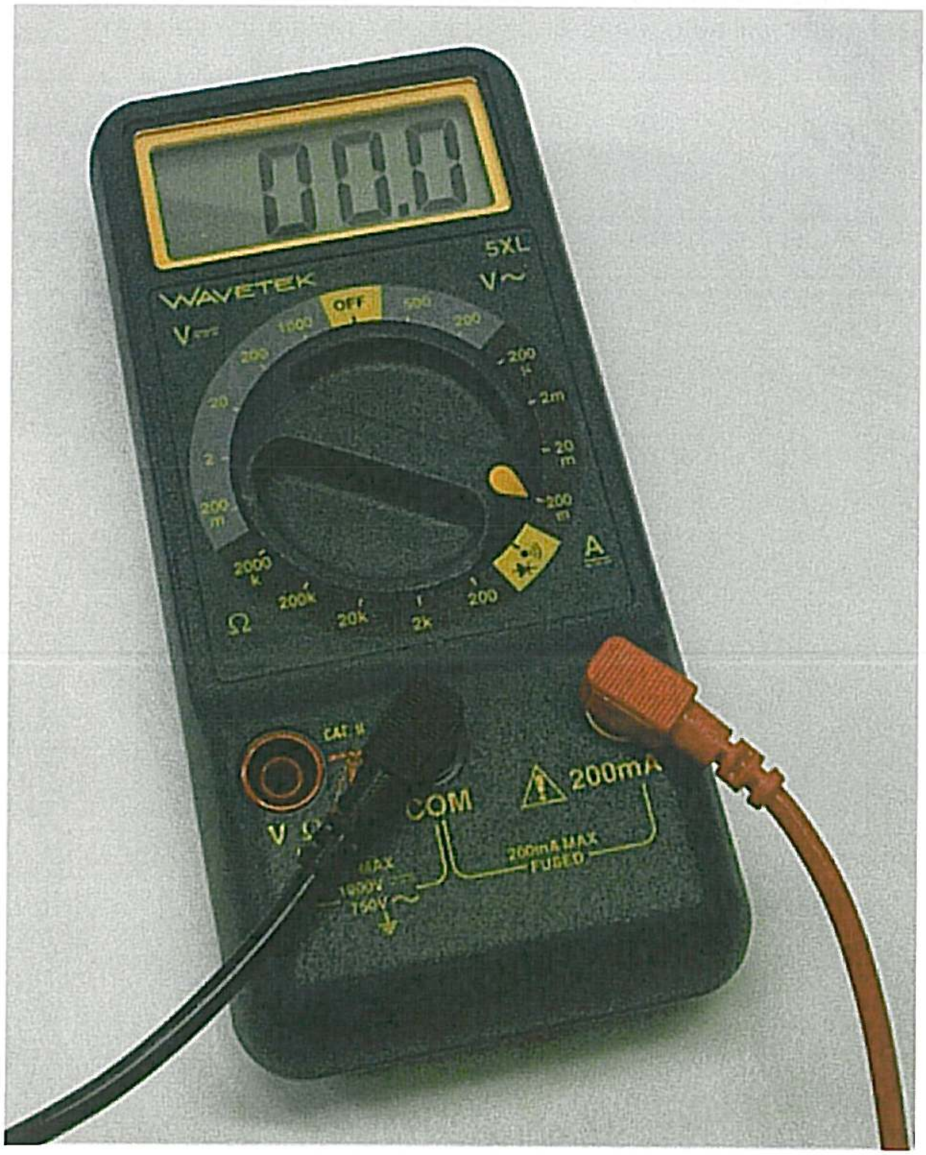
How is current measured ?

Refer to the picture below. The selector switch is set to the "mA μA "or "A" selection, depending on the range of the current to be measured. The black test lead is plugged into the "COM" jack and the red lead is plugged into the "ma μa" or "A" jack.

If the current to be measured is unknown, start with the red lead plugged into the "A" jack. If the current is small, it can be moved to the "ma μa" jack for better resolution. The maximum current the meter can read is 10 amps.

Fluke 87 Configured For Amps

The manual multimeter is configured as shown to read milliamps.



How is resistance measured ?

Refer to the picture below. The selector switch is set to the "Ω" position. The black test lead is plugged into the "COM" jack and the red test lead is plugged into the "VΩ" jack. Place the test probes across the connections of the device to be measured. The meter will auto range and display the resistance value in ohms.

Fluke 87 Configured For Resistance

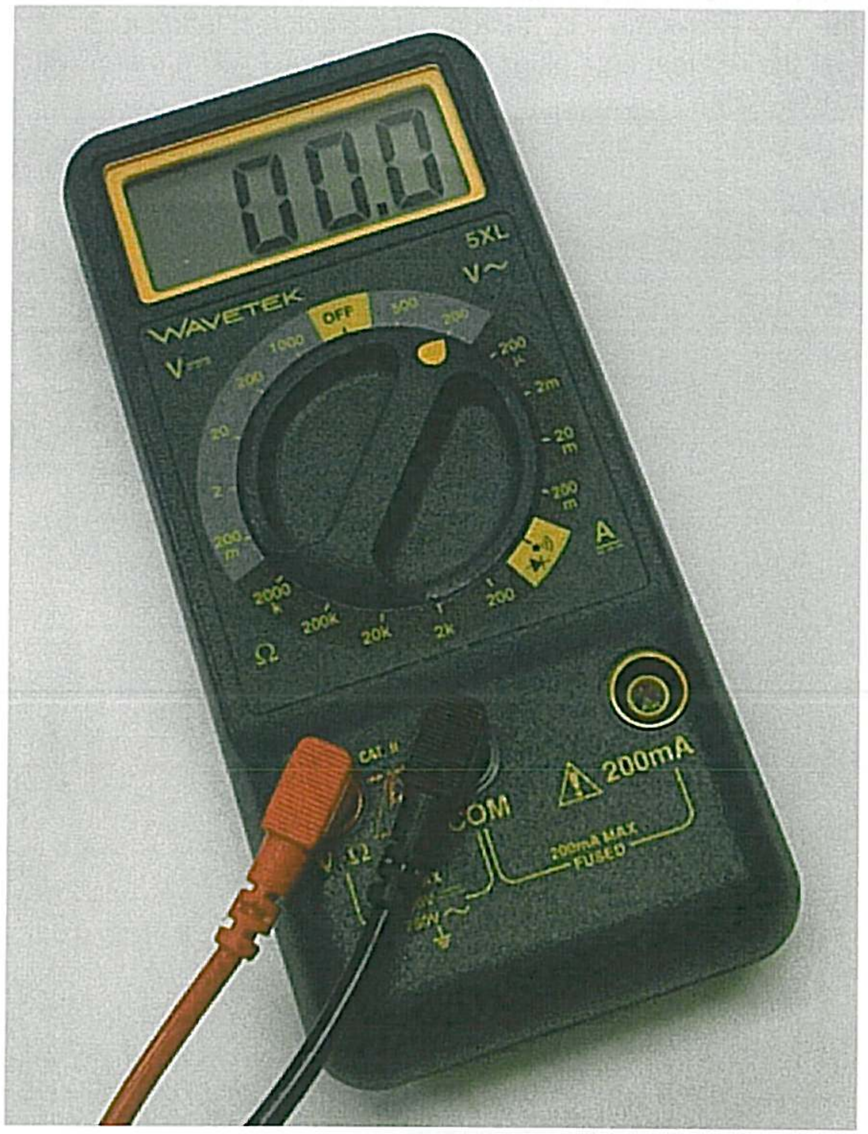
The manual multimeter is configured as shown to read resistance.

How is AC voltage measured ?

Refer to the picture below. The selector switch is set to the "V" selection with the sine waveform over the "V". This refers to the frequency nature of AC voltage vs constant DC voltage. The black test lead plugs into the "COM" jack and the red lead into the "VΩ" jack. The meter will measure true rms AC voltage to 1000 V.

Fluke 87 Configured For AC Volts

The manual multimeter is configured as shown to read AC volts.



How is frequency measured ?

Refer to the picture below. The selector switch is set to the "V" selection with the sine waveform over the "V". Press the "HZ" button. The black test lead plugs into the "COM" jack and the red test lead plugs into the "VΩ" jack. The meter will display frequencies to 250 KHz.

Fluke 87 Configured For Frequency

How is duty cycle measured ?

Refer to the picture below. Setup the meter to measure frequency. Press the "HZ" button an additional time and the "%" symbol should show on the display. The meter will now show the duty cycle of a waveform.

Fluke 87 Configured For Duty Cycle

How is a diode tested ?

Refer to the picture below. The selector switch is set to the “ ▸ ” (diode symbol) position. The black test lead is plugged into the “COM” jack and the red test lead is plugged into the “VΩ” jack. To read the forward bias, place the red test lead on the anode or + of the diode and the negative test lead on the cathode or – of the diode. The meter should read 0.5 to 0.8 volts for a good device.

Fluke 87 Configured For Diode Test

The manual multimeter is configured as shown for diode test.

How is continuity measured ?

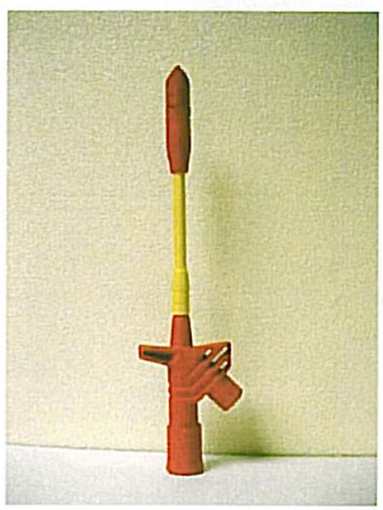
Refer to the picture below. The selector switch is set to the "Ω" position. The black test lead is plugged into the "COM" jack and the red test lead is plugged into the "VΩ" jack. Touching the probes together should produce a beep. If not, press the button labeled "PEAK MIN MAX". This button is used to turn the beeper on / off. The meter will beep when the test leads are placed on a complete path for current flow.

The manual multimeter is configured for continuity test.

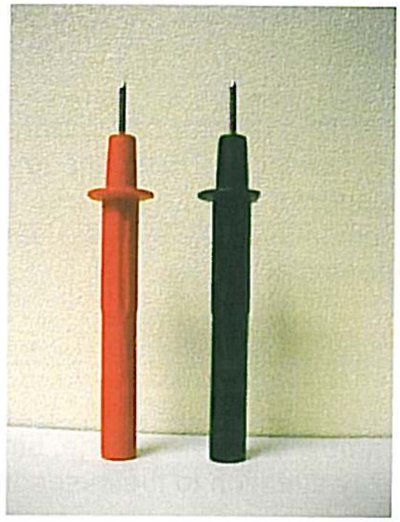
Special test leads

The following test probes are available to make connections to various devices easier. These are available as accessories to the standard product.

Model AC-20 Alligator Clips



Model AC89 Wire Piercing Probe



Model TP20 Needle Probes

MEASURING VOLTAGE, RESISTANCE, FREQUENCY AND DUTY CYCLE

General Measuring Guidelines:

Since the electrical system uses sealed connectors and splices, access of test points can be difficult. It is recommended that a test probe kit be used to access the signals to prevent damage to wires and connectors. Back probing connectors and poking holes in the wire insulation can cause damage that will cause future failures.

Measuring Voltage:

A digital voltmeter is recommended to make measurements. Voltage measurements are made by connecting the RED + lead to the desired signal and the BLACK – lead to the common. The test lead connections must be secure or incorrect readings will result. Use circuit common for the BLACK – lead, not chassis ground or other metal connection.

Measuring Resistance:

Extra care must be taken when making resistance measurements. Test probe connections are crucial to correct readings. Ensure the test probe makes a solid connection with the wire(s) or connector pin(s) under test. The test probe kit may help with these types of measurements. Make sure system power is turned OFF while making resistance measurements.

Measuring Frequency:

Frequency is measured in the same manner as voltage, but the meter is set to the “HZ” or equivalent setting. Pay attention to the meter display to see if it is showing “HZ” or “KHZ”.

Measuring Duty Cycle:

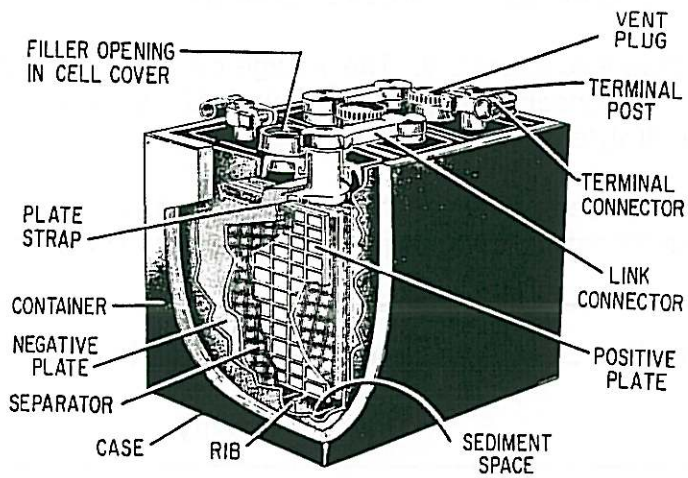
Duty cycle is measured in the same manner as voltage, but the meter is set to the “%” or equivalent setting. Duty cycle will de displayed as a percent such as 10%, 45.8%, 90%,etc.

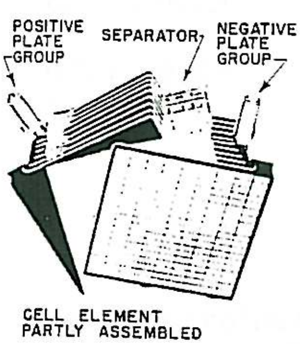
SECTION 3
BATTERIES

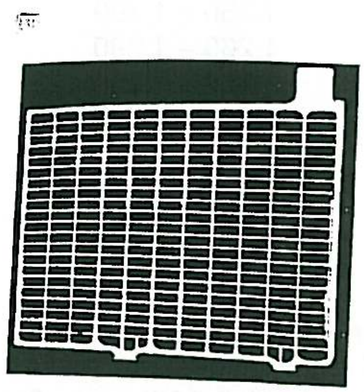
What are some of the basic battery types ?

Some basic battery types are lead acid, dry cell, nickel cadmium, lithium ion and gel cell. The most common battery type in portable off road equipment is lead acid. There are several types of lead acid batteries for specific uses. There are batteries for propulsion, for secondary power and for emergency systems. This section will focus on the SLI or automotive type batteries.

The following picture shows a cutaway of a typical lead acid battery, identifying the components. Also show is how the battery plates are assembled and a picture of a plate structure.







Lead Acid Battery Description

The lead acid battery uses lead dioxide as the active material for the positive electrode and metallic lead as the negative active material. The electrolyte is a sulfuric acid solution, about 1.28 specific gravity or 37% acid by weight in a fully charged condition. The positive active material, which is formed electrochemically from the cured plate, is a major factor influencing the performance and life of the battery. In general, the negative, or lead electrode controls cold temperature performance such as engine starting.

As the battery discharges, both the positive and negative electrodes are converted to lead sulfate. The process reverses on charging. As a cell discharges, the voltage decreases due to depletion of material, internal resistance losses and polarization. If the discharge current is constant, the voltage under load decreases smoothly to the cutoff voltage and the specific gravity decreases in proportion to the ampere-hours discharged.

The nominal voltage of the lead acid cell is 2 V. The voltage on open circuit is a direct function of the electrolyte concentration, ranging from 2.125 V for a cell with 1.28 specific gravity electrolyte to 2.05 V with 1.21 specific gravity.

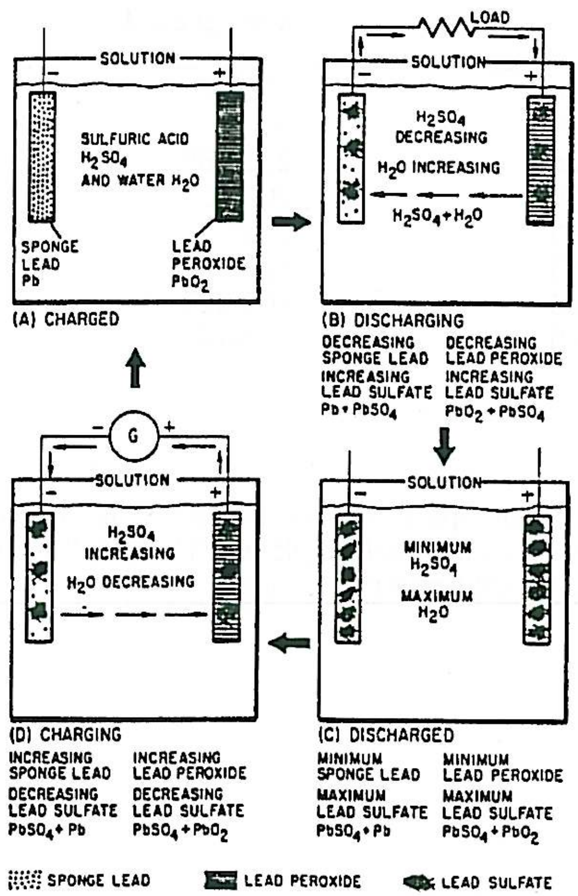
The selection of specific gravity used for the electrolyte depends on the application and service requirements. The Table below shows some specific gravity requirements.

Electrolyte Specific Gravity at Full Charge at 25° C

	Specific Gravity	
Battery type	**Temperate climates**	**Tropical Climates**
SLI (automotive)	1.260 – 1.290	1.210 – 1.230
Heavy Duty	1.260 – 1.290	1.210 – 1.240
Golf Cart	1.260 – 1.290	1.240 – 1.260
Traction	1.275 – 1.325	1.240 – 1.275
Diesel Starting (railroad)	1.250	

The electrolyte concentration must be high enough for good ionic conductivity and to fulfill electrochemical requirements, but not so high as to cause separator deterioration or corrosion of other parts of the cell. During discharge, the specific gravity decreases in proportion to the ampere-hours discharged. The specific gravity is thus a means for checking the state of charge of the battery.

Below is a picture showing how the battery chemistry changes from charged to discharged and then back to charged.



Battery Sizes

Battery are sized according to Cold Cranking Amps, **CCA**, and reserve capacity, **RC**. CCA determines the capability of the battery to deliver power to crank an engine at cold temperatures. The cranking test rating is the current that a fully charged battery can deliver at –17.8° C (1.4° F) for 30 seconds at a voltage of 1.2 V per cell.

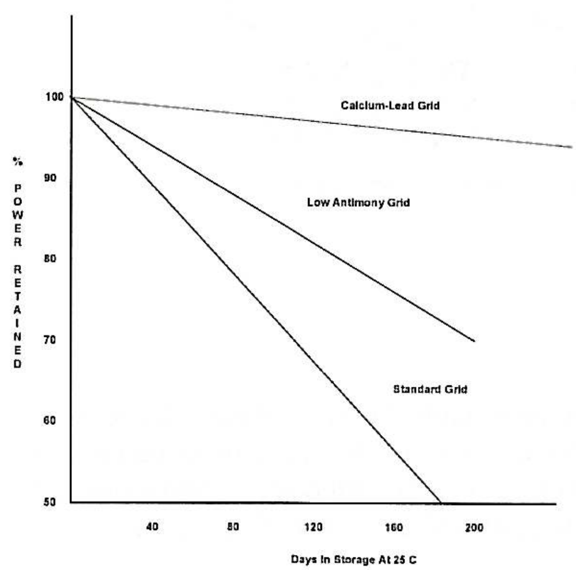
The RC is the number of minutes the battery can deliver 25 amps until a cell voltage of 1.75 V is reached at 25° C (77° F). This is a test of the battery's capability to provide power for lights and auxiliaries. The Table below list some common batteries used in off road equipment.

Heavy Duty Commercial Batteries

BCI Group Number	Cold Amps @ 0°F	Reserve Capacity Min @ 80° F
4D	490-950	225-325
6D	750	310
8D	850-1250	235-465
28	400-535	80-135
29H	525-840	145
30H	380-685	120-150
31	455-950	100-200
27	270-700	102-140

Battery Self Discharge

A lead acid battery losses charge during open circuit conditions. The amount depends on the type of material used on the positive plates. The graph below shows the discharge rate for the different types of materials.



Self discharge is temperature dependent and can be minimized by storing batteries in cool areas between 5° C (41° F) and 15° C (59° F)

The life of lead acid batteries is affected by the design, the processing and the operational environment. The average age of returned batteries in 1982 was 34 months. Improvements have been made in materials and processes to extend battery life. A higher incidence of short - circuited batteries used in warmer climates suggests that grid corrosion is still a major failure mode. The "worn out" category includes low electrolyte level, and it should be noted that many maintenance free batteries are sealed so that water, lost to evaporation and electrolysis cannot be replaced.

By far, 80%, ***plate sulfation*** is the major cause of battery failure. Batteries are removed from service due to this condition which can be corrected using a pulse technique to remove the sulfate from the plates and put it back into the electrolyte solution.

SLI (automotive) batteries are not designed for deep-cycling service, and very short lives are generally obtained with such operation. SLI batteries are designed for starting service, to deliver high currents for a short cycle. Deep cycle batteries are not suitable for starting service as their plate size and number are designed for long periods of use with high current loads.

Lead Acid Battery Charging

A lead acid battery can generally be charged at any rate that does not produce excessive gassing, overcharging, or high temperatures. Proper charging is important to obtain optimum life from any lead acid battery under any conditions of use. In the charging process, DC electric power is used to reform the active chemicals of the battery system to their high-energy charge state. This involves the conversion of lead sulfate in the positive electrodes to lead oxide, and the conversion of lead sulfate of the negative electrode to metallic lead, and the restoration of the electrolyte from a low-concentration sulfuric acid to a higher concentration of approximately 1.28 specific gravity.

Some rules of charging are:

1. The charge current at the start of recharge can be any value that does not produce average cell voltage greater than the gassing voltage of 2.4 per cell.

2. During recharge, the current should be controlled to maintain a voltage below the gassing voltage.

3. When 100% of the discharged capacity has been returned under this voltage control, the charge rate will have normally decayed to the charge finishing

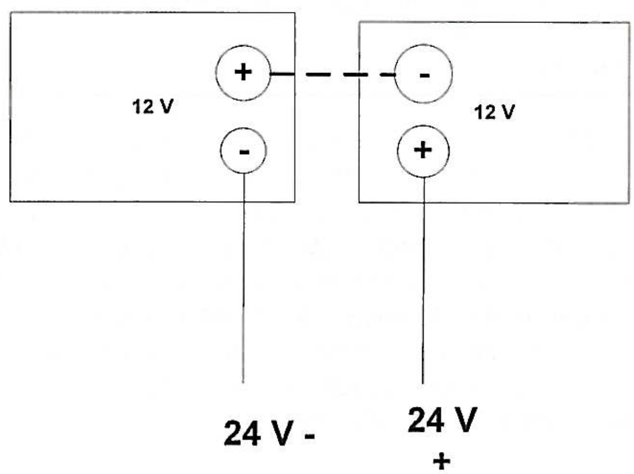
rate. The charge should be finished at a constant current no higher than this rate, normally 5 amps per 100 amp-hour of rated capacity.

Testing Lead Acid Batteries

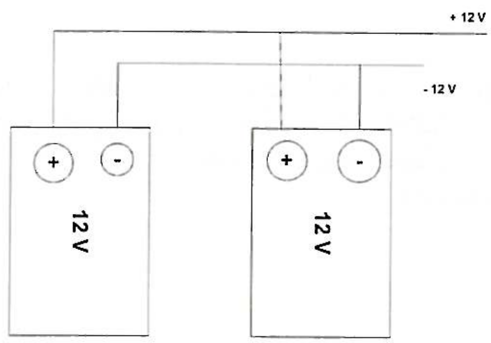
There are two basic test instruments used for testing, the hydrometer and a voltmeter. The hydrometer will measure the specific gravity of the electrolyte, giving an indication of the state of charge. The voltmeter (multimeter) can be used to read the terminal voltage, giving an indication of the state of charge.

Battery Configurations

Batteries are sometimes used in multi-unit configurations. They are connected in either series or parallel to meet the specific power requirement. In off road equipment the series connection of two 12 volt batteries is used to achieve a 24 volt system. The CCA capacity of these batteries is the same as that of one of the batteries. The CCA capacity remains the same but the voltage doubles.



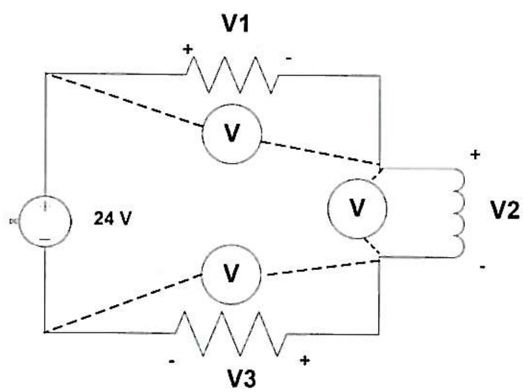
Batteries can be connected in parallel for higher current delivery.



The voltage available is 12 volts, but the current capacity is twice that for a single battery. The CCA is now twice what it is for one battery.

Battery Connections

Battery connections are extremely important in order for the starting system to function properly. The resistance of these connections should be very low, approximately .001 ohms. This also applies to the connections at the starter motor. The diagram below shows how these connections can be tested.



The inductor represents the engine starter motor. The resistors represent the resistance in the B+ and B- battery cables. Measuring V1 and V3 and knowing the current draw during engine cranking will allow these resistance to be

calculated. For example: V1 and V3 are 1.0 volts, starting current is 1000 amps.
Using ohm's law: R = V / I

= 1 / 1000

= .001 ohms.

Most engine manufacturers prefer V1 and V3 to be no more than 1 volt. This will ensure the resistance of the connections is low. The basic digital multimeter cannot accurately measure small resistances. That is why a voltage drop is measured and the resistance calculated.

SECTION 4
SCHEMATIC DIAGRAMS

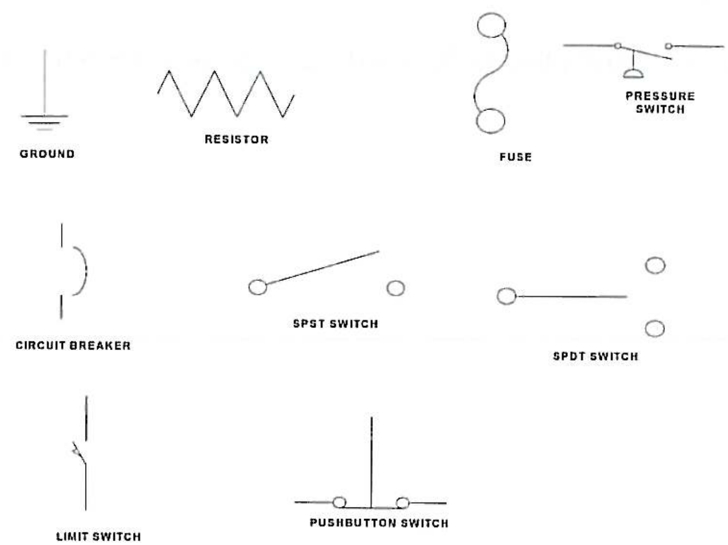
What is a schematic diagram ?

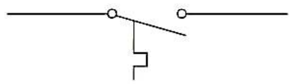
A schematic diagram is a graphical method of presenting a circuit layout. It uses standard symbols to represent various circuit elements and shows how these elements are interconnected.

Schematic diagrams are also used for other layouts such as plumbing, duct systems and room layouts.

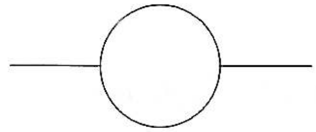
What are some of the schematic symbols ?

The following are typical electrical schematic symbols:





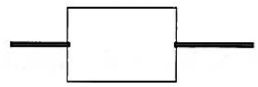
TEMPERATURE SWITCH



RELAY COIL

RELAY CONTACTS

RELAY COIL



RELAY COIL

The following pages are from the ANSI standard for schematic symbols.

ANSI Y32.2-1975
CSA Z99-1975
IEEE Std 315-1975

Revision of
ANSI Y32.2-1972
CSA Z99-1972
IEEE Std 315-1971

American National Standard
Canadian Standard
IEEE Standard

Graphic Symbols for Electrical and Electronics Diagrams
(Including Reference Designation Letters)

Sponsor
IEEE Standards Coordinating Committee 11, Graphic Symbols

Secretariat for American National Standards Committee Y32
American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers

Approved October 31, 1975
American National Standards Institute

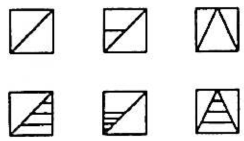
Approved October 9, 1975
Canadian Standards Association

Approved September 4, 1975
Institute of Electrical and Electronics Engineers

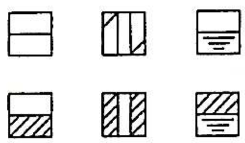
Adopted for Mandatory Use October 31, 1975
Department of Defense, United States of America

Quick Reference to Symbols

21.2 Hydroelectric generating station



21.3 Thermoelectric generating station



21.4 Prime mover

21.5 Substation

22. Class Designation Letters

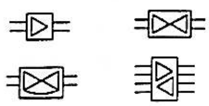
A	DS	J	PU	TP
AR	E	K	Q	TR
AT	EQ	L	R	U
B	F	LS	RE	V
BT	FL	M	RT	VR
C	G	MG	RV	W
CB	H	MK	S	WT
CP	HP	MP	SQ	X
CR	HR	MT	SR	Y
D	HS	N	T	Z
DC	HT	P	TB	
DL	HY	PS	TC	

17

Quick Reference to Symbols

16.3 Rectifier

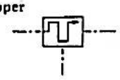
16.4 Repeater



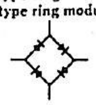
16.5 Network

16.6 Phase Shifter
Phase-Changing Network

16.7 Chopper



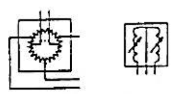
16.8 Diode-type ring demodulator
Diode-type ring modulator



16.9 Gyro
Gyroscope
Gyrocompass

16.10 Position Indicator

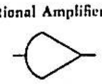
16.11 Position Transmitter



16.12 Fire Extinguisher Actuator Head

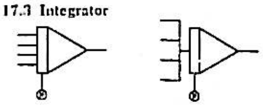
17. Analog Functions

17.1 Operational Amplifier



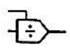
17.2 Summing Amplifier

17.3 Integrator

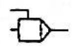


17.4 Electronic Multiplier

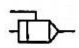
17.5 Electronic Divider



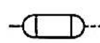
17.6 Electronic Function Generator



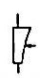
17.7 Generalized Integrator



17.8 Positional Servo-mechanism



17.9 Function Potentiometer

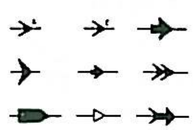


18. Digital Logic Functions

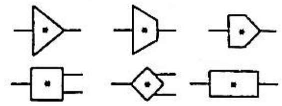
18.1 Digital Logic Functions
(See cross references)

19. Special Purpose Maintenance Diagrams

19.1 Data flow code signals

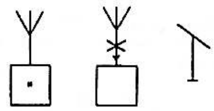


19.2 Functional Circuits

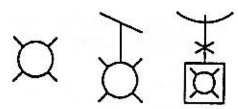


20. System Diagrams, Maps and Charts

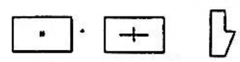
20.1 Radio station



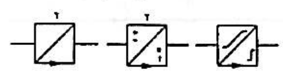
20.2 Space station



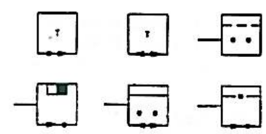
20.3 Exchange equipment



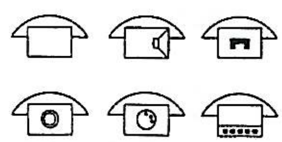
20.4 Telegraph repeater



20.5 Telegraph equipment

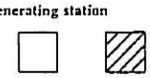


20.6 Telephone set



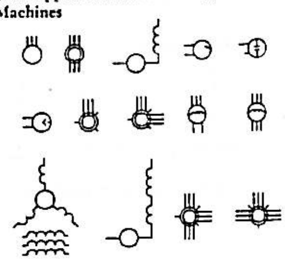
21. System Diagrams, Maps and Charts

21.1 Generating station

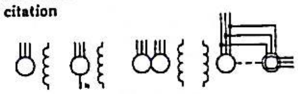


Quick Reference to Symbols

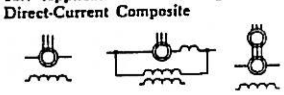
13.5 Applications: Alternating-Current Machines



13.6 Applications: Alternating-Current Machines with Direct-Current Field Excitation



13.7 Applications: Alternating- and Direct-Current Composite

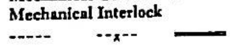


13.8 Synchro

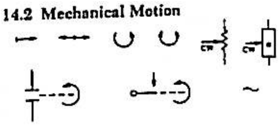
CDX TDX
CT TR
CX TX
TDR RS

14. Mechanical Functions

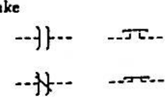
14.1 Mechanical Connection
Mechanical Interlock



