UNITED STATES MARINE CORPS
ENGINEER EQUIPMENT INSTRUCTION COMPANY
MARINE CORPS DETACHMENT
FORT LEONARD WOOD, MISSOURI 65473-8963

LESSON PLAN

ELECTRICAL SYSTEMS

LESSON ID: NCOM-B01

ENGINEER EQUIPMENT MECHANIC NCO

A16ACU1

REVISED 05/09/2014

APPROVED BY______________________________ **DATE**__________________

INTRODUCTION **(5 MIN)**

(ON SLIDE #1)

1. GAIN ATTENTION. Where would we be without electricity? There would be no phones, no computers none of the creature comforts that we all know and love. Think how hard it would be for you to crank your car without electricity. Can it be done yes but with a handle and crank? Would you want to do that every time you had to go somewhere? I know that I wouldn't. Ask yourself could you live without electricity?

(ON SLIDE #2)

2. OVERVIEW. Good morning/ afternoon class, my name is___________. The purpose of this period of instruction is to familiarize you with advanced techniques that will allow you the mechanic to isolate, identify, diagnose, and repair electrical system malfunctions.

INSTRUCTOR NOTE
Introduce learning objectives

(ON SLIDE #3)

3. **LEARNING OBJECTIVES**

a. **TERMINAL LEARNING OBJECTIVE.** Provided a service request, malfunctioning electrical system, appropriate tools, test measurement and diagnostic equipment (TMDE), and references, conduct advance repair to equipment electrical system to restore system to proper function. (1341-MAINT-2002).

b. **ENABLING LEARNING OBJECTIVES.**

(1) Without the aid of reference, identify electrical systems theory of operation per the FOS2007NC. (1341-MANT-2002a)

(2) Provided an electrical schematic, an electrical training board, and references, identify electrical components per the Hampden-Bulletin 285-EX Ed. 2d. (1341-MANT-2002b)

(3) Provided an electrical training board, and reference, complete a circuit per the Hampden-Bulletin 285-EX Ed. 2d (1341-MANT-2002d)

(4) Provided an item of engineer equipment, with an electrical malfunction, (TMDE), and references, correct the malfunction per the TM 11412A-OI/1, TM 11412A-OI, TM 10996A-OI/A, TM 10794B-OI/A. (1341-MANT-2002e)

(ON SLIDE #4)

4. METHOD/MEDIA. This period of instruction will be taught by the informal lecture method, demonstration, practical application methods, aided by a detailed outline, and computer generated slides.

INSTRUCTOR NOTE
Explain Instructional Rating Forms to students.

(ON SLIDE #5)

5. EVALUATION. There will be a fifty question written examination, without the aid of references and a troubleshooting procedures performance examination, with the aid of references, in accordance with your training schedule.

(ON SLIDE #6)

6. SAFETY/ CEASE TRAINING (CT) BRIEF. In case of fire follow the evacuation plan and meet in the parking lot for a head count. There is no safety brief associated with this lecture portion. There will be safety briefs given before certain demonstrations and practical applications.

(ON SLIDE #7)

TRANSITION: Are there any questions on what you're going to be taught, how it's going to be taught, or how you're going to be evaluated? If not, let's answer the question "What is electricity?"

____

____

____

BODY **(61 HRS 40 MIN)**

(ON SLIDE #8)

1. LAWS AND PRINCIPLES OF ELECTRICITY. (4 Hrs)

(ON SLIDE #9)

INSTRUCTOR NOTE
Show embedded computer generated graphics "Electrical Introduction" (.29 MIN)

(ON SLIDE #10)

a. Composition of Electricity. To understand electricity, we must first study matter, the name for all material substances. Everything (solids, liquids, and gases) is made up of tiny particles known as atoms. These atoms combine in small groups of two or more to form molecules. When atoms are divided, smaller particles are created, some of which have positive and others, negative electrical charges.

(ON SLIDE #11)

(1) The basic particles that make up all the atoms, and thus all the universe, are called protons, electrons, and neutrons. A proton is a basic particle having a single positive charge; whereas a group of protons produces a positive electrical charge. An electron is a basic particle having a single negative charge; therefore, a group of electrons produces a negative electrical charge. A neutron is a basic particle having no charge; a group of neutrons, therefore, would have no charge.

(ON SLIDE #12)

(2) If a point that has an excess of electrons (negative) is connected to a point that has a shortage of electrons (positive), a flow of electrons (electrical current) will move through the connector until an equal electric charge exists between the two points.

(ON SLIDE #13)

b. **Theories of Electricity**. Before scientists understood what electricity was, they assumed that voltage flowed from positive to negative. This is called the Conventional Theory of Electricity. However, their studies showed that this was wrong, because they learned that it is the movement of electrons from negative (concentration of electrons) to positive (lack of electrons).

(1) A charge of electricity is formed when numerous electrons break free of their atoms and gather in one area. When the electrons begin to move in one direction (as along a wire, for example), the effect is a flow of electricity or an electric current. Because the electrons repel each other (the same type of electrical charges repel), the electrons push out through the circuit and flow to the positive terminal (different types of electrical charges attract). Thus, we can see that an electric current is actually a flow of electrons from negative to positive. This is called the Electron Theory of Electricity.

INSTRUCTOR NOTE
Whichever direction the electrical charge flows, it is important for the mechanic to remember it moves in **ONLY ONE DIRECTION** at a time when determining the flow of electricity

(ON SLIDE #14)

INTERIM TRANSITION: Are there any questions over theories of electricity? If not, let's take a 10 min break and then we'll talk about voltage.

____

____

____

(BREAK - 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk about voltage.

____

____

____

(ON SLIDE #15)

c. Voltage (Appendix 1). Voltage can be defined as an electrical pressure and is the electromotive force (or push) that causes the movement of electrons. It is the difference in electron concentration. Electrons are caused to flow by this difference in electron balance in a circuit; that is, when there are more electrons in one part of a circuit than in another, the electrons move from the area where they are concentrated to the area where they are lacking.

(ON SLIDE #16)

(1) There are three conditions that must exist in order to have voltage:

(a) A lack of electrons on one side.

(b) Excess of electrons on the other side.

(c) A path for the electrons to flow.

(ON SLIDE #17)

(2) Higher voltage results from greater electron imbalance. Therefore this electron imbalance is a harder push on the electrons (more electrons repelling each other). For example, when there are many electrons concentrated at the negative terminal of a battery (with a corresponding lack of electrons at the positive terminal), there is a much stronger repelling force on the electrons, and consequently the potential for many more electrons to move.

(ON SLIDE #18)

INSTRUCTOR NOTE
Have students close their books and probe the class for the below answers.

(3) Voltage can be generated in many ways such as friction, light, heat, pressure, magnetism, and chemical reaction.

(a) <u>Static electric</u>. Electricity generated through friction is commonly known as static electricity. Because static electricity is stationary it can go unnoticed until the electrical imbalance reaches the point of discharge, and cause damage to sensitive electronic circuits.

(b) Photoelectric. When light strikes the surface of certain sensitive materials, such as selenium or cesium, electrons are released. (Solar Power)

(c) Thermoelectric. Electron movement can be created by heating the connection of two dissimilar metals. If the two metals are connected to a voltage sensitive gauge, an increase in the temperature of the wire junction will increase the voltage reading.

INSTRUCTOR NOTE
Piezo means pressure.

(d) Piezoelectric. Certain crystals become electrically charged when pressure is applied to the crystal. The potential difference produced increases with increased pressure. Piezoelectric units are used in air pressure and fuel pressure sensors on computer-operated systems.

INSTRUCTOR NOTE
Load sensor on the 5k.

(e) Magnetic induction. Magnetic induction occurs when there is relative movement between a conductor and a magnetic field that causes the conductor to cut the lines of force surrounding the magnet. A difference of potential is set-up between the ends of the conductor and a voltage is induced.

(f) Electrochemical. A battery is a chemical device that produces a voltage potential between two different metal plates submerged in an acid. Lead-acid batteries are of this type.

(ON SLIDE #19)

(g) Voltage does not flow through a conductor; it is the pressure that “pushes” the electricity. However, voltage can be used as a signal – for example, difference in voltage levels, frequency of change, or when it is switching from positive to negative.

(4) A digital voltage signal is in one of two states either on-off, yes-no, or high-low. The simplest generator of a

digital signal is a switch. A pulse is a sudden ON and OFF of electricity within a circuit. In its basic form, an on-off switch will cause a pulse of electron flow within a circuit when the switch is turned on and off. The width of the pulse is the length of time the switch was turned on. The height of the pulse is known as the amplitude and is determined by the amount of voltage.

(ON SLIDE #20)

(5) An analog voltage signal is one that is infinitely variable, or can be changed within a given range. For example, ambient temperature sensors do not change abruptly. The temperature varies in infinite steps from low to high. Unlike pulses created by the on-off flow of electricity, waves (also called sine waves) are created by varying a continuous flow of electrons within a circuit. This variation of electricity is accomplished by different types of devices within a circuit. For example, in sound recording, fluctuations in air pressure (that is to say, sound) strike the diaphragm of a microphone which induces corresponding fluctuations in the current produced by a coil in an electromagnetic microphone, or the voltage produced by a condenser microphone. The voltage or the current is said to be an "analog" of the sound.

(ON SLIDE #21)

(6) Controlled pulses and waves require a certain amount of time for one cycle to be completed. Frequency is the number of cycles occurring in one unit of time (usually one second). These cycles are measured in Hertz (Hz). A Hertz is one cycle per second. The term was derived from the name of the 19th Century German physicist Heinrich Hertz. For example, the electricity in commercial power lines is 60 Hz – a frequency of 60 cycles/second.

(ON SLIDE #22)

d. **Amperes**. Current can be defined as the rate of electron flow and is measured in amperes. The ampere (symbol: A) is unit of electric current. It is named after André-Marie Ampère (1775-1836), French mathematician and physicist, considered the father of electrodynamics. In practice, its name is often shortened to amp. Current is a measurement of the electrons passing any given point in a circuit in one second. Because the flow of electrons is at the speed of light, it would be impossible to physically see electron flow. However, the rate of flow can be measured.

(1) An electrical current will continue to flow through a conductor as long as the electromotive force is acting on the conductor's atoms and electrons.

(ON SLIDE #23)

(2) There are two classifications of electrical current flow; direct current (DC) and alternating current (AC). The type of current flow is determined by the type of voltage that drives them.

(ON SLIDE #24)

(a) Direct Current (DC) is produced by a battery and has a current that is the same throughout the circuit and flows in the same direction. Voltage and current are constant if a switch is turned on or off. Most of the electrical circuits encountered by the mechanic will be DC.

(ON SLIDE #25)

(b) Alternating Current (AC) is produced any time a conductor moves through a magnetic field. In an alternating current circuit, voltage and current do not remain constant. Alternating current changes from positive to negative. The voltage in an AC circuit starts at zero and rises to a positive value, it then falls back to zero and goes to a negative value, and finally, it returns to zero.

(ON SLIDE #26)

e. Resistance. Even though a copper wire will conduct electricity with relative ease, it still offers resistance to electron flow. This resistance is caused by the energy necessary to break the outer shell electrons free, and the collisions between the atoms of the conductor and the free electrons. It takes force (or voltage) to overcome the resistance encountered by the flowing electrons. This resistance is expressed in units called ohms.

(ON SLIDE #27)

There are five basic characteristics that determine the amount of resistance in any part of a circuit:

(1) The atomic structure of the material: the number of electrons in the outer valence ring directly affects the resistance of the conductor.

(2) The length of the conductor: the longer the conductor the higher the resistance.

(3) The diameter of the conductor: the smaller the cross-sectional area of the conductor, the higher the resistance.

(4) Temperature: normally an increase of temperature of the conductor causes an increase in the resistance.

(5) Physical condition of the conductor: if the conductor is damaged by nicks, cuts, or corrosion, the resistance will increase because the conductor’s diameter is decreased by these.

(ON SLIDE #28)

(6) Resistance (load) is required to change electrical energy to light, heat, or movement. There is resistance in any working device of a circuit, such as a lamp, motor, relay, or other load component.