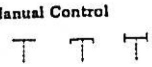
14.2 Mechanical Motion



14.3 Clutch
Brake

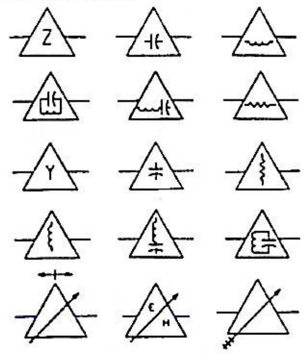


14.4 Manual Control

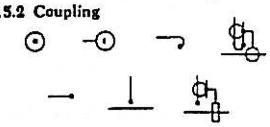


15. Commonly Used in Connection with VHF, UHF, SHF Circuits

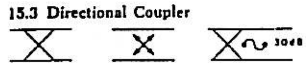
15.1 Discontinuity



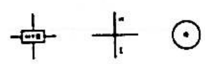
15.2 Coupling



15.3 Directional Coupler

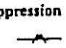


15.4 Hybrid
Directionally Selective Transmission Devices

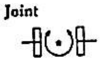


15.5 Mode Transducer

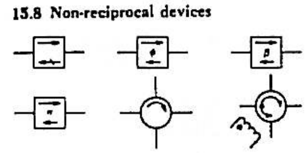
15.6 Mode Suppression



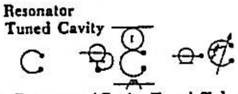
15.7 Rotary Joint



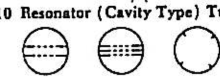
15.8 Non-reciprocal devices



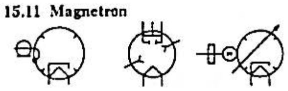
15.9 Resonator
Tuned Cavity



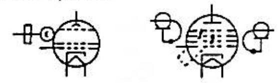
15.10 Resonator (Cavity Type) Tube



15.11 Magnetron

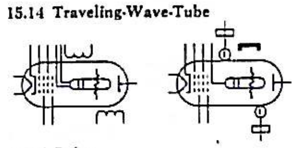


15.12 Velocity-Modulation (Velocity-Variation) Tube

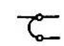


15.13 Transmit-Receive (TR) Tube

15.14 Traveling-Wave-Tube



15.15 Balun

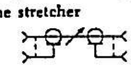


15.16 Filter

15.17 Phase shifter

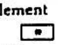
15.18 Ferrite bead rings

15.19 Line stretcher



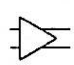
16. Composite Assemblies

16.1 Circuit assembly
Circuit subassembly
Circuit element

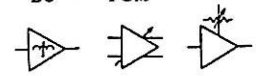


EQ FL-BP RG TPR
FAX FL-HP RU TTY
FL FL-LP DIAL CLK
FL-BE PS TEL IND
ST-INV

16.2 Amplifier



BDG EXP PRE
BST LIM PWR
CMP MON TRQ
DC PGM



15

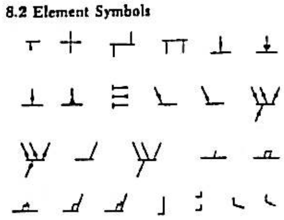
Quick Reference to Symbols

7.7 Nuclear-Radiation Detector
Ionization Chamber
Proportional Counter Tube
Geiger-Müller Counter Tube

8. Semiconductor Devices

8.1 Semiconductor Device
Transistor
Diode

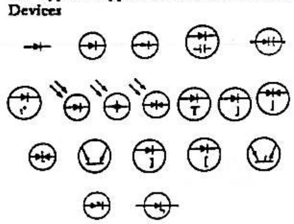
8.2 Element Symbols



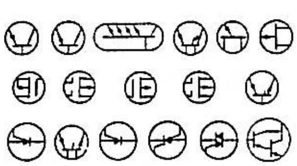
8.3 Special Property Indicators

8.4 Rules for Drawing Style 1 Symbols

8.5 Typical Applications: Two-Terminal Devices

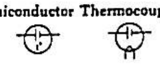


8.6 Typical Applications: Three- (or More) Terminal Devices

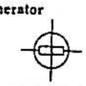


8.7 Photosensitive Cell

8.8 Semiconductor Thermocouple



8.9 Hall Element
Hall Generator

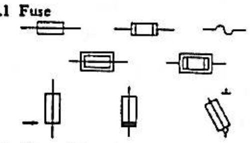


8.10 Photon-coupled isolator

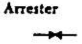
8.11 Solid-state-thyratron

9. Circuit Protectors

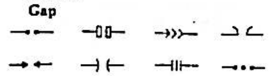
9.1 Fuse



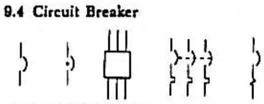
9.2 Current Arrester



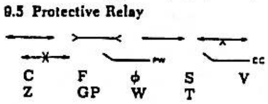
9.3 Lightning Arrester
Arrester
Gap



9.4 Circuit Breaker

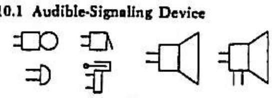


9.5 Protective Relay

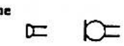


10. Acoustic Devices

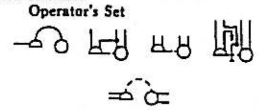
10.1 Audible-Signaling Device



10.2 Microphone



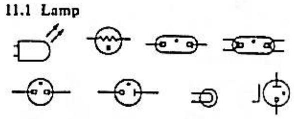
10.3 Handset
Operator's Set



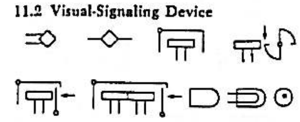
10.4 Telephone Receiver
Earphone
Hearing-Aid Receivers

11. Lamps and Visual-Signaling Devices

11.1 Lamp



11.2 Visual-Signaling Device

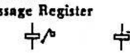


12. Readout Devices

12.1 Meter
Instrument

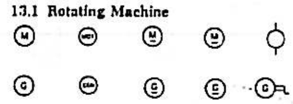
A	DB	I	OP	RF	VA
AH	DBM	INT	OSCG	SY	VAR
C	DM	μA	PH	TLM	VARH
CMA	DTR	UA	PI	t°	VI
CMC	F	MA	PF	THC	VU
CMV	G	NM	RD	TT	W
CRO	GD	OHM	REC	V	WH

12.2 Electromagnetically Operated
Counter
Message Register

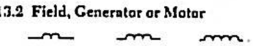


13. Rotating Machinery

13.1 Rotating Machine

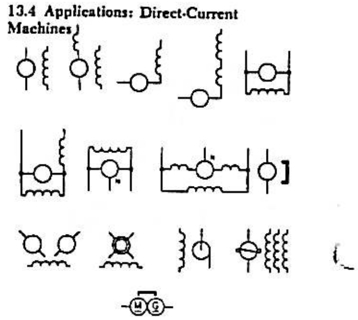


13.2 Field, Generator or Motor



13.3 Winding Connection Symbols

13.4 Applications: Direct-Current Machines



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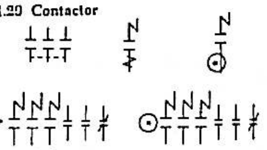
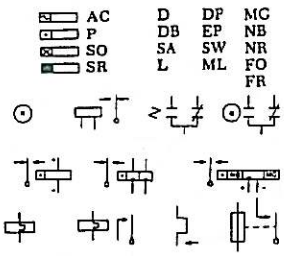
Quick Reference to Symbols

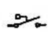
4.29 Contactor



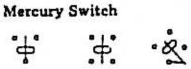
4.30 Relay



4.31 Inertia Switch



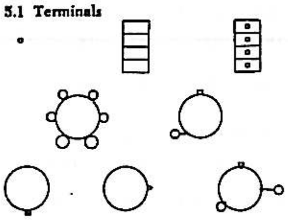
4.32 Mercury Switch



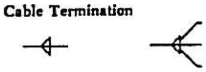
4.33 Aneroid Capsule

5. Terminals and Connectors

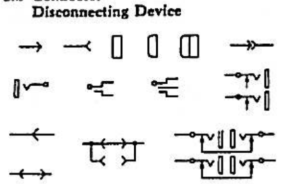
5.1 Terminals



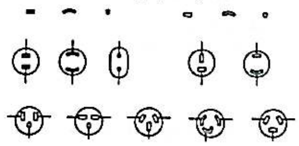
5.2 Cable Termination



5.3 Connector
Disconnecting Device

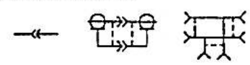


5.4 Connectors of the Type Commonly Used for Power-Supply Purposes



5.5 Test Blocks

5.6 Coaxial Connector

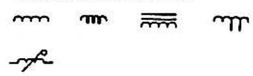


5.7 Waveguide Flanges
Waveguide junction

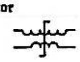
6. Transformers, Inductors, and Windings

6.1 Core

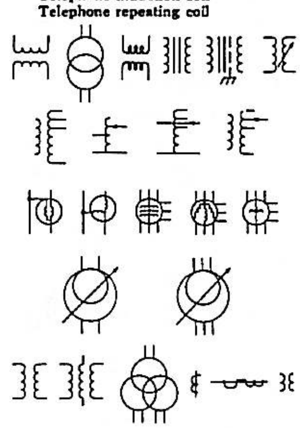
6.2 Inductor
Winding
Reactor
Radio frequency coil
Telephone retardation coil



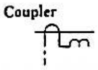
6.3 Transductor



6.4 Transformer
Telephone induction coil
Telephone repeating coil

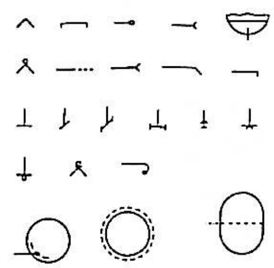


6.5 Linear Coupler



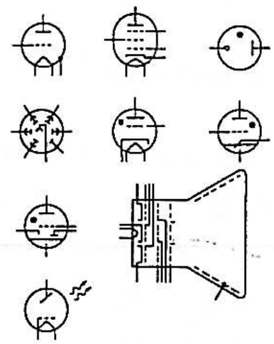
7. Electron Tubes and Related Devices

7.1 Electron Tube

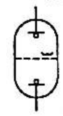


7.2 General Notes

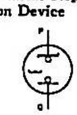
7.3 Typical Applications



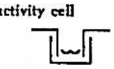
7.4 Solion
Ion-Diffusion Device



7.5 Coulomb Accumulator
Electrochemical Step-Function Device

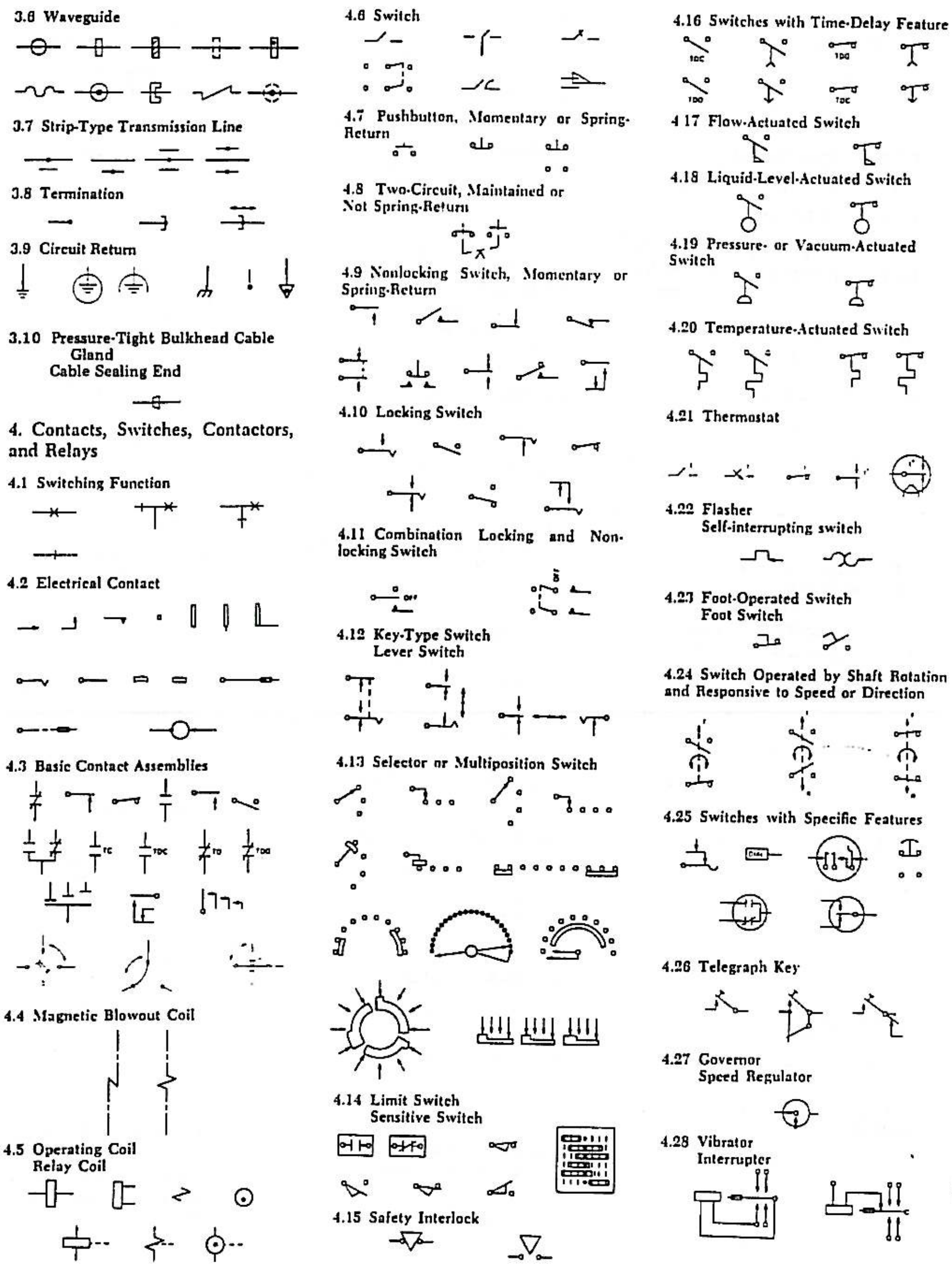


7.6 Conductivity cell



13

Quick Reference to Symbols

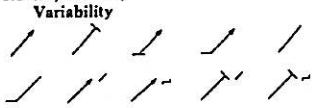


12

Quick Reference to Symbols

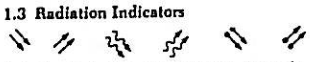
1. Qualifying Symbols

1.1 Adjustability
Variability

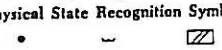


1.2 Special-Property Indicators

1.3 Radiation Indicators

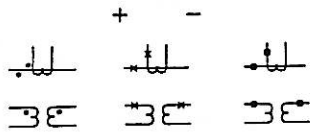


1.4 Physical State Recognition Symbols

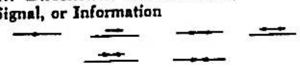


1.5 Test-Point Recognition Symbol

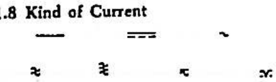
1.6 Polarity Markings



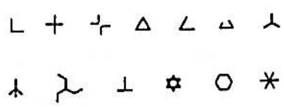
1.7 Direction of Flow of Power, Signal, or Information



1.8 Kind of Current



1.9 Connection Symbols



1.10 Envelope
Enclosure

1.11 Shield
Shielding

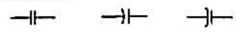
1.12 Special Connector or Cable Indicator

1.13 Electret

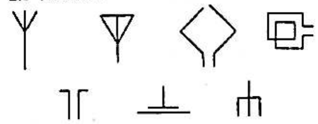
2. Fundamental Items

2.1 Resistor

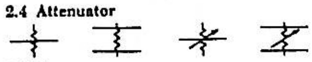
2.2 Capacitor



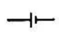
2.3 Antenna



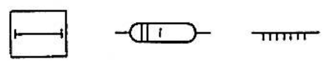
2.4 Attenuator



2.5 Battery



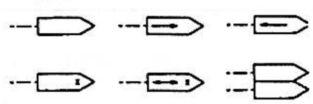
2.6 Delay Function
Delay Line
Slow-Wave Structure



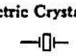
2.7 Oscillator
Generalized Alternating-Current Source

2.8 Permanent Magnet

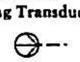
2.9 Pickup
Head



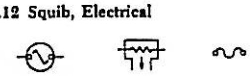
2.10 Piezoelectric Crystal Unit



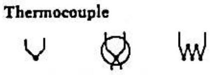
2.11 Primary Detector
Measuring Transducer



2.12 Squib, Electrical



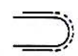
2.13 Thermocouple



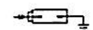
2.14 Thermal Element
Thermomechanical Transducer

2.15 Spark gap
Igniter gap

2.16 Continuous Loop Fire Detector (temperature sensor)

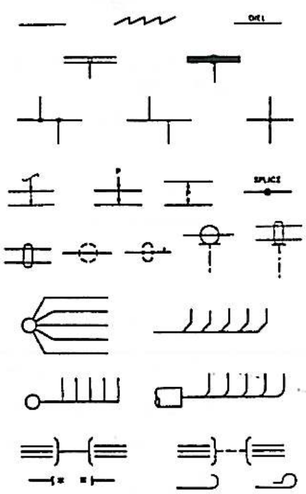


2.17 Ignitor Plug



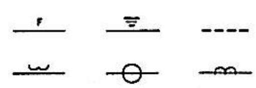
3. Transmission Path

3.1 Transmission Path
Conductor
Cable
Wiring



3.2 Distribution lines
Transmission lines

F S T V



3.3 Alternative or Conditioned Wiring

3.4 Associated or Future

3.5 Intentional Isolation of Direct-Current Path in Coaxial or Waveguide Applications

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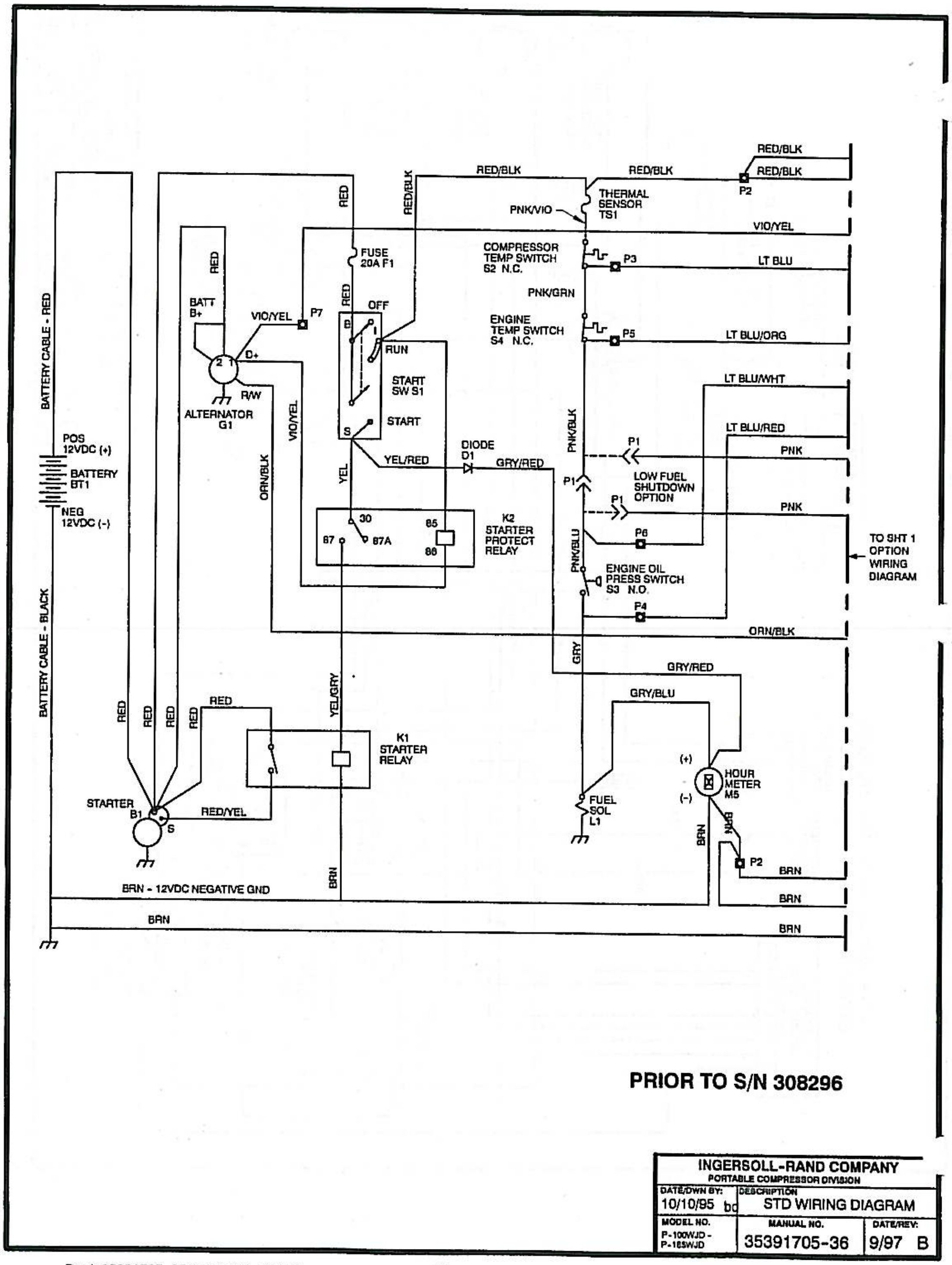
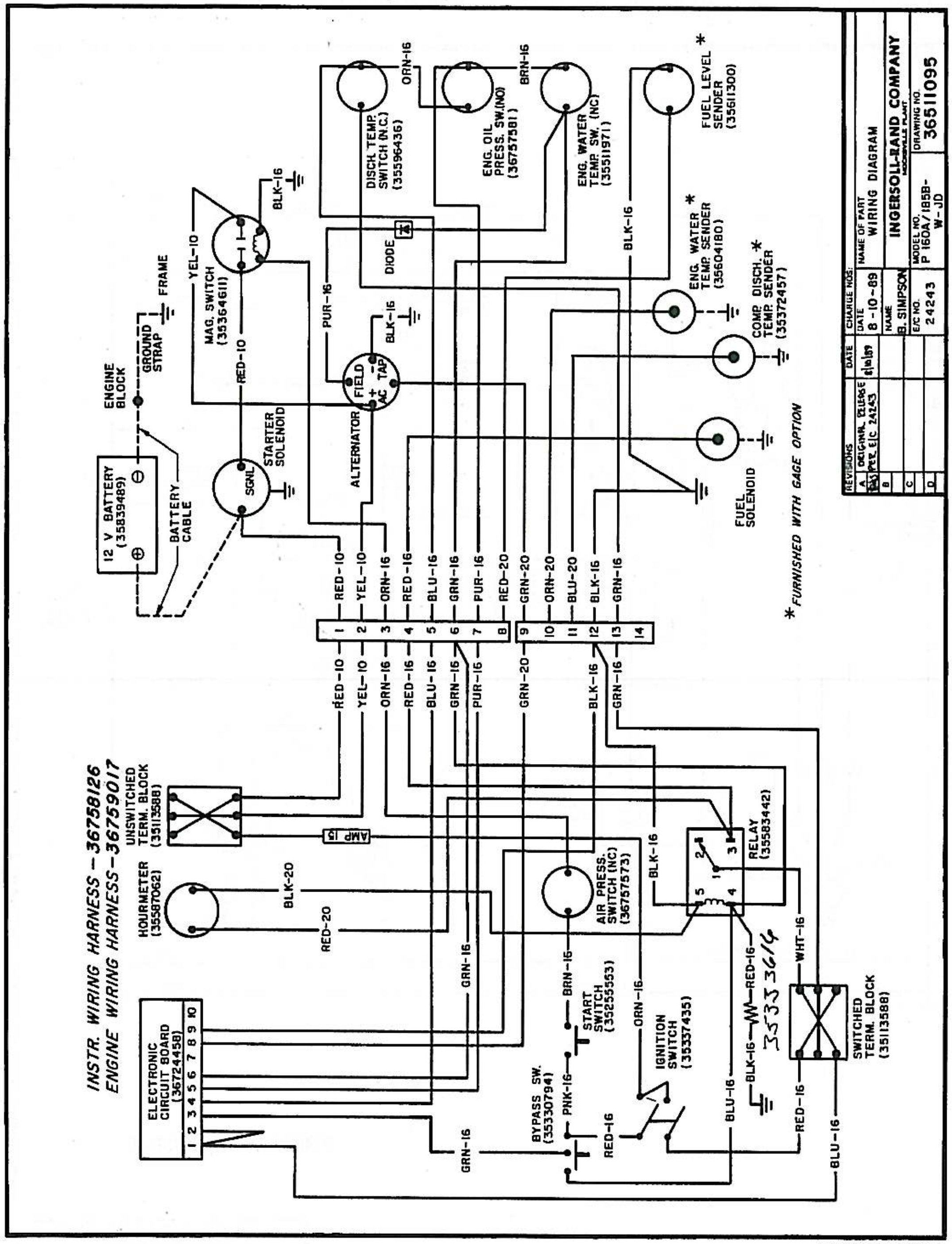
The following page shows a typical schematic from a portable air compressor. This schematic is for an electrical system only machine, no electronics.



This is another example of a portable air compressor schematic.

Parts List — 9-28



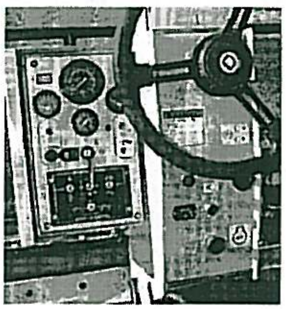
35374602 V.5 E/C 24243

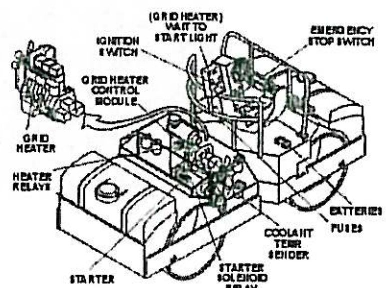
Following are two schematics from a DD110 and DD190 compactors.

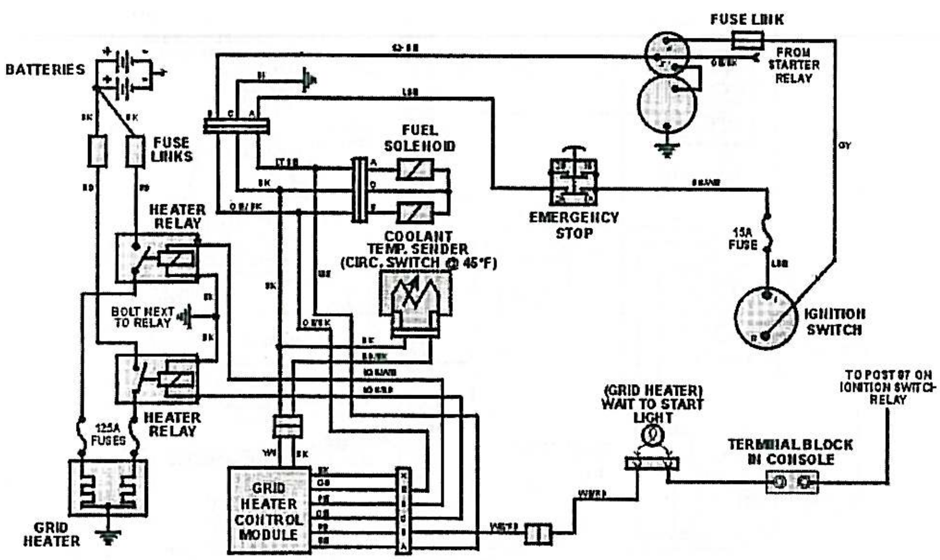
DD-110/110HF Electrical System
Cummins Elite Engine
effective with serial number 150303

Wire Color Code Reference Chart

Notes







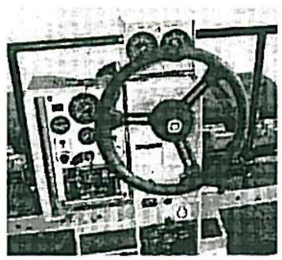
DD-90/90HF Electrical System
Starter/Alternator Circuit

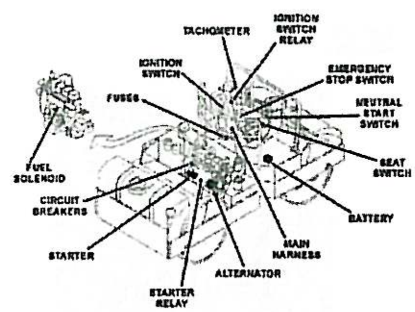
effective with serial number 149027

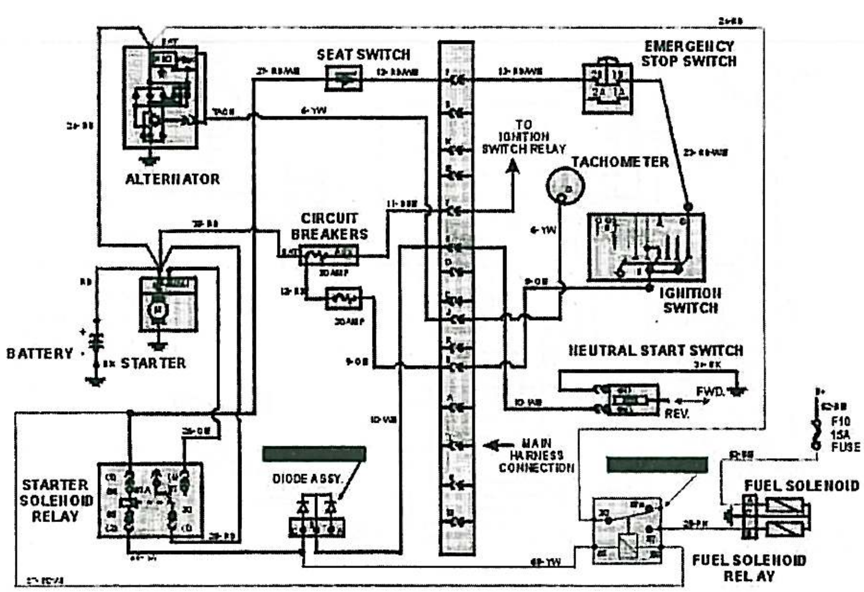
Wire Color Code Reference Chart

Notes

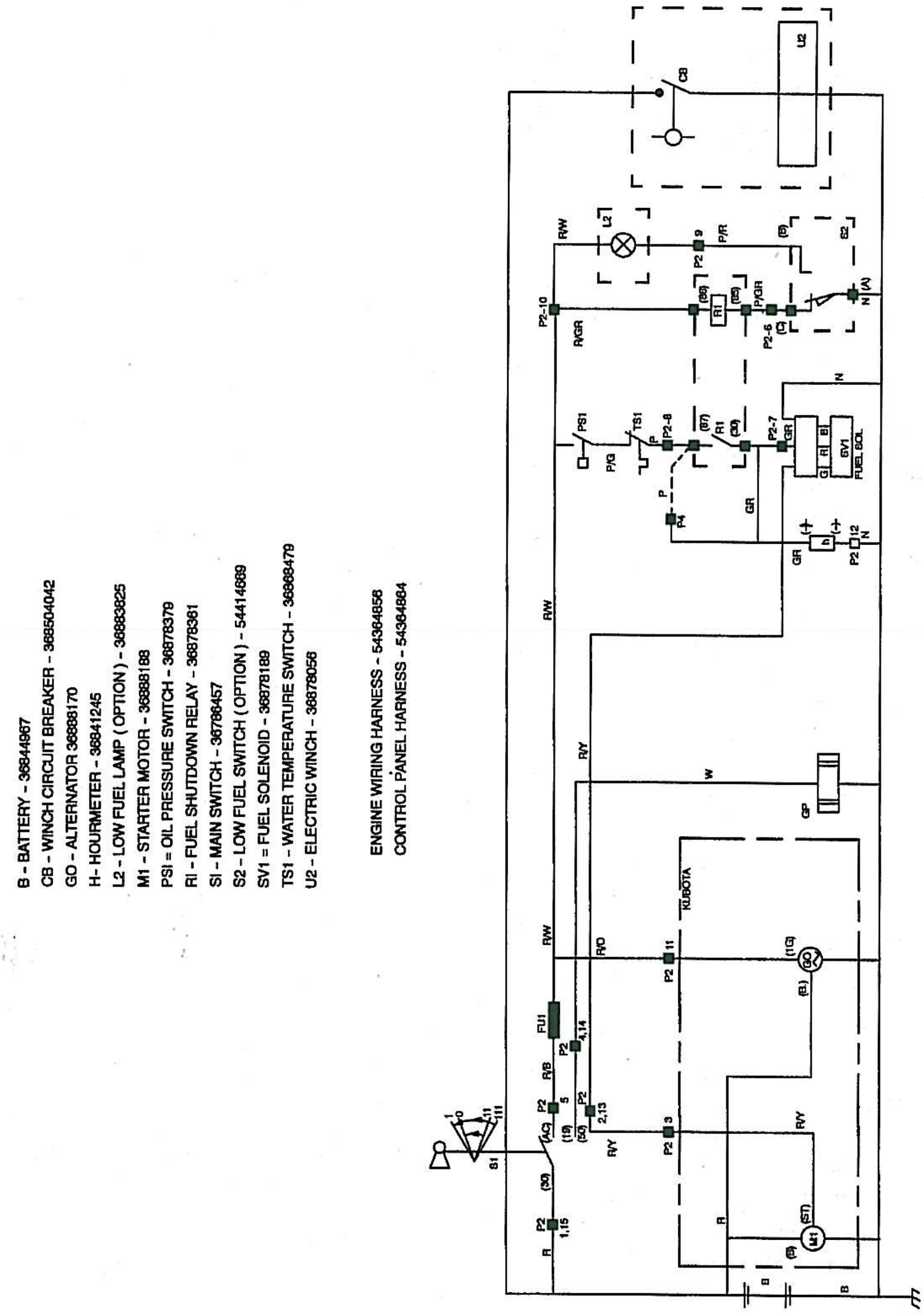
S







This schematic is from a Lightsource light tower.



SECTION 5
WIRING HARNESSES

What constitutes a wiring harness ?

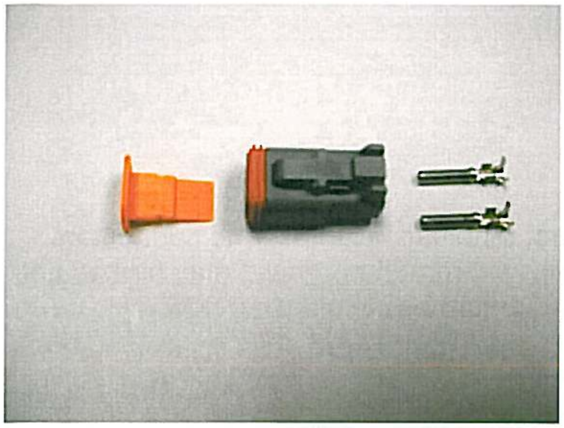
A wiring harness consists of the conductors, terminals, clamps, and connectors used to interconnect the machine electrical system. The harness may or may not connect to electronic devices. A typical wiring harness is shown below.

Why are wiring harnesses so important ?

The wiring harness is the nervous system of the machine. It carries all signals from controllers to sensors to actuators. It is mission critical and just as important as the sensors, controller, or any mechanical system. It is typically the most overlooked element during the troubleshooting process. Harnesses and connections should be inspected during regular machine maintenance.

Harness Connectors

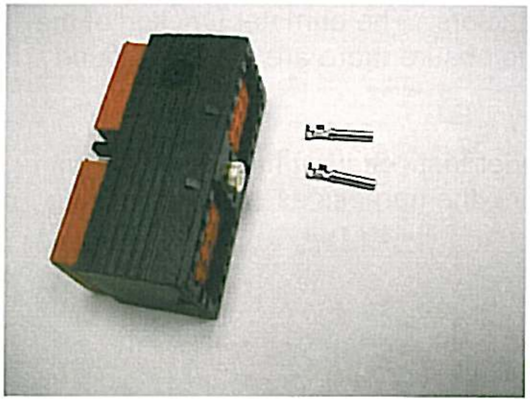
Wiring harnesses use a variety of connectors. The pictures below show some examples of these types. Packard Electric and Deutsch are two of the more popular brands.



Deutsch DT Series Connector
Note the orange wedgelock

Packard Metri Pack Series Connector
Note the green wire seals and blue Terminal Position Assurance connection

Deutsch HD Series Connector



Deutsch DRC Series Connector

It is very important that connectors be properly assembled. Use of the correct pin crimp tool is required to ensure high quality terminations. The manufacturer's instructions must be followed as to selection and use of crimp tools. Improper crimps not only provide unreliable connections but can damage the connector housing.

Troubleshooting harnesses

For extensive harness troubleshooting a detailed schematic will be required. Wire number and/or color identification will be needed to trace circuits. Splice location details can be very useful since problems do occur at splices.

The proper test adapters are recommended for harness troubleshooting. Some examples of these are shown in Section 2 concerning multimeters. Use of these adapters will prevent harness damage during testing.

The first item to perform during harness troubleshooting is a physical inspection of the harness for damage. Look for cut or frayed conductors, melted insulation and conductors pulled from connectors.

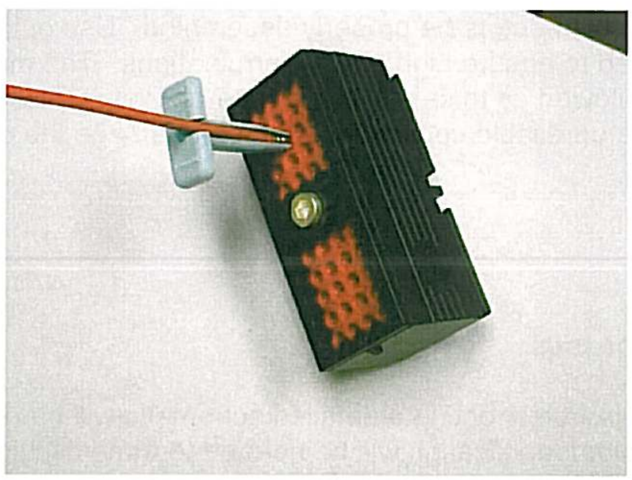
The next item to check is connector pin seating. Ensure the connector pins in the circuit under test are properly seated in the connector housing. A tug on the wire should confirm this.

If the harness is not physically damaged and all connector pins are seated, perform a continuity check of the circuit conductors. The ohmeter function of the multimeter can be used for this test. Check to ensure there are not any ground faults or conductor shorts to ground.

Finally, measure the signals on the circuit under test. Start at the point of origin of the signal and verify at as many points along the harness as possible, ending at the termination point.

Use of Harness Tools

The following pictures describe the proper methods of use of harness tools.



Removal Tool Usage

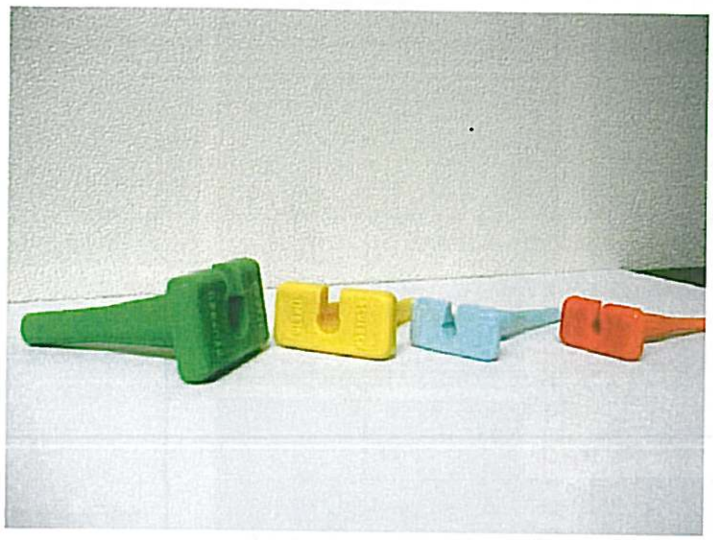
Proper removal tool usage is shown in the above picture. The removal tools are color coded as to wire size. The Table below lists the colors and wire sizes.

Removal Tool Color	Wire Size	I-R Part Number
Red	20 – 24	54699640
Blue	16 – 18	54699632

Yellow	12 – 14	54699624
Green	8 – 10	54699616

The wire is placed into the slot on the removal tool and the tool is slid along the wire and inserted into the back side of the connector. Gently pull on the wire as the tool is pushed in to the connector. The pin should release from the connector. To insert a pin, push it into the connector until it locks.

The picture below shows the various removal tools for the Deutsch connectors.



The following two pages show how the Deutsch crimp tools are to be used. One is used for machined contacts and the other for stamped and formed contacts.

SECTION 6

BASIC COMPUTER CONTROL SYSTEMS

Sensors and Transducers

Sensors and transducers are required to translate machine physical parameters into electrical signals that can be read by the controller. These parameters include temperature, pressure and RPMs. Special devices are available to measure these parameters. These devices are powered by the controller and convert some physical quantity into an electric quantity that can be interpreted by the controller.

Temperature is measured using a temperature sensor. These are typically a resistive device that exhibits a change in resistance as the temperature changes. Typical temperature sensors used are ***RTD's*** and ***thermistor*** probes.

The RTD is a device that exhibits a small change in resistance with a change of temperature. A typical RTD is a 100 ohm platinum device. It has a resistance value of 100.00 ohms at 0° C. At -30°C the resistance is 88.22 ohms and at 120° C the resistance is 146.06 ohms. The typical response time is 1 second. Below is a picture of an RTD probe.

Selected values of resistance vs temperature for a 100 ohm platinum RTD is shown below.

Temp °C	Resistance (ohms)
-20	92.19
-10	96.09

-5	98.04
0	100.0
5	101.95
10	103.90
20	107.79
40	115.54
60	123.24
80	130.89
100	138.50

A thermistor is a device that exhibits a large change in resistance with a change of temperature. A typical thermistor is a 10,000 ohm device. It has a resistance of 10,000 ohms at 25° C. The typical response time is 15 seconds. Below is a picture of a thermistor probe.

A temperature vs resistance table for a typical thermistor is shown below.

Temp °C	Resistance (ohms)
-20	25490
-10	18088
-5	12221
0	9369
5	7240
10	5640
20	3500
40	1460
60	668.7
80	332.7
100	177.5

Pressure is measured using a transducer. The types of pressure transducers covered by this text are referred to as High Output devices. This means the signal level output is from .45 volts DC to 4.5 volts DC nominal. These devices sense pressure changes by measuring a change in capacitance within the measuring cavity. Some devices use a change in resistance to measure pressure.

Pressure transducers require an ***excitation*** voltage of 5.0 Volts DC. These are three wire devices consisting of (1) +5 VDC (2) ground and (3) signal. The response time of the transducer is approximately 10 milliseconds. They are able to sense pressure transients. A typical pressure transducer is shown below.

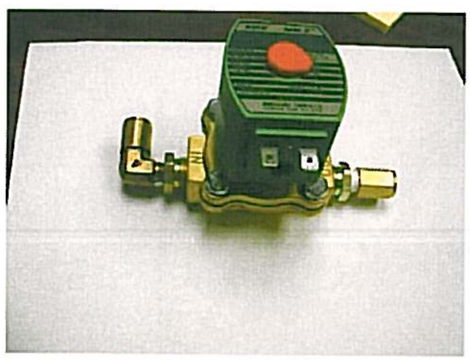
Parameters such as engine speed or other device speeds are measured by variable reluctance (magnetic) pickups or hall effect sensors. These devices sense gear teeth and generate an output pulse for each tooth that passes by the sensor. These pulses are connected to the controller and converted to an RPM number. A variable reluctance pickup produces a sine wave output. A hall effect sensor produces a square wave output. A variable reluctance pickup is shown below.

Digital Inputs

The sensors and transducers section discussed analog inputs. The second type of input is digital. These types of inputs have only two states – ON or OFF. ON means power applied and can be 12 V, 5 V, 24 V, etc. OFF means no power applied. These inputs are typically associated with switches or contacts.

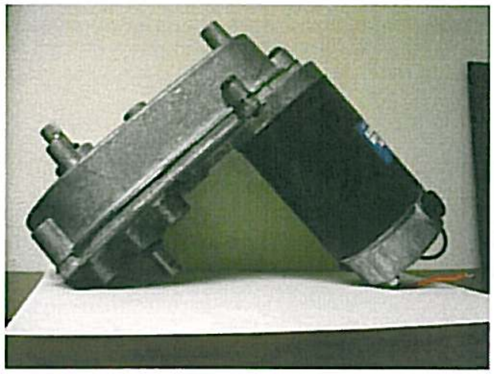
Actuators

Once the control system reads the inputs and executes the algorithms an output signal is generated. This output signal must be connected to a device to perform work. This device is referred to as an actuator. Actuators are usually electromechanical devices such as motors, solenoids, solenoid valves and linear actuators. The pictures below show different types of actuators.



Solenoid Valve

The solenoid is used to control fluid flow. Fluid could be air, water or oils. The coil controls a plunger that opens or closes the flow through the valve. Some solenoids are designed for proportional operation. These are driven by a PWM signal instead of a ON / OFF signal.



Gear Motor

A gear motor assembly is used to move a mechanical unit such as a valve. The gear motor has high torque due to the gear reduction drive. Some units can have a 10,000 : 1 gear reduction, resulting in high torque capability.

Linear Actuator

The linear actuator has similar features as the gear motor. Its output is a linear motion instead of the rotary motion of the gear motor.

What is software and how is it created ?

Software is basically a set of instructions for the controller. These instructions instruct the microprocessor or microcontroller to perform various tasks such as addition, subtraction, store in memory, read memory and input and output. Each microprocessor or microcontroller has its own unique instruction set. These must be used to create software or "***Programs***" for that microprocessor or microcontroller.

In order to simplify the programming process, universal "languages" have been created. These allow the programmer to create a program in a common language and then have that program translated into the specific instructions for a particular microprocessor or microcontroller. Using this technique, the programmer only has to know one language. It is not necessary for him to know all the various instruction sets for different microprocessors. One of the most popular languages is "***C***". An example of a "C" program is shown below.

```
/************************************************************************
/*                            Output Control Function
/*    Purpose:  Sets or clears all outputs.
*/
/* Parameters:  pin, status
*/
/*    Returns:  N/A
*/
/*      Calls:  N/A
*/
/************************************************************************
*****/

#include <includes.h>

void output_control(unsigned int pin, unsigned char status)
{
        asm di;
        if ((status & 0x01) == ON)
        /* turn on outputs */
        {
                io_data_1 |= (pin & 0x00ff);
                io_data_2 |= pin >> 8;
        }

        else
        /* turn off outputs  */
        {
                io_data_1 &= ~(pin & 0x00ff);
                io_data_2 &= ~pin >> 8;
        }
        /* output to DOUT1 */
        digital_output_1 = io_data_1;

        /* output to DOUT2 */
        digital_output_2 = io_data_2;
        asm ei;
}
```

This program reads an input called "status" and turns two outputs ON or OFF, depending on the setting of "status".

SECTION 7

TROUBLESHOOTING COMPUTER SYSTEMS

First Steps

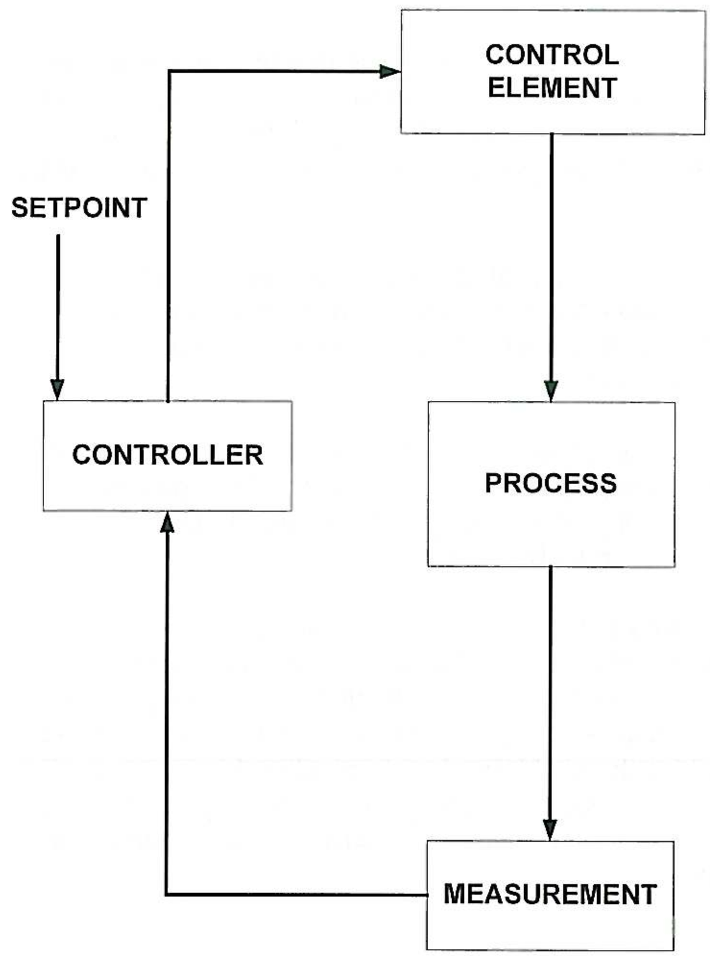
An understanding of the operation of a control system is necessary in order to diagnose and repair the system. Most computer control systems are similar in architecture an operation. Once a general understanding of these types of systems is achieved, understanding the operation of an unfamiliar system will be much easier.

The first step is to collect as much information from the operator or responsible party describing the machine operation before it failed. If the machine was operating unattended, check any status indicators, fault logs, etc. These may provide clues as to the cause of failure.

The next step is to verify all power sources are operating properly. In the case of off road equipment, this is the battery system. The condition of the batteries should be measured. Specific gravity and terminal voltage should be checked. Proper alternator charging output should be verified.

The machine is comprised of many subsystems interconnected to form a functioning machine. Initial diagnostics should be at the systems level to determine which subsystem(s) could be at fault. Selecting the proper path to pursue will shorten the diagnostic time and get the machine back on line faster. The electronic system may not be the problem. Mechanical problems may manifest themselves as electronic problems. Always, perform a systems check of the mechanical system. This can save hours of electronics troubleshooting, looking for non-existent problems.

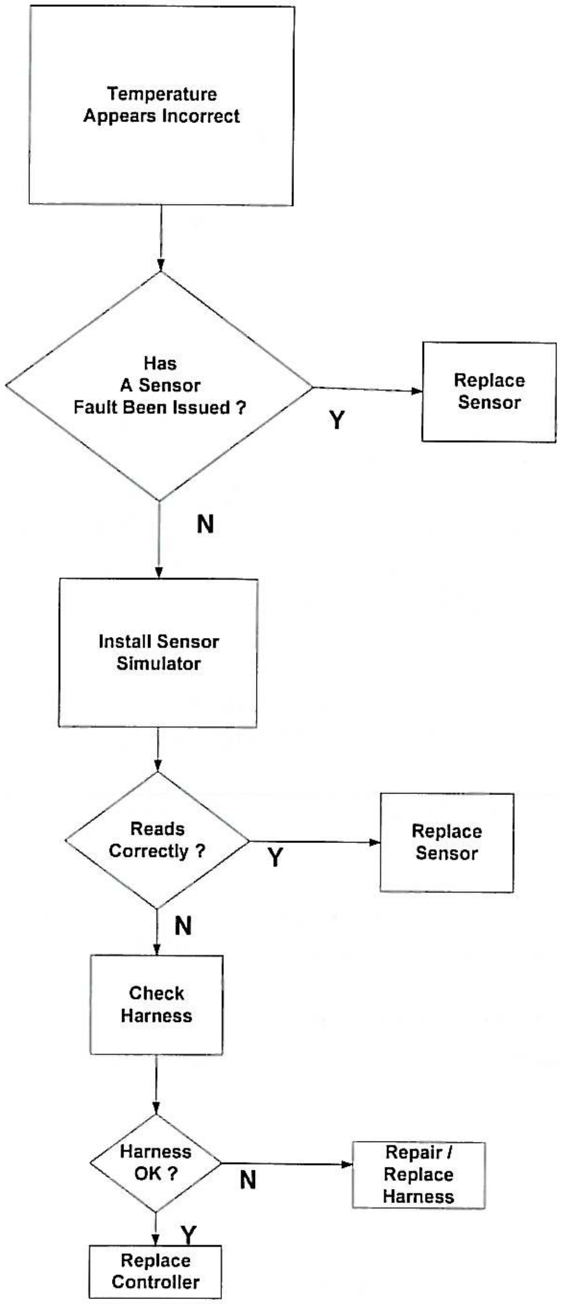
During the troubleshooting process, keep a mental picture of the block diagram shown below. This the basic diagram of a control loop as discussed previously. Each element of the loop must be scrutinized to determine the source of the problem(s). Work from the inside out. Start at the PROCESS first, then go to the measurement, next the control element and finally the controller.



The Troubleshooting Process

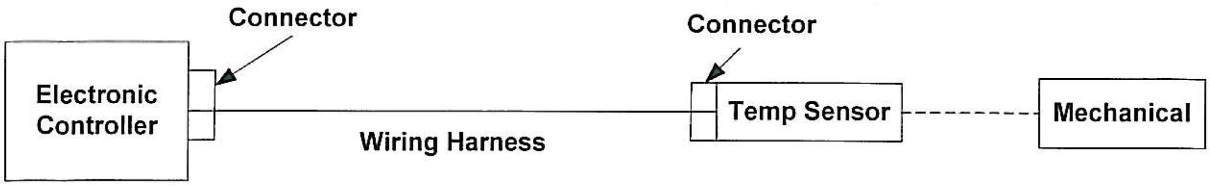
The objective of the troubleshooting process should be to find ***root cause*** of the problem. If root cause is not found, the problem will occur again some time later. One must understand how the machine operates, in order to effectively troubleshoot the machine.

For example, A machine has a suspect temperature reading form one of its thermistor sensors. The machine is experiencing erratic operation that could result from an incorrect temperature reading. The electronic controller has not issued a sensor fault for the suspect thermistor. The flow chart shown outlines the troubleshooting <u>thought</u> process.



In this case a hard failure has not been indicated. It is important to initiate activity that will *quickly* produce results.

The basic hardware configuration for a temperature input is shown below. The possible failure items are: Controller, connector, harness, connector, temperature sensor and mechanical.

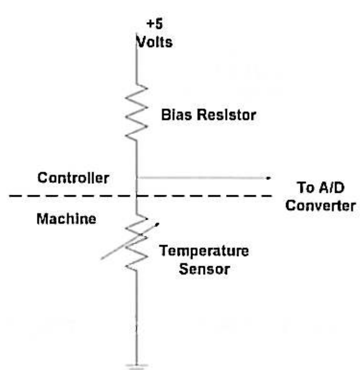


Since a hard failure did not occur, all items in the hardware platform are suspect. Unless the machine is a prototype, you must assume the software is operating properly. The troubleshooting process will start at the temperature sensor. If a temperature simulator is available, disconnect the temperature sensor and connect the simulator. If the temperature reading is correct, this would indicate the temperature sensor could be defective. Replace the temperature sensor. If a temperature simulator is not available, substitute a new sensor if available or perform tests on the existing sensor.

If the simulator or a new temperature reading is not correct, the problem must be the harness or controller. Check the harness connectors for loose pins and bad wire crimps. Perform a continuity check on the wires running from the controller to the sensor. If the harness checks OK then replace the controller. Go back and perform the simulator plug test using the new controller.

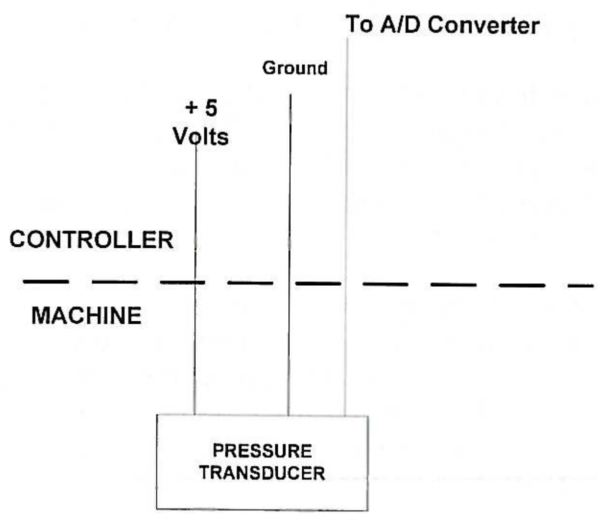
Most problems with electronic systems occur in the wiring and connectors. The sensors, transducers and electronic controllers are very reliable units.

As discussed previously, most temperature sensors are variable resistance devices. A typical configuration for a temperature sensor input is shown below.



The bias resistor supplies power from the 5 volt power source to the temperature sensor. It also limits the current that can be drawn by the sensor. If too much current is drawn by the sensor , self heating will result. This will affect the temperature reading. The sensor is shown as a resistor with an arrow through it. This is a schematic symbol that designates a variable resistor. The input to the controller analog-to-digital converter is connected above the sensor as shown.

A typical input for a pressure transducer is shown below.



Most pressure transducers used today in off road equipment use a resistance or capacitance technique to sense pressure. These transducers have an electronic circuit that conditions the pressure signal before it exits the device. Most devices are of the three-wire type as shown in the schematic above. The three wires consist of an excitation line or power input, a ground line and the signal line. The output signal is measured across the signal and ground lines.

Sensor and Transducer Testing

Temperature sensors are not difficult to test since most consist of a resistive element. The ohmeter function of the digital multimeter is used for this test. Setup the multimeter for ohms test as described in Section 2 of this text.

Remove the temperature sensor from the machine. Connect the meter test leads to the two pins of the sensor and note the ohms reading. Put the sensor probe tip into a cup of ice water and let it sit for approximately one minute. Note the new ohms reading.

Remove the probe from the ice water and using a heat source (heat gun, hair dryer, torch) heat the probe slowly. Note the new ohms reading. It should continue to increase while the heat source is supplied.

A pressure transducer is more difficult to test than the temperature transducer. A fluid source that can be pressurized will be required for testing. Compressed air is usually the best choice. An excitation source will be required. A DC power supply or batteries with appropriate dropping resistors can be used.

Remove the transducer form the machine. In most cases for the three terminal transducer, a 5 VDC excitation supply is required. Connect the excitation source to the transducer supply and ground leads. Setup the digital multimeter to read DC volts as described in Section 2. Connect the multimeter to the signal and ground lines of the pressure transducer.

Connect a regulator and pressure gauge into the air source and connect this to the pressure transducer. Vary the air pressure and note the voltage of the signal output of the transducer. Most of the three wire transducers have a signal output of .45 V to 4.5 V nominal. This will be across the stated pressure range of the transducer. Varying the air pressure across the range of the transducer should produce an output voltage of .45 to 4.5 volts.

Grounds

The grounding system is very important on computer based control systems. Loose, intermittent, high impedance and broken ground connections can cause havoc with the computer system. If the control system is experiencing erratic behavior, the ground connections should be inspected for problems.

The main ground connection fed from the battery negative cable must be clean and torqued to the proper setting. Bonding straps should be checked for corrosion free and tight connections. Rusty fasteners should be replaced.

Metal-to-metal contact is the best ground connection. All paint, rust, etc. should be removed from surfaces and cable terminations before the joint is assembled. Star washers should not be used as a substitute for a good metal-to-metal connection.

Ground connections deteriorate with time and will require maintenance at some point in time.

The integrity of ground connections is important for removal of electrical noise from sensitive circuits. Grounding straps are much more effective for noise removal than grounding cables.

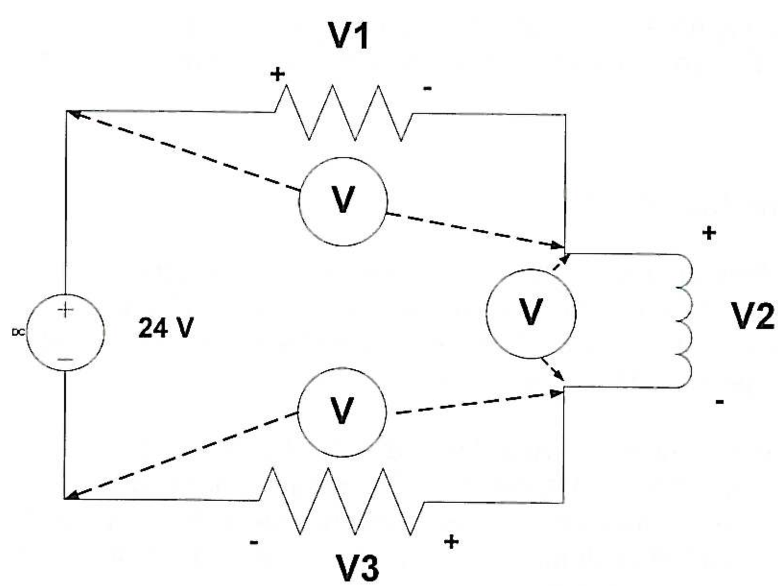
Use of "Voltage Drop" As A Test Technique

The first section of this text explained simple DC circuits and introduced the concept of "voltage drop". Voltage drop testing can be used to quickly identify certain problems. Voltage drop testing can be used instead of continuity checks to find root cause. Continuity checks can provide false indications of bad circuits.

Ground connections on off road equipment are a key source of electrical problems. Many are improperly done when the machine is manufactured and most will deteriorate with time.

To test the integrity of a ground connection, place the BLACK (-) meter lead on the ground connection and the RED (+) lead on the battery positive post. Note the reading. Now place the BLACK (-) lead on the negative battery post and the RED (+) lead on the battery positive post. These two measurements should be equal. If not, there is a problem with the ground connection.

Voltage drops can be used to analyze many different types of circuits.



The circuit above shows an example. Assume the inductor is a solenoid. The solenoid will not pull in. The voltage drop, ***V2***, is less than the pull in voltage requirement of the solenoid. This means the full power supply voltage of 24 V is not reaching the solenoid.

There are three possible situations: (1) There is a problem with the wire from + 24V to the solenoid (2) There is a problem with the wire from – 24V to the solenoid (3) There is a problem with both wires. A continuity check of these two wires can be performed but, a voltage drop measurement provides more information.

First , measure ***V1***. It should be a low value, 1 volt or less. The same applies for ***V3***. If these measurements are voltages larger than 1 volt, the resistance in the wiring is too large, indicating a harness problem. For example, assume the solenoid draws .50 amps. If V1 is 1 volt then the resistance would be 48 ohms.

$$R = V / I$$
$$= 24 / .5$$
$$= 48 \text{ ohms}$$

Unless the length of this wire is several hundred feet, the resistance should be less than 1 ohm.

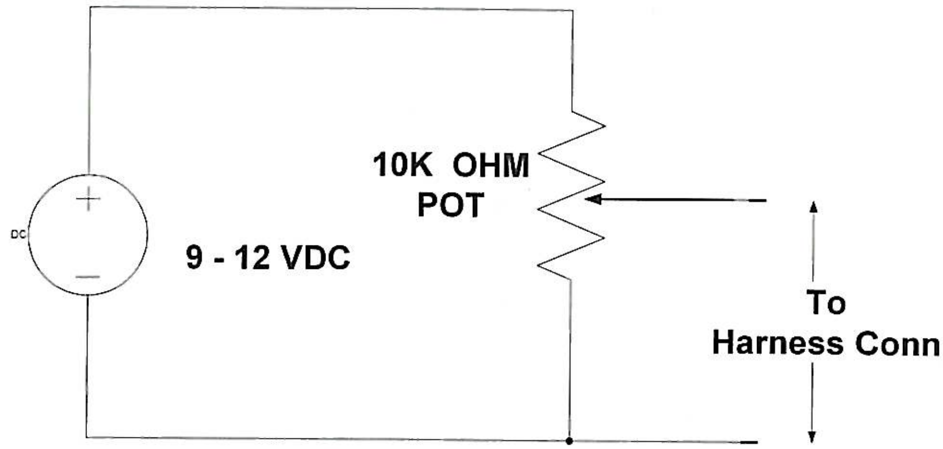
If V3 is 1 volt or larger, it would indicate a similar problem except the problem could be in a ground circuit instead of the B+ circuit. If the ground is through the chassis or frame, V2 would be the voltage drop across the ground connection. This would indicate a deteriorated ground connection.

If the continuity measurement is used, it may not have indicated a bad ground or B+ wiring. The voltage drop method is more reliable and can produce quicker results.

Component Substitution

One of the fastest ways to confirm a defective component is substitution. This works well unless removal of a sensor or transducer will cause a loss of fluid. Swapping an engine coolant temperature probe usually will result in loss of coolant as the sensors are swapped.

There is another method that will produce similar results but does not require removal of the sensor or transducer. The signal produced by the sensor or transducer can be simulated. A basic potentiometer (pot) and a DC power source can be used to simulate the output signal. The following schematic shows the components required.