(ON SLIDE #29)

(7) There may be unwanted resistance in a circuit. This could be in the form of a corroded connection or a broken conductor. In these instances, the resistance may cause the load component to operate at a reduced efficiency or to not operate at all.

(8) It does not matter if the resistance is from the load component or from unwanted resistance. There are certain principles that dictate its impact in the circuit:

(a) Voltage always drops as current flows through the resistance.

(b) An increase in resistance causes a decrease in current.

(c) All resistance changes the electrical energy into another form of energy to some extent.

(ON SLIDE #30)

INTERIM TRANSITION: Are there any questions over resistance? If not, let's take a 10 min break and then we'll talk about circuit configurations.

____
____
____

(BREAK – 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk about circuit configurations.

____
____
____

(ON SLIDE #31)

f. **Circuit Configurations**.

(1) A very basic circuit consists of a power source, a unit to be operated (load device), and a wire to connect the two together. If the unit to be operated is to be controlled, a switch will also be included in the circuit.

(ON SLIDE #32)

(2) Series Circuits. A series circuit consists of two or more load devices (electrically operated components) that are connected together in an end-to-end manner so that any current flow in the circuit is dependent on a complete path through all of the units. The following characteristics of series circuits are important:

(a) Any break in the circuit (such as a burned out light bulb) will render the entire circuit inoperative.

(b) The current (amperage) will be constant throughout the circuit.

(c) The total resistance of the circuit is equal to the sum of the individual resistances.

(d) The total voltage of the circuit is equal to the sum of the individual voltage drops across each component. *(Kirchoff's Voltage Law of Electricity).*

(ON SLIDE #33)

(3) Parallel Circuits. A parallel circuit consists of two or more resistance units (electrically operated components) connected in separate branches. In a parallel circuit, each component receives full voltage from the source. The following characteristics of parallel circuits are important.

(a) The total resistance of the circuit will always be less than the resistance of any individual component.

(b) The disconnection or burning out of any individual component in the circuit will not affect the operation of the others.

(c) The current will divide itself among the circuit branches according to the resistances of the individual components. The sum of the individual amperages will be equal to the total circuit current *(Kirchoff's Current Law of Electricity).* In other words, the sum of individual amperages entering a junction will equal the sum of amperage leaving a junction.

(d) The voltage will be constant throughout the circuit when measured across the individual branches.

(ON SLIDE #34)

(4) Series-Parallel Circuit. The series-parallel circuit is a combination of the two configurations. There must be at least three resistance units to have a series-parallel circuit. The following characteristics of series-parallel circuits are important.

(a) The total circuit voltage will be equal to the sum of the total parallel circuit voltage drop plus the voltage drops of the individual series circuit components.

(b) The total circuit resistance will be equal to the sum of the total parallel circuit resistance plus the individual resistances of the series circuit components.

(ON SLIDE #35)

(c) Current flow through the total parallel circuit will be equal to the current flow through any individual series circuit component.

(d) The disconnection or the burning out of any of the series components will completely disable the entire circuit, whereas a failure of any of the parallel circuit components will leave the balance of the circuit still functioning.

(ON SLIDE #36)

g. **Ohm's Law**. The general statements about voltage, amperage, and resistance can all be related in a statement known as Ohm's Law, so named for the scientist Georg Simon Ohm who first stated the relationship. This law states that voltage is equal to amperage times resistance. It can also be stated as the mathematical formula: E = I x R.

(1) Where E (Electromotive Force) is volts, (Intensity) is current in amperes, and R is resistance in ohms. For the purpose of solving problems, the ohms law formula can be expressed three ways:

INTERIM TRANSITION: We've just discussed Ohm's Law. Are there any questions? If not, let's move on to the demonstration of the relationship between current, voltage, and resistance as proven by Ohm's Law.

____
____
____

(ON SLIDE #37)

INSTRUCTOR NOTE
Perform the following demonstration.

DEMONSTRATION. **(15 MIN)** Demonstration will be conducted on the dry erase board. Explain how the formula works. The purpose of this demonstration is to shows the student the relationship between current, voltage, and resistance as proven by Ohm's Law. Normal class size is 25. There is one instructor required for this evolution.

STUDENT ROLE: This exercise is classroom interactive. Ohm's Law is applied to find an unknown value when two other values are known. Students should highlight or write down formula, ask questions if they have any. It is vital they understand this relationship. Without it no electrical troubleshooting will be comprehended by the student.

INSTRUCTOR (S) ROLE: The instructor fills in the two known values on the circle (on the dry erase board) and the student must find the unknown value and put it in the remaining place. It is important to relate this activity to electrical circuits.

Example: (e24/i7.5=r?)   Answer: (24/7.5=3.2)

Example: (e24/r4.1=i?)   Answer: (24/4.1=5.8)

Example: (e18.5/r3.2=i?) Answer: (18.5/3.2=5.78)

1. Safety Brief: N/A

2. Supervision and Guidance: Allow the student's time to work the problems on their own; Instructor is walking around the room helping with students who have questions. Then the Instructor works out the problems on the dry erase board to capture any student that may not have understood but didn't ask questions.

3. Debrief: N/A

INTERIM TRANSITION: During the demonstration we covered the relationship between current, voltage, and resistance as proven by Ohm's Law. Do you have any questions? If not, let's talk more about the formula.

____
____
____

(ON SLIDE #38)

(a) To find voltage: E = I x R

(b) To find amperage: I = E ÷ R

(c) To find ohms: R = E ÷ I

(1). This formula is a valuable one to remember because it makes understandable many of the things that happen in an electric circuit. For instance, if the voltage remains constant, the current flow goes down if the resistance goes up. Example: (e24/i7.5=r?) (24/7.5=3.2)

(2). A great majority of electrical troubles on equipment result from increased resistance in circuits due to bad connections, deteriorated wiring, dirty or burned contacts in switches, or other such problems. With any of these conditions, the resistance of the circuit goes up and the current through that circuit goes down. Example: (e24/r4.1=i?) (24/4.1=5.8)

(3). If the resistance stays the same but the voltage increases, the amperage also increases. This is a condition that might occur if an alternator voltage regulator became defective. In such a case, there would be nothing to hold the alternator voltage within limits, and the voltage might increase excessively. This would force excessive amounts of current through various circuits and cause serious damage. If too much current went through light bulb filaments, for example, the filaments would overheat and burn out. Also, other electrical devices probably would be damaged.

(4). On the other hand, if the voltage is reduced, the amount of current flowing in a circuit will also be reduced if the resistance stays the same. For example, with a run-down battery, battery voltage will drop excessively with a heavy discharge. When trying to start an engine with a run-down battery, the voltage will drop very low. This voltage is so low that it cannot push enough current through the starter for effective starting of the engine. Example: (e18.5/r3.2=i?) (18.5/3.2=5.78)

(ON SLIDE #39)

h. **Power (Watt’s Law of Electricity)**. In addition to voltage and current, there is another measure of free electron activity in a circuit: *power*. It is a measure of how much work can be performed in a given amount of time. For example, the power of a car's engine won't indicate how tall of a hill it can climb or how much weight it can tow, but it will indicate how *fast* it can climb a specific hill or tow a specific weight. The watt is the unit of measure.

(1) In electric circuits, power is a function of both voltage and current. Not surprisingly, this relationship bears striking resemblance to the Ohm’s Law. In this case, however, power (P) is exactly equal to current (I) multiplied by voltage (E). It can also be stated as the mathematical formula: P = I x E. When using this formula, the unit of measurement for power is the *watt* (abbreviated with the letter "W").

<u>INTERIM TRANSITION</u>: We've just discussed Ohm's Law. Are there any questions? If not, let's move on to the demonstration of the relationship between current, voltage, and resistance as proven by Ohm's Law.

____
____
____

(ON SLIDE #40)

INSTRUCTOR NOTE
Perform the following demonstration.

<u>DEMONSTRATION</u>. (15 MIN) Demonstration will be conducted on the dry erase board. Explain how the formula works. The purpose of this demonstration is to shows the student how electricity is changed to power. Normal class size is 25. There is one instructor required for this evolution.

STUDENT ROLE: This exercise is classroom interactive. Watt's Law is applied to find an unknown value when two other values are known. Students should highlight or write down formula, ask questions if they have any. It is vital they understand this relationship. Without it electrical troubleshooting will be VERY difficult to comprehend and Diesel Engine troubleshooting will be nearly impossible.

INSTRUCTOR (S) ROLE: The instructor fills in the two known values on the circle (on the dry erase board) and the student must find the unknown value and put it in the remaining place. It is important to relate this activity to electrical circuits. Example: (e24xi7.5=p?) Answer: (24x7.5=180)

1.Safety Brief: N/A

2.Supervision and Guidance: Allow the student's time to work the problem on their own; He/She is walking around the room helping with students who have questions. Then the Instructor works out the problem on the dry erase board to capture any student that may not have understood but didn't ask questions.

3.Debrief: N/A

(ON SLIDE #41)

(a) To find power: P = I x E

(b) To find amperage: I = P ÷ E

(c) To find voltage: E = P ÷ I

(d) Example: (e24xi7.5=p?)

INTERIM TRANSITION: We've just performed the demonstration over the different formulas for power, amperage, and voltage. Are there any questions? If not, let's take a 10 min break and then we'll talk more about voltage and current.

____
____
____

(ON SLIDE #42)

(BREAK – 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk more about voltage and current.

____
____
____

(ON SLIDE #43)

(2) It must be understood that neither voltage nor current by themselves constitute power. Rather, electrical power is the combination of both voltage *and* current in a circuit. Remember that voltage is the specific work (or potential energy), while current is the rate at which electric charges move through a conductor. Together as a product (multiplication), voltage (work) and current (rate) constitute power.

(3) Like Ohm's Law, this formula is a valuable one to remember because it makes understandable many mechanical failures that cause an increase (overload) in electricity in a circuit. For example; when a mechanical device wears, it takes more electrical power (Watts) to generate the same amount of mechanical power (Horsepower). If voltage remains the same, this translates to an increase in current.

(ON SLIDE #44)

i. **<u>Voltage Drop (Kirchoff's Voltage Law of Electricity)</u>**.

(1) A German physicist, Gustav Robert Kirchhoff, developed laws about electrical circuits. Kirchhoff's Voltage Law of Electricity basically states that the sum of the voltage drops in an electrical circuit will always equal source voltage. In other words, all of the voltage is used by the circuit.

(2) Voltage drop occurs when current flows through a load component or resistance. Voltage drop is the amount of electrical pressure lost or consumed as it pushes current flow through resistance. Electricity is energy. Energy cannot be created nor destroyed but it can be changed. As electrical energy flows through a resistance, it is converted to some other form of energy such as light heat or movement. The amount of voltage drop over a resistance or load device is an indication of how much electrical energy was converted to another energy form. After a resistance the voltage is lower than before the resistance.

(3) There must be a voltage present for current to flow through a resistor, and current must be flowing in order to measure voltage drop.

<u>INTERIM TRANSITION</u>: We've just discussed Voltage Drop (Kirchoff's Voltage Law of Electricity). Are there any questions? If not, let's move on to the demonstration of the relationship between current, voltage, and resistance as proven by Ohm's Law.

____
____
____

(ON SLIDE #45)

INSTRUCTOR NOTE
Perform the following demonstration

<u>DEMONSTRATION</u>. (15 MIN) Demonstration will be conducted on the dry erase board. Explain how the formula works. The purpose of this demonstration is to shows the student the effect of both intentional and unintentional loads on a circuit. Bosch© has recommends that less than 1% of total circuit voltage be lost to unintentional voltage drops (loose connections, corrosion, frayed wires, etc.). However, for practical application the “general” rule is >0.5 V at contacts, >0.1V across wires, and >0.05V at computer contacts.

STUDENT ROLE: This exercise is classroom interactive. Kirchhoff’s Voltage Law of Electricity is applied to find the amount of electricity lost (consumed) after a resistance. Electric Motive Force is changed to another form of energy (light, heat, or movement) because of resistance encountered in a circuit. Additionally, ALL electricity is consumed by a circuit. This Electrical Law proves it. Students should highlight or write down formula, ask questions if they have any. It is vital they understand this relationship. Without it no electrical troubleshooting will be comprehended by the student.