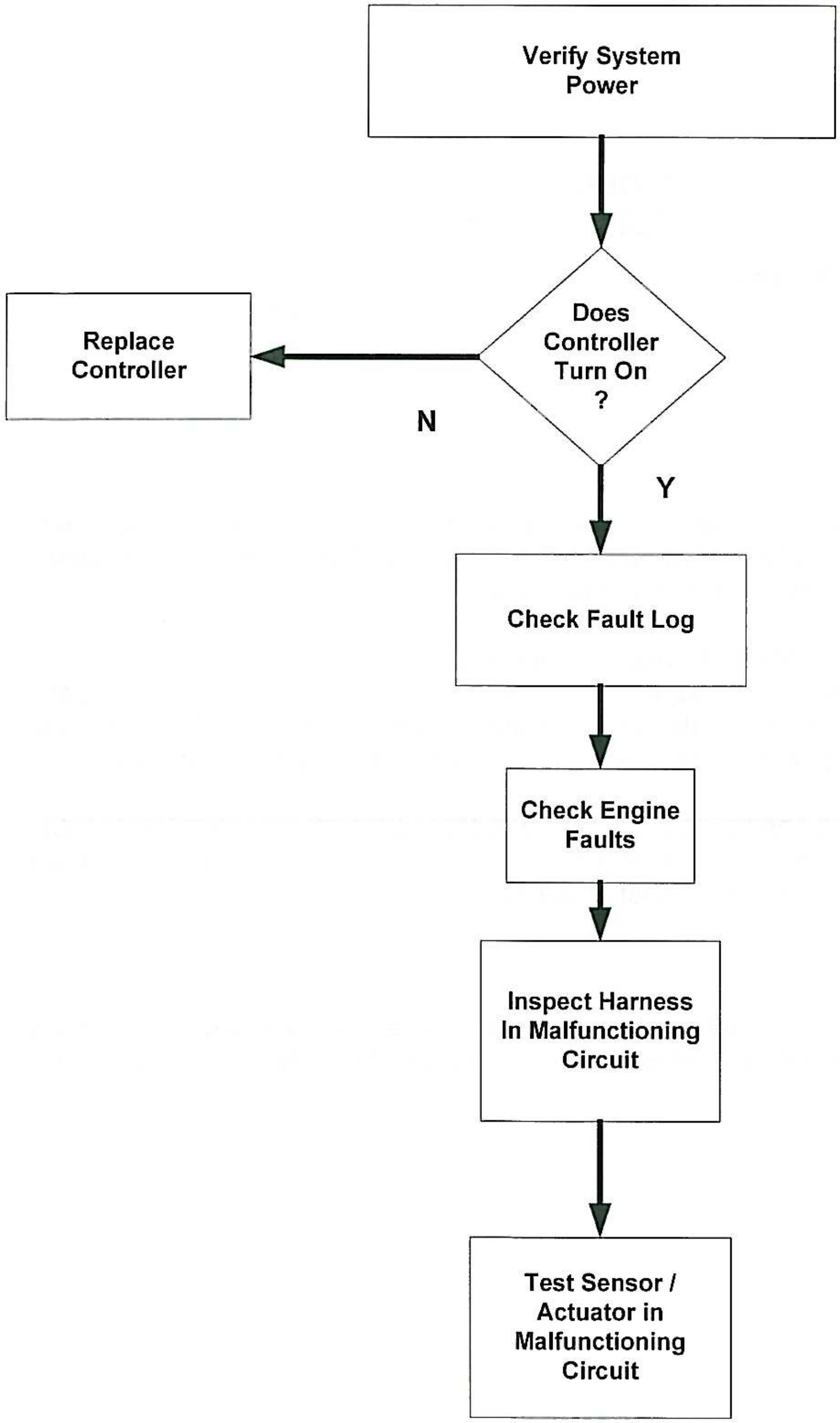


The 10K Ω pot acts as a voltage divider and can be adjusted to any output level from 0 V to battery volts. Knowing the output range of the sensor or transducer, the pot can be adjusted to simulate the range.

The output of this circuit is connected to the harness side of the sensor connection. Disconnect the sensor or transducer and connect the pot output as shown to this input to the controller. If the pot terminals have alligator clips, then various connector pins can be inserted to connect to the harness connector.

The pot-battery unit can be used for pressure transducer, thermistor, level probe, fuel sender, temperature sender and other resistive sensor applications. A 9 volt battery is a convenient power source to use.

If potential mechanical problems have been eliminated, the following page shows a general troubleshooting flowchart. This can be used to establish a direction for diagnosis.


Verify System Power
Does Controller Turn On ?
Replace Controller
N
Y
Check Fault Log
Check Engine Faults
Inspect Harness In Malfunctioning Circuit
Test Sensor / Actuator in Malfunctioning Circuit

The service technician should have spare sensors when he makes a service call. He should have the necessary service manuals and service aids such as simulators and test adapters. These devices will make him more productive.

SECTION 8

WEDGE CONTROL SYSTEMS

What is the WEDGE Controller ?

The WEDGE controller was designed as a cost effective control module for use on off road equipment. It is a general purpose controller that can be used for many functions. It is currently use on Portable Power's diesel driven air compressors. A picture of the WEDGE is shown below.

WEDGE Hardware Features

The WEDGE has two thermistor temperature inputs, two high level pressure transducer inputs, one fuel level input, 8 digital inputs, 8 digital outputs, one J1939 CAN communications port and one RS232 communications port.

The WEDGE operates on 8 – 40 volts DC input power over a temperature range of –40° C to 85° C. It can handle vibration as high as 40 grms.

What products us the WEDGE Controller ?

The WEDGE is currently installed on oil flooded screw compressor products.

WEDGE Controller Functions

The WEDGE controller is the heart of the machine monitor and control system. It provides data collection, alarming and control functions for compressor operations. It is a microcontroller based unit with analog and digital inputs and outputs. The WEDGE is usually attached to the back of the machine control panel. The LED annunciators are part of the front panel of the WEDGE. They can be seen through the laminate on the front of the control panel.

The first function of the WEDGE is to scan all analog and digital inputs at a fixed interval. These inputs are scanned every 50 milliseconds. The analog values are then compared against minimum and maximum values and an ALERT or SHUTDOWN is issued, if a value is out of range.

The second function of the WEDGE controller is machine discharge pressure control. The WEDGE monitors the regulation system air pressure and varies the engine throttle to maintain the setpoint discharge air pressure. The setpoint pressure is set using the regulator on the separator tank.

The third function of the WEDGE controller is to communicate with the diesel engine via the J1939 CAN network. The WEDGE controller provides the engine throttle setting to the engine controller and retrieves diagnostic information from the engine.

Two methods are used to provide a throttle signal to the engine. The Cummins engine uses a square wave frequency of 150 – 375 hertz and the CAT engine uses a 500 hertz PWM signal with 10-90% duty cycle.

The WEDGE also provides a "keyswitch" signal to the engine. This is an ON/OFF, 24 VDC signal to tell the engine to turn ON or OFF. This signal along with the throttle signal are the only two required to control the engine.

Sensors and Transducers

The WEDGE uses sensors and transducers to collect parameters from the compressor. Temperature is measured by a thermistor probe. Pressure is measured by a pressure transducer. Pressure transducer ranges are 0 to 100, 225, or 500 psi. The pressure transducers are 3 wire devices: excitation, signal and ground. The signal output is .45 to 4.5 volts.

Digital Inputs and Outputs

The WEDGE controller scans digital inputs such as switch contacts. These are either "ON" (24VDC) or "OFF" (0VDC). These digital inputs are connected to switches within the package such as the key start switch, air filter switches and IQ filter switches.

The WEDGE controller provides 24 VDC digital outputs to control solenoids, start compressor and DC heaters. These are 24 VDC "ON" and 0 VDC "OFF". They are current limited and short circuit protected.

Controller Outputs

The WEDGE controller has three types of outputs: frequency, pulse width modulated (PWM) and 24 VDC digital (ON/OFF). A frequency output signal is used as an engine throttle signal.

The WEDGE controller varies the frequency output signal signal from 150 hertz to 375 hertz, corresponding to 1200 to 1800 RPM for use with the Cummins QSX15 engine. This frequency signal is a 50% duty cycle, 24 VDC square wave.

The PWM signal is used as a throttle signal for the Caterpillar engine. It has a base frequency of 500 hertz and the duty cycle varies from 10% to 90%.

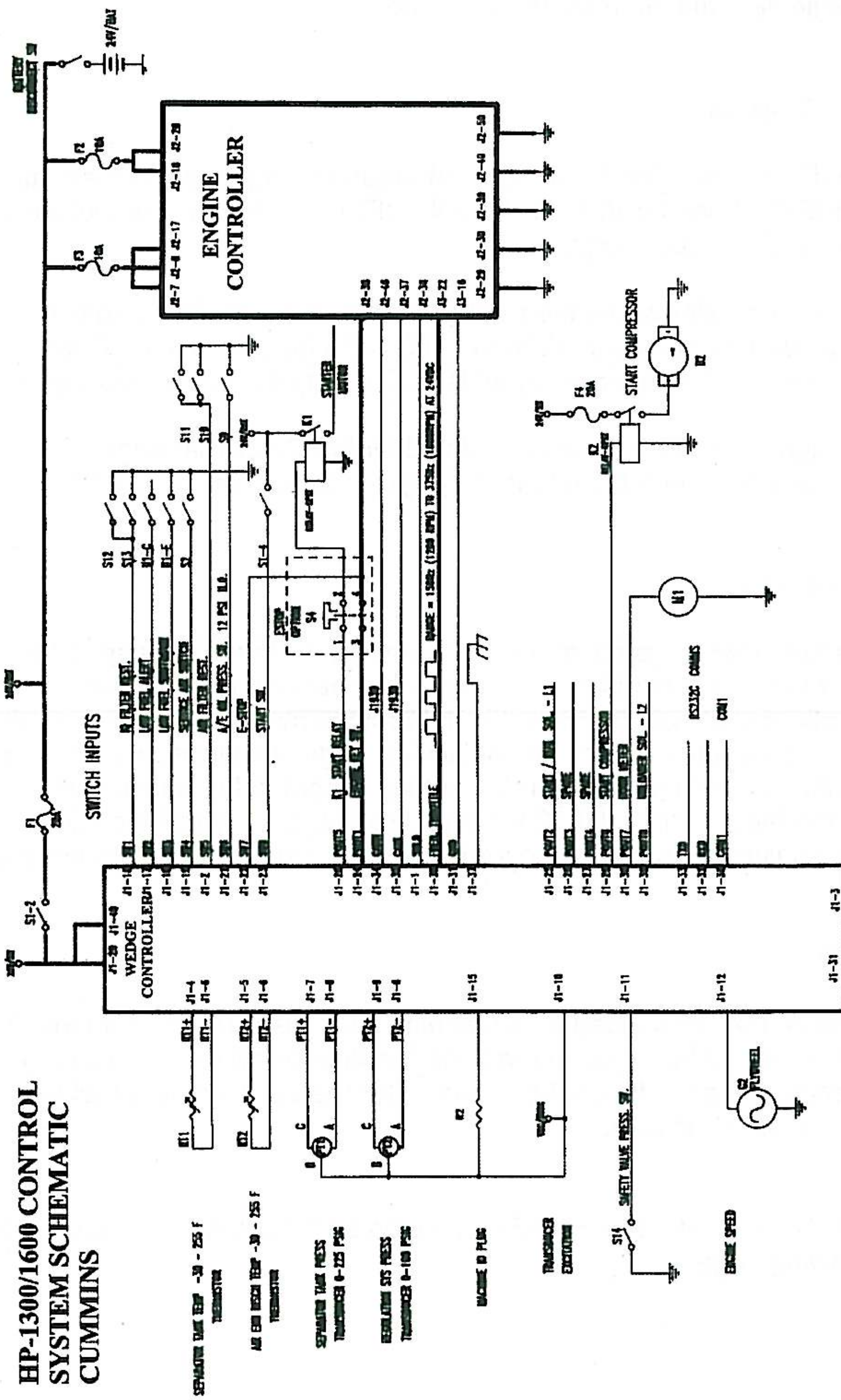
Pressure Control

The discharge pressure is controlled by manipulating the engine speed and compressor inlet valve position. The inlet valve position is controlled pneumatically and the engine speed is determined by the WEDGE controller. The WEDGE measures the pneumatic system regulation pressure and computes an engine throttle setting. This throttle setting is sent to the engine via the frequency throttle, PWM or J1939 throttle, depending on which technique is used. The engine controller will control engine speed to this throttle setting.

Machine ID

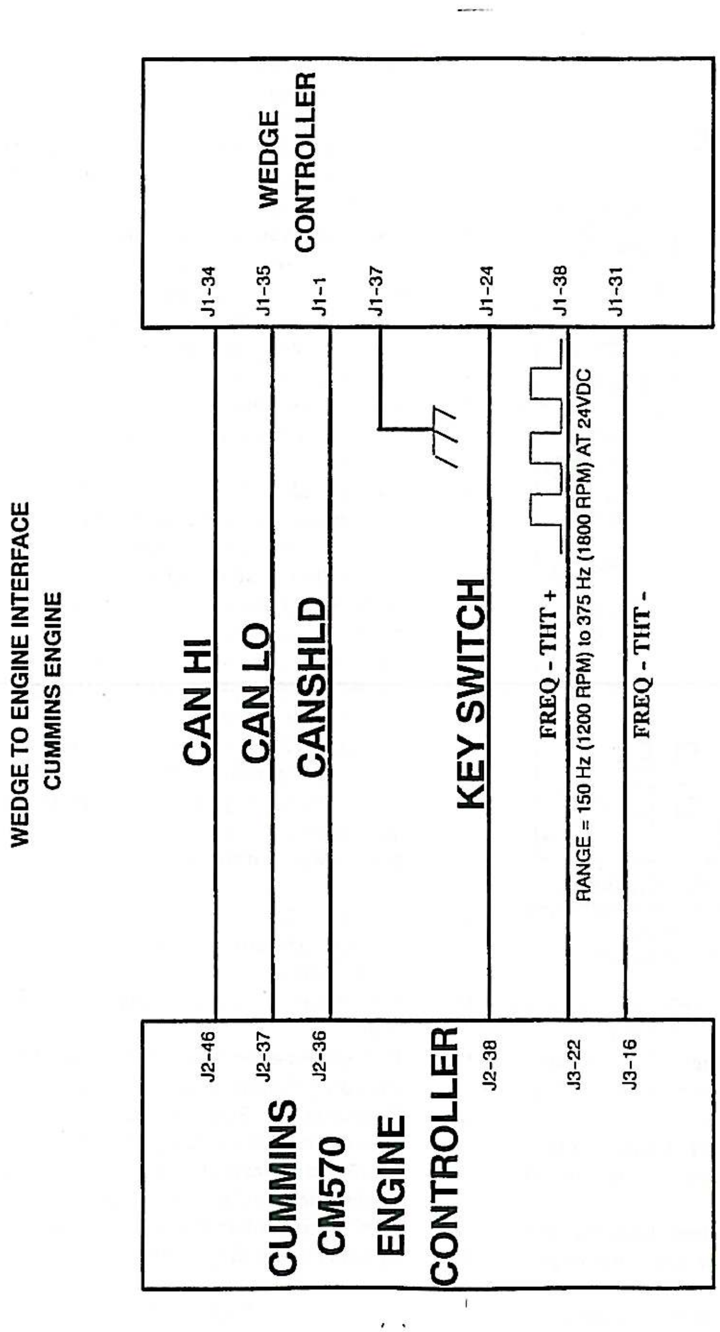
A resistor plug, R2, is provided as a machine ID. This is required so the WEDGE controller will know which type of machine it is connected to. The ID plug is normally located behind the control panel. The resistor plugs are molded in colors for easy identification.

A system schematic of the WEDGE system on a HP1600 compressor is shown on the following page.



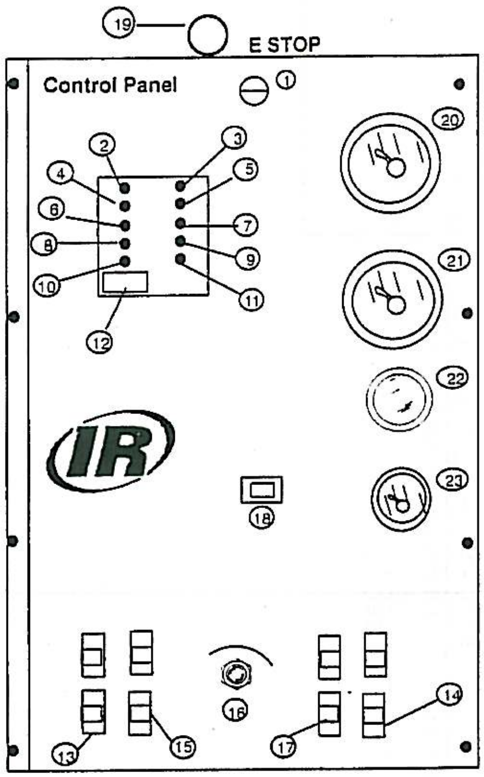
HP-1300/1600 CONTROL SYSTEM SCHEMATIC CUMMINS

Shown below are the important connections between the WEDGE controller and the engine.



A picture of a typical machine control panel using a WEDGE controller is shown below.

CONTROL PANEL

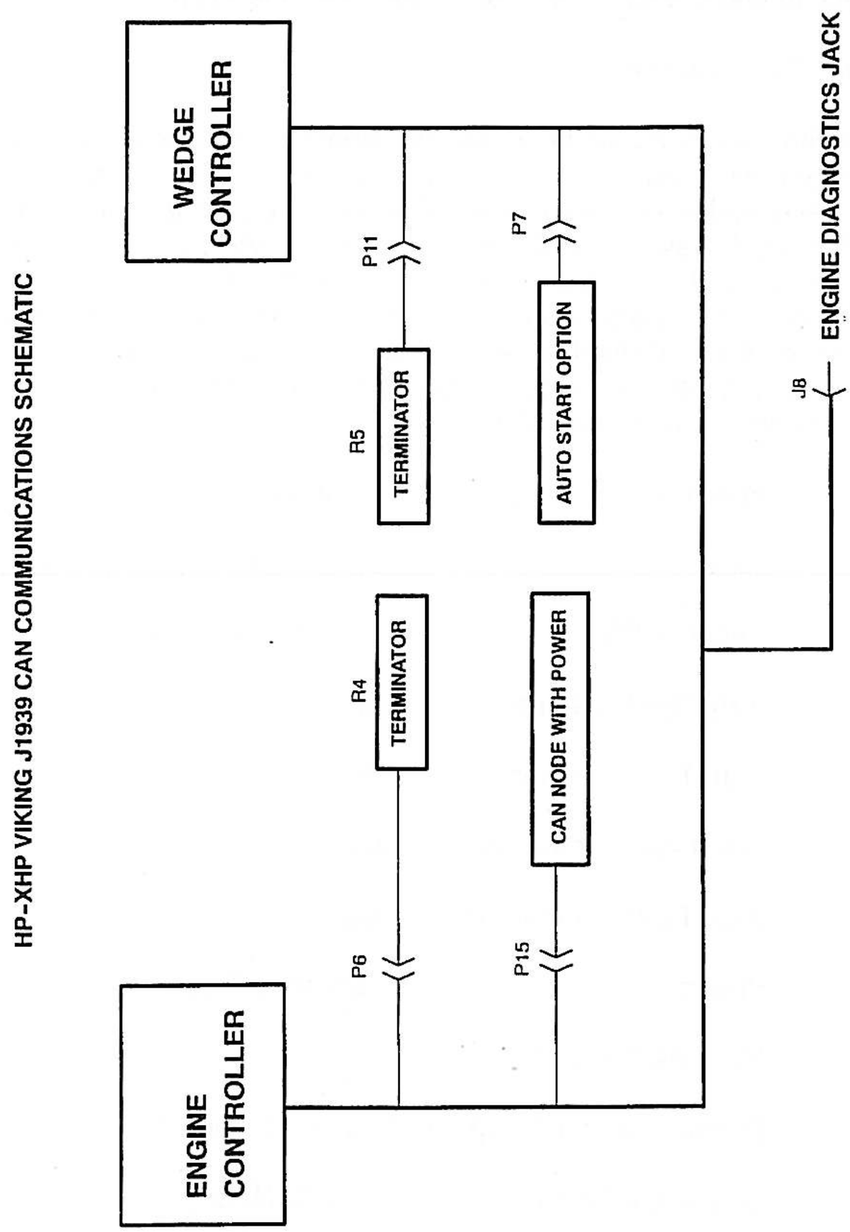


<u>OPERATING CONTROLS AND INSTRUMENTS</u>

The operating controls and instruments are arranged on the control panel as shown on previous page. A description of each panel device is as follows:

1. **Panel Light:** Illuminates PHE instrument and control panel controlled by Switch 14.
2. **High Compressor Temp**: Fault indicator lamp. Indicates shutdown due to high compressor temperature.
3. **Low Radiator Coolant Level:** Alarm indicator lamp. Indicates engine coolant needs service.
4. **Low Engine Oil Pressure:** Fault indicator lamp. Indicates shutdown due to low engine oil pressure.
5. **Restricted Air Filter:** Alarm indicator lamp. Indicates engine/compressor air inlet filters need service.
6. **High Engine Coolant Temp:** Fault indicator lamp. Indicates shutdown due to high engine water temperature.
7. **Restricted IQ Air Filters:** Fault indicator lamp. Indicates shutdown due to high Pon IQ air filters (if equipped).
8. **Low Fuel Level:** Fault indicator lamp. Indicates shutdown due to low fuel level. Lamp blinks at low fuel warning.
9. **Compressor Malfunction:** Fault indicator lamp. Indicates shutdown due to compressor system fault. Refer to Fault Code List.
10. **Low Battery Voltage**: Alarm indicator lamp. Indicates battery or charging system requires service.
11. **Engine Malfunction:** Engine Fault code. Refer to service card or engine manual for codes and service requirements.
12. **Malfunction Code (4 Digit)**: Compressor or engine fault. Refer to manual for list of codes and service requirements.
13. **Ether Inject**: Injects a measured shot of ether for aid in cold weather starting of engine. Caution: Use Sparingly.
14. **Panel Light Switch**: Controls panel lamp # 1.
15. **Pressure Control:** Momentary contact switch. Allows engine to warm up at low compressor pressure.
16. **Main Power Control Switch:** ON/OFF Start Switch.
17. **Heaters:** ON/OFF Power Switch for regulation and IQ heaters. Prevents freeze up in cold weather.
18. **Hourmeter:** Indicates machine operating hours.
19. **E-STOP:** Emergency Stop Push Button (ESA units only). Push to stop, turn to release.
20. **Discharge Air Pressure Gage:** Indicates pressure in receiver tank, normally from 0 psi(kPa) to the rated pressure of the machine.
21. **Engine Tachometer:** Indicates engine speed in RPM from 0 when stopped to full speed.
22. **Systems Gage:** Engine Water Temp
    Compressor Oil Temp
    Engine Oil Pressure
    Battery Voltage
23. **Fuel Level Gage:** Indicate fuel level in tank.

The following is a schematic of the J1939 CAN network layout for a large compressor.



Diagnosis and Troubleshooting of WEDGE Systems

A WEDGE control system is similar to any other control system. It has inputs and outputs and performs monitor and control of various machine parameters. The built in ALERT and SHUTDOWN software will protect the engine and compressor system and provide indication of improper operation.

WEDGE Service Diagnostics

The WEDGE controller has a built-in diagnostic capability that allows various internal parameters to be viewed on the 4-digit LED display. These can be accessed with the machine stopped or while it is operating. If the machine is stopped, the “Service Air” switch on the control panel is used to toggle through the list of parameters. If the machine is operating, the “Start” position of the key switch is used. To view the parameters, toggle the switch or key and a number (2-15) will appear on the LED display. After 3 seconds, it will extinguish and the parameter will be displayed. The toggle only works in the ascending order direction, but it will wrap around and start over.

Display	Parameter	Remarks
2	RPM	From Engine Flywheel Sensor
3	Engine RPM	Filtered RPM Value
4	Reg. Sys Pressure	PSI
5	Sep. Tank Pressure	PSI
6	Discharge Temperature	Deg F
7	Sep. Tank Temperature	Deg F
8	Phertz	Frequency Throttle Output
9	Machine Type	*
10	Engine Coolant Temp.	From CAN, Deg F
11	Engine Oil Temp.	From CAN, Deg F
12	Engine Oil Pressure	From CAN, PSI
13	Intake Manifold Temp.	From CAN, Deg F

14	RPM	From CAN
15	Fault Code List	Cummins/CAT Codes
16	Throttle Position	From CAN
17	Boost Pressure	From CAN
18	Engine Hours	From CAN

* Machine Types: 0 = HP Cu 4 = XHP CAT 1 = XHP CU

SECTION 9

INTELLISYS CONTROL SYSTEMS

What is the Intellisys Controller?

The Intellisys is a general purpose controller designed for use on off road equipment.

Intellisys Hardware Features

The Intellisys has 8 temperature inputs that can use RTD's or thermistor probes, 8 high level pressure inputs, 8 digital inputs, 10 digital outputs, one J1939 CAN communication port and one RS232 communications port.

The Intellisys operates on 8-40 volts DC input power over a temperature range of -40°C to 85°C. It can handle vibration as high as 25 grms.

What Products Use The Intellisys Controller ?

The NHP1500 compressor.

Intellisys Controller Functions

The WEDGE controller is the heart of the machine monitor and control system. It provides data collection, alarming and control functions for compressor operations. It is a microcontroller based unit with analog and digital inputs

and outputs. The WEDGE is usually attached to the back of the machine control panel. The LED annunciators are part of the front panel of the WEDGE. They can be seen through the laminate on the front of the control panel.

The first function of the WEDGE is to scan all analog and digital inputs at a fixed interval. These inputs are scanned every 50 milliseconds. The analog values are then compared against minimum and maximum values and an ALERT or SHUTDOWN is issued, if a value is out of range.

The second function of the WEDGE controller is machine discharge pressure control. The WEDGE monitors the regulation system air pressure and varies the engine throttle to maintain the setpoint discharge air pressure. The setpoint pressure is set using the regulator on the separator tank.

The third function of the WEDGE controller is to communicate with the diesel engine via the J1939 CAN network. The WEDGE controller provides the engine throttle setting to the engine controller and retrieves diagnostic information from the engine.

Two methods are used to provide a throttle signal to the engine. The Cummins engine uses a square wave frequency of 150 – 375 hertz and the CAT engine uses a 500 hertz PWM signal with 10-90% duty cycle.

The WEDGE also provides a "keyswitch" signal to the engine. This is an ON/OFF, 24 VDC signal to tell the engine to turn ON or OFF. This signal along with the throttle signal are the only two required to control the engine.

Sensors and Transducers

The WEDGE uses sensors and transducers to collect parameters from the compressor. The temperature is measured by a thermistor probe. Pressure is measured by a pressure transducer. Pressure transducer ranges are 0 to 100, 225, or 500 psi. The pressure transducers are 3 wire devices: excitation, signal and ground. The signal output is .45 to 4.5 volts.

Digital Inputs and Outputs

The WEDGE controller scans digital inputs such as switch contacts. These are either "ON" (24VDC) or "OFF" (0VDC). These digital inputs are connected to switches within the package such as the key start switch, air filter switches and IQ filter switches.

Controller Outputs

The WEDGE controller has three types of outputs: frequency, pulse width modulated (PWM) and 24 VDC digital (ON/OFF). A frequency output signal is used as an engine throttle signal.

The WEDGE controller varies the frequency output signal signal from 150 hertz to 375 hertz, corresponding to 1200 to 1800 RPM for use with the Cummins QSX15 engine. This frequency signal is a 50% duty cycle, 24 VDC square wave.

The PWM signal is used as a throttle signal for the Caterpillar engine. It has a base frequency of 500 hertz and the duty cycle varies from 10% to 90%.

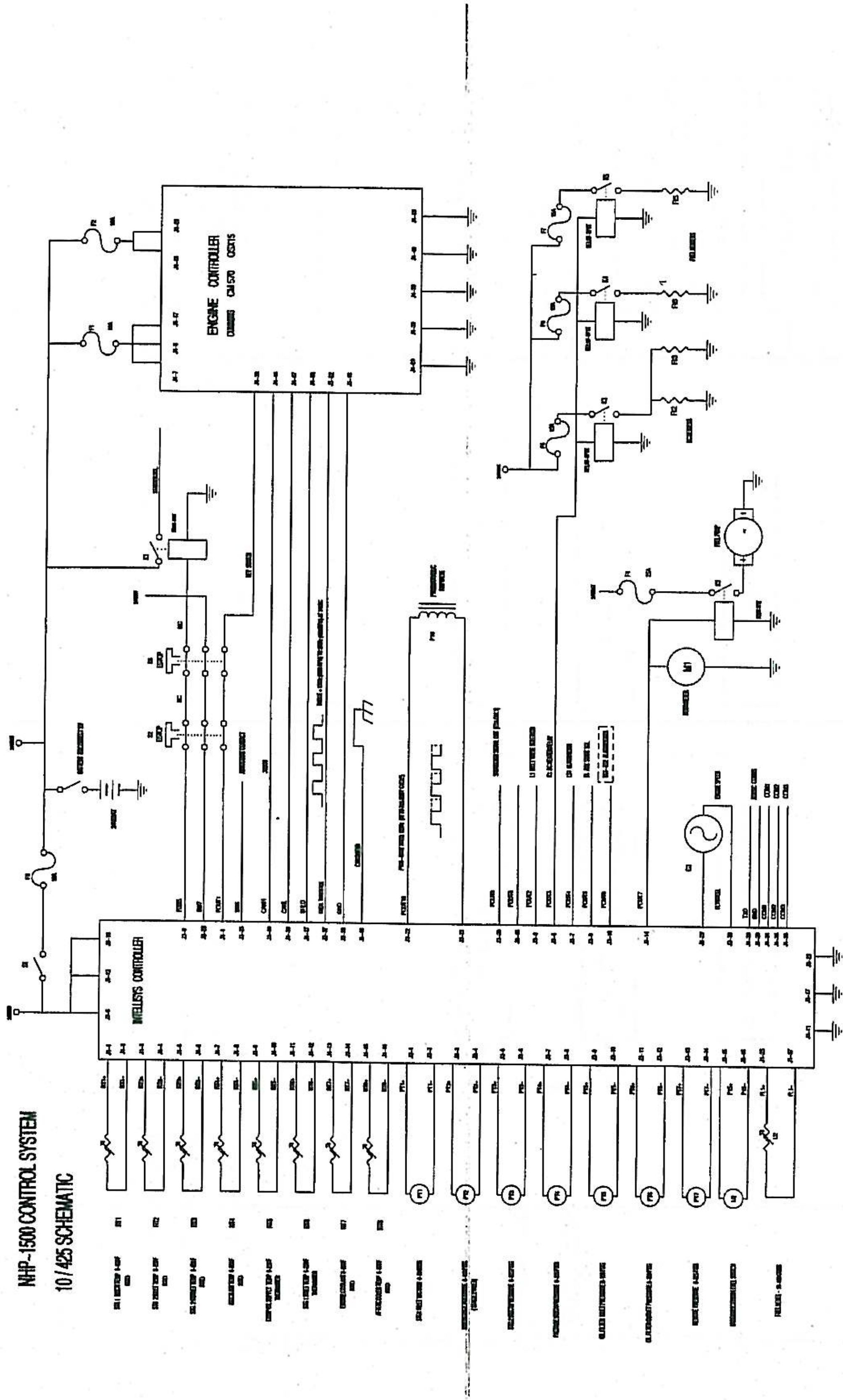
Pressure Control

The discharge pressure is controlled by manipulating the engine speed and compressor inlet valve position. The inlet valve position is controlled pneumatically and the engine speed is determined by the WEDGE controller. The WEDGE measures the pneumatic system regulation pressure and computes an engine throttle setting. This throttle setting is sent to the engine via the frequency throttle, PWM or J1939 throttle, depending on which technique is used. The engine controller will control engine speed to this throttle setting.

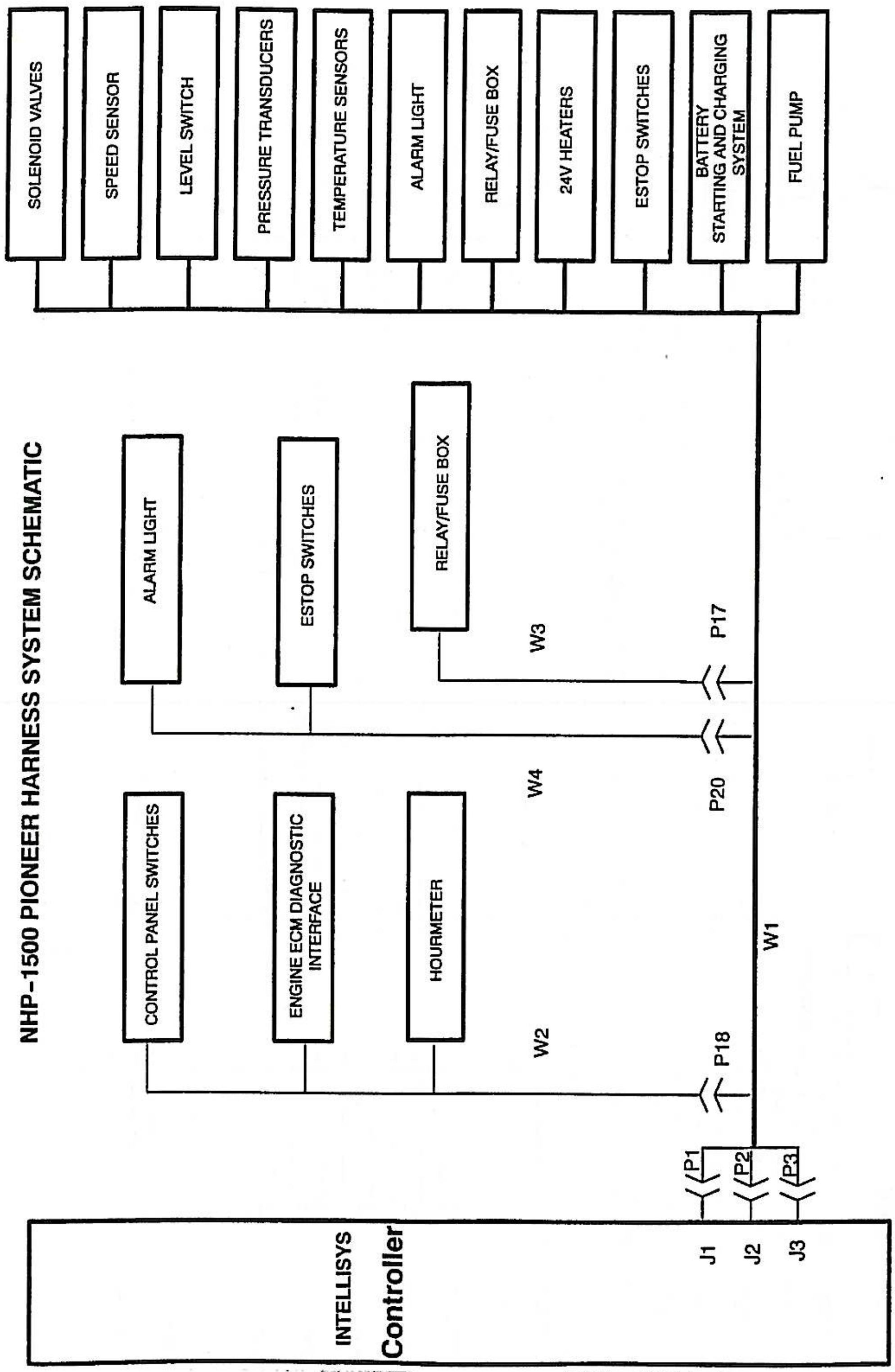
Aftercooler Fan Control

The Intellisys controls the speed of the hydraulically driven aftercoller fan. The aftercooler discharge temperature is the input for this control loop. The Intellisys provides a PWM signal to control a hydraulic by-pass valve at the hydraulic motor.

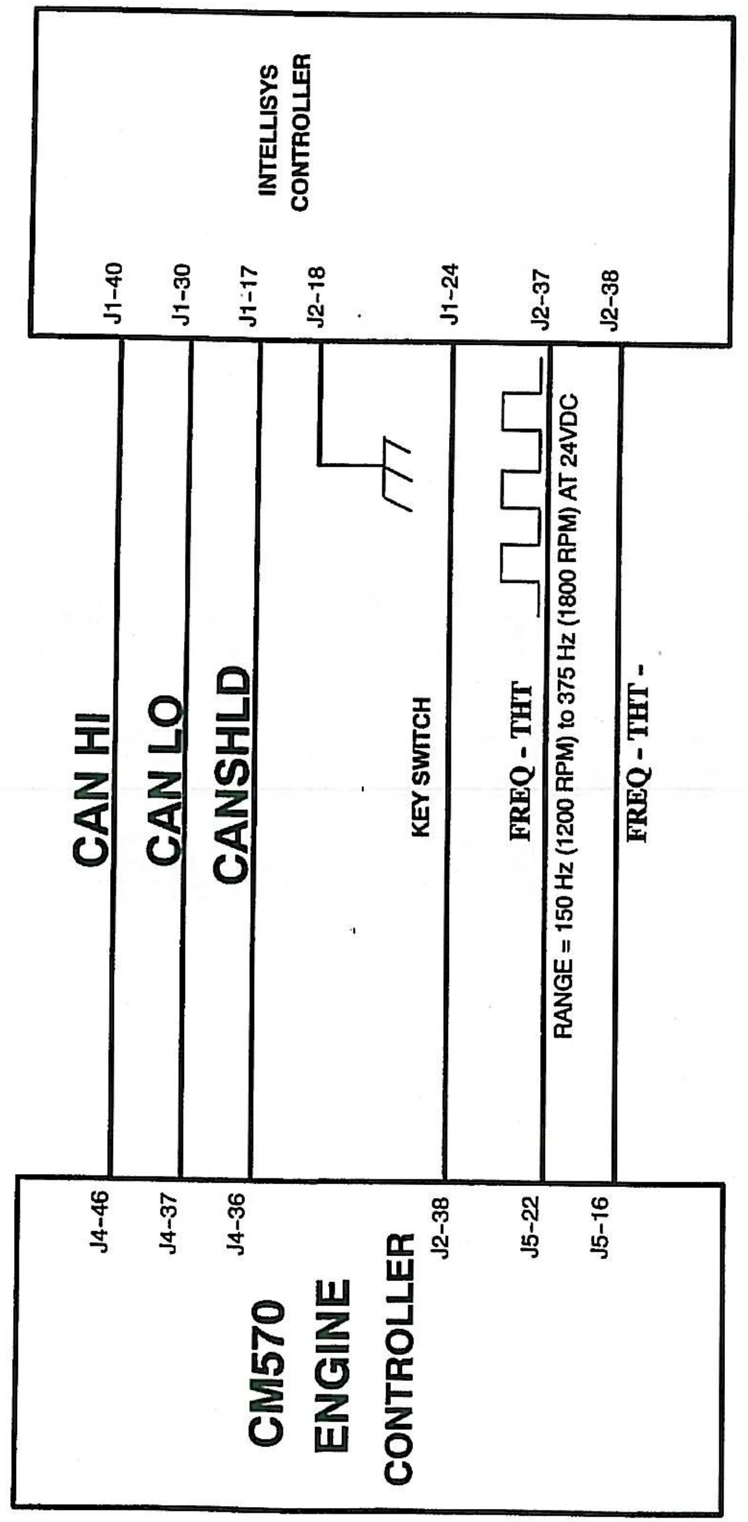
A schematic of an Intellisys system is shown on the following page. This is for the NHP1500 compressor.


NHP-1500 CONTROL SYSTEM
10 / 425 SCHEMATIC
ENGINE CONTROLLER
INTELLISYS CONTROLLER

NHP-1500 PIONEER HARNESS SYSTEM SCHEMATIC



INTELLISYS CONTROLLER TO ENGINE INTERFACE
CUMMINS ENGINE



SECTION 10

COMMUNICATION SYSTEMS

Communication Systems in Off Road Equipment

There are several types of communication systems used in off road equipment. RS232, RS485, J1587 and J1939 CAN are examples. Many electronic systems contain more than one of the types listed. Each of these types has specific advantages and is best suited for certain applications.

RS232 System

The RS232 serial communication system has been in use since the early years of the computer. It is a general purpose serial communications technique for low to medium speed data transfer. Most computing devices have an RS232 port. It speed limitation is 56K baud and it is being superceded in many new computer platforms by a higher through put USB serial port.

RS485 System

The RS485 system is somewhat different than the RS232 system. Its main difference is speed, it can communicate up to 1M baud. It can be a two or four wire system with master / slave protocol. It is basically a current driven physical layer instead of the voltage physical layer of the RS232.

J1587 System

The J1587 system is the predecessor to the J1939 system. It is a serial communications network that operates at 9600 baud. It allows a small number of nodes and has some similarities to the RS232 system.

J1939 CAN System

The J1939 CAN (Controller Area Network) system has been adopted by most diesel engine manufacturers. It is used in automotive as well as off road and marine equipment applications. It is a medium speed network at 1 Mb rate. The CAN physical layer is similar to CAN used in industrial applications.

The J1939 software protocol is a standard provided by the SAE (Society of Automotive Engineers). It has a specific message structure for communications with engines, transmissions, trailers, etc.

SECTION 11

ELECTRONIC ENGINES

What is an electronic diesel engine ?

An electronic diesel engine is a diesel engine using electronics for control of the fuel system and other engine systems. It has an on board ECM (Electronic Control Module) to implement the control functions, alert for faults and shutdowns and log these for historical purposes.

What are the basic features of an electronic engine ?

Depending upon the extent of electronic control, the engine will have an electric fuel pump, electrically activated injectors, camshaft position sensor crankshaft position sensor, ambient air pressure sensor, fuel pressure sensor, timing actuators and fueling actuators. Simple electronic fuel systems may only have a fuel inlet valve under computer control and the injectors are actuated mechanically. Most engines will have temperatures and pressures monitored by the ECM.

Basic Electronic Fuel Injection Operation

All fuel injection systems have similar functions. Some have enhancements but basic functions include delivery of a burst of fuel to each cylinder at the proper time. Some systems control the fuel pump only and other systems control the pump and injectors.

John Deere, Cummins and Caterpillar supply electronics engines to Ingersoll Rand. They all have similar features, but each is unique. They all have an electronic control module with various sensors, depending on system configuration. The following is a list of some of the sensors used and their function:

1. Engine oil pressure sensor –
   Measure engine oil pressure, used in engine derate function by distinguishing between low oil pressure and very low oil pressure.

2. Boost pressure sensor –
   This is the turbocharger outlet pressure which is used in determining the amount of fuel injected.

3. Atmospheric pressure sensor –
   Measures atmospheric pressure, used to determine altitude, used to reduce smoke emissions at different altitudes.

4. Coolant level sensor –

Senses coolant level in the radiator

5. Engine timing sensor –
Used to determine engine speed and timing for fuel injection points.

6. Fuel pressure sensor –
Used to measure fuel pressures in fuel injector rails and other points.

7. Intake air temperature sensor –
Measures inlet air temperature and used to adjust injection timing.

8. Intake manifold pressure –
Measures boost pressure in the manifold and is used to reduce smoke emissions during acceleration.

9. Coolant temperature sensor –
Measures engine coolant temperature, used to determine timing on cold vs. warm engine and for derate function.

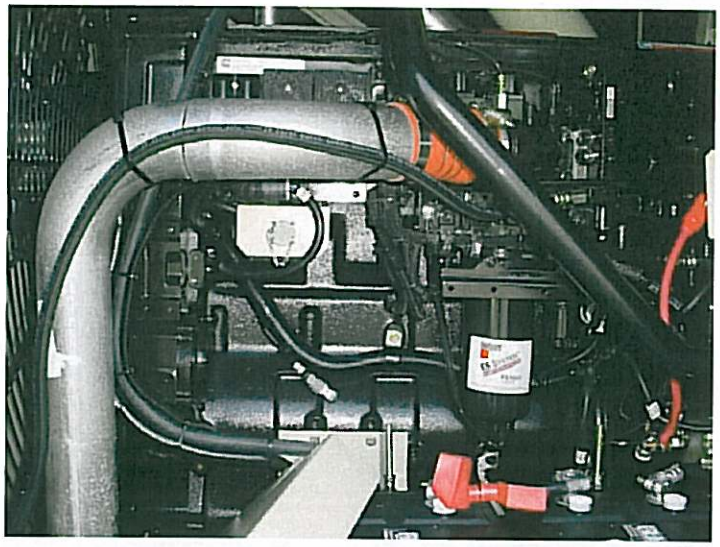
How do electronic engines interface with I-R electronics ?

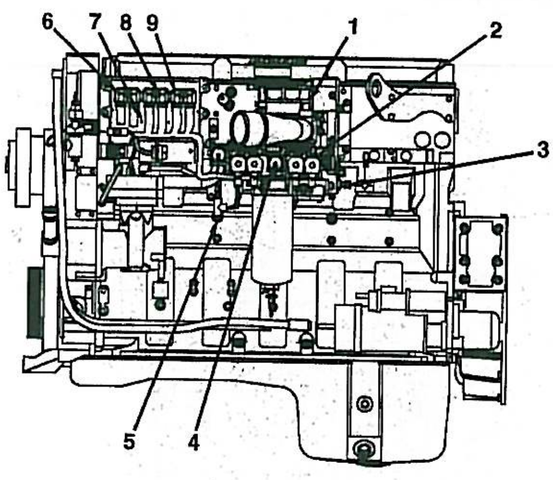
Currently, I-R electronics use two engine interface methods: J1939 CAN and frequency throttle. The J1939 CAN is a communications network that is supplied by all electronic based diesel engine manufacturers. It provides a means of extracting information form the engine such as RPM, pressures and temperatures. It also defines commands that can be sent to the engine to initiate certain actions. The J1939 is a specification created by the SAE (Society of Automotive Engineers) to provided commonality in the market place.

The frequency throttle is an analog method, as opposed to the J1939 which is a digital method, of communicating with the engine. It allows a throttle setting to be sent to the engine. This throttle setting is in the form of a variable frequency or a PWM signal.

Electronic Engine Examples

Shown below is a picture of one manufacturer's 15 liter electronics based engine. The location of the Electronic Control Module (ECM) is shown by the arrow. Most of the ECMs used in these applications are engine mounted.

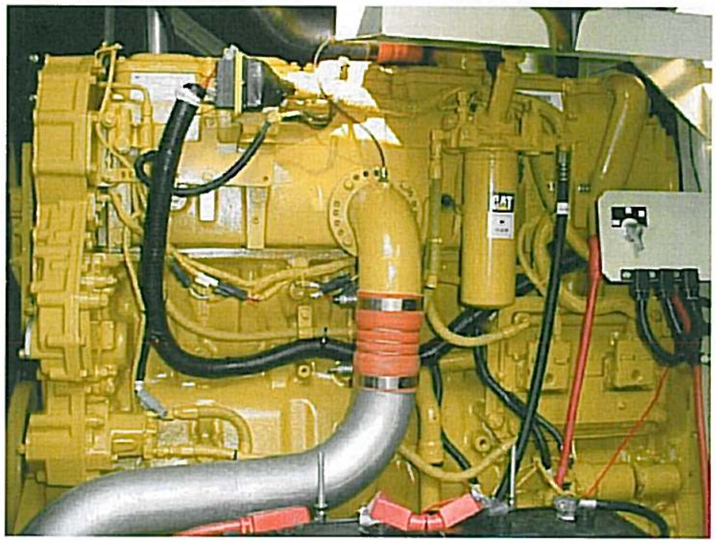




Intake Side

1. Intake Manifold Pressure/Temperature Sensor
2. Fuel Drain
3. Fuel Inlet
4. Fuel Shutoff Valve
5. Oil Pressure/Temperature Sensor
6. ECM OEM Harness Port
7. Electronic Control Module (ECM)
8. ECM Actuator Harness Port
9. ECM Sensor Harness Port.

Here is an example of another engine manufacturer's 15 liter electronics based engine. The arrow shows the location of the ECM.



Component Locations (3126B)

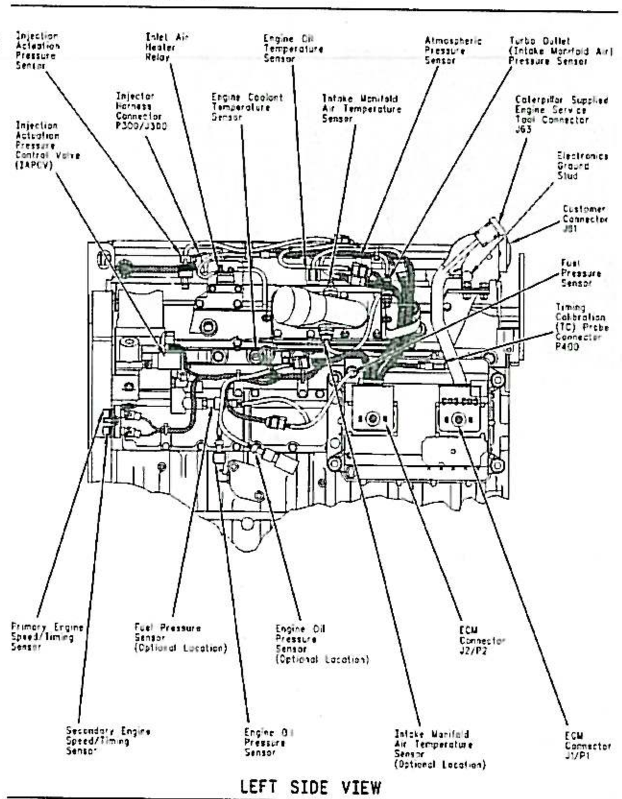


Illustration 3 g00742086

System Component Diagram (MEUI)

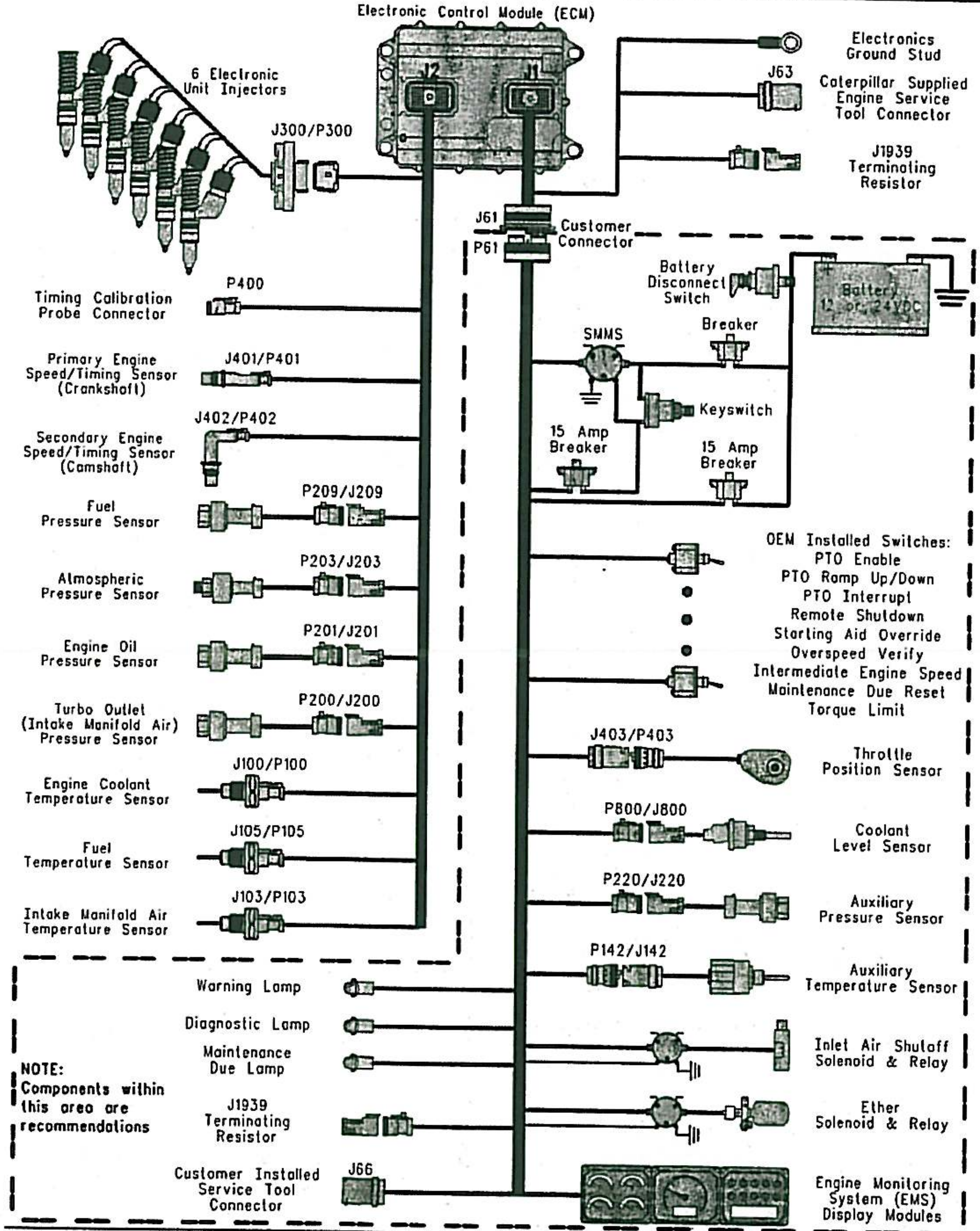


Illustration 2

g00725379

SECTION 12

PDA SERVICE TOOL

What is the PDA Service Tool ?

The PDA Service Tool is a general purpose device that provides the service technician with a terminal to connect the machine controller(s). This terminal can be used to extract fault logs to help diagnose problems, reprogram the controller and configure accessory equipment connected to the machine controller.

PDA Service Tool Features

The PDA Service Tool has the following features implemented:

1. Reprogramming an electronic controller
2. Fault log extraction from an electronic controller
3. J1939 network communications to engine

Controller Reprogramming

Fault Log Extraction

J1939 Network Communications

VIRTUAL TECHNICIAN
Service Tool

USER'S GUIDE

INGERSOLL RAND
PORTABLE POWER
Mocksville, N.C.

Information in this document is subject to change without notice and Does not represent a commitment on the part of Ingersoll Rand Company. The software described in thei document and furnished as part of the service tool is the property of Ingersoll Rand. The software may not be copied or reproduced in any form without the expressed written consent of Ingersoll Rand.

TABLE of CONTENTS

1.0 General Overview

The ***VIRTUAL TECHNICIAN*** is a PDA (Personal Digital Assistant) based service tool. The tool provides the capability to re-program a WEDGE or INTELLISYS controller and extract the fault log from these controllers. The tool also retains all of the functions of the PDA. The Ingersoll Rand functions are a menu option like any other PDA menu option.

The PDA selected for the tool is the Handspring, Inc. Platinum model. It is a basic PDA with 16M of memory. It has the Springboard module interface and throw-away batteries. Below is a picture of the Platinum PDA and RS232 Springboard module.

The protective holster is used to provide some protection from physical damage and bad weather conditions. A handle is provided to allow hanging the unit in a machine or providing a stand so the unit can sit up on a horizontal surface.

The RS232 Springboard module is a custom interface unit that provides a RS232 input to the PDA. Connection through a springboard module provides a reliable connection method. The holster helps hold the springboard module in place. A rugged serial cable is provided to connect the ***VIRTUAL TECHNICIAN*** to the RS232 connector on the machine.

Currently, the ***VIRTUAL TECHNICIAN*** has two functions: 1) controller re-programming and 2) Fault load extraction from controller. Additional features will be added. These will require a simple software upgrade to the PDA, and possibly the machine controller.

Step 3:

The startup screen will appear, click "NEXT" at the bottom right. On the next screen, click in the box beside virtual technician and then click "NEXT". The program will complete the configuration process and a screen will appear indicating it is complete and to run the hot sync manager. Click the "OK" on this screen.

This completes the setup of the loader program.

Step 4:

Remove the PDA from the holster and place it into the cradle. (The hot sync software must already be installed and the PDA cradle connected to your computer). Press the hot sync button on the front of the cradle.

The hot sync process will begin and run until completion. If the process ends with no errors, the next step is to load the ***VIRTUAL TECHNICIAN*** software into the springboard module on the PDA.

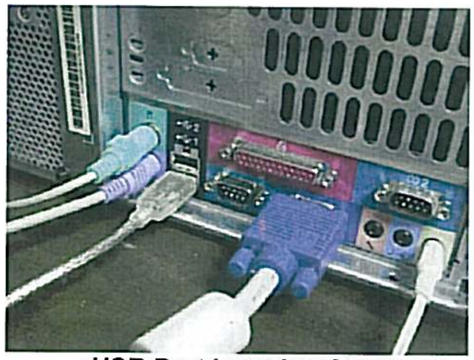
Step 5:

Remove the PDA from the cradle. Tap the "House" symbol on the lower left of the PDA screen. The main menu will appear. Tap the down arrow on the right to go to page 2 of the menu. The Ingersoll Rand logo will appear on the right side. Tap the I-R logo. A screen will appear entitled "SOFTWARE INSTALLATION". Tap "OK" at the lower left.

Another screen will appear entitled "IR Module Flash Updater". Tap the box "Update Now" in the middle of the screen. Another screen will appear entitled "Update Software". Tap "OK" on this screen. This will start the memory programming process. It will take a few seconds to complete.

When complete, a screen entitled "Reset" will appear. Tap the "Reset" in the left corner. This will complete the loading process.

The ***VIRTUAL TECHNICIAN*** is now ready for use.



USB Port Location On PC

5.0 Loading Hex File Into the PDA

The hex file that is loaded into the WEDGE or Intellisys controller is contained on the CD that has the ***VIRTUAL TECHNICIAN*** software. It is loaded at the same time the ***VIRTUAL TECHNICIAN*** software is loaded.

V1.52 software is included with the kit. If this hex file is later changed, a CD will be issued containing the new software.

6.0 Connecting the PDA To A Controller

The black serial cable in the kit is used to connect the PDA to a controller on a machine. One end of the cable has a DB9 style connector that connects to the RS232 Springboard module that is inserted into the PDA. The other end of this cable has a 9-pin Deutsch connector that connects to the serial port connector on the machine. This connector is usually located inside the control panel and usually labeled as J5. This is the only connector on the machine the 9-pin serial cable connector will mate with.

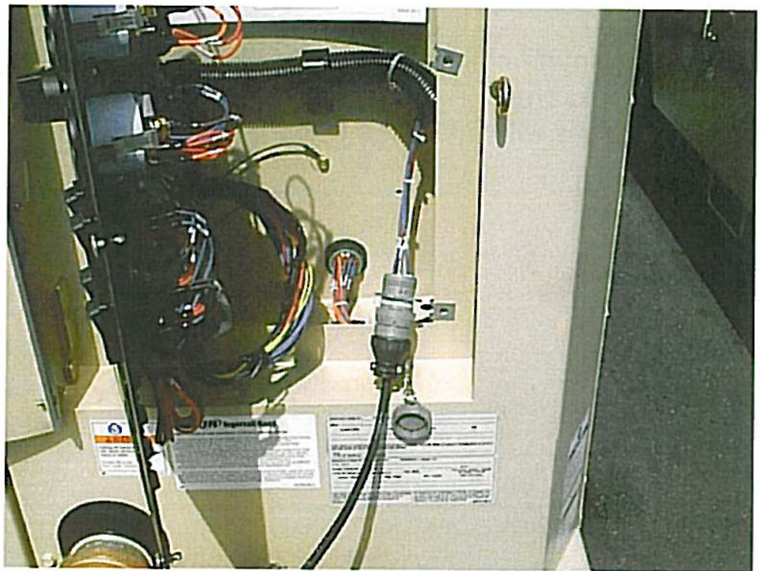
Serial Cable

7.0 Re-Programming a Controller

Before a controller can be re-programmed, the .Hex file for the new version software must be loaded into the service tool. This is done using the PDA cradle connected to a desk or lap top computer. The Hot Sync feature of the PDA is used to transfer the software. Refer to section 5.0 for details on loading the .Hex file.

First, connect the serial cable to the RS232 connector on the machine. This connector is usually located inside the control panel or located as a stub on the harness near the controller. It is a nine pin circular connector with a quarter turn to lock the two halves of the connectors together.

Next connect the other end of the serial cable to the service tool. This will be the nine pin (DB9) on the springboard at the top of the service tool. Screw in the jack screws to hold the connector onto the springboard.



Serial Connector Location

Turn on the service tool by taping the key in the lower left corner with the green dot (Refer to Handspring manual for PDA features), using the stylus. The stylus is stored in the top portion of the holster next to the RS232 connector. Next tap the house symbol that is on the lower left side of the PDA screen. This will display the main menu. The main menu has two pages, so tap the lower part of the down arrow at the right side of the first page to go to the second page of the menu. The arrow appears on the right side of the PDA screen.

The Ingersoll Rand icon will appear on the second page of the main menu. Tap the icon to enter the ***VIRTUAL TECHNICIAN*** software. The screen will display two options: download or fault log. Tap the download box. The version of the hex file will be shown at the top of the screen along with the time and date it was created.

If the serial cable is not connected, a window will appear requesting the serial cable be connected to the machine. If the serial cable is connected, tap the OK box. The service tool will download the hex file into the controller. The records loaded will be counted down on the display as it loads. Loading time is approximately 2.5 minutes for V1.52.

8.0 Fault Log Extraction

The fault log is a record of the last 25 shutdowns that have occurred. It is stored in the controller's non-volatile memory so it is not lost at power down. The current software version numbers the faults and displays the most current fault first. The second most recent fault is displayed next and so on.

A snap shot of the machine parameters are stored with each fault. This snap shot was taken when the fault occurred. The snap shot could be useful in the troubleshooting process, especially with intermittent problems.

The fault log appears as follows:

Fault Log Record Number 1

Parameters

Alarm Code
= 53
IQ Filter Switch
= OPEN
Fuel Alert Switch
= CLOSED
Fuel Shutdown Switch
= CLOSED
Service Air Switch
= OPEN
Air Filter Switch
= OPEN
Air End Oil Pressure Switch
= CLOSED
Estop Switch
= CLOSED
Start Switch
= OPEN
Engine RPM
= 1535 RPM
Reg. System Pressure
= 35 PSI
Sep. Tank Pressure
= 51 PSI
Discharge Temperature
= 95 F
Sep. Tank Temperature
= 65478 F
Target RPM
= 1500 RPM
Machine Type
= 0
Engine Coolant Temperature
= 78 F
Engine Fuel Pressure
= 65535 PSI
Engine Oil Temperature
= 78 F
Engine Oil Pressure
= 47 PSI
Intake Manifold Temperature
= 73 F
Throttle Position

= 49%

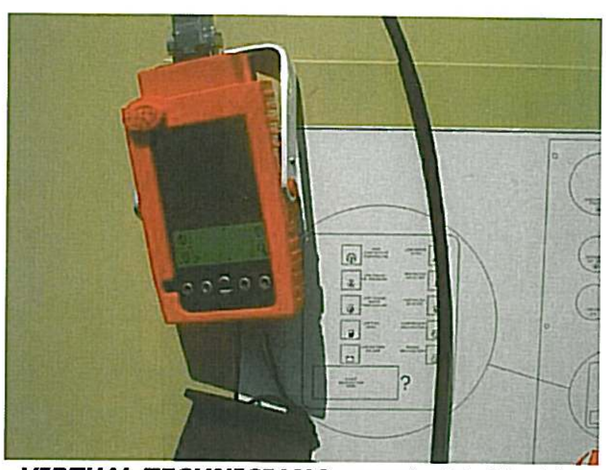
Boost Pressure
= 6PSI
Engine Hours
= 65535
Engine Load
= 34%
Engine Fault 1
= 0
Engine Fault 2
= 0
Engine Fault 3
= 0

The "Alarm Code" is the shutdown code. A list of these can be found in the Electrical/Electronic Service Manual for the particular machine. All switch type inputs have two states: OPEN or CLOSED. Up to 3 engine faults are listed. The engine fault number can be found in the Electrical/Electronic Service Manual with a corresponding explanation.

Anytime a number such as 65XXX appears for the parameter, it means this parameter is not currently monitored. The number 65,535 is an out of range value read by the controller.

There is a box at the bottom of the fault log listing "View Shutdown Code". Tapping this box will show a window with the name of the shutdown code and another box labeled "Troubleshooting". Taping the "Troubleshooting" box will list a description of the fault and information on how to troubleshoot the problem.

Connect the service tool to the machine using the serial cable as described earlier.



***VIRTUAL TECHNICIAN* Connected To Machine**

9.0 PDA Battery Management

Typical battery life on the ***VIRTUAL TECHNICIAN*** should be from 1 to 3 months. This will depend upon usage. A low battery indication is issued by the Platinum PDA. When this occurs, the batteries should be replaced before they go completely dead. The battery indication is shown on the main menu page at the upper left of the screen. There is a picture of a battery. The battery is filled in according to the charge level.

There is an internal capacitor that powers the memory while the main batteries are being replaced. Do not leave the main batteries out of the PDA for any extended period. Once they are removed, replace them with fresh ones immediately. The internal capacitor can power the memory for 1 minute.

The PDA uses two AAA alkaline batteries that are available at many retail outlets. Alkaline batteries are recommended for maximum use time. Standard carbon battery type can also be used.

If the batteries go completely dead, all information entered into the PDA will be lost, EXCEPT FOR THE VIRTUAL TECHNICIAN PROGRAM. It is stored in flash memory in the springboard module. Information stored in the PDA, such as phone numbers and addresses, are saved to the PC using the hot sync process. If they are lost due to dead batteries they can be recovered using hot sync. See the Handspring manual for further information.

SECTION 13
AC GENERATOR THEORY

Objectives

At the end of this lesson you will have reviewed:

1. The basis of AC generator theory
2. The output of a single phase generator
3. Three Phase Generator
4. Phase Rotation
5. Frequency
6. 2 pole and 4 pole output rotor output
7. Simplified Generator Theory

Review of Magnetism and Electricity:

The Relationship

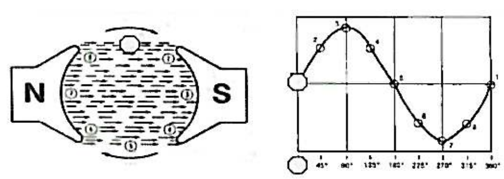
Michael Faraday's discovery of Electromagnetic Induction gave us the key to the practical *generation* of electricity: electromagnetic induction. Faraday discovered that a voltage would be generated across a length of wire if that wire were exposed to a perpendicular magnetic field flux of changing intensity.

By taking that discovery and applying it in a practical manner we used it to produce electrical power with the development of the AC alternator. As previously mentioned that if we take length of wire and expose it to a changing magnetic field we can generate a voltage in that wire.

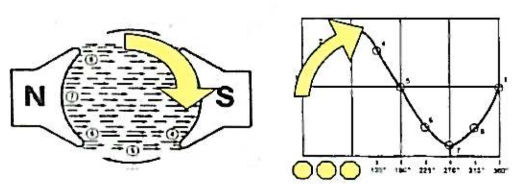
As shown in the illustrations below, we will describe how a single-phase voltage is produced in a stationary field/rotating armature generator. In this application the magnetic field will be stationary and the wire/armature will be moved through the magnetic field.

Development of AC Sinewave

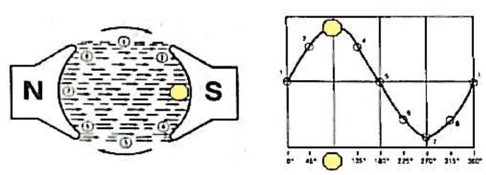
1. Starting at the twelve o'clock position and rotating the armature in the clockwise direction, the armature conductors start to cross the magnetic lines of flux.