INSTRUCTOR (S) ROLE: The instructor fills in the two known values on the circle (on the dry erase board) and the student must find the unknown value and put it in the remaining place. It is important to relate this activity to electrical circuits.

Examples:

Question:
What is the total circuit current?

Answer:
1) First find Total Voltage (battery voltage) and Total Resistance (add all resistances together).
2) Divide voltage by resistance (the **I**ndian sees the **E**agle flying over the **R**abbit).
3)12v divided by 40 ohms is .3 amps

Question:
What is the individual voltage drop?

Answer:
1) Once you have **total circuit current** and **total circuit resistance**….solve for voltage
(The Eagle sees the Indian and Rabbit on the plane).

Question:
How do I use it?

Answer:
1) If a component has an **OPEN CIRCUIT.** Voltage drop will be the same as battery voltage but no current.
2) If a component is **SHORTED** (or grounded)….voltage drop will be lower and current will go up due to less resistance.

3) If a component has **HIGH RESISTANCE.** Voltage drop will be higher and current will go down due to more resistance.

1. Safety Brief: N/A

2. Supervision and Guidance: Allow the student's time to work the problems on their own; Instructor is walking around the room helping with students who have questions. Then the Instructor works out the problems on the dry erase board to capture any student that may not have understood but didn't ask.

3. Debrief: N/A

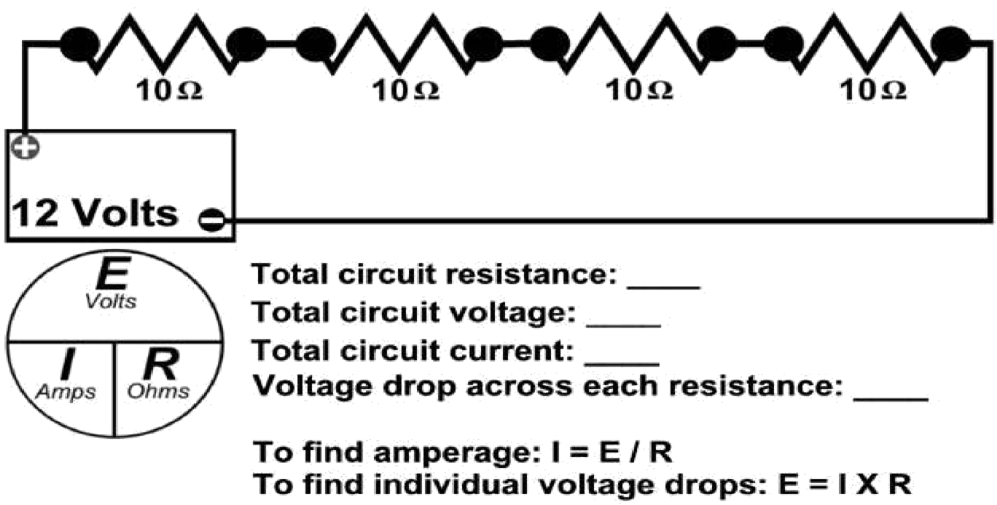
INTERIM TRANSITION: We've just performed the demonstration over Voltage Drop (Kirchoff's Voltage Law of Electricity). Are there any questions? If not, let's talk about current divide.

____

____

____

(ON SLIDE #46)



INSTRUCTOR NOTE

ANSWERS:
Total circuit resistance: 40 ohms (add each)
Total circuit voltage: 12 (see battery)
Total circuit current: .3 (dived 40 and 12)
Voltage drop across each resistance: 3 volts (multiply each resistor by total current 10x.3)

Question: How do I use it?

Answer:
1) If a component has an **OPEN CIRCUIT.** Voltage drop will be the same as battery voltage but no current.
2) If a component is **SHORTED** (or grounded)….voltage drop will be lower and current will go up due to less resistance.
3) If a component has **HIGH RESISTANCE.** Voltage drop will be higher and current will go down due to more resistance.

INSTRUCTOR NOTE

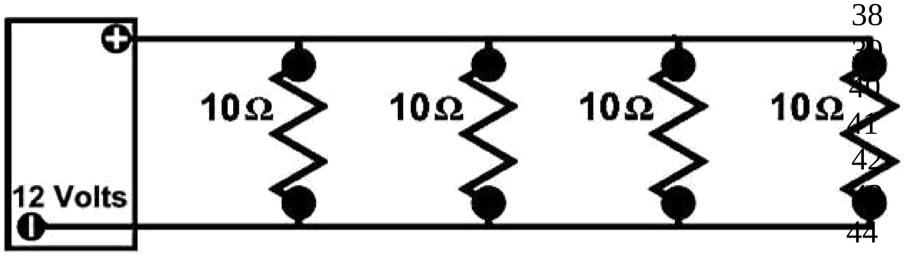
This is a good time to explain the principle of opposing voltage. When the voltages on both sides of a lamp are equal (for example a "No Charge Indicator Lamp"), the lamp will not operate, because the voltage going through a component is a measure of potential difference, in order to make the component work there ***MUST*** be a difference for the component to work.

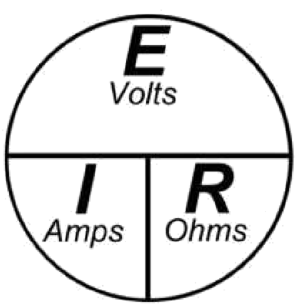
(ON SLIDE #47)

j. **Current Divide (Kirchhoff's Current Law of Electricity)**.

(1) Gustav R. Kirchhoff's Current Law of Electricity states "The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction." In other words, the sum of individual amperages in a circuit will equal the total current in that circuit.

(2) Current divide explains what happens in a circuit that becomes overloaded. When one circuit shorts to an adjacent circuit or ground, each additional pathway allows current a path to ground. Ohm's Law dictates how much current will flow according to the voltage and resistance.





Individual circuit current_____
Total circuit voltage_____
Total circuit current_____
Total circuit resistance_____

To find individual current: I = E / R
To find total circuit resistance: R = E / I

INTERIM TRANSITION: Are there any questions? If not, let's go into the next demonstration.

____
____
____

INSTRUCTOR NOTE
Perform the following demonstration

(ON SLIDE #48)

DEMONSTRATION. (30 MIN) Demonstration will be conducted on the dry erase board. Explain how the formula works. The purpose of this demonstration shows the student the effect of electrical shorts and grounds. Because electricity always takes the shortest path to ground, all electricity flowing into a junction is equal to the amount of electricity leaving that junction, and the amount of resistance, voltage, and current are related, when an electrical short (or ground) occurs there will be an increase in current flowing through the circuit BEFORE the unintentional contact. This results in tripped circuit protection devices or fried wires.

STUDENT ROLE: This exercise is classroom interactive. Kirchhoff's Current Law of Electricity is applied to find the amount of current flowing through a circuit. Current will always increase as resistance decreases (Ohm's Law) and total circuit resistance decreases as additional legs are added to a circuit. This Electrical Law proves it. Students should highlight or write down the formula, ask questions if they have any. The student should use the formula and compute it to find the unknown values to complete this demonstration.

INSTRUCTOR (S) ROLE: The instructor writes the formula to find Individual circuit current and to find Total circuit resistance then draw the circle with the three letters representing Amps, Volts, and Ohms (The Eagle sees the Indian and Rabbit on the plane)on the dry erase board.

ANSWERS
1. Individual circuit current: 1.2 (dived battery by resistor 12/10)
2. Total circuit voltage: 12 (look at the battery)
3. Total circuit current: 4.8 (add all resistors 1.2+1.2+1.2+1.2)
4. Total circuit resistance: 2.5 (dived battery by resistors 12/4.8)

1. Safety Brief: N/A

2. Supervision and Guidance: Allow the student's time to work the problems on their own; Instructor is walking around the room helping with students who have questions. Then the Instructor works out the problems on the dry erase board to capture any student that may not have understood but didn't ask questions.

3. Debrief: N/A

(ON SLIDE #49)

INTERIM TRANSITION: We've just performed the demonstration over the different formulas for power, amperage, and voltage. Are there any questions? If not, let's take a 10 min break and then we'll talk more about voltage and current.

____
____
____

(BREAK – 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk about Conductors, Insulators, and Semiconductors.

____
____
____

(ON SLIDE #50)

k. **Conductors, Insulators, and Semiconductors**. Any material that has little to no resistance to the flow of electrical current is a good electrical conductor. Conductors are used in equipment to carry electric current to all of the electrical equipment. Any material that has high resistance or blocks electric current flow is an electrical insulator. Insulators are necessary to keep the electric current from taking a shorter route to ground instead of going to the intended component. Any material capable of being either a conductor or insulator (depending on how it's prepared) is a semiconductor. Semiconductors are the basis for all modern electronic equipment.

(ON SLIDE #51)

(1) Conductors. Whenever there are less than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be free. This will cause the substance to permit free motion of electrons, making it a good conductor. Copper is an example of a good conductor because it has one free electron. This electron is not held very strongly in its orbit and can get away from the nucleus of the atom very easily. Silver is a better conductor of electricity but it is too expensive to be used in any great quantity. Because of this, copper is the conductor used most widely in electrical applications.

(2) Insulators. Whenever there are more than four electrons in the outer orbits of the atoms of a substance, such as phosphorus, these electrons will tend to be bound, causing restriction of free electron movement, making it a good insulator. Common insulative materials in electrical systems include rubber, plastic, and mica.

(ON SLIDE #52-53)

(3) A special case exists whenever a substance contains four electrons in the outermost orbits of its atoms. This is called a semi conductor. The most popular of all semiconductors is silicon. In its pure state, silicon is neither a good conductor nor insulator. But by processing silicon in the following ways, its conductive or insulative properties can be adjusted to suit just about any need.

(ON SLIDE #54)

(a) When a number of silicon atoms are jammed together in crystalline (glasslike) form, they have a covalent (sharing) bond. Therefore, the electrons in the outer ring of one silicon atom join with the outer ring electrons of other silicon atoms, resulting in a sharing of outer ring electrons between all of the atoms. That covalent sharing gives each atom eight electrons in its outer orbit, making the orbit complete.

This makes the material an insulator because it contains more than four electrons in its outer orbit.

(ON SLIDE #55)

(b) When certain materials such as phosphorus are added to the silicon crystal in highly controlled amounts the resultant mixture becomes a conductor. This is because phosphorus, which has five electrons in forming a covalent bond with silicon (which has four electrons in its outer shell), will yield one free electron per molecule, thus making the material an electrical conductor. The process of adding impurities to a semiconductor is called doping.

INSTRUCTOR NOTE
Examples: 1) Engine coolant temperature sensor – Semi-conductor. 2) Diode is P-type and N-type material. 3) Manifold air pressure sensor. 4) transistor- two diodes sandwiched together.

(ON SLIDE #56)

INTERIM TRANSITION: Now that you understand the effect certain materials have on the movement of electricity, let's discuss the principles of magnetism.

____

____

____

(ON SLIDE #57)

1. **Principles of Magnetism**. Magnetism is a fundamental force of nature and should be studied to learn what causes an alternator to concentrate electrons at the negative terminal and take them away from the positive terminal.

(1) Magnetic Lines of Force. If iron filings were sprinkled on a piece of glass on top of a table magnet the filings would become arranged in curved lines. These curved lines extend from the two poles of the magnet (north and south). This is known as magnetic flux. Scientists have formulated the following rules for these lines of force.

(ON SLIDE #58)

(a) The lines of force (outside the magnet) pass from the north to the south pole of the magnet.

(b) The lines of force act somewhat as rubber bands and try to shorten to a minimum length.

(c) The rubber band characteristic opposes the push-apart characteristic.

(d) The lines of force never cross each other.

(e) The magnetic lines of force, taken together, are referred to as the magnetic field of the magnet.

(ON SLIDE #59)

(2) Effects between Magnetic Poles. When two unlike magnetic poles are brought together, they attract, but when like magnetic poles are brought together, they repel. These actions can be explained in terms of the rubber band and the push-apart characteristics.

(a) When unlike poles are brought close to each other, the magnetic lines of force pass from the north to the south poles. They try to shorten (like rubber bands), and, therefore try to pull the two poles together.