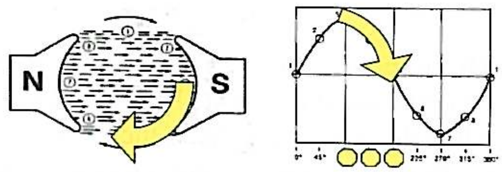
2. As the armature continues to cut more lines of magnetic flux a larger voltage is generated into it as shown by the illustration at the right. Such that when the armature is at the three o'clock position it is in strongest part of the magnetic field and the highest voltage is generated andthe peak positive voltage is obtained (90° on the sine wave).



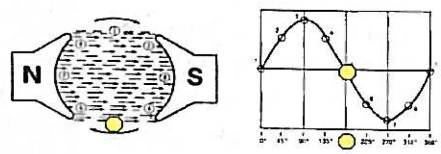
3. As the armature begins to rotate from the three o'clock to the six o'clock position the armature begins to cut less and weaker lines of magnetic flux.



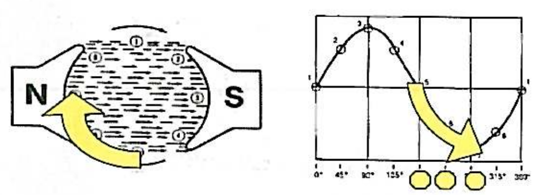
4. So that less voltage is generated into the armature and the voltage begins to drop to zero volts at the 180° point of the sine wave.



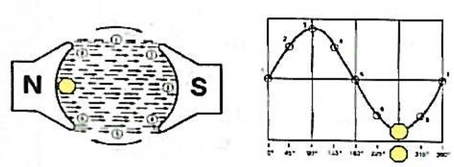
5. Now that the armature is at the six o'clock position and is not cutting any lines of flux voltage is zero. It now continues to rotate to the nine o'clock position and starts to cut the lines of magnetic flux in increasing intensity and voltage begins to develop but in the opposite polarity (negative).



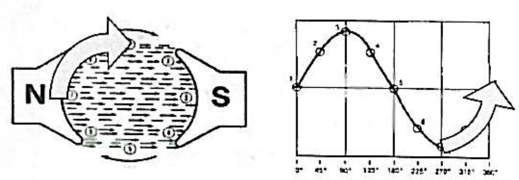
6. As the armature rotates towards the nine o'clock position voltage begins build as it begins to cut stronger lines of magnetic flux. Such that when it reaches the nine o'clock position the voltage is at its peak negative voltage at 270° on the sine wave.



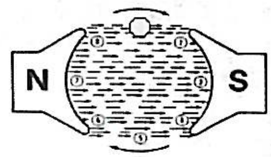
7. Once again the armature has cut the strongest lines of magnetic flux and has achieved the maximum negative voltage.

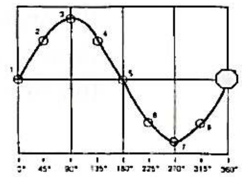


8. Now the armature continues to rotate from the nine o'clock position to the twelve o'clock position it begins to leave the strongest concentration of magnetic flux and voltage will decrease as it travels clockwise out of the magnetic field.



9. The armature has completed one complete revolution and one cycle has been generated when the armature reaches the twelve o'clock position and no longer cuts any magnetic lines of flux.





Single Phase Generator and Output

At the left is schematic showing a two-phase generator with a two-pole rotor. By tracing out the windings you will notice that they are wound such that when a pole passes each one that a voltage that is equal in polarity is developed in both windings.

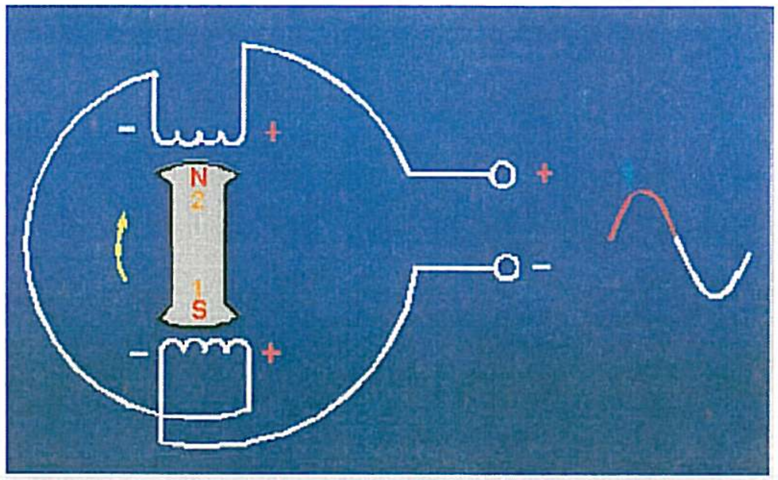


Figure 3-5.—Single-phase alternator.

Three Phase Generator and Output

In a three-phase generator there are three sets of windings that are physically spaced 120° from each other. As rotor passes each set of windings a voltage is generated in those windings with resultant out put of each sine wave being electrically 120° out from each other.

The two connections shown here are the common connections for the output of an AC generator; wye and delta. In our genset we use the wye configuration to allow using three phase and

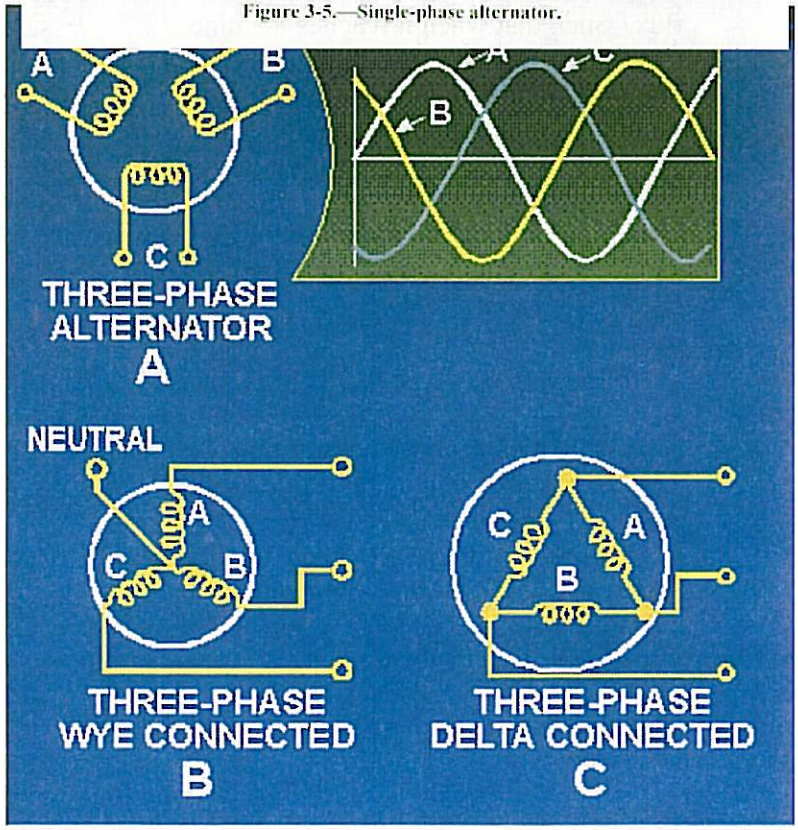
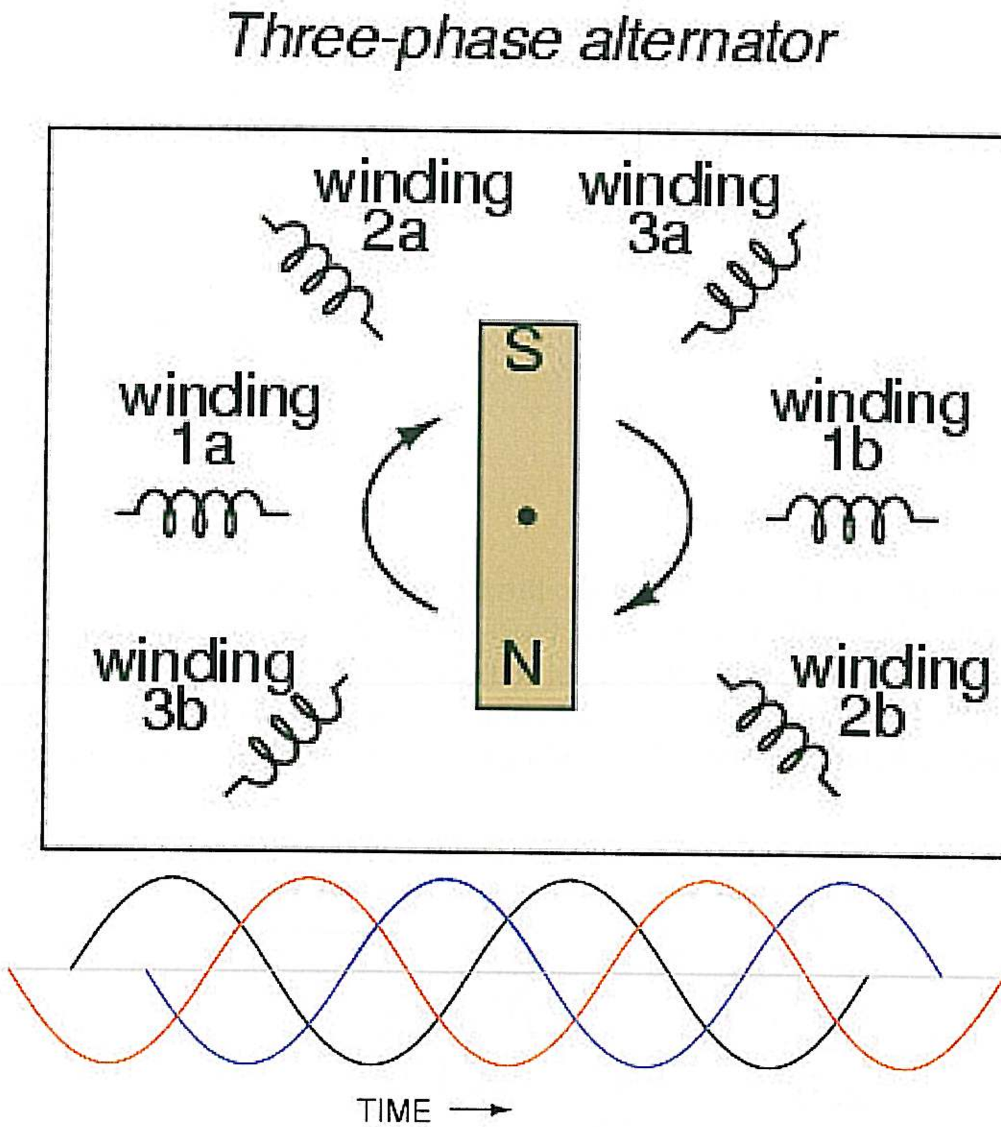


Figure 3-8.—Three-phase alternator connections.

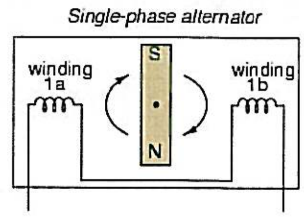
single phase power off of the generator.

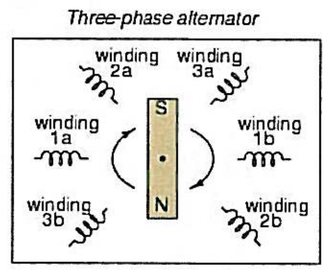
3 Phase WYE (Y) Connection



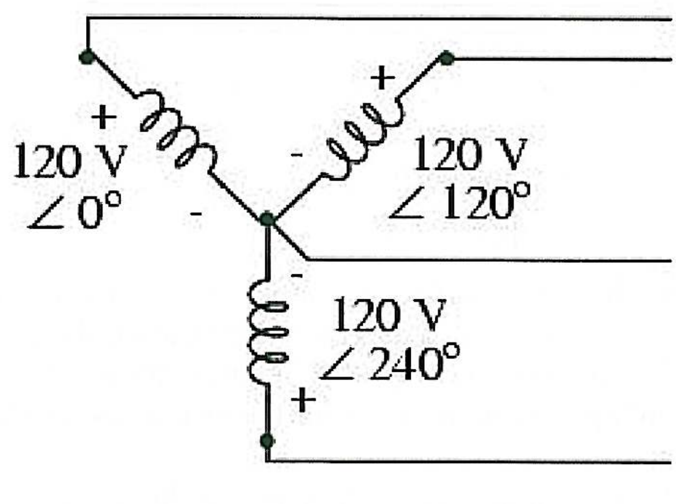
The best way to get the phase shifts we're looking for is to generate it at the source: construct the AC generator (alternator) providing the power in such a way that the rotating magnetic field passes by three sets of wire windings, each set spaced 120° apart around the circumference of the machine:

Together, the six "pole" windings of a three-phase alternator are connected to comprise three winding pairs, each pair producing AC voltage with a phase angle 120° shifted from either of the other two winding pairs. The interconnections between pairs of windings (as shown for the single-phase alternator: the jumper wire between windings 1a and 1b) have been omitted from the three-phase alternator drawing for simplicity.





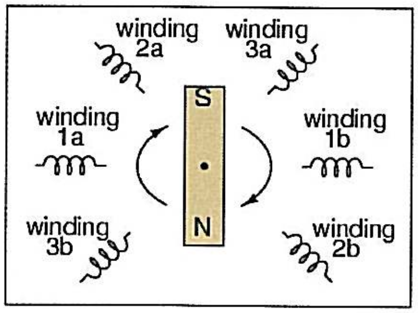
In our example circuit, we showed the three voltage sources connected together in a "Y" configuration (sometimes called the "star" configuration), with one lead of each source tied to a common point (the node where we attached the "neutral" conductor). The common way to depict this connection scheme is to draw the windings in the shape of a "Y" like this:



Phase rotation

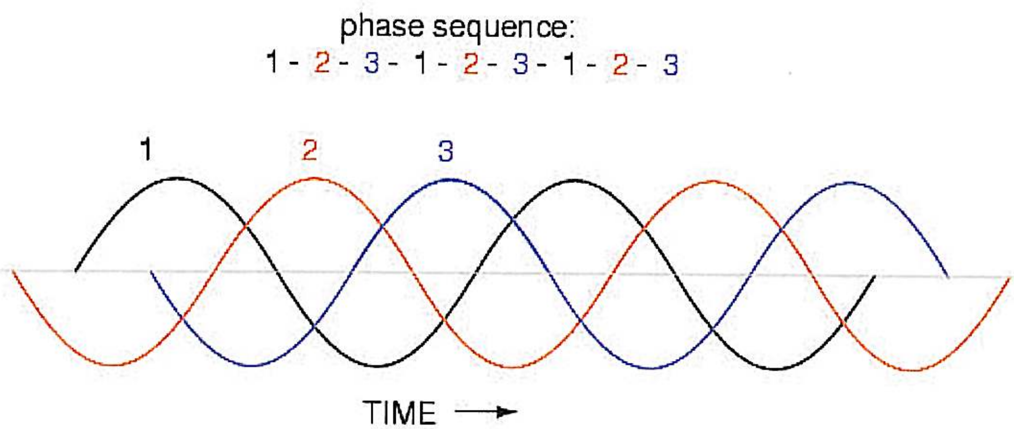
Let's take the three-phase alternator design laid out earlier and watch what happens as the magnet rotates:

Three-phase alternator

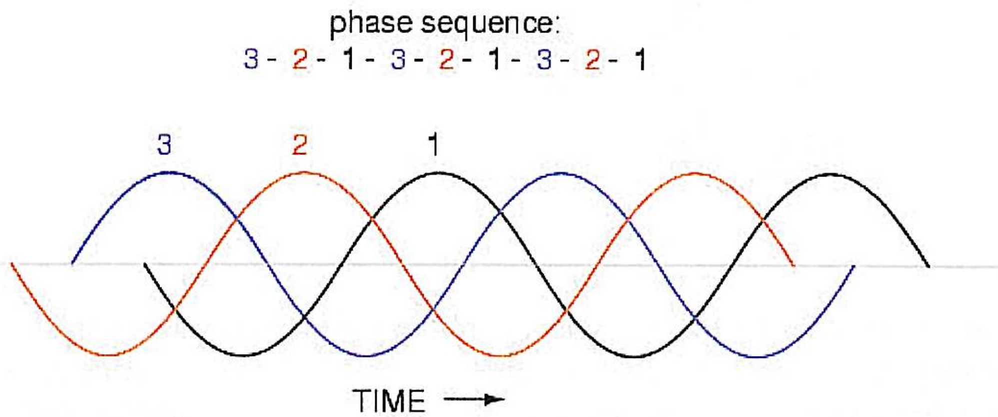


The phase angle shift of 120° is a function of the actual rotational angle shift of the three pairs of windings. If the magnet is rotating clockwise, winding 3 will generate its peak instantaneous voltage exactly 120° (of alternator shaft rotation) after winding 2, which will hit its peak 120° after winding 1. The magnet passes by each pole pair at different positions in the rotational movement of the shaft. Where we decide to place the windings will dictate the amount of phase shift between the windings' AC voltage waveforms. If we make winding 1 our "reference" voltage source for phase angle (0°), then winding 2 will have a phase angle of -120° (120° lagging, or 240° leading) and winding 3 an angle of -240° (or 120° leading).

This sequence of phase shifts has a definite order. For clockwise rotation of the shaft, the order is 1-2-3 (winding 1 peaks first, then winding 2, then winding 3). This order keeps repeating itself as long as we continue to rotate the alternator's shaft:

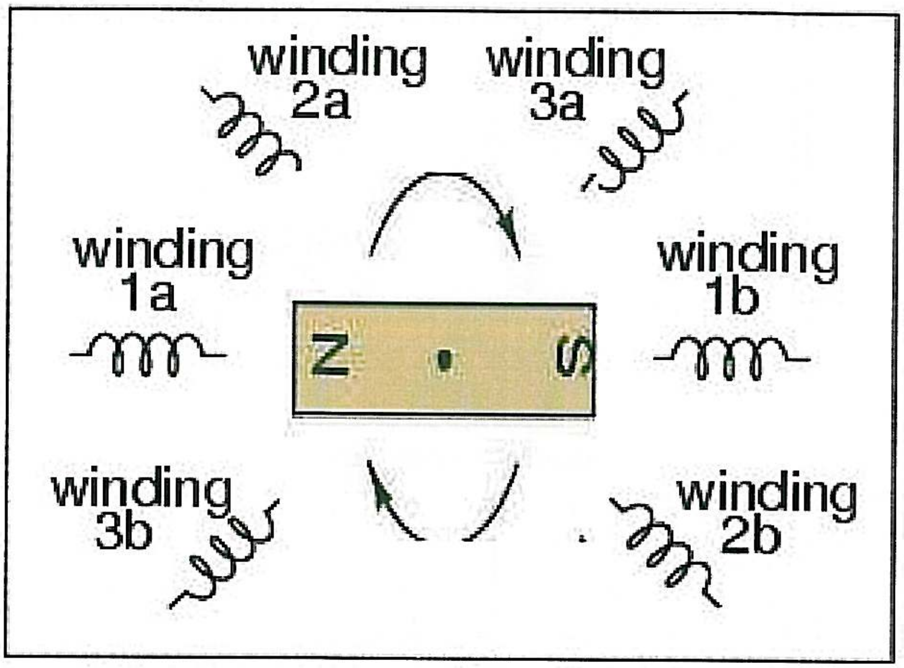


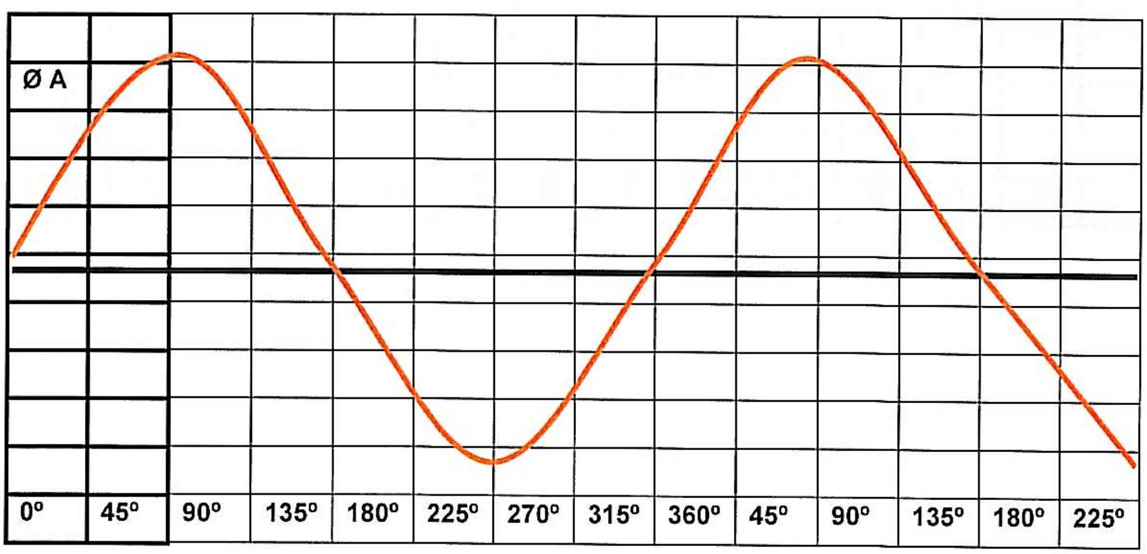
However, if we *reverse* the rotation of the alternator's shaft (turn it counter-clockwise), the magnet will pass by the pole pairs in the opposite sequence. Instead of 1-2-3, we'll have 3-2-1. Now, winding 2's waveform will be *leading* 120° ahead of 1 instead of lagging, and 3 will be another 120° ahead of 2:

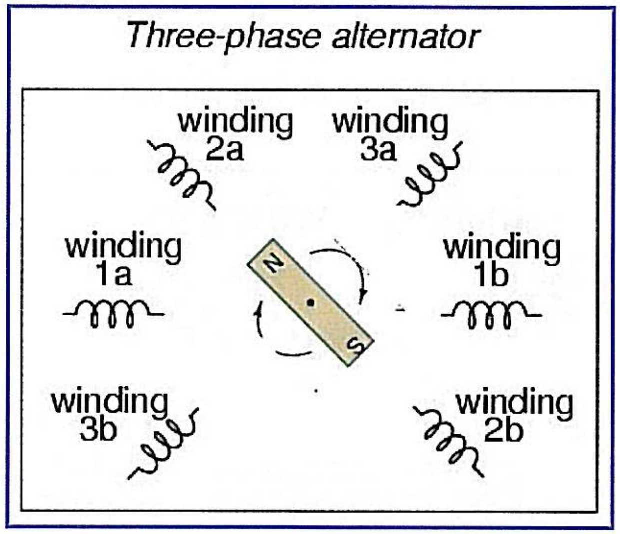


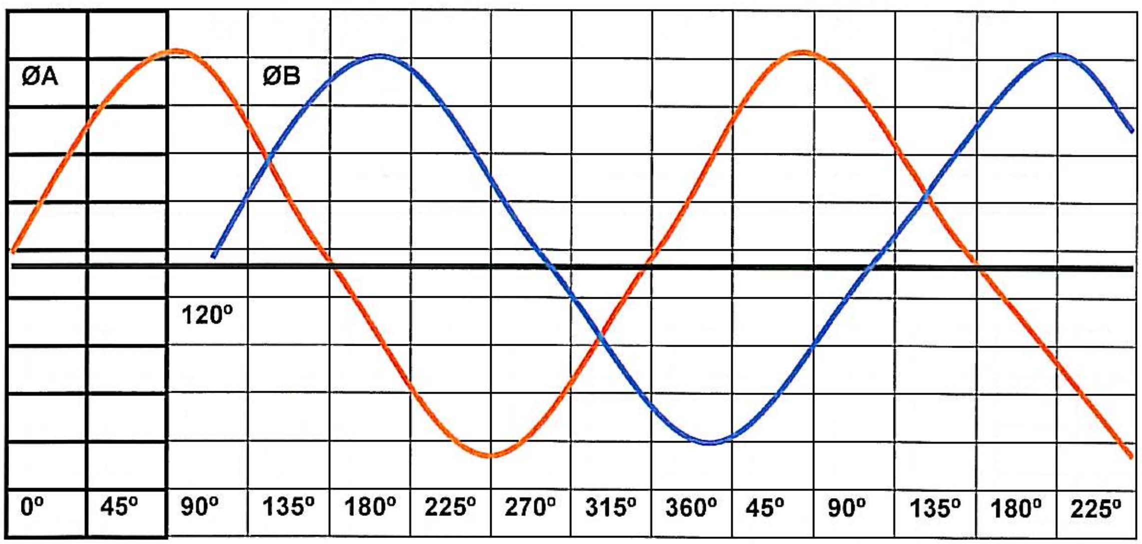
The order of voltage waveform sequences in a polyphase system is called *phase rotation* or *phase sequence.*

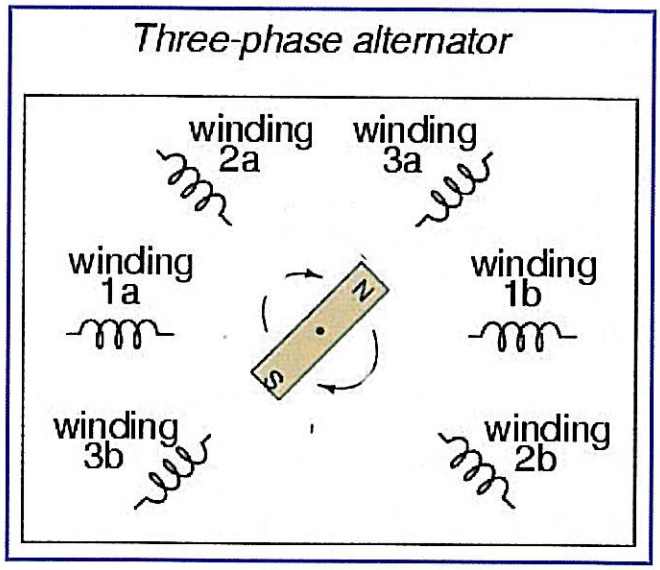
Three-phase alternator

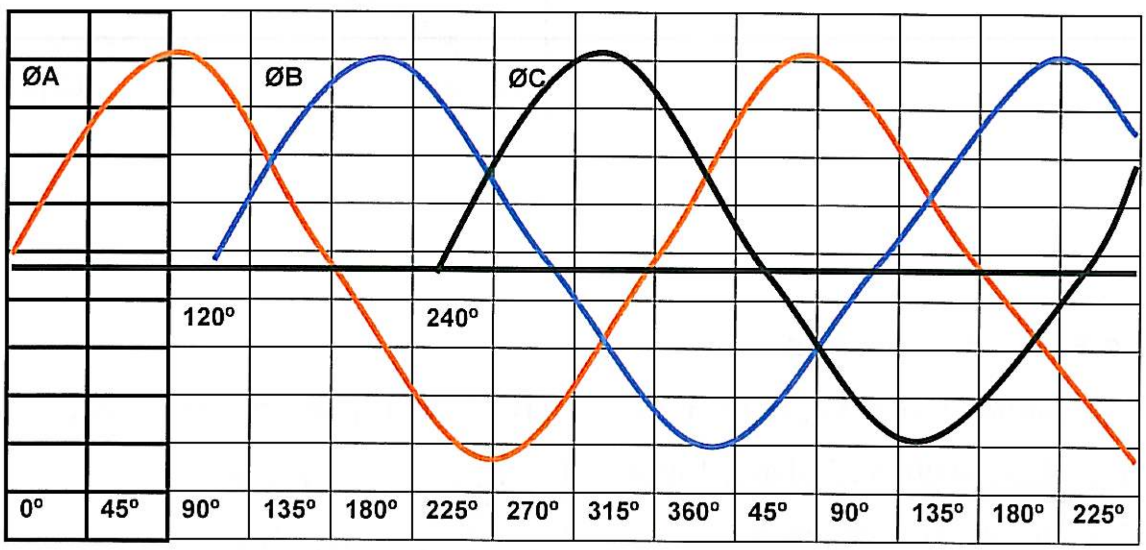





Three-phase alternator
winding 2a
winding 3a
winding 1a
winding 1b
N
S
winding 3b
winding 2b


ØA
ØB
120°
0°
45°
90°
135°
180°
225°
270°
315°
360°
45°
90°
135°
180°
225°


Three-phase alternator
winding 2a
winding 3a
winding 1a
winding 1b
winding 3b
winding 2b
N
S


ØA
ØB
ØC
120°
240°
0°
45°
90°
135°
180°
225°
270°
315°
360°
45°
90°
135°
180°
225°

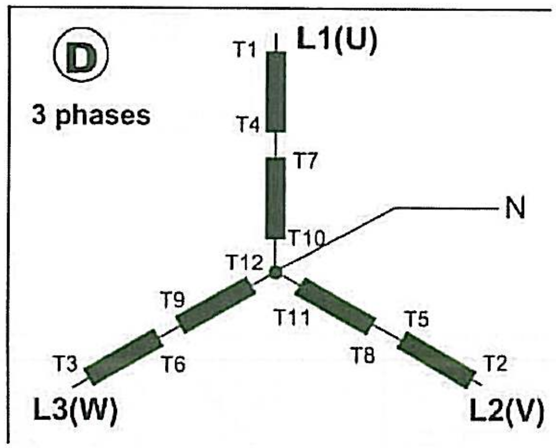
IR Winding Configurations

IR Gensets use six sets of windings with twelve leads to form three winding configurations to obtain different voltages.

480 VAC 3 Ø	G20 - G575 - High Wye
208 VAC 3 Ø	G20 - G575 - Low Wye
240 VAC 2 Ø	G20 - G190 - Zig Zag

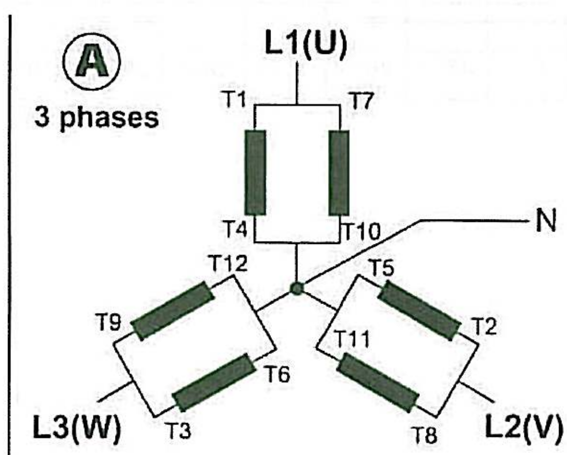
High Wye Connection

For Nominal 277/480V, 3Ø, 4W which means 277 volts phase to neutral, 480 volts phase to phase, 3 phase, and 4 wire industrial and sub-distribution voltage



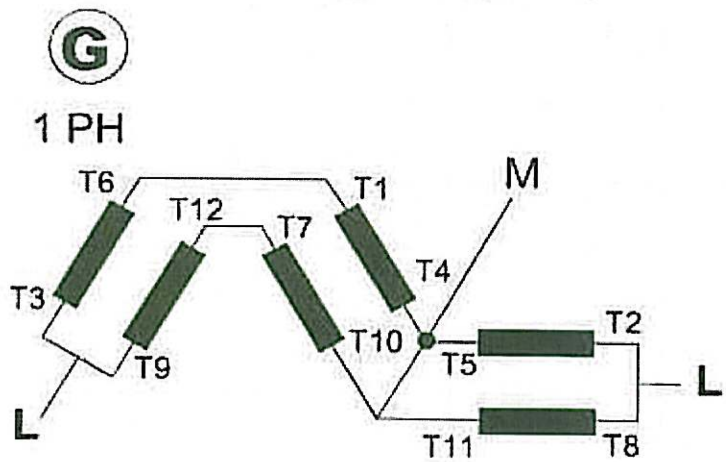
Low Wye Connection

For Nominal 120/208V,3?,4W which means 120 volts phase to neutral, 208 volts phase to phase, 3 phase, 4 wire User voltage, very common



Zig-Zag

For Nominal 120/240V,1Ø,3W which means 120 volts phase to neutral, 240 volts phase to phase, single phase, 3 wire
Light commercial, industrial, and residential where 120V is heavily used.
This configuration usually reduces generator efficiency



LM voltage = 1/2 LL voltage

Frequency

Frequency is the term used for the rate of change AC voltage and current from zero to a maximum positive value to maximum negative value and back to zero over a period of time, which is called one cycle. The unit of measure is Hertz, (Hz) which is equal to one cycle per second.

One cycle per second (CPS) is one Hertz (Hz)

US Standard is 60Hz

Other standards exist in other countries (ie 50Hz)

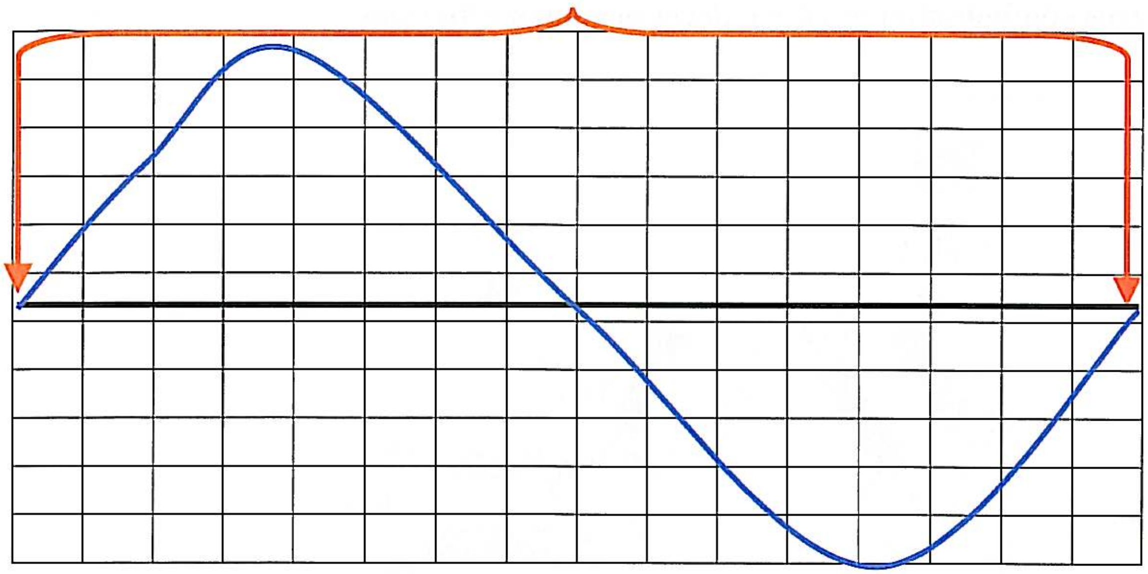
400Hz for flight line and onboard avionics

With a 2-pole generator, engine speed of 3600RPM gives 60Hz output and engine speed of 3000RPM gives 50Hz output.

With a 4-pole generator, engine speed of 1800RPM gives 60Hz output and engine speed of 1500RPM gives 50Hz output.

One Cycle of 60Hz AC

1 Hertz or Cycle



Output from a 2-pole generator for one rotation of the rotor

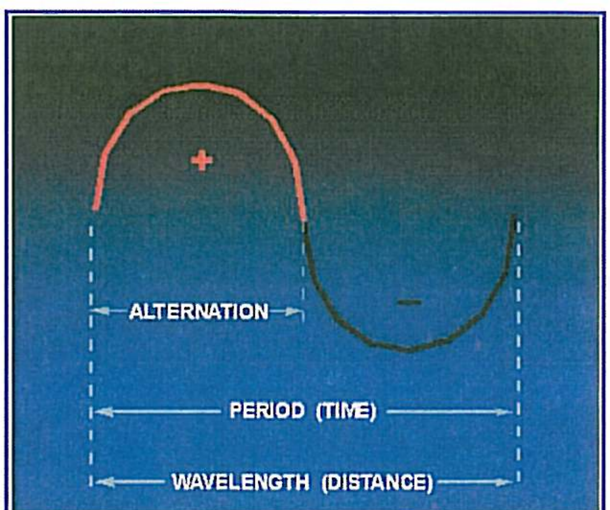


Figure 1-11.—Wavelength.

Output from a 4-pole generator for one rotation of the rotor

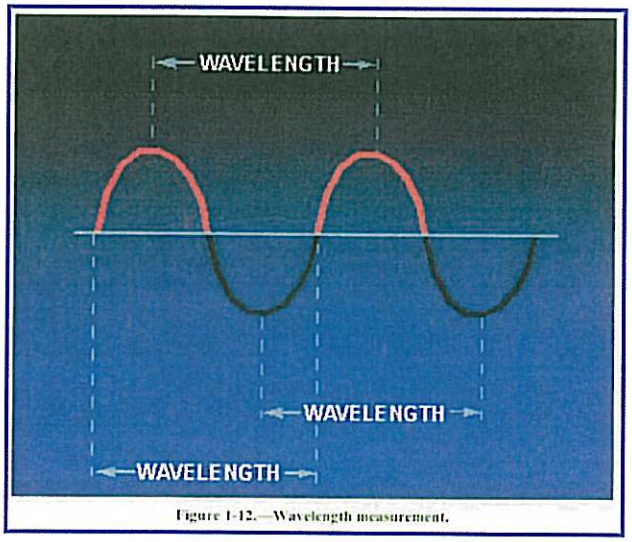


Figure 1-12.—Wavelength measurement.

Frequency = f

$$f = \frac{N \times P}{120} = \text{Hertz (Hz)}$$

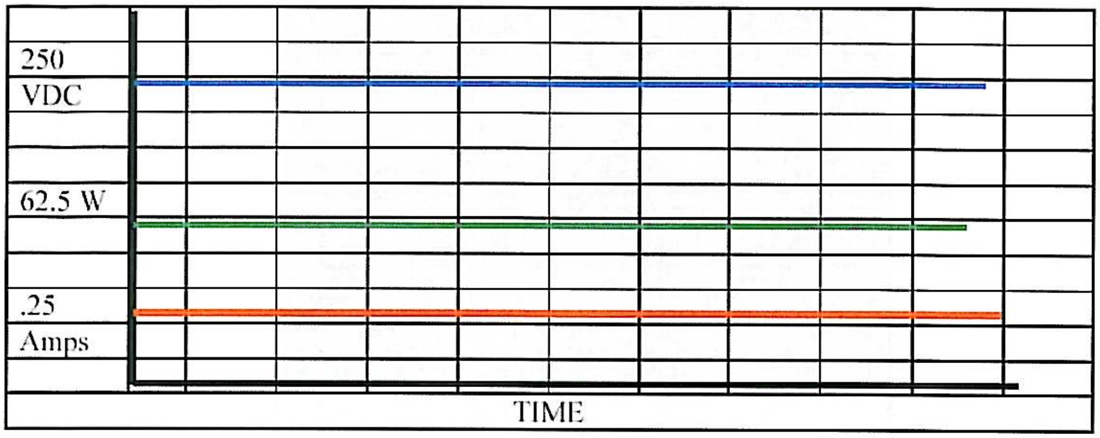
- Number of poles = P = 4
- Engine speed = N = 1,800 rpm

$$f = \frac{4 \times 1{,}800}{120} = 60 \text{ Hertz (Hz)}$$

(For our machines 30 RPM = 1 HZ, 1800 RPM / 60Hz = 30 RPM/Hz)

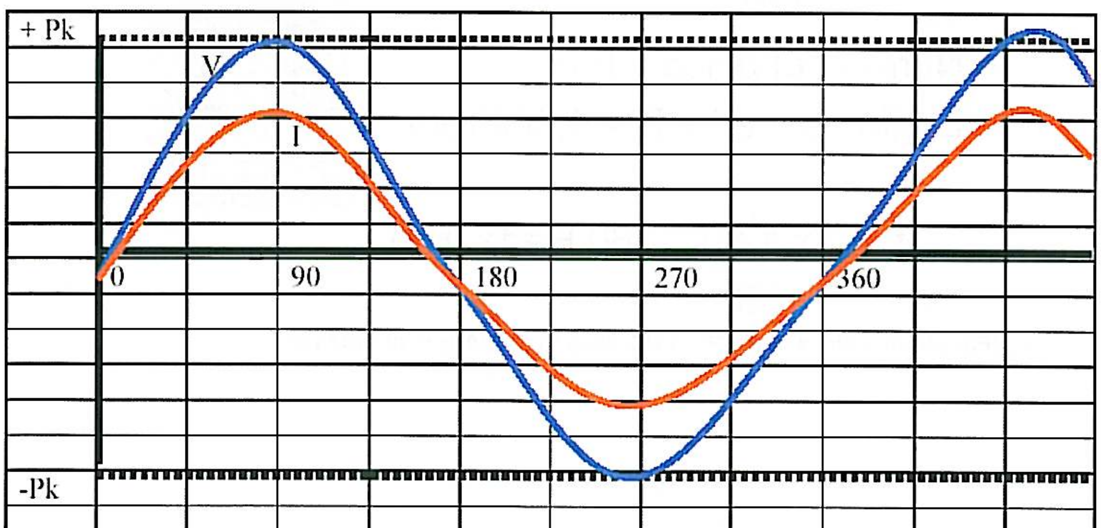
AC Current, Voltage and Power

In the illustration below a 250 VDC source is supplying 0.25 amps for a power output of 62.5 watts or 0.0625 kW (kilowatts).



In DC circuits power is calculated by Power = volts X amps or P = EI.
Since voltage and current are constant over time then power is constant over time.

In AC circuits, during one cycle or hertz voltage and current are going from zero to some maximum positive peak value back to zero then to a maximum negative value and back to zero. Then power is also following the same value as voltage and current and its value changes over time.



Voltage and Current Relationship in a purely restive circuit. 1.0 pf

In order to make measurements that are meaningful, we look at RMS values for AC quantities. RMS stands for Root Mean Square and simply means that looking at a standard meter the voltage or current reading is 0.707 of the peak value of the voltage or current in the sine wave.

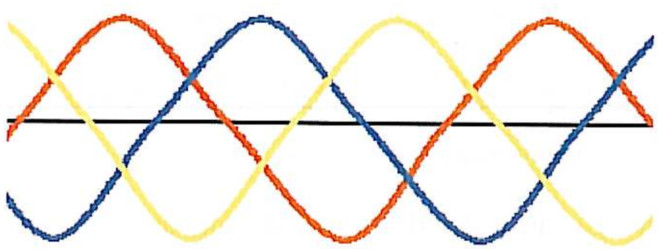
This RMS value of AC is equivalent to the DC value of voltage and current in a resistive circuit. In other words the calculated from the readings on a AC meter is equal to the power produced in a DC circuit for the same voltage and current.

The same power equation used for DC circuits can also be applied to single phase AC circuits.

So that a light in single phase 120 VAC circuit drawing 10 amps is using 1200 watts.

Power = E X I > 120 VAC X 10 amps = 1200 watts or 1.2 kW

In a three-phase circuit, there are three instantaneous voltages and current values at any given time. So to be able to calculate power in a three-phase circuit we use the square root of 3 or 1.732 to take the three phases into account within the equation.



So for a three-phase 208 VAC circuit with a three-phase motor drawing 10 amps the power consumed would be 3602.6 watts or 3.6026 kW.

Power = E X I X 1.732
Power = 208 VAC X 10 amps X 1.732
Power = 3602.6 watts or 3.6026 kW

Apparent Power and True Power

When we look at a nameplate rating for a motor, a generator, etc. we normally find a kVA rating and a kW rating along with voltage, current, number of phases, etc. The kVA rating is the apparent power rating and the kW rating is the true power rating.

The kVA rating is calculated by using the formula that we used above P = EI for single phase and P = EI 1.732 for three phase systems. This is the apparent power of the system.

When you look at a generator's kVA rating, you are seeing the current rating of the generator when supplying a system with a purely resistive load, which is a system without any capacitive or inductive elements in it. Under these conditions this the maximum current that the generator could produce for the rated voltage. This is the apparent power of the generator.

However, there are not any purely resistive electrical systems. Some may be more resistive than others, some may be more inductive than others, and some even be more capacitive than others, but there is not a system that is purely, resistive, inductive, or capacitive. Every conductor contains some value of resistance and inductance, and depending on the construction of the system the conductors themselves can produce a capacitive effect.

First lets discuss inductive and capacitive circuits. An inductive circuit contains and inductor in it. Electrical components such as motors, solenoids, lamp ballasts, etc. are inductors. A capacitive circuit contains capacitors, which is exactly what they are an electrical device for storing energy. In fact inductors and capacitors are both energy storing devices and do not do any work or consume actual power.

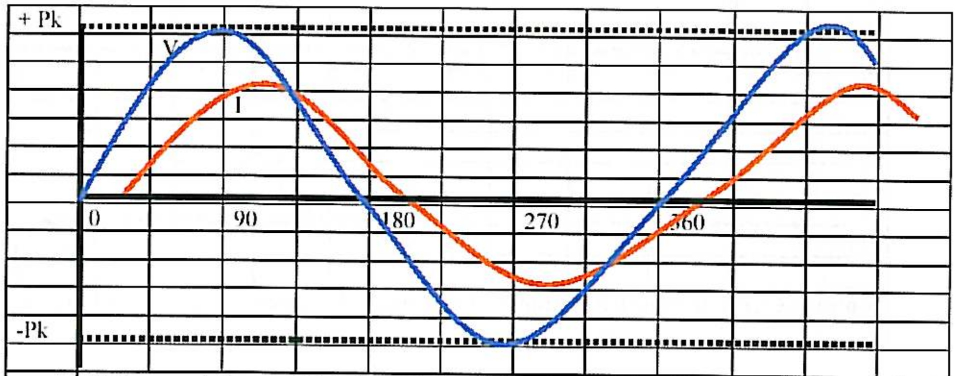
However, they do affect the power output of a generator. Since they do not do work but store energy they use a part of the generators output that is not actively used in producing power and is not seen by the instrumentation.

Inductance is the characteristic of an electrical circuit that opposes the starting, stopping, or a change in value of current and in a inductive circuit voltage leads current. Inductance is found in the windings of motors, solenoid coils, and lamp ballast's, anywhere there is a coil of wire or conductors' inductance will affect the system. Energy is stored in the form of a magnetic field in an inductor and a portion of the generator output is used to produce and maintain that magnetic field. In an inductive circuit voltage will lead current in the system in that the voltage must build the magnetic fields before current will flow, and if current stops to flow then the magnetic field will start collapse to support current flow.

As we discussed previously, voltage is generated in a conductor by the changing intensity of a magnetic field imposed on that conductor. In an inductor as the voltage in a AC circuit changes in a cycle, the magnetic field in an inductor is also changing. It goes from a maximum strength to a minimum strength through every half cycle. That magnetic field is cutting the conductors that it is surrounding and generating a voltage in that conductor every time is goes from maximum strength to minimum and back to maximum. So a counter voltage is also generated in that conductor to maintain current flow.

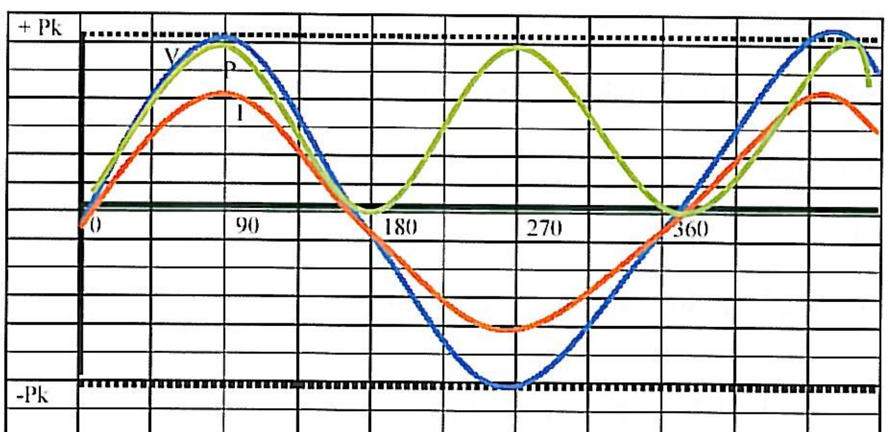
If there were a purely inductive circuit current would lag voltage by 90°, but in reality the majority of circuits are only partially inductive such that current lags voltage by about 37°. That angle is referred to as the cosine θ and when trigonometric functions are calculated it has a value of 0.8, or 0.8 lagging (current lags voltage by 37°. That value is called power factor (pf), or in this case a 0.8 lagging power factor. Which is the amount of usable power that can be taken from a generator. Which is called true power.

The illustration below represents a single phase with a 0.8 lagging pf, as you can see current lags voltage by 37°.



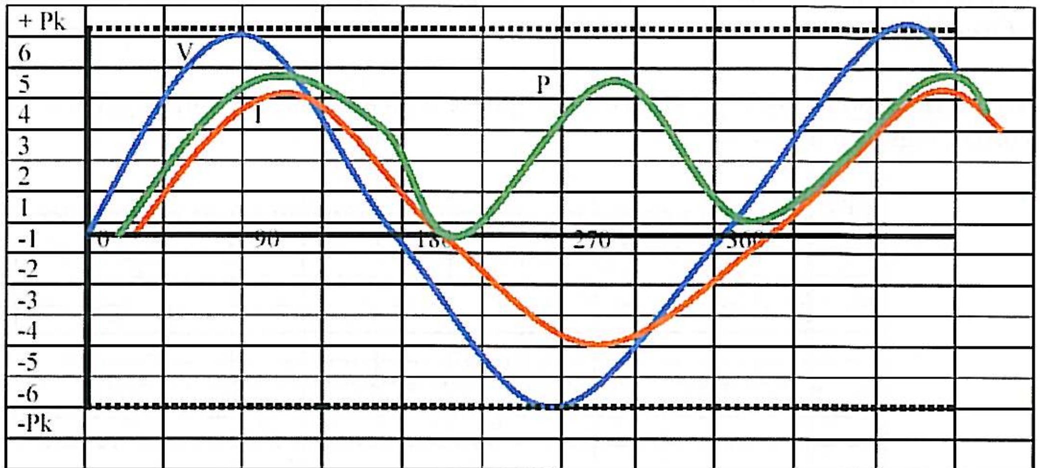
Voltage and Current Relationship in a inductive circuit with a 0.8 pf lagging

As we previously mentioned, in a purely resistive circuit current and voltage are in phase with a 0° phase angle, which would be a 0 pf. At any point and time when power is calculated the maximum value of voltage and current can be used. So that actual output of the generator is equal to its voltage and current rating. So its apparent power is equal to its true power or the power available to do work.



Voltage and Current Relationship in a purely restive circuit. 1.0 pf

In an inductive circuit with a 0.8 lagging pf, current and voltage are never at their maximum peaks at the same time. So at any point in time on the sine wave the full power of the unit is not available and is reduced by twenty percent.



Voltage Current Power Relationship in a inductive circuit with a 0.8 pf lagging

So to calculate True Power, power factor must be taken in account and used in the power equation. So that True power whose units are watts is P = E x I x pf for a single-phase system and P = E x I x 1.732 x pf for a three-phase system.

CAPACITANCE is similar to inductance because it also causes storage of energy, but it is not as much of a factor as inductance and is basically ignored. Since the majority of capacitors used are small in comparison to the inductive qualities found in most systems.

So now we have two ratings to look at for a generator its kVA rating and kW rating or Apparent Power and True Power. Where:

kVA = E x I for a single phase system

kVA = E x I x 1.732 for a three phase system

and

kW = E x I x pf for a single phase system

kW = E x I x 1.732 x pf for a three phase system

Another rating that needs to be looked at is the engine horsepower or brake horsepower, that rating is directly proportional to the kW rating of the generator. The conversion factor from horsepower to kW is 0.746 hp/kW. Such that a generator rate at 20 kW at a 0.8 pf lagging, should have an engine with at least 27 bhp, with a kVA rating of 25 kVA.

SECTION 14

INTELLISYS FOR STANDALONE GENERATORS

Intellisys
For
Stand Alone Systems

<u>For Training Use Only!</u>

Always refer to the applicable technical manual when operating or working machinery.

Intellisys for Stand Alone Systems/Backup Power

Introduction

The Intellisys controller provides the means to start, stop, monitor and protect the engine and generator. This can be done in the manual mode, or standby/automatic mode. The controller consists of a CB12 Board and a display unit.

The controller / CB12 board is a programmed micro-controller that provides control, instrumentation, and protection via inputs from the generator and engine. It is also programmable in that the numerous functions and setpoints can be changed or adjusted.

Description

The Intellisys is standard on all S models, and the same panel used on all models

Advantages

- 1% Voltage accuracy
- Twice the accuracy of mechanical meters
- 0.3% Frequency accuracy
- Six times the accuracy of mechanical meters
- Multiple languages
- Simultaneous information display
- Memory
- Last 25 actions / diagnostics and
- Last 50 alarms / faults for troubleshooting
- Easy to read diagnostics
- Screen will indicate up to three shutdowns and alarms simultaneously.
- Records last fifty alarms and faults
- Records last twenty-five actions
- Alarm lights for
  - Low oil pressure
  - High coolant temperature
  - Over Speed
  - Over Cranking

Charging Alternator

Auto start package can be fitted without changing the panel

Tamper-proof hour meter

Emergency Shutdowns & Alarms

Engine water temperature ....shutdown

Engine oil pressure......................................shutdown

Engine overspeed ....shutdown

Engine Over Crank.....................................shutdown

Alternator voltage ....alarm (min/max +/- 5%)

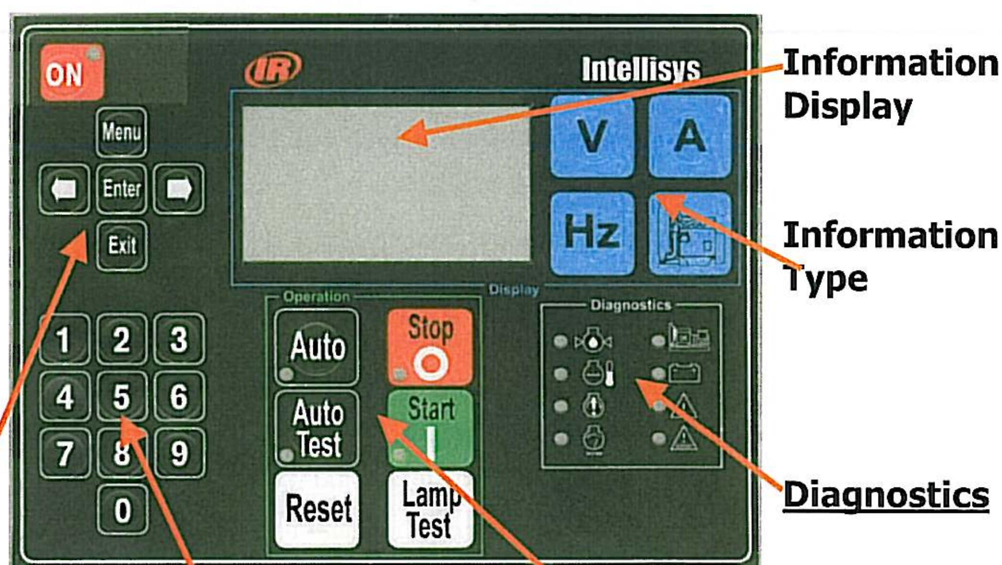
Alternator Voltage High.............................Shutdown

Battery voltage ....alarm (min 12% / Max 20%)

Alternator frequency ....alarm (min/max +/- 4%)

Low fuel level..shutdown

Overload ....alarm (Breaker setting)



Intellisys Display Unit

The Intellisys display consists of a display screen where operational, alarm, fault, and programming information can be displayed.

The display shown above is called the normal display and shows fuel level, RPM, and Battery Voltage, and system status.

Information Display Keys - Upper right hand corner and to the right of the display screen.

V - When the V button is pressed the first time, it will display phase to phase voltage values. When it pressed the second time it displays phase to neutral voltages or single-phase voltages. To return to the normal screen press the engine button.

A - When the button is pressed the first time, it will display phase amps for each leg of the generator. The second time that it is pressed, it will indicate the amps on the neutral leg. To return to the normal screen press the engine button.

Hz - When the Hz button is depressed the display will indicate frequency in Hz and run time in hours and minutes. To return to the normal screen press the engine button.

The Engine Symbol - Normal indication is of fuel level, engine speed in rpm, and battery voltage. When it is pressed the first time, oil pressure and water temperature will be displayed in Bar and degrees Celsius. The second time that it is pressed, oil pressure in psi and water temperature in degrees Fahrenheit is displayed. The third time that it displayed it will return to the normal screen.

> **Note:** Anytime a screen other then the normal screen is displayed and the engine symbol is pressed the normal screen will be displayed.

Operation Keys - Located just below the display screen.

Auto - when the Auto pressed the controls are now in standby and are waiting for a signal to start the engine. Which would be sensed by the closure of contacts in an automatic transfer switch.

Auto Test - When the unit is in the standby mode and the Auto Test button is depressed, the unit will start and run for 5 minutes and return to the standby position.

Reset - Is used to reset any faults that may be present after the condition that caused the fault or faults is corrected. This must be done before the controller will allow the machine to restart.

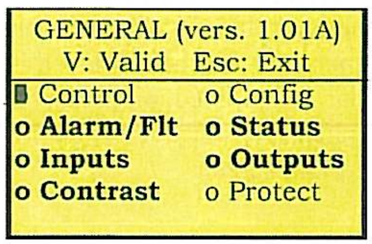
Stop - Stop button will automatically stop the machine when depressed in either the auto or manual mode.

Start - When depressed will start the machine. If the generator was in the standby mode and the start button is used to start the generator, then the Auto button must be pushed after the machine has been stopped to put it back into standby.

Lamp Test - When depressed, every lamp light will light up on the panel.

Red **On** Button - Is the power on button used to power up the controller after it has powered its self down after being energized for six hours. Once power has been applied to the controller, it will automatically power down after six hours to conserve energy, to view the screen the On button must be pressed.

> Note: After the controller has powered down and power is removed from the unit by opening the battery disconnect switch or disconnecting the battery. The on button has to be pressed to bring the unit back up.



Menu - The menu button is used to gain access to the various menus within the controller.

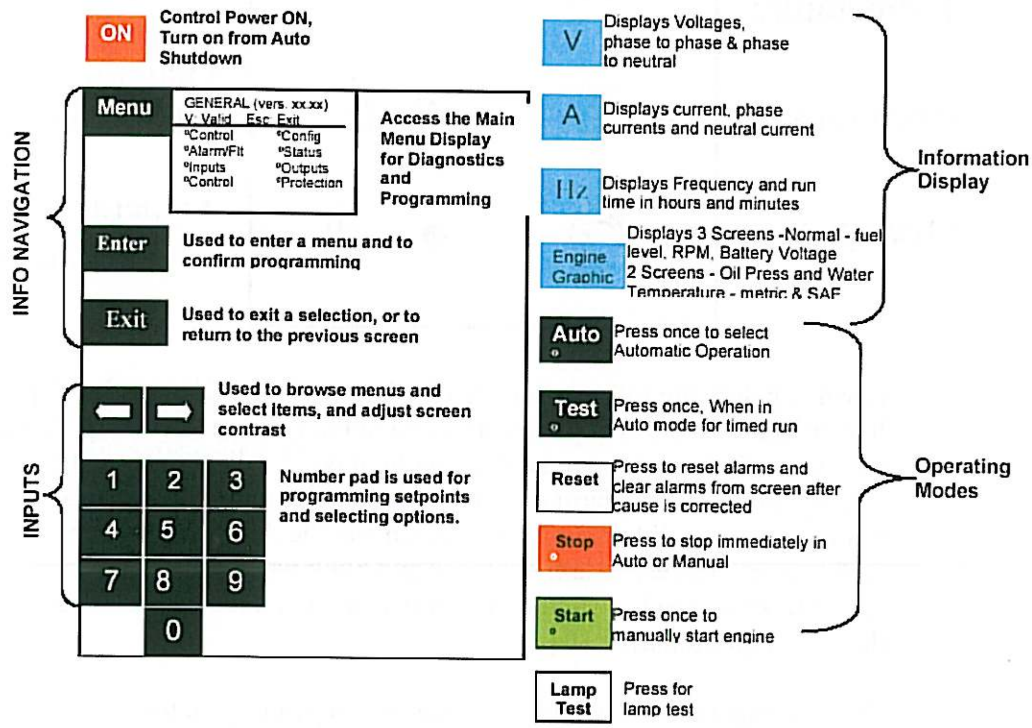
As shown in the above figure, there eight to nine menus depending on the version of software being used.

The **Arrow** keys have two functions. The first being to navigate through the menus and the second is to darken or lighten the display screen when the normal screen is displayed. The right key is used to scroll down through the menus and to darken the screen when the normal screen is displayed. The left arrow is used to scroll up through the menus and to lighten the display screen when the normal screen is displayed.

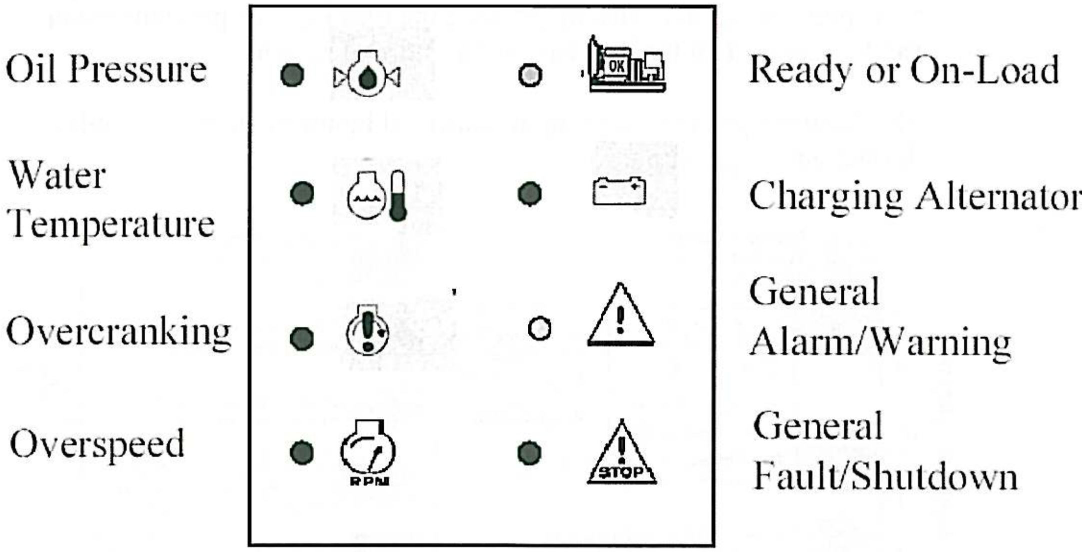
The **Enter** key is used to enter a menu or to access a variable in the program. If the Enter key is used access a variable and that variable is changed, then it must be pressed again to lock in that variable.

The **Exit** key is used to exit a menu or a variable. If a variable has been changed and the Exit key was pressed then the variable will default back to its previous value. Also by pressing the Exit key, the previous menu can be accessed all the way back to the Normal screen.

The **Number** pad is used to input numerical inputs to change variables throughout the program.



Diagnostics Display



Located below the Information Display buttons is the Diagnostic Display which indications of shutdown faults, alarms, and ready or on load lamp. Whenever an alarm or a fault is generated a flashing light will be displayed by the symbol corresponding to the alarm or fault. With the exception of the Ready / On Load Lamp which is solid or continuous green and the Alarm light which is an blinking amber lamp, the rest of lamps are red and blink when actuated.
Low Oil Pressure is a shutdown that depending on the model of engine will shut down at approximately 10 psi.

Water Temperature is a shutdown that also depending on the model of engine will shut down at approximately 250 °F.

Engine Overcranking, the start controls are programmed such that engine will have three chances of starting, if after the third crank cycle the engine has not started a overcranking fault will be received and the engine will be prevented from starting until the alarm has been reset.

Overspeed; set at 120% of nominal speed, or approximately 2160 RPM.

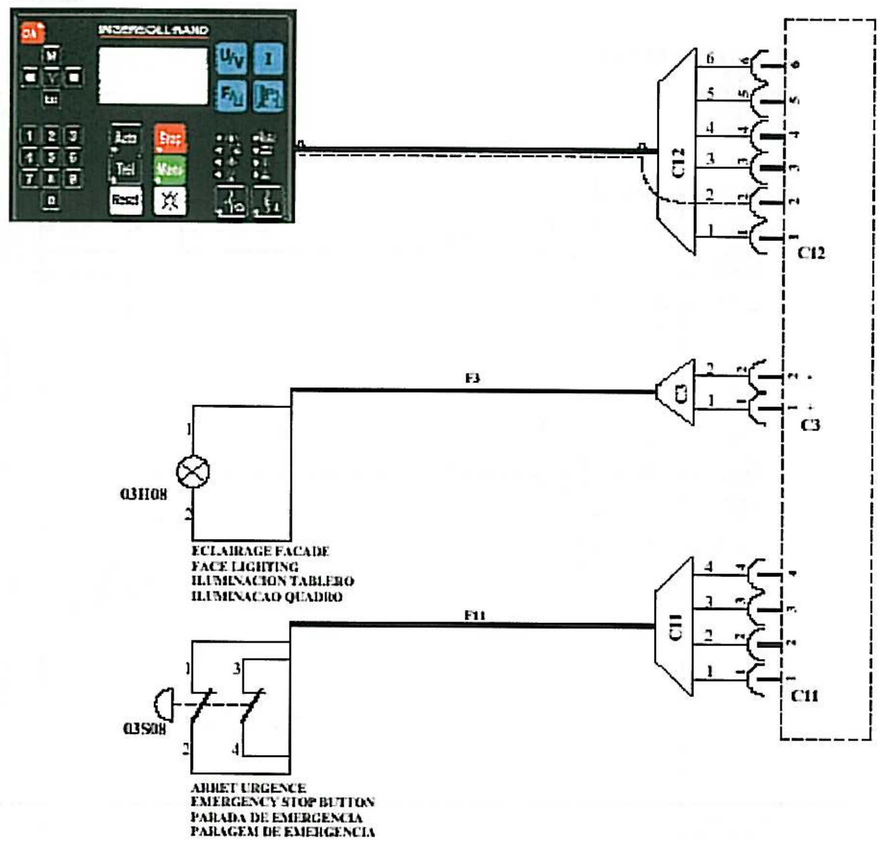
Green **Engine Ready or Loaded** light indicates that the unit is running ready to be loaded.

Charging Alternator light indicates a problem with the battery charging alternator either charging at too high of a voltage or voltage is too low.

General Alarm/Warning - Will flash for any alarm that is present.

General Fault/Shutdown - Will flash for any fault/shutdown that is present.