(b) On the other hand, if like poles are brought close to each other, lines of force are going in the same direction and these lines of force attempt to push apart, a repelling effect results between the like poles.

(ON SLIDE #60)

m. **Principles of Electromagnetism**.

(1) An electric current (flow of electrons) always produces a magnetic field. In a wire, a current flow causes lines of force to circle the wire. It is thought that these lines of force result from the movement of the electrons along the wire. As they move, the electrons send out the lines of force. When many electrons move, there are many lines of force (the magnetic field is strong). Few electrons in motion mean a weak magnetic field or few lines of force.

(2) Electron movement, as the basis of magnetism in bar and horseshoe magnets, can be explained by assuming that the atoms of iron are so lined up in the magnets that the electrons are circling in the same direction. With the electrons moving in

the same direction, their individual magnetic lines of force add to produce the magnetic field.

(ON SLIDE #61)

(3) A magnetic field that is produced by current flowing in a single loop of wire will have magnetic lines of force circle the wire, but here they must follow the curve of the wire. If two loops are made in the conductor, the lines of force will circle the two loops. In the area between the adjacent loops, the magnetic lines are going in opposite directions. In such a case, because they are of the same strength (from same amount of current traveling in both loops), they cancel each other out. The lines of force, therefore, circle the two loops almost as though they were a single loop. However, the magnetic field will be twice as strong because the lines of force of the two loops combine.

(ON SLIDE #62)

(4) When many loops of wire are formed into a coil, the lines of force of all the loops combine into a pattern that resembles greatly the magnetic field surrounding a bar magnet. A coil wrapped around the core is known as an electromagnet. As current flows through the wraps of an electromagnet, it resists the formation of magnetic flux (magnetic field) this is known as reluctance. Once the reluctance has been overcome, and the magnetic field has been formed, the amperage of the circuit will stabilize. This is the electromagnets saturation point.

(ON SLIDE #63)

INTERIM TRANSITION: Are there any questions? If not, let’s go into the next demonstration.

____
____
____

INSTRUCTOR NOTE
Perform the following demonstration

Demonstration: (45min) Demonstration will be conducted in the work bay.

Purpose – The purpose of this demonstration shows how an electromagnet is created and how an electromagnet's magnetic field is increased with increased Ampere Turns or an increase in voltage.

Practice – The instructor should take a large flat head screwdriver (any soft iron rod will work), wrap it with 10 or more coils of 16 gage wire, connected in series to a variable resistor, attach it to a standard 12V battery, and show the student how once current is flowing the screwdriver will pick-up washers. Also show how small washers are picked up, but medium and large ones aren't.
Supplies – Hampden-Bulletin 285-EX Ed. 2d 1341-MANT-2011d

1. Safety Brief: EYE PROTECTION AND LEATHER GLOVES ARE REQUIRED FOR THIS DEMONSTRATION OR PERSONAL INJURY WILL RESULT!

2. Supervision and Guidance: Allow the student's to ask any questions they may have about the principles of magnetism.

3. Debrief: N/A

INTERIM TRANSITION. We've just performed the demonstration over how an electromagnet is created and how an electromagnet's magnetic field is increased with increased Ampere Turns or an increase in voltage. Are there any questions? If not, let's talk more about electromagnets.

____
____
____

(BREAK – 10 MIN)

INTERIM TRANSITION. Are there any more questions before we move on..

____
____
____

(ON SLIDE #64)

(5) The strength of an electromagnet can be increased greatly by wrapping the loops of wire around an iron core or by increasing the number loops. The iron core passes the lines of force with much greater ease than air because it permits the

lines of force to pass through it more easily (a higher permeability). Wrought iron is 3,000 times more permeable and less reluctant than air. In other words, it allows 3,000 times as many lines of force to get through. With this great increase in the number of lines of force, the magnetic strength of the electromagnet is increased greatly, even though no additional current flows through it.

(ON SLIDE #65)

n. **Electromagnetic Induction.** When a current is induced to flow through a conductor by the relative motion of a magnetic field this is referred to as electromagnetic induction.

(1) If the wire is moved through the magnetic field between the two magnetic poles, it cuts the lines of force, and current is induced in it. The reason for this is that the lines of force resist cutting, and tend to wrap around the wire. With lines of force wrapping around the wire, current is induced. The wire movement through the magnetic field produces a magnetic whirl around the wire, which pushes the electrons along the wire.

(ON SLIDE #66)

(2) If the wire is held stationary and the magnetic field is moved, the effect is the same; that is, current will be induced in the wire. All that is required is that there is relative movement between the two so that lines of force are cut by the wire. It is this cutting and whirling, or wrapping, of the lines of force around the wire that produces the current movement in the wire.

(a) The magnetic field can be moved by moving the magnet or, if it is a magnetic field from an electromagnet, it can be moved by starting and stopping the current flow in the electromagnet.

(ON SLIDE #67)

(3) Self-Induction. When an electromagnet is connected to a battery, current will start to flow through it. This current, as it starts to flow, builds up a magnetic field. This magnetic field might be considered as expanding (like a balloon, in a sense) and moving out from the electromagnet. As it moves outward, its lines of force will cut through its windings. These windings will have current induced into them. The current will result from the lines of force cutting across the wire. If the

electromagnet is disconnected from the battery, its magnetic field will collapse and disappear. As this happens, the lines of force move inward toward the electromagnet. Again, the windings of the electromagnet will be cut by moving lines of force and will have a current induced into them. This time, the lines of force are moving in the opposite direction and the wire will have current induced in it in the opposite direction.

(4) Mutual-Induction. Any wire held in an electromagnetic field while it is expanding or collapsing will have current induced in it. The amount of current induced into a secondary conductor circuit by mutual induction will depend on the strength of the magnetic field of the primary conductor circuit. With mutual-inductance, circuits that are electrically separated can be magnetically coupled together.

(ON SLIDE #68)

(5) Thus electrical current can be induced in the wire by three methods:

(a) The wire can be moved through the stationary magnetic field.

(b) The wire can be held stationary and the magnet can be moved so the field is carried past the wire.

(c) The wire and electromagnet both can be held stationary and the current turned on and off to cause the magnetic field buildup and collapse, so the magnetic field moves one way or the other across the wire.

(ON SLIDE #69)

INSTRUCTOR NOTE
Image of common electrical failure slide

(ON SLIDE #70)

m. **Common Electrical Failures**. Most electrical problems can be classified as being one of four types of problems: high resistance, an open, a ground, or a short. Each one of these will cause a component to operate incorrectly or not at all. Understanding effect of these failures is the key to proper diagnosis of any electrical problem.

(ON SLIDE #71)

(1) A high resistance can result in slow, dim, or complete failure of the component to operate. Since the resistance becomes an additional load, the effect is that the intended component, with reduced voltage and current applied, operates with reduced efficiency. High resistance may be caused by loose, corroded, dirty or oily terminals, or by broken strands in electrical wiring that reduces the capacity of that wire to carry current.

(ON SLIDE #72)

(2) An open is a break in the electrical path that results in a complete failure of electrical component to operate. When there is an open, current does not flow and the component doesn't work. Because there is no current flow, there are no voltage drops in the circuit. Source voltage is available everywhere in the circuit up to the point at which it is open. An open may be caused by a tripped circuit protection device, a disconnected terminal, a broken wire, or failed electrical component.

(ON SLIDE #73)

(3) An unintentional ground (sometimes referred to as short to ground) is caused by non insulated wire connections or frayed insulation on a wire that unintentionally comes in contact with the grounded frame. This type of failure allows current a direct path to ground, and either overloads circuit protection devices or burns circuit wiring.

(ON SLIDE #74)

(4) A short usually results in two components operating when only one of two switches is turned on or when current by-passes it's designed component. A short causes an increase in current flow. This increase in current can also cause overloaded circuit protection devices or burned circuit wiring.

(a) One example of a short would be where two un-insulated wires from two different circuits touch which creates one parallel circuit. Because the total resistance of the parallel circuit is less than the resistance of the individual circuits, more current flows through the circuit protection devices and wiring.

(b) Another common example of a short occurs when the insulation on the windings of a solenoid (or relay) break down. Because the current no longer travels the length of the winding, resistance goes down, voltage goes up, and current increases.

(ON SLIDE #75)

TRANSITION: During the past 5 hours we covered the Laws and Principles of Electricity, do you have any questions? If not, I have several for you,

(Q1) What are the basic particles that make up all atoms?
(A1) Protons, Electrons and Neutrons

(Q2) What is the result if you have a point of excess electrons connected to a point that has a shortage of electrons?
(A2) A flow of electrons (electrical current) will move through the connector until an equal electric charge exists between the two points.

(Q3) What is it called when voltage is generated by heat?
(A3) Thermo-electric

(Q4) What are the two different types of current and what are they measured in?
(A4) Alternating current and Direct current, they are measured in Amperes.

(ON SLIDE #76)

(Q5) What is the unit used to measure resistance?
(A5) The ohm

(Q6) What is Ohm's Law?
(A6) Voltage is equal to amperage multiplied by resistance.

(Q7) What is Watt's Law?
(A7) Power is exactly equal to current multiplied by voltage.

(Q8) What is a good example of a conductor?
(A8) Silver or Copper

(Q9) What's a good example of a insulator?
(A9) Rubber or plastic

(Q10) What is a good example of a semiconductor?

(A10) Silicone

(Q11) What are the four common electrical failures?
(A11) High resistance, an open, a ground, and a short.

At this time take a 10 min break and we'll move into Electrical Schematics and Wiring Diagrams.

____
____
____

(ON SLIDE #77)

(BREAK – 10 MIN)

TRANSITION: Before the break we have covered the Laws and Principles of Electricity. Now let's talk about Electrical Schematics and Wiring Diagrams.

____
____
____

(ON SLIDE #78)

QUIZ (30 MIN)
Before moving on to next main idea, handout the "Laws and Principles of Electricity" quiz, then review it to check for understanding.

(ON SLIDE #79)

2. ELECTRICAL SCHEMATICS AND WIRING DIAGRAMS. (1 Hr)

a. A **schematic diagram** represents the elements of a system using abstract, graphic symbols rather than realistic pictures. A schematic usually omits all details that are not relevant to the information the schematic is intended to convey, and may add unrealistic elements that aid comprehension. For example, a subway map intended for riders may represent a subway station with a dot; the dot doesn't resemble the actual station at all but gives the viewer information without unnecessary visual clutter. A schematic diagram of a chemical process uses symbols to represent the vessels, piping, valves, pumps, and other equipment of the system, emphasizing their interconnection paths and suppressing physical details. In an electronic circuit diagram, the layout of the symbols may not resemble the layout in the physical circuit. In the schematic diagram, the symbolic elements are arranged to be more easily interpreted by the viewer.

(ON SLIDE #80)

b. An electrical schematic is the plan (scheme) of how electrical components are connected together. It is like a roadmap of the electrical circuits.

(ON SLIDE #81)

c. It identifies wires and connectors from each circuit; it also shows where different circuits are interconnected, where they receive their power, where the ground is located, and the colors of the different wires. It is similar to a map, it uses different colors and symbols and it will have a key or legend to let you decipher what each symbol stands for.

(ON SLIDE #82)

d. Electrical schematics do not usually explain how the circuit works. They just show how the components are connected and the order they follow each other. The knowledge of how the circuit works is left to the mechanic

(ON SLIDE #83)

e. Original Equipment Manufacturers (OEM) develop corporate electrical schematics styles, symbols, and color codes that are particular to their company. Always refer to the legend or key of the schematic, the schematic itself or the technical manual.

(ON SLIDE #84)

f. System Functional Schematic: An electrical diagram of the complete machine. It may be made up of several foldouts of circuits divided into subsections.

(ON SLIDE #85)

g. Subsystem Functional Schematic: A sectional division of the system functional schematic and shows the same letter/number designations of wires and components

(ON SLIDE #86)

h. System Wiring diagrams illustrate the physical connections, or wiring, between components. They are crucial to the assembly of the circuit or system. Parts that are shown broken down into their sub-components, for the schematic, retain their complete package format for the wiring diagram.

(ON SLIDE #87)

i. Component Location Drawing: A pictorial view of a harness showing the location of all the electrical components, connectors, harness main ground locations, and harness band and clamp locations. Each component is identified by the same identification letter/number and description used in the subsystem functional schematic.

(ON SLIDE #88)

j. Subsystem Diagnostic Schematic: A diagram that combines the subsystem functional schematic with all harness connections and pin locations to aid in diagnosing the subsystems.

(ON SLIDE #89)

k. Block Diagram: A block diagram is used in conjunction with schematics to aid in circuit comprehension and accelerates troubleshooting procedures. Each block is assumed to represent all schematic symbols related to that part of the circuit and represents it as a block. Each block is labeled with a description of the circuit it represents. The block diagram does little or nothing to explain the actual makeup of the circuit it represents. Instead they are functional in nature; they describe the circuit function rather than depicting actual components.

(ON SLIDE #90)

TRANSITION: During the past hour we covered how to read a schematic, do you have any questions?

____
____
____

(BREAK - 10 Min)

(ON SLIDE #91)

TRANSITION: Before the break for the past hour we learned how to read a schematic and locate circuits on a computer. Do you have any questions? If not, I have a couple for you,

(Q1) Do electrical schematics usually explain how the circuit works?
(A1) No, this is left up to the mechanic to decipher.

(Q2) What does OEM stand for?
(A2) Original Equipment Manufacturers.

Now, that we are comfortable with reading and following a schematic, let's discuss where the power originates from, the battery.

INSTRUCTOR NOTE
Image of common electrical failure slide

(ON SLIDE #92)

3. **STORAGE BATTERY OPERATION/TROUBLESHOOTING** **(3 Hrs)**

(ON SLIDE #93)

a. **Purpose**. The storage battery provides electrical energy through chemical reactions. The battery stores electrical surplus by reversing the chemical reaction when the electrical system produces more electrical energy than required for operating electrical accessories. This is known as charging the battery. When the alternator is not producing the necessary electrical energy, the battery, through chemical reaction, can supply the energy required in the electrical system of the vehicle. The battery then is said to be discharging. The most common battery used in equipment is the lead-acid battery.

(ON SLIDE #94)

b. The batteries have several important functions, including:

(1) Operating the starting motor and other electrical devices for the engine during cranking.

(2) Supplying all the electrical power for the vehicle's accessories whenever the engine is not running or when the equipment's charging system is not working.

(3) Furnishing current for a limited time whenever electrical demands exceed charging system output.

(4) Acting as a stabilizer of voltage for the entire electrical system.

(5) Storing energy for extended periods of time.

(ON SLIDE #95)

c. **<u>Construction</u>**. The storage battery may consist of three or more cells, depending on the voltage desired. A battery of three cells (2.1 volts each) connected in series is a 6-volt battery (6.3 VD/C), and a battery of six cells connected in series is a 12-volt battery (12.6 VD/C).

(ON SLIDE #96)

(1) <u>Plates</u>.

(a) Each cell consists of a hard rubber jar or compartment into which two kinds of lead plates, known as positive and negative are placed. These plates are insulated from each other by suitable separators and are submerged in a sulfuric acid solution.

(b) The backbone of both the positive and negative plates is a grid made of stiff lead alloy casting. The grid, usually composed of vertical and horizontal cross members, is designed carefully to give the plates mechanical strength and, at the same time, to provide adequate conductivity for the electric current created by the chemical action. The active material, composed chiefly of lead oxides, is applied to the grids in paste form, and then allowed to dry and harden like cement. The plates are then put through an electrochemical process that converts the hardened active material of the positive plates into brown lead peroxide, and that of the negative plates into gray, spongy, metallic lead. This process is known as forming the plates.

(ON SLIDE #97)

(2) Groups. After the plates have been formed, they are built into positive and negative groups. The plates of each group are permanently joined by melting a portion of the lug on each plate to form a solid weld with a connecting post strap. The heat necessary for this process, termed lead burning, is produced by a gas flame or an electric arc. The connecting post strap to which the plate lugs are burned contains a cylindrical terminal that forms the outside connection for the cell. The negative group of plates has one more plate than the positive group to provide a negative plate on both sides of all positive plates.

(ON SLIDE #98)

(3) Separators. To prevent the plates from touching and causing a short circuit, sheets of insulating material (micro-porous rubber, fibrous glass, or plastic impregnated material), called separators, are inserted between the plates. These separators are thin and porous so the electrolyte will flow easily between the plates.

(4) Cell elements. The assembly of a positive and negative group, together with the separators, is called a cell element. Because the storage battery plates are more or less of standard size, the number of plates in a cell is, roughly, a measure of the battery capacity.

(ON SLIDE #99)

(5) Electrolyte.

(a) Composition. An electrolyte is a liquid that conducts electricity readily and is decomposed when an electric current passes through it. The electrolyte in the lead-acid storage battery is composed of one part of chemically pure sulfuric acid (36%) and approximately two and three-fourths parts, by volume, of distilled water (64%). A small quantity of some impurity introduced into the acid solution by using impure water might interfere with the chemical action and cause battery failure.

(b) Specific Gravity Readings. Specific gravity is the ratio of the weight of the same volume of chemically pure water at 39°F (4°C). The specific gravity of sulfuric acid is 1.835; that is, sulfuric acid is 1.835 times heavier than water. The electrolyte of a storage battery is a mixture of water and sulfuric acid. The amount of sulfuric acid in the electrolyte changes with the amount of electrical charge; also, the specific gravity of the electrolyte changes with the amount of electrical charge. This provides a convenient way of measuring the degree of charge in a battery. A fully charged battery will have a specific gravity of 1.265 at 80°F (26.6°C). The figure will go higher with a temperature decrease and lower with a temperature increase.

(ON SLIDE #100)

(6) Container.

(a) A battery container is a receptacle for the cells that make up the battery. It is made of hard rubber or a polypropylene plastic, which is resistant to acid and mechanical shock. Most batteries are assembled in one-piece containers with three or six compartments for the individual cells. One element and enough electrolytes to cover the plates are inserted into each cell compartment.

(b) Stiff ridges, or ribs, molded in the bottom of the container form a support for the plates and a sediment recess for the flakes of active material that drop off the plates during the life of the battery. The sediment is thus kept clear of the plates so it will not cause a short circuit across them.

(ON SLIDE #101)

(7) Cover. After all of the elements have been fitted into the case, they are connected together in series by burning lead cell connectors across the terminals. The battery top then is sealed with a hard rubber cover that provides openings for the two battery posts and a vent plug for each cell. The vent plugs allow gas to escape and prevent the electrolyte from splashing outside the battery. The battery is filled through the vent plug openings.

(ON SLIDE #102)

d. **Principles of operation**. When a cell is fully charged, the negative plate is spongy lead, the positive plate is lead peroxide, and the electrolyte contains a maximum amount of sulfuric acid. Both the negative and positive plates are very porous and are acted upon readily by the acid. A cell in this condition can produce electrical energy through reaction of the chemicals.

Pb-Lead, O2-Oxygen, H2-Distilled Water, SO4-Sulfuric Acid

(ON SLIDE #103)

(1) Discharge. If the terminals of the battery are connected to a closed circuit, the cell discharges to supply electric current. The chemical process that occurs during discharge changes both the lead of the negative plate and the lead peroxide of the positive plate to lead sulfate and the sulfuric acid to water. Thus, the electrolyte becomes weaker during discharge, because the water increases and the sulfuric acid decreases. As the discharge continues, the negative and the positive plates finally contain considerable lead sulfate and the electrolyte turns to almost pure water. At this point the battery will stop providing current flow.

(ON SLIDE #104)

(2) Charge. To charge the cell, an external source of direct current must be connected to the battery terminals. The chemical reaction is then reversed and returns the positive and negative plates and the electrolyte to their original condition. When all sulfates on the plates have been returned to the electrolyte to form sulfuric acid, the cell is recharged fully and ready to be used for the next discharge. Charging should be started before both plates have become fully sulfated.

(ON SLIDE #105)

e. **Battery Ratings**. Temperature has a dramatic effect on a battery’s ability to crank an engine. Not only does cold rob batteries of power, it also stiffens motor oil, making engines harder to start. And heat can damage batteries by causing internal components to wear out quickly while also making engines difficult to start.

(1) Ampere-hour rating. Some batteries are given normal capacity ratings according to the ampere-hours obtained from the battery under certain working conditions. The capacity of a battery is the number of amperes delivered, multiplied by the number of hours the battery is capable of delivering this current. One of the inherent characteristics of a storage battery is that its ampere-hour rating depends upon the rate of discharge. A battery will give more ampere-hours at a long, low, or intermittent discharge rate than at a short, high, or continuous discharge rate. This is because the voltage drops faster at higher rates. Like other chemical processes, the

battery is less efficient in cold weather than in hot weather. At 0°F (-18°C), a battery has only approximately 40 percent of the full cranking capacity available at 80°F (27°C). In an emergency, little, if any, permanent harm will result if the battery is discharged at a very high rate, provided it is promptly recharged. The battery is likely to deteriorate if left in a discharged condition. An approximate measurement of a battery's ability to provide energy i.e it's charge capacity, is its rating in ampere hours (Ah) or amp hours. So a 100 Ah battery will produce 100 amps for 1 hour. This capacity can be divided up any way you choose.
100 Ah could produce 1 amp for 100 hours, or 50 amps for 2 hours, 4 amps for 25 hours or 25 amps for 4 hours etc.
Battery capacity (Ah) = Current drawn (I) x Time (H) or you could cross multiply and get. Time = Battery capacity / Current drawn Current drawn = Battery capacity / Time

(ON SLIDE #106)

(2) Cold Cranking Amp rating. Cold cranking amp rating is determined by the load a battery is able to deliver for 30 seconds at 0° F without terminal voltage falling below 7.2 volts for a 12-volt battery. The cold cranking rating is given in total amperage and is identified as 300 CCA, 400 CCA, 500 CCA, and so on. Some batteries are rated as high as 1,100 CCA.

(ON SLIDE #107)

(3) State of Charge for a battery refers to the open circuit voltage of the battery when it is tested across the positive and negative terminals. It is important to remove any surface charge from the battery when the state of charge is being checked.

Conventional Lead-Acid

Open Circuit Voltage	State of Charge
12.6 or greater	100%
12.4 to 12.6	70–100%
12.2 to 12.4	50–70%
12.0 to 12.2	25–50%
11.7 to 12.0	0–25%
11.7 or less	0%

Sealed Lead-Acid Battery (AGM).

Open Circuit Voltage	State of Charge
12.9 volts	100%
12.7 volts	75%
12.4 volts	50%
12.1 volts	25%

(ON SLIDE #108)

INSTRUCTOR NOTE

Play embedded movie on slide "State of Charge" 2.10 minutes long.

(ON SLIDE #109)

<u>INTERIM TRANSITION</u>: Are there any questions over cold cranking amp rating? If not, let's take a 10 min break and then we'll talk about Absorbed Glass Mat (AGM) or valve regulated lead-acid (vrla) batteries.

____
____
____

(BREAK - 10 Min)

<u>INTERIM TRANSITION</u>: During the break did anyone come up with any questions? If not, let's talk about Absorbed Glass Mat (AGM) or valve regulated lead-acid (vrla) batteries.

____
____
____

(ON SLIDE #110)

f. **<u>Absorbed Glass Mat (AGM) or Valve Regulated Lead-Acid (VRLA) Batteries</u>.** The newest type of battery in use by the Marine Corps (Hawker Armstrong Batteries). It uses "Absorbed Glass Mats", or AGM between the plates. This is a very fine fiber Boron-Silicate glass mat. These type of batteries have all the advantages of a Gel (distinguishable by its six pack shaped cells), but can take much more abuse. AGM batteries are also called "starved electrolyte", as the mat is about 95% saturated rather than fully soaked. That also means that they will not leak acid even if broken.

(ON SLIDE #111)

(1) AGM batteries have several advantages over both gelled and flooded, at about the same cost as gelled:

(a) All the electrolyte (acid) is contained in the glass mats. They cannot spill, even if broken. This also means that since they are non-hazardous and the shipping costs are lower. In addition, since there is no liquid to freeze and expand in a fully charged battery, they are practically immune from freezing damage. AGM's do not have any liquid to spill, and even under severe overcharge conditions hydrogen emission is far below the 4% max specified for aircraft and enclosed spaces.

(b) Nearly all AGM batteries are "recombinant". This means that the Oxygen and Hydrogen recombine INSIDE the battery. These types of batteries use gas phase transfer of oxygen to the negative plates to recombine them back into water while charging and prevent the loss of water through electrolysis. The recombining is typically 99+% efficient, so almost no water is lost.

(c) AGM's have a very low self-discharge (approximately 1% per month is usual) compared to **The 6TL Battery has a 4.4% self-discharge rate per month** (as identified by the USMC AVTB, Report, dated 20 March 00). This means that they can sit in storage for much longer periods without charging than standard batteries. **The only way to prevent self-discharge & sulfation is with frequent charging or by adding hardware.**

(d) They can be almost fully recharged (95% or better) even after 30 days of being totally discharged. This also means they can withstand up to six deep cycles (a complete discharge followed by a complete recharge) and retain efficiency above 95%.

(e) The plates in AGM's are tightly packed and rigidly mounted, and will withstand shock and vibration better than any standard battery.

(ON SLIDE #112)

(2) Even with all the advantages listed above, they do have some disadvantages when compared to conventional style batteries.

(a) AGM's cost 2 to 3 times as much as flooded batteries of the same capacity. In many installations, where the batteries are set in an area where you don't have to worry about fumes or leakage, a conventional battery is a better economic choice.

(b) AGM batteries require a charging voltage that does not exceed 14.00 volts (summer temperatures may require even lower voltages). Unfortunately almost all charging systems have a permanently fixed set point voltage that exceeds 14.00 and this spells trouble. Subjecting the batteries to (commonly found) 14.6 volts for a prolonged period will eventually destroy them. Some Engineer Equipment, such as the ACE and TRAM, have alternators and voltage regulators with internal set screws which can be fine-tuned (to lower the voltage set point). In extreme cases, charging systems can be modified to accept an exterior adjustable voltage regulator. Local automotive electrical rebuild shops can be a lifesaver. *"For your edification, 14.05 volts is an acceptable "upper limit" for charging valve regulated batteries."* And finally the owner of the Valve Regulated Battery must understand that even one unsupervised service station "quick-charge" will destroy even the best maintained AGM battery.

(3) AGM batteries insist on being located in an environment well away from high under hood engine or radiator temperatures. As a matter of fact the manufacturers of these types of batteries insist that all charging must cease altogether if the core of the battery reaches one hundred twenty degrees Fahrenheit.

(ON SLIDE #113)

(4) Occasionally an AGM battery will exhibit a condition referred to as **"THERMAL RUNAWAY"**. When "thermal runaway" happens to an Absorbed Glass Mat battery the results can be dramatic. An electro chemical reaction can take place inside an "AGM" battery if it is overheated while being charged. This can be the result of too high a charging voltage, which will overheat any battery, too high an environmental temperature or a combination of both elements. Instead of tapering off, the charging current actually increases as the battery temperature increases. In extreme cases the electrolyte and binder material can be forcibly ejected from the battery vents. Obviously the battery will be destroyed. The point here is to pay attention to the battery's location and charging voltage limit.

(ON SLIDE #114)

g. **Solargizer**. A Solargizer is a battery maintenance device used on equipment to prevent and break up large crystal sulfates on battery plates which occur in discharged batteries. It can be powered by either sunlight (Solar panel) or an AC receptacle.

(1) Sulfur has the properties of a semiconductor, as such sulfate crystal formations slowly destroy the battery's capacity because the longer the sulfur has to crystallize the harder it will be to change those crystals to sulfuric acid.

(2) A Solargizer will offset the 6TL's self-discharge from 4.4% to .8% per month, and eliminate the AGM's self discharge. That means the capacity the battery was losing in 30 days now takes 5.5 months to lose.

(ON SLIDE #115)

h. **Battery Installation Considerations**. The design of a battery installation will vary with the type of equipment. There is, however, certain design features that can be applied to equipment meeting military specifications.

(1) The battery should always be mounted in a location that is clean and protected from accumulations of mud, dust, and excess moisture. Protection from the elements is beneficial not only to the operation of the battery itself, but can be the means to prevent unforeseen accidents. For example, if saltwater comes in contact with the positive plates of a damaged lead-acid battery, it will produce chlorine gas. Proper design will avoid the possibility of such an occurrence. Also, provisions for periodic cleaning of the battery installation should be made.

(2) The battery should be mounted to facilitate maintenance and provide ready access to the batteries without the need for removing other components. All access plates should be hinged and employ quick release fasteners when feasible. Allow for adequate clearance so that maintenance personnel wearing arctic clothing can gain access for removal and replacement. Allow enough overhead room to provide for easy, accurate testing and servicing of the batteries.

(3) Battery boxes should be designed to protect the vehicle and crew from gases produced during battery charging. These gases are oxygen and hydrogen, which constitute a highly explosive mixture. Thus, adequate ventilation must be provided to allow all gas to escape. This ventilation also is necessary to limit temperature rise in hot climates.

(ON SLIDE #116)

i. **Battery Pack Configurations**.

INSTRUCTOR NOTE

Because of the difficulty involved in starting a diesel engine and NATO requirements, all of our currently designed construction equipment has two or more batteries.

(1) Most of the current equipment configurations use more than one battery. There are two reasons for this:

(a) Because the standard batteries are 12 volts, two batteries are required to meet the 24-volt requirement of military vehicles.

(b) Additional batteries may be required to meet heavy current demands of certain military applications.

(ON SLIDE #117)

(2) Two 12-Volt Batteries in Series. The connection of two 12-volt batteries in series will add their voltages together to deliver 25.2 volts (each battery has the potential of 12.6 VDC). It should be noted that the amount of current output, however, will remain the same as for one battery.

(ON SLIDE #118)

(3) Four 12-Volt Batteries in Series-Parallel. By taking two pairs of 12-volt batteries connected in series and connecting them in parallel with each other, a battery pack of 25.2 volts will result, with twice the current output of each individual battery. This battery configuration is used to meet the demands of heavy-duty use and to provide extra power for cold weather cranking.

INSTRUCTOR NOTE

Many times a battery that can be recovered is condemned or replaced because of improper charging practices.

j. **Battery Charging**.

(ON SLIDE #119)

INSTRUCTOR NOTE

Show embedded movie “Caterpillar Battery Charging” 2.49 minutes.

(1) Battery chargers. ***MUST BE DESIGNED FOR THE SPECIFIC BATTERY TYPE!***

(a) Flooded lead acid batteries use conventional automotive type chargers, and when possible the charger should be and automatic type as to not accidentally overcharge battery if it's left connected.

(ON SLIDE #120)

INTERIM TRANSITION: Are there any questions about Absorbed Glass Mat (AGM) or valve regulated lead-acid (vrla) batteries? If not let's take a ten minute break.

(BREAK - 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk more about AGM batteries.

(ON SLIDE #121)

(b) AGM batteries need a high quality charger because the voltage needs to be properly controlled. The recommended (by Military Battery Systems INC) is the Pulse Charger (Part No. 746x725, NSN: 6130-01-398-6951, GSA Price: $556.00). It incorporates a safety feature that prevents it from starting its charge regimen if a battery is below approximately 6 volts. (A battery below 6 volts can seldom be recovered). It is four products in one.

1 Switch (on back) for unique requirements of flooded lead-acid batteries and AGM batteries.

2 There is a Pulse Only setting that is designed to pulse cleans the battery internally.

3 Pulse & Charge, which simultaneously pulses the battery while it is being charged.

4 It’s also a 20 amp “smart” charger that constantly tests the battery to insure a proper charge. Once the battery is fully charged, the unit switches to Pulse Only to maintain the battery.

(ON SLIDE #122)

(2) Trickle charging. Trickle charging is a method of charging for maintaining a battery that is already at a good state of charge. This charging method compensates the self-discharge losses suffered by all rechargeable batteries during storage. Used for mothballed vehicles and batteries which must be kept in a good state of charge for special operational needs are some of the possible applications for trickle charging.

(ON SLIDE #123)

INSTRUCTOR NOTE
Batteries are the source of power for the electrical system when the engine isn’t running. Though their installation and configuration may be different, they usually fail in obvious ways.

k. **Common Causes of Battery Failure**. Whenever battery failure is suspected, first perform some simple visual inspections. Check the case for cracks, check the electrolyte level in each cell (if possible), and check the terminals for corrosion. The sulfuric acid that vents out with the battery gasses attacks the battery terminals and battery cables. As the sulfuric acid reacts with the lead and copper, deposits of lead sulfate and copper sulfate are created. These deposits are resistive to electron flow and limit the amount of current that can be supplied to the electrical and starting systems. If the deposits are bad enough, the resistance can increase to a level that prevents the starter from cranking the engine.

(ON SLIDE #124)

(1) One common cause of early battery failure is overcharging. If the charging system is supplying a voltage level higher than the manufacturer’s recommendation, the plates may become warped. Plate warping results from the excess heat that is generated as overcharging occurs. Overcharging also causes the active material to disintegrate and shed off the plates.

(2) If the charging system does not produce enough current to keep the battery charged, the lead sulfate can become crystallized on the plates. If this happens, the sulfate is difficult to remove and the battery will resist recharging. The recharging process converts the sulfate on the plates. If there is an under charging condition, the sulfate is not converted and it will harden on the plates.

(ON SLIDE #125)

(3) Vibration is another common reason for battery failure. If the battery is not secure, the plates will shed the active material as a result of excessive vibration. If enough material is shed, the sediment at the bottom of the battery can create an electrical connection between the plates. The shorted cell will not produce voltage, resulting in a battery that will have only 10.5 volts across the terminals. With this reduced amount of voltage, the starter will not be capable of starting the engine. Proper holds down fixtures are used to prevent excessive vibration.

(4) During normal battery operation, the active materials on the plates will shed. The negative plate also becomes soft. Both of these events will reduce the effectiveness of the battery.

(5) Insufficient engine run time. It takes a tremendous amount of electrical energy (depending on environmental conditions) to start an engine. To avoid battery failure due to this, anytime an engine is started, it should be ran for approximately 10 minutes at a minimum.

(ON SLIDE #126)

INSTRUCTOR NOTE
Movie “How Lead Batteries Are Made” 2.48 minutes.

(ON SLIDE #127)

l. **Charging AGM Batteries**.

(1) Measure the open-circuit voltage of the battery after the surface charge has been removed = ____ volts (red lead of the voltmeter to positive [+] and black lead to negative [-]).

(2) Determine the state of charge =____.

(3) Do not use a conventional lead acid battery charger to charge AGM batteries, use only battery chargers appropriate to charge these battery types, restricted to a nominal voltage of 14.05 VDC. Any other battery charger will shorten the life of the battery and cause internal damage.

INSTRUCTOR NOTE

To remove the surface charge, disable the fuel injection pump and crank the engine for five seconds

(4) Charge AGM batteries in accordance with the time, state of charge and the *INITIAL* output (of Amps) of the charger.

(ON SLIDE #128)

Battery State Of Charge	**Approximate time in hours required to Full Charge at 14.0 volts (Charger Output in Amps)**		
	40 Amps	20 Amps	10 Amps
10%	5.0 hours	6.0 hours	9.0 hours
25%	3.0 hours	4.0 hours	7.0 hours
50%	2.0 hours	3.0 hours	5.0 hours

(5) After charging, let stand for 3 to 10 hours to dissipate the surface charge and test voltage.

m. **Conventional Battery Charging**.

(1) Measure the open-circuit voltage of the battery after the surface charge has been removed = ____ volts (red lead of the voltmeter to positive [+] and black lead to negative [-]).

(2) Determine the state of charge =____.

(3) Determine the cold cranking amperes (CCA) of the battery = _______. (The charge rate should be 1% of the CCA. For example, a battery with a 500 CCA rating should be charged at 5 ampere rate.)

(4) The battery should be charged at ___ amperes.

(ON SLIDE #129)

n. **Storage Battery Operation and Trouble Shooting**. Many times Technical Manuals will not give a detailed description of how to eliminate a battery set as the cause of electrical failure. The most common specification is "batteries are bad-------replace known bad batteries". This practical application will help you to reduce replacement of good batteries. However, specific testing procedures will vary between end items and manufactures. ***ALWAYS*** refer to the technical manual for available testing procedures. After your team has completed a task, you will back brief the instructor and answer questions about how you conducted the procedure ***BEFORE*** proceeding to the next exercise.

(1) Determining state of charge. State of charge is used to determine if a battery is in need of charging and for how long it should be charged.

(a) Open circuit voltage is the amount of voltage when measured across the positive "+" and negative "-" terminals of the battery. Measure the open-circuit voltage of the battery after the surface charge has been removed = ______ VDC.

(b) State of charge =____.

Conventional Lead-Acid

Open Circuit Voltage	State of Charge
12.6 or greater	100%
12.4 to 12.6	70–100%
12.2 to 12.4	50–70%
12.0 to 12.2	25–50%
11.7 to 12.0	0–25%
11.7 or less	0%

Sealed Lead-Acid Battery (AGM)

Open Circuit Voltage	State of Charge
12.9+ volts	**100%**
12.7 volts	**75%**
12.4 volts	**50%**
12.1 volts	**25%**
11.8 volts	**10%**

(2) Battery connection voltage drop testing.

(a) With current flowing through the circuit, the multimeter is connected in parallel over the battery connections to measure voltage drop.

(b) The multimeter will indicate the amount of voltage lost between the two points at the connection. The voltage reading indicates the difference between the amount of voltage available to the load and the amount of voltage after the load.

(ON SLIDE #130)

TRANSITION: During the past 3 hours we covered Storage Battery Operation and Troubleshooting, do you have any questions? If not, I have several for you,

(Q1) What are the five functions of the batteries?
(A1) 1. Operating the starting motor and other electrical devices for the engine during cranking. 2. Supplying all the electrical power for the vehicle's accessories whenever the engine is not running or when the equipment's charging system is not working. 3. Furnishing current for a limited time whenever electrical demands exceed charging system output. 4. Acting as a stabilizer of voltage for the entire electrical system. 5. Storing energy for extended periods of time.

(Q2) What kind of battery is a Hawker Armstrong battery?
(A2) Absorbed Glass Mat or AGM.

(Q3) Can vibration cause a battery to fail?
(A3) Yes.

At this time take a 10 min break and we'll move into Storage Battery Operation and Troubleshooting.

____
____
____

(BREAK – 10 MIN)

TRANSITION: Before the break we have covered the Laws and Principles of Electricity. Now let's talk about Electrical and Electronic Component Failure Isolation and Identification.

____
____
____

(ON SLIDE #131)

4. **ELECTRONIC COMPONENT FAILURE ISOLATION AND IDENTIFICATION. (3 Hrs)**

(ON SLIDE #132)

a. **Switches**. A switch is the most common means of providing control of electrical current flow to an accessory. It can be thought of as a draw bridge type gate that controls the flow of cars across the bridge by closing to allow cars to cross and opening to stop the flow of cars. Likewise, a switch can control the on/off operation of a circuit or direct the flow of current through various circuits. When the contacts inside the switch assembly carry are closed, the current flows, and when they are open, current flow is stopped.

(ON SLIDE #133)

(1) The simplest type of switch is the single-pole, single-throw (SPST) switch. This switch controls the on/off of a single circuit. However, switches can have multiple poles with any combination of throws. Some examples include:

(a) Single-pole single-throw (SPST).

(b) Single-pole double-throw (SPDT).

(c) Double-pole single-throw (DPST).

(d) Double-pole double-throw (DPDT).

(2) One of the most complex switches is the multiple contact switch (sometimes referred to as a ganged switch or multi switch). The wipers of this type of switch are all "ganged" together and will move together. One common example of this type of switch is an ignition key switch.

(3) Switches may also be classified as "normally open" or "normally closed".

(ON SLIDE #134)

(a) A normally open switch will not allow current flow when it is in its rest position. The contacts are open until they are acted on by an outside force that closes them to complete the circuit.

(b) A normally closed switch will allow current flow when it is in its rest position. The contacts are closed until they are acted on by an outside force that opens them to stop current flow.

(ON SLIDE #135)

(4) <u>There are Four Common Methods Manufactures use to Actuate Switches</u>:

(a) Manually-activated. This type of switch is controlled by the operator. The most common manually actuated switches are toggle switches, push-pull switches, cutout switches (emergency shutdown), and push button switches.

(ON SLIDE #136)

(b) Mechanically-activated (proximity) switch. This type of switch is dependent on the operation of a mechanical device. This type of switch may also use the proximity of a permanent magnetic field to open or close the switch contacts. An example of this type of switch is a parking lever position switch or neutral start switch.

(ON SLIDE #137)

(c) Pressure-activated. This type of switch uses a pressure change to open or close the switch contacts. It is operated by an outside force from oil, water, or air. Usually it is a spring type unit that opens or closes a circuit automatically in response to pressure. One example of this type of switch is an oil pressure switch.

(ON SLIDE #138)

(d) Temperature-activated (Thermostatic). This type switch contains a set of contact points that are operated by the bending of a bimetallic strip that is calibrated to turn on or turn off a circuit at a specified temperature. A common usage for this switch is the high coolant temperature light.

(ON SLIDE #139-140)

b. **Relays**. An electromagnetic switch that uses a movable arm is called a relay. It is a device that uses low current to control a high current circuit. With this type of draw bridge gate, there is no manual control of its raising and lowering, rather it is done remotely with electricity. When electricity is sent through the relay's coil it will pull the switched contacts closed. The coil in a relay has a high resistance, thus it will draw very low current. This low current is used to energize the coil, while high current is able to pass over the relay contacts. The contacts are designed to carry the high current required to operate the load component.

(ON SLIDE #141)

(1) Normally open (NO) relays start out with their contacts open. When current is applied to the coil, the contacts close and heavy battery current flows to the load component that is being controlled.

(2) Normally closed (NC) relays start out with their contacts closed. When current is applied to the coil, the contacts open causing heavy battery current to stop flowing to the load component that is being controlled.

(ON SLIDE #142)

c. ISO relays conform to the specifications of the International Organization for Standardization (ISOS is Greek for "equal") for common size and terminal patterns. The terminals are identified as 30, 87A, 87, 86, and 85. *(Draw arrows to the terminal.)*

(1) Terminal 86. connected to battery voltage to supply current to the electromagnetic coil when it is switched on.

(2) Terminal 85. provides ground for the electromagnetic coil when it is switched on.

(3) Terminal 30. usually connected to battery voltage. This source voltage can be either switch controlled or connected directly to the battery.

(4) Terminal 87. connected to terminal 30 when the relay is energized.

(5) Terminal 87A. connected to terminal 30 when the relay is de-energized.

(ON SLIDE #143)

INTERIM TRANSITION: Are there any questions about relays, if not let's talk about another electromagnetic switch called a solenoid.

(ON SLIDE #144)

d. Solenoids. An electromagnetic switch that uses a movable iron core is called a solenoid.

(ON SLIDE #145-146)

Solenoids can do mechanical work, such as pulling a fuel shut-off lever, pushing a hydraulic valve, or moving a starting gear into mesh with the engine flywheel.

(1) The iron core inside the coil of the solenoid is spring loaded. When current flows through the coil, the magnetic field around the coil attracts the core and moves it into the coil.

(2) Once the core is moved, the current required to hold the core is reduced. This prevents overheating of the solenoid and allows the current that was used to move the core to be used elsewhere in the electrical system (such as powering the starting motor).

(3) To do work, the core is attached to a mechanical linkage, which causes something to move. When current flow through the coil stops, the spring pushes the core back to its original position.

(ON SLIDE #147)

e. Direct Current Motors.

(1) Construction. A simple D/C motor is constructed of a brushes, armature, commutator, and pole shoes.

(ON SLIDE #148)

(2) DC motor design generates an oscillating current in a wound rotor, or armature, with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of one or more coils of wire wound around a core on a shaft; an electrical power source is connected to the rotor coil through the commutator and its brushes, causing current to flow in it, producing electromagnetism. The commutator causes the current in the coils to be switched as the rotor turns, keeping the magnetic poles of the rotor from ever fully aligning with the magnetic poles of the stator field, so that the rotor never stops (like a compass needle does) but rather keeps rotating indefinitely (as long as power is applied and is sufficient for the motor to overcome the shaft torque load and internal losses due to friction, etc.)

(ON SLIDE #149)

f. <u>Circuit Protection Devices</u>. Most electrical circuits are protected from high current flow that would exceed the capacity of the circuits conductor's and/or loads. Excessive current results from a decrease in the circuit's resistance. Circuit resistance will decrease when too many components are connected in parallel or when a component or wire becomes shorted or grounded. When the circuit's current reaches a predetermined level, most circuit protection devices open and stop current flow in the circuit.

(ON SLIDE #150)

(1) <u>Fuses</u>. The most commonly used circuit protection device is the fuse. It contains a metal strip that will melt when the current flowing through it exceeds its rating. The thickness of the metal strip determines the rating of the fuse. When the metal strip melts, excessive current is indicated (overloaded). The cause of the overload must be found, repaired, and the fuse is then replaced. Fuses are typically located in a central fuse block or power distribution box. However, fuses may also be found in relay boxes and electrical junction boxes. There are two basic types of fuses:

(2) Glass type fuses are found mostly on older equipment. They are small glass cylinders with metal caps. The metal strip connects the two caps. The rating of the fuse is normally marked on one of the caps.

(3) Blade type fuses are flat plastic units and are available in Mini, Auto, and Maxi sizes. The plastic housing is formed around two male blade type connectors inside the plastic housing. The metal strip connects these connectors inside the plastic housing. The rating of the fuse is indicated on the top of the fuse and by the color of the plastic.

(ON SLIDE #151)

INSTRUCTOR NOTE
Movie circuit-breaker 1.2 minutes.

(ON SLIDE #152)

(4) <u>Circuit Breakers</u>. A circuit that is susceptible to an overload on a routine basis is usually protected by a circuit

breaker. A circuit breaker uses a bimetallic strip that reacts to excessive current. There are two types of circuit breakers:

(ON SLIDE #153)

(a) Self-resetting. When an overload occurs that causes an excessive amount of current, the current flowing through the bimetallic strip causes it to heat. As the strip heats, it bends and opens the contacts. Once the contacts are opened, current no longer flows and the strip cools resetting itself. The process will continue until the overload is corrected.

(b) Manual-resetting. This type of circuit breaker operates in much the same manner; however, it requires the strip to be pushed back into position usually through a push button or complete removal from the circuit.

(ON SLIDE #154)

INTERIM TRANSITION: Are there any questions over circuit breakers? If not, let's take a 10 min break and then we'll talk about resistors.

(BREAK – 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk resistors.

(ON SLIDE #155)

g. **Resistors**.

(1) Fixed Resistors. Resistors represent an electrical load, or resistance to current flow. Most electrical and electronic devises use resistors of specific values to limit and control the flow of electrical current. Resistors are available in various sizes and resistance values. The size of the resistor is related to how much current the resistor is designed to control.

(ON SLIDE #156)

(2) Variable resistors. A variable resistor provides for an infinite number of resistance values within a specified range. The most common types of variable resistors are mechanically variable resistors, thermally variable resistors, and pressure sensitive resistors.

(a) Mechanically variable resistors. A mechanically variable resistor is used to regulate the strength of an electrical current by the position of a wiper on a electrically resistive material. The two most common mechanically variable resistors are rheostats and potentiometers.

1. A rheostat has two-terminals, one terminal is connected to the fixed end of a resistor and a second terminal is connected to a movable contact called a wiper. By changing the position of the wiper on the resistor, the amount of resistance to the load device can be increased or decreased. A fuel level sending unit is typical application of a rheostat.

(ON SLIDE #157)

2. A potentiometer has three terminals, one terminal is connected to the power source, the second terminal is usually grounded, and the third terminal provides signal voltage to another device. The majority of the current flow travels through the resistance of the unit and a wiper contact returns a variable voltage.

(ON SLIDE #158)

(b) A thermistor (thermal resistor) is a solid state resistor made from semiconductor material. Its resistance changes predictably as its temperature changes. It is used for measuring air and water temperatures because even a small change in temperature will result in a change in its resistance. The most commonly used thermal resistor is a thermistor usually used as temperature sensors.

(ON SLIDE #159)

(c) A pressure sensitive resistor is made from crystal whose resistance value changes as stress is applied. These devices are referred to as piezoresistive (*Piezo* in Greek means pressure). The most common piezoresistors are used in oil, fuel, or air pressure sensors as inputs to On-Board Diagnostic and computer management systems.

(ON SLIDE #160)

(d) De-spiking Resistors. All relay coils in modern equipment must use some protection against high-voltage spikes that occur when the voltage is stopped to the coil. A resistor is more durable than a diode and can suppress voltage spikes similar to a diode, but the resistor will allow current to flow through it whenever the relay is on. Therefore resistance of the resistor must be fairly high (about 600 ohms) in order to prevent too much current flow in the circuit. High ohm resistors are not quite as efficient at suppressing a voltage spike as diodes.

(ON SLIDE #161)

h. **Capacitors**. The capacitor has the capacity to store electrical charges briefly; therefore, it acts as a storage place for the surge of current caused by the counter voltage during magnetic collapse.

(ON SLIDE #162)

(1)In a way, a capacitor is a little like a battery. Although they work in completely different ways, capacitors and batteries both **store electrical energy**. A capacitor is much simpler than a battery, as it can't produce new electrons -- it only stores them. Here are a few examples of how capacitors are used.

(2) When heavy bass notes hit in your car, your battery can lose voltage. Capacitors can stop this from happening.

(3) Capacitors are used in camera flashes to store voltage until you are ready to take a picture.

(4) In a subway car, an insulator at a track switch may cut off power from the car for a few feet along the line. You might use a large capacitor to store energy to drive the subway car through the insulator in the power feed.

(ON SLIDE #163)

i. Diodes. A diode is a device that is used to control current flow in a circuit. It will allow current to pass through itself in only one direction. A diode can be thought of as an electrical check valve. The positive side of the diode is called the anode and the negative side is the cathode.

(ON SLIDE #164)

(1) Zener Diodes. A zener diode is a special type of diode that allows reverse current to flow as long as the voltage is above a value that is built into the device when it is manufactured. This device is used in control circuits such as alternator voltage regulators.

(ON SLIDE #165)

(2) Light-Emitting diodes (LED). All diodes radiate some energy during normal operation. Most diodes radiate heat because of the junction barrier voltage drop (typically 0.6 volt for silicon diodes). Light-emitting diodes (LEDs) radiate light when current flows through the diode.

(a) An LED will only light if the voltage at the anode (positive electrode) is higher than the voltage at the cathode (negative electrode).

(b) If an LED were connected across a conventional 12-volt battery, the LED would light brightly, but only for a second or two due to the high difference in voltage between the anode and cathode. Excessive current that flows across the junction of any electronic device can destroy the junction. A resistor is typically connected with every diode (including LEDs) to control current flow.

(ON SLIDE #166)

(3) Clamping Diodes. A clamping diode is nothing more than a standard diode, the term clamping refers to its function.

(a) Diodes can be used as a high-voltage clamping device when the power is connected to the cathode (negative electrode) of the diode. If a coil (such as a solenoid or relay) is pulsed on and off, a high-voltage spike is produced when the coil is turned off.

(b) To control and direct this possibly damaging high voltage spike, a diode can be installed across the leads to the coil to redirect the voltage spike back through the coil windings to prevent possible damage to the rest of the electrical or electronic circuits. Clamping diodes may also be called de-spiking or suppression diodes.

(ON SLIDE #167)

j. **Transistors**. A transistor (a combination of the words *transfer and resistor*) can also be thought of as a draw bridge. It controls the flow of cars across the bridge by closing to allow cars to cross and opening to stop the flow of cars. However, with a transistor there is the addition of a gate keeper ***"MR. COMPUTER".*** When he switches the "***TRANSISTOR***" bridge type gate (or just gate for short) closed, the cars move across. The transistor can switch comparatively large amounts of electric current on and off using relatively small amounts of electrical current. Because transistors operate electronically, they last much longer than the relays they replace. This is because they have no contact points to burn. The major applications of transistors are for voltage regulators and computer controlled systems.

(ON SLIDE #168)

k. **Integrated Circuits**. An integrated circuit is a device that contains circuits composed of resistors, diodes, transistors, and capacitors or any other electronic component. They can contain a few components to form a simple circuit or can be made into a complex circuit with hundreds of thousands of components. There are two types of integrated circuits:

(ON SLIDE #169)

(1) Analog integrated circuit. Analog IC's are circuits composed to produce, amplify, or respond to variable voltages. They include many kinds of amplifier circuits that involve analog-to-digital conversion and vice versa, such as timers, oscillators, and voltage regulators (alternators).

(ON SLIDE #170)

(2) Digital integrated circuits. Digital IC's are composed of circuits that produce voltage signals or pulses that have only two levels that are either ON or OFF. They include microprocessors, memories, microcomputers, and many kinds of simpler chips.

(ON SLIDE #171)

INSTRUCTOR NOTE
Movie integrated circuits .5 minutes.

(3) Printed circuit boards are used to hold components in place and to provide current paths from component to component without the paths ever touching each other. If they did they would short circuit.

(ON SLIDE #172)

INTERIM TRANSITION: Are there any questions over integrated circuits? If not, let's take a 10 min break and then we'll talk about types and construction of gauges.

____

____

____

(BREAK – 10 Min)

INTERIM TRANSITION: During the break did anyone come up with any questions? If not, let's talk types and construction of gauges.

____

____

____

(ON SLIDE #173)

l. **Types and Construction of Gauges**.

(ON SLIDE #174)

(1) Thermostatic Gauge. This gage contains an electrically heated bimetallic strip (usually steel and copper) that is linked to a pointer. The bimetallic strip consists of two dissimilar metals that, when heated, expand at different rates, causing it to deflect or bend. In the case of the instrument panel gage, the deflection of the bimetallic strip will result in the movement of the pointer, causing the gage to give a reading.

(ON SLIDE #175)

(a) The thermostatic gauge can be self-regulating, or it may require the use of an external regulator. In this case the power supply to the gage is kept constant through the use of a voltage limiter. The voltage limiter consists of a set of contact points that are controlled by an electrically heated bimetallic arm. Through this regulator, voltage to the gauge is limited to an average that is lower than circuit voltage.

(ON SLIDE #176)

(b) The differential-type thermostatic gage uses two electrically heated bimetallic strips that share equally in operating and supporting the gage pointer. The pointer position is obtained by dividing the available voltage between the two strips (differential). The sending unit in this system contains a wire-wound rheostat that is connected between two external terminals. Each one of the external terminals connects to one of the instrument panel gage bimetallic strips. Movement of the grounded brush raises resistance progressively to one terminal, while lowering the resistance to the other. In effect this causes a division of voltage and the resulting heat differential to the gage strips that formulate the gage readings.

(ON SLIDE #177)

(2) <u>Electromagnetic Gauge</u>.

(a) <u>Single coil gauge</u>. The basic instrument panel gage consists of a pointer that is mounted on an armature (permanent magnet) and a coil. Current flows through the coil to produce a magnetic effect that deflects the needle in proportion to the amount of current. This coil is matched to the maximum amount of expected current flow. The needle is returned to its zero position by a calibrated hair spring. The ammeter is the most common application for this type of gauge due to the high current involved.

(ON SLIDE #178)

(b) <u>Two Coil (Unbalanced) Gauge</u>. The gage is motivated by a magnetic field that is created by two separate magnetic coils that are contained within the gage. One of these coils is connected directly to the battery, producing a constant magnetic field. The other coil produces a magnetic field whose strength s determined by a variable resistance sending unit. The coils are usually placed 90 degrees apart.

(ON SLIDE #179)

(3) Speed gauge. The type of speed gauge that is common to engineer equipment is the tachometer. A tachometer is a device that is used to measure engine speed in revolutions per minute (RPM). The tachometer may also contain a device known as an engine-hours gage. The engine-hours gage (hourmeter) is usually installed on equipment that uses an odometer to keep a record of engine use.

(ON SLIDE #180)

(a) Electronic Tachometers. Electronic tachometers are self-contained units that use an electrical signal from the engine or transmission as an indicator to formulate a reading. They differ from the electric units described previously in that it uses a generated signal as the driving force. The gage unit is usually transistorized and will supply information through either a magnetic analog (dial) or a light emitting diode (LED) digital gage display. The gage unit derives its input signal in the following ways:

(ON SLIDE #181)

(b) The tachometer can use the alternating current generated at the stator terminal of the alternator as a signal. The frequency of the A/C current will change proportionally with engine speed. The tachometer can derive its signal from a magnetic pickup (discussed later) coil that has its field interrupted by a rotating pole piece. The pickup coil may interact with the teeth located on the input shaft of the transmission or the flywheel in the engine bell housing.

(ON SLIDE #182)

INSTRUCTOR NOTE
Movie Gauges .35 minutes.

m. **Gauge Applications**. The instrument panel is usually placed so that the instruments may be read easily by the operator. They inform the operator of the approximate engine speed, engine temperature, oil pressure, rate of charge or discharge of the battery, amount of fuel in the fuel tank, and the hours of operation.

(ON SLIDE #183)

(1) Fuel Gages. Most fuel gages are operated electrically and are composed of two units: the gage, mounted on the instrument panel; and the variable resistance sending unit, mounted on the fuel tank. The ignition switch is included in the fuel gage circuit so that the electrical fuel gage operates only when the ignition switch is on.

(ON SLIDE #184)

INSTRUCTOR NOTE
Movie testing a fuel gauge 2.32 minutes.

(ON SLIDE #185)

(2) Pressure Gages. Pressure gages are used widely in equipment applications to keep track of things such as engine oil pressure, fuel line pressure, air brake system pressure, and in some applications the pressures of the hydraulic systems.

(ON SLIDE #186)

(3) Temperature Gages. The temperature gage is a very important indicator in equipment. The most common use is to indicate engine, transmission, differential oil temperatures, and engine coolant temperatures. The instrument panel gage may be of the thermostatic type, or of the magnetic type.

(ON SLIDE #187)

n. **Indicators and Warning Lamps**. The indicator lamp (warning lamp) has gained increasing popularity as a system condition gage over the years. Although it does not provide as detailed an analysis of the system condition as a gage, it is usually considered more useful to the average operator. This is because it is highly visible when a malfunction occurs, whereas a gauge is easily overlooked.

(ON SLIDE #188)

(1) Pressure Indicator Lamp and Temperature Indicator Lights. On some equipment, the oil pressure warning light and temperature indicator lights are used in place of gauges. The warning lights, although not an accurate indicator, are valuable because of their high visibility in the event of a low oil pressure condition or high engine coolant temperature.

(2) Because an engine can fail or be damaged permanently in less than a minute of operation without oil pressure or high temperature the warning light often is used as a backup for a gauge to attract instant attention to a malfunction.

(ON SLIDE #189)

INTERIM TRANSITION: Are there any questions before you take the quiz?.

____
____
____

QUIZ (30 MIN)
Picture slide of gauges. Pass out electronic component failure and isolation quiz prior to practical application.

(BREAK - 10 Min)

(ON SLIDE #190)

INTERIM TRANSITION: We've just discussed Indicators and Warning Lamps. Are there any questions? If not, let's move on to the Practical Application on Troubleshooting electrical on the MMV.

____
____
____

INSTRUCTOR NOTE
Perform the following Practical Application. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION. **(12 HRS)** This is a Practical Application for the MMV. The purpose of this practical application is to get the students to follow troubleshooting steps in the manual, locate and fix any faults observed. Normal class size is 25. There is one instructor required for this evolution

PRACTICE: The students should find the troubleshooting steps in the technical manual and trace the schematics to find the open cab fuse. This trouble shooting step is located on page 0009 00-4 through 0009 00-6 in the TM 10794B-OI/A.

PROVIDE-HELP: You as the instructor will replace the Open Cab