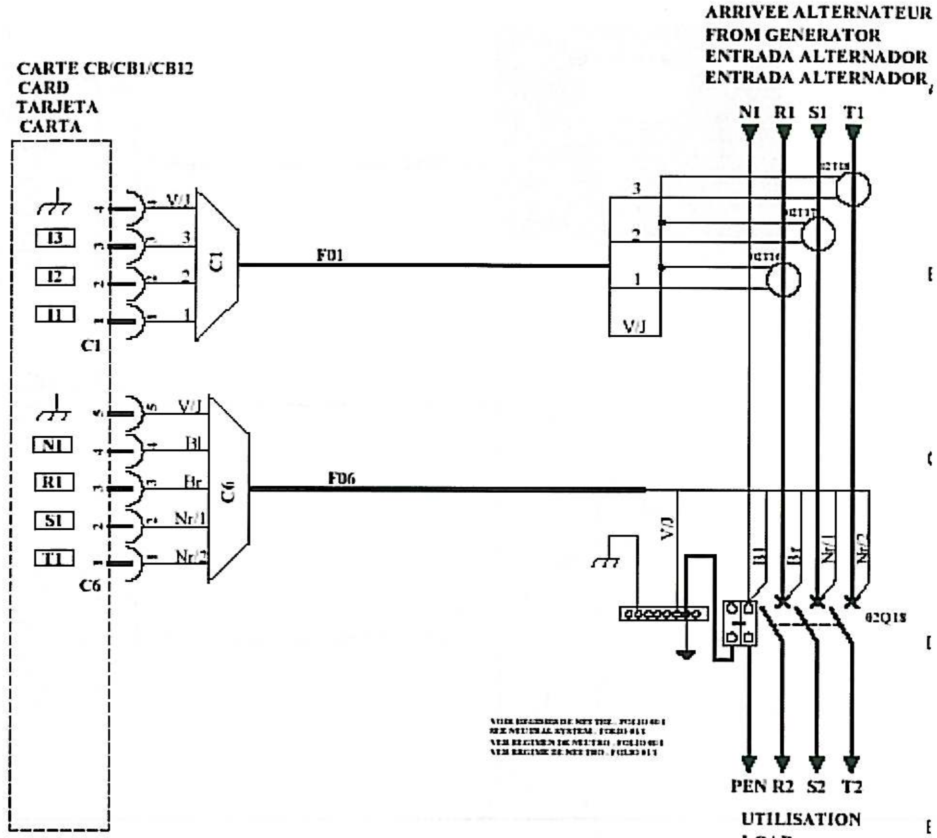
Basic Connection Diagram



Every component that is connected to the CB12 Board is connected to it by a plug that cannot be inserted into another position.

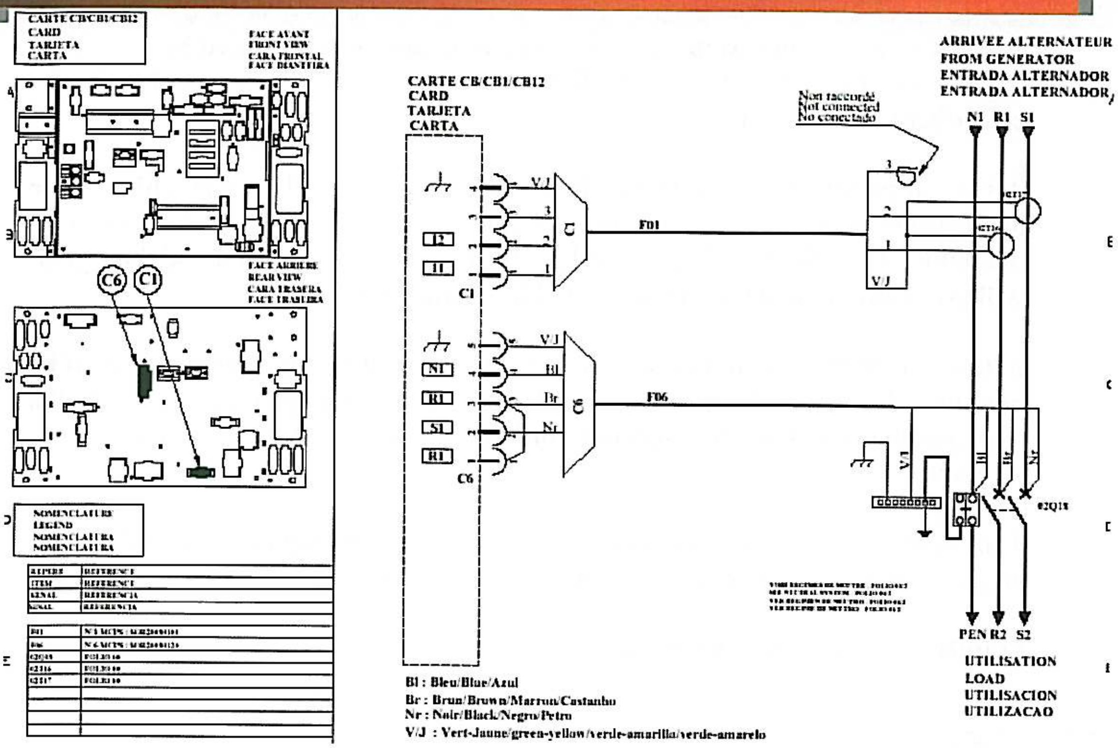
The above drawing shows the connections of the display panel to the CB12 board, along with the E Stop Switch and Panel Light.

The drawings located below shows the voltage and current sensing connections to the CB12 Board through C6 and C1 respectively. The current is sensed through current transformers while the voltage is sensed directly before the output breaker.

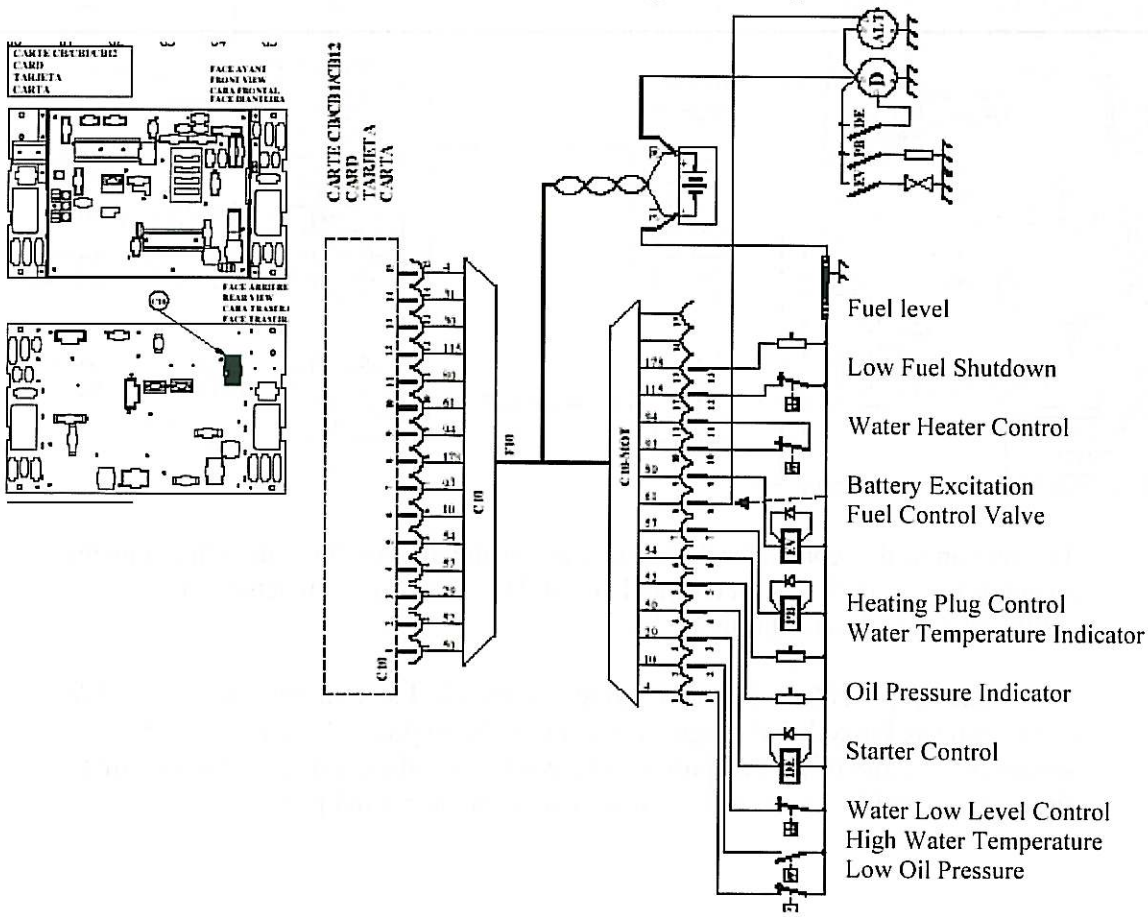


Bl : Bleu/Blue/Azul
Br : Brun/Brown/Marron/Castanho
Nr : Noir/Black/Negro/Petro
V/J : Vert-Jaune/green-yellow/verde-amarillo/verde-amarelo

3 Phase Sensing Diagram



2 Phase Sensing Diagram
Standard Engine Wiring



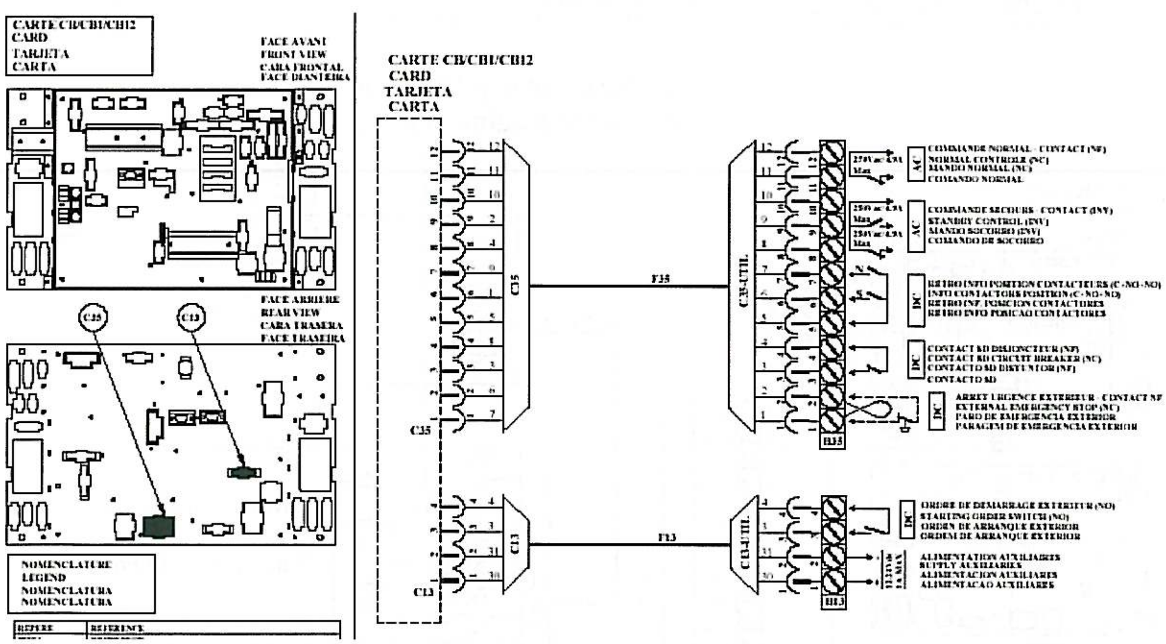
All of the engine start, stop, and protective functions are controlled by the Intellisys controller, and all wiring from and to the engine is connected to the controller via the C10 plug.

All of the switches used protective functions such as low oil pressure, high water temperature, and low fuel level, are all normally open switches during normal operation. On a fault such as low oil pressure the switch will shut and the signal will go to ground and the shutdown and /or alarm will occur.

In the case of the low oil pressure switch, on startup it will be shut due to no oil pressure. To allow oil pressure to build during the starting process, the controller bypasses the switch for five seconds until oil pressure build up above the trip setpoint.

The controller also limits the number of successive cranking cycles that the engine will go through before shutting down on overcrank.

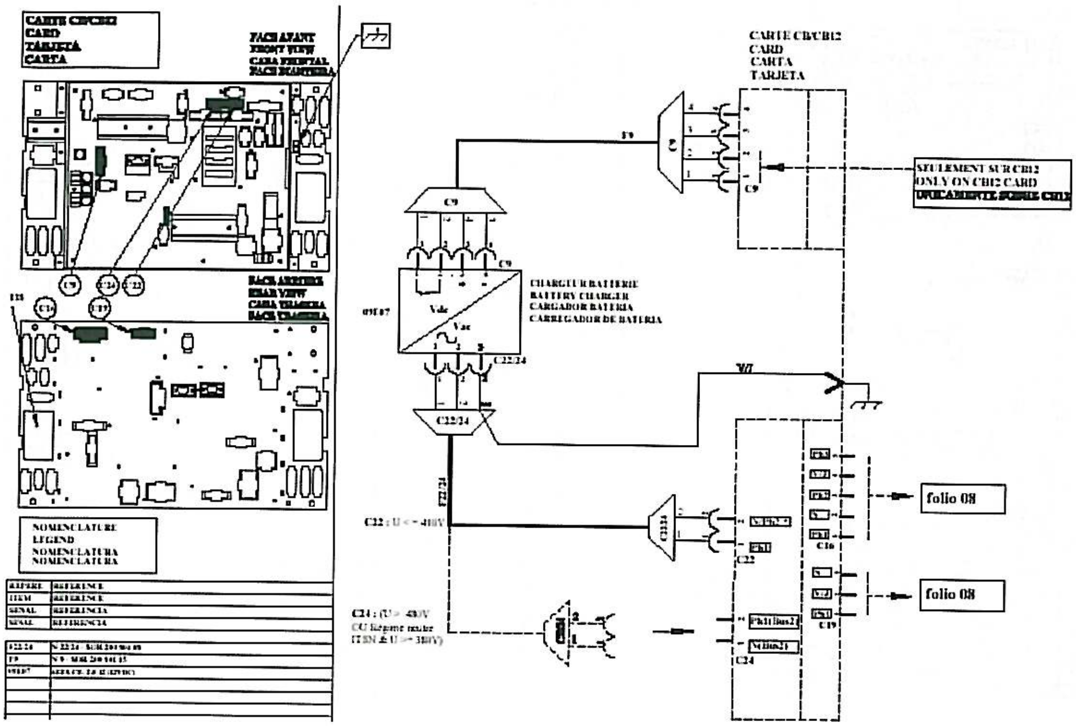
Standby or Automatic Circuits



The section of this controller that is used in the standby application with a transfer switch is terminals 3 & 4 on terminal board B13. Which is connected to the controller/CB12 Board through C13.

The controller provides a DC signal to terminals 3 & 4 so that when terminals 3 & 4 are connected together through a dry contact the engine will go into a start sequence on a loss of normal power. The engine will then start and run until that circuit is opened by the transfer switch on a return of normal power.

Battery Charger



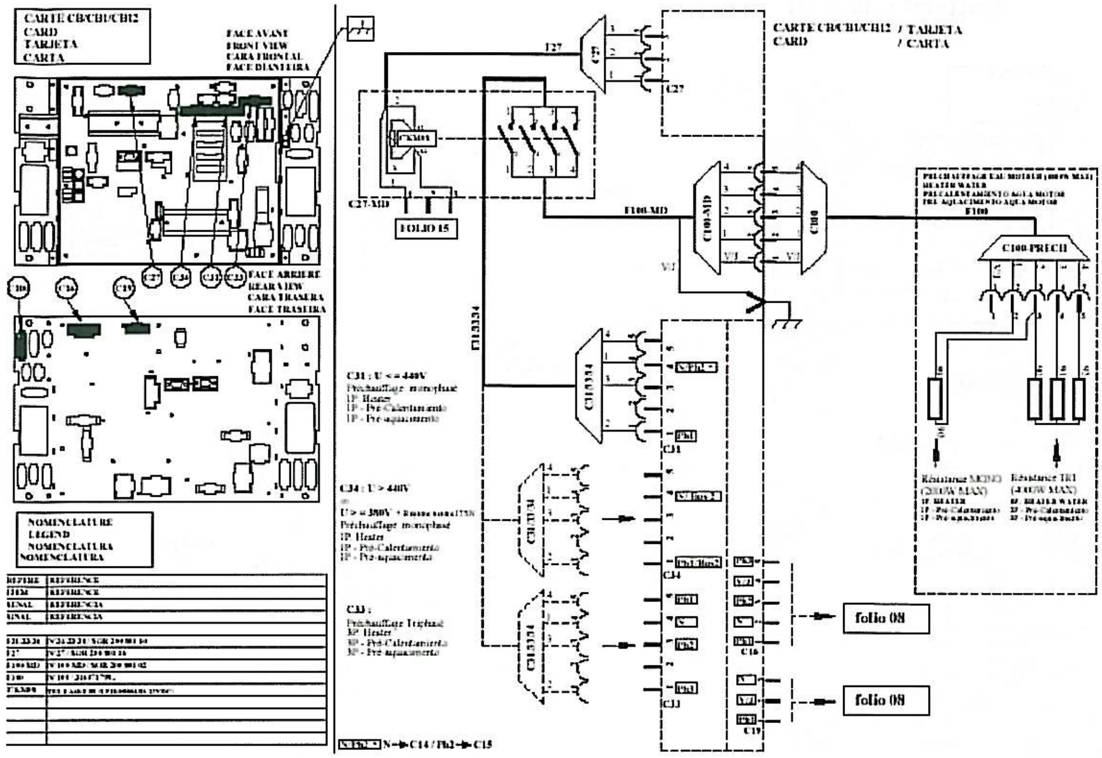
Each unit will be equipped with a battery charger to maintain the battery fully charged at all times. The battery charger is controlled by the controller/CB12 Board and power is provided by an external source and is of a voltage appropriate to the type of charger being used.

While the unit is either off or in standby the controller/CB12 will all power to be applied to the charger, and once the starting sequence is initiated, power will be removed from the charger.

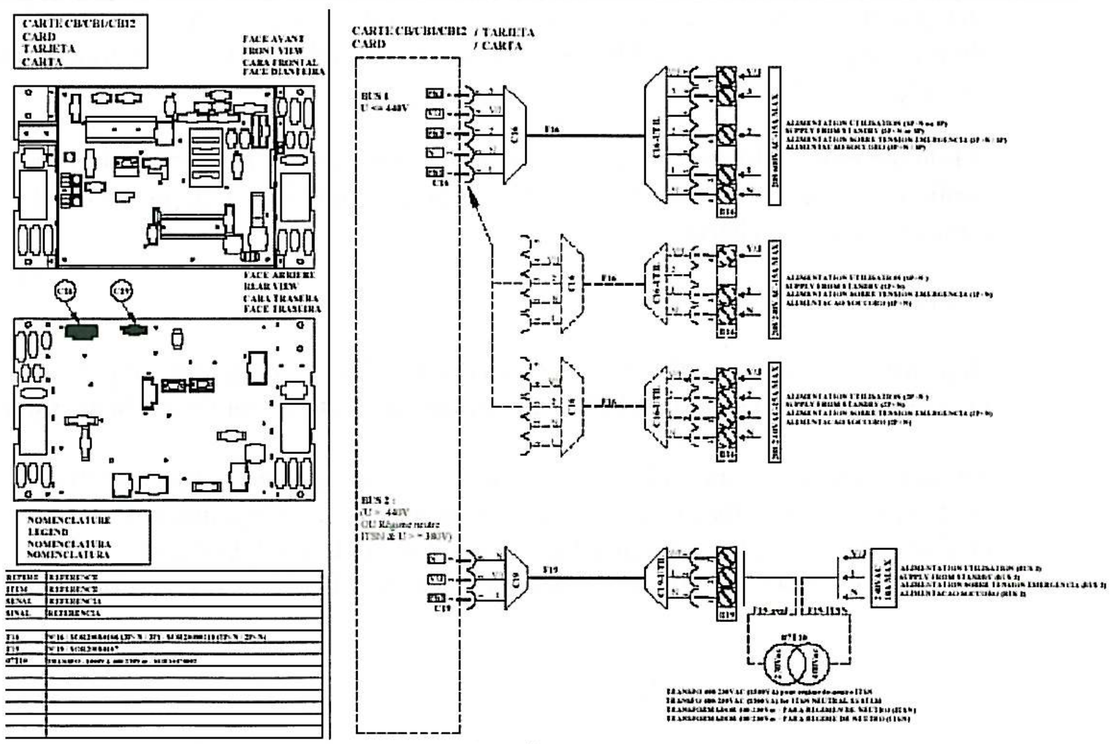
Engine Preheat

Depending on the type of standby system used and the climate, engine preheat may be required. The circuit below shows the connections for the preheat system.

The controller/CB12 provides the controls to monitor the temperature of the engine and controls the system to maintain temperature. Once again when the engine goes into a start sequence the system will be de-energized and when the engine is stopped or returns to the standby condition it will be re-energized.



Engine Preheat



Standby Power

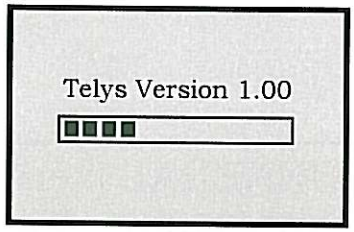
Standby Power

The power supply for the battery charger and Engine preheat is shown in the previous diagram. Typically both options are 120 VAC single phase and power is connected through the terminals located on B19, and is provided from an external source.

Operation

Initial Startup

1. Shut the battery disconnect to apply power to the unit and the controller will begin booting up.



The display should go to the Normal screen displaying fuel level, engine rpm, and battery voltage.

Next press the **Menu** button and hold it until the language screen appears.

The blinking cursor should be blinking in front of the English selection, if not use the **Arrow** buttons to select English and press the **Enter** button.

This will bring up the Date / Time screen. Using the **Arrow** keys scroll up and down the selections entering the proper day, month, year, hour, and minute. Use the **Enter** key to access the numerical values and the **Number** key pad to change the parameters, and then use the **Enter** key to lock in the value entered and return to the cursor so that the next parameter can be selected and changed.

DATE / TIME
V: Valid Esc: Exit

■ Day	: 12
o Month	: 01
o Year	: 2000
o Hour	: 16
o Minute	: 30

Once the Date and Time have set, press the **Exit** key and return to the main or Normal screen.

Menus

GENERAL (vers. 1.01A)
V: Valid Esc: Exit

■ Control	o Config
o **Alarm/Flt**	o **Status**
o **Inputs**	o **Outputs**
o **Contrast**	o Protect

By pressing the **Menu** key the Menu Display will appear. The Control and Config menus are covered in more depth in Troubleshooting and Repair, but they are used to set how the generator set is controlled, setpoints and time delays, and types of sensor used. To access the Control and Config menu a password is required to be entered if either of two menus is selected.

The Menus are selected by using the **Arrow** keys to scroll up and down through the menus. To enter a menu simply press the **Enter** key, to exit a menu just press the **Exit** key to exit that menu and return to the previous menu.

The Alarm/Flt and Status menus are very helpful menus that can be used to troubleshoot problems and to have historical status of the alarms, faults, and operational status of the machines.

The Alarm/Flt menu maintains a chronological record of the last alarms and faults that have occurred with each event date and time stamped. To enter the Alarm/Flt menu press the **Enter** key and use the **Arrow** keys to scroll up and down through the list of past alarms/faults. To exit the menu just press **Exit.**

Once the menu is full of information and the 51st fault or alarm occurs, it will appear at the top of the list, and the last one will be removed from the list.

The Status menu functions the same as the Alarm/Flt menu, except that it records the last twenty-five events when the machine was placed in Auto, Manually Started, Shutdown, Manually Shutdown, and if the program was accessed. It is accessed the same as the Alarm/Flt menu.

Installation

The unit comes installed from the factory, see Troubleshooting and Repair for installation of replacement parts.

Maintenance

Maintenance is minimal, with the only requirements are to ensure that the components are kept clean and dry, and periodically checking that all connections are tight.

Troubleshooting and Repair

The CB12 Board and Intellisys Display Panel are relatively trouble free. The unit not powering up or incorrect information being displayed for the actual operating conditions notes most failures.

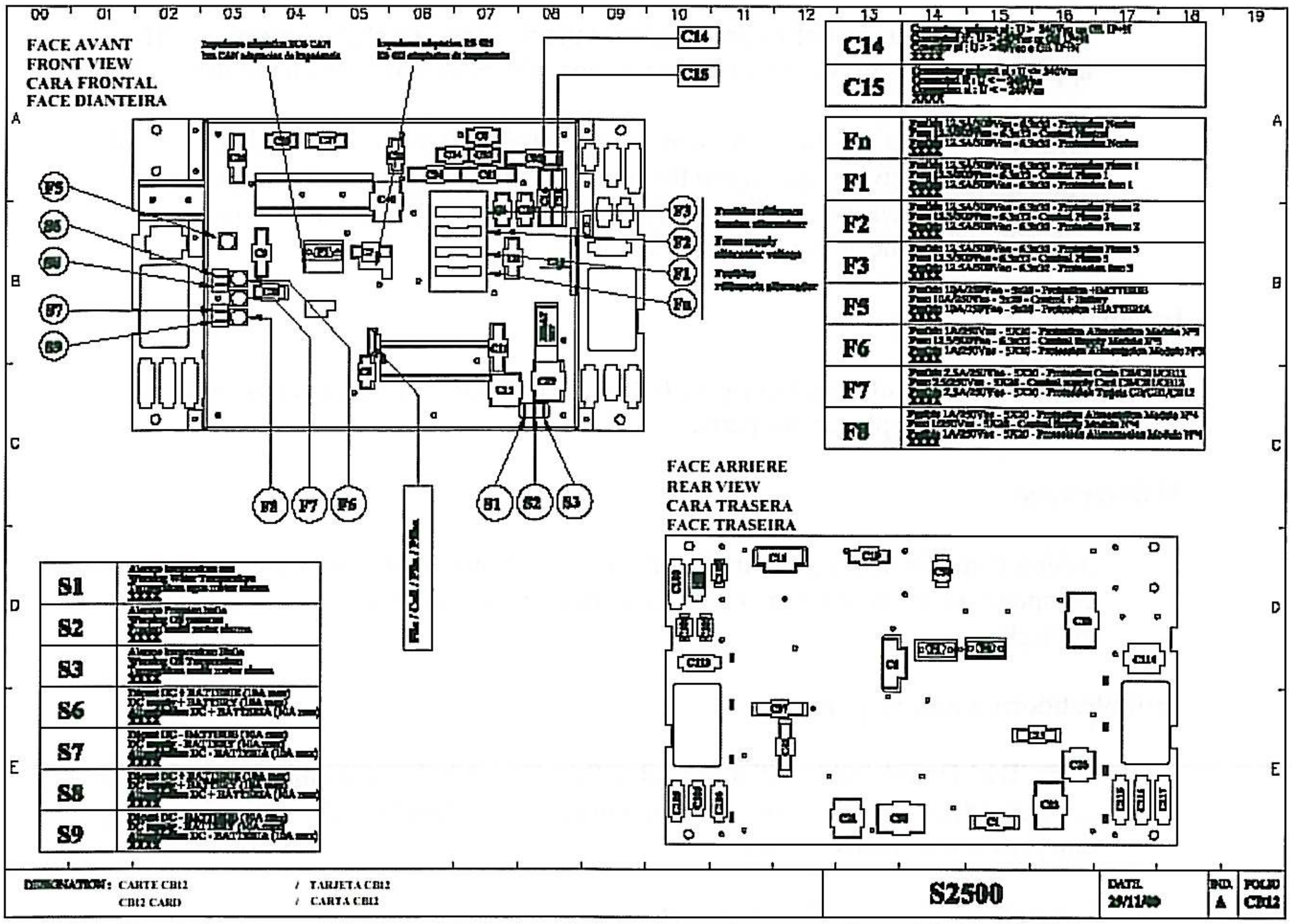
Located on the front of the CB12 Board are the power supply fuses that provide power to the unit, and the sensed voltage and frequency. If the board fails to power up the F5 fuse should be checked and if blown replaced. If voltage and frequency are not being displayed then the protective fuses (F1, F2, F3, FN) that are located on the front of the board should be checked and replaced if necessary.

When verifying proper operation of the board, a good quality multimeter must be used to ensure that the parameters being checked are what are being displayed by the display. If the parameters are incorrect on the display then the board needs to be replaced, if functions change without cause or the board malfunctions such that the machine will not start, the board is suspect and should be replaced.

Board replacement is fairly simple.

1. Disconnect power from the unit, and mark and remove all connections from the board.
2. Remove the mounting screws and remove the board from the mount.

3. Install the new board and install the mounting screws and re-plug all connections into the new board and reprogram it.



Programming

The CB12 Board that is shipped with the unit is already programmed. However, if the board is replaced, the replacement board is not pre-programmed for all applications and must be programmed after it has been installed.

A programming sheet will be shipped with the board, and the parameters must be re-entered for the unit to properly operate in the mode it is selected for.

Additionally, if the operation of the board is suspected, or the engine and generator do operate within the design band then the current program will need to be checked against programming sheet.

Step 1. Press the **Menu** button and the menu screen will be displayed.

GENERAL (vers. 1.01A)
V: Valid Esc: Exit

▮ Control	o Config
o Alarm/Flt	**o Status**
o Inputs	**o Outputs**
o Contrast	o Protect

With the blinking cursor in front of the Control Menu, press **Enter** and a password will have to be entered. Enter the password _____ and press **Enter** to validate the password and the Control menu will come up.

Control Menu

GROUP 1

Parameter	REQUIRED SETTING
SimpleExtCommand	0
ExtCommand+Delay	1
Start UsingClock	0
External Order Input NO	1
External Order Input NC	0

The parameter sheet will have the required settings on it like the one display above; the blinking cursor will be beside the required setting. To change a required setting, press the **Enter** button and the cursor will move over to the Required Setting column. Using the **Number Key Pad** enter the desired setting and press the **Enter** key to validate the setting. The cursor will return to the Parameter column, use the **Arrow** keys to scroll up and down through menu to make the desired changes.

Once all of the changes have been made to Control Menu and it has been verified to be correct. Press the **Exit** key and the previous General Menu screen will be displayed.

Step 2. Using the **Arrow** keys scroll over to the Config Menu and press **Enter** to access the Config menu. When the Config menu comes up, it will have several sub menus under it. Some of which will be:

Delays

Thresholds

Options

Factory

Sensors

Using the **Arrow** keys select each menu as specified on the programming sheet and make changes and validate them using the same procedure as in step one.

Once completed, and all of the parameters have been verified to be correct, open the battery disconnect and re-shut it. This removes power to the board and resets the security access, so that unauthorized personnel cannot gain access to the program.

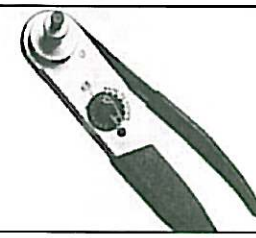
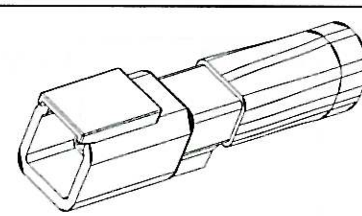
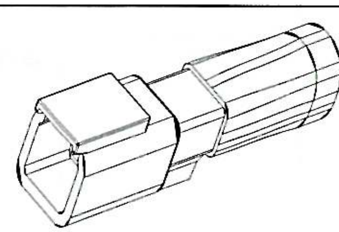
APPENDIX A

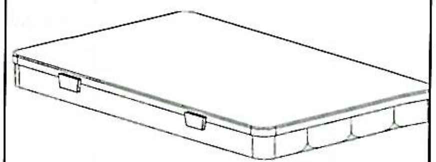
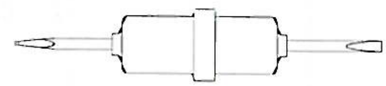
Laboratory Exercises

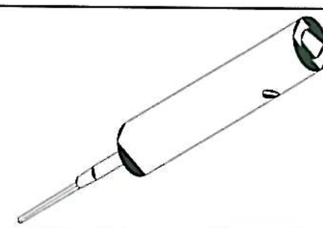
APPENDIX B

Service Tools Information

Tool No.	Tool Description	Tool Illustration
Fluke 87	**Digital Multimeter**	
54729660	**Weather-Pack Terminal Removal Tool**	
54699632	**Deutsch Terminal Removal Tool (Blue)**	
54699640	**Deutsch Terminal Removal Tool (Red)**	

54699624	**Deutsch Terminal Removal Tool (Yellow)**	
DT-RT1	**Crimp Tool for Deutsch Pins Crimp** Available from: Ladd Industries (800-223-1236)	
54729710	**Electrical Contact Cleaner**	
54729728	**PDA Service Tool**	
54699616	**Deutsch Terminal Removal Tool (Green)**	
54749544	**RTD Simulator Plug**	
22073878	**Thermistor Plug**	

54749635	**Connector Repair kit**	
54699657	**Deutsch Terminal Removal Tool**	

54749643	**Packard Metri-Pack Removal Tool**	
22168868	**Pressure Transducer Tester**	
22147540	**Test Lead Kit**	
22146393	**Removal Tool Kit**	

DTT-16-00	**Deutsch Crimp Tool** **Available from:** **Ladd Industries 800-223-1236**	
12085270	**Packard Elec. Crimp Tool** **Available from:** **Pioneer Standard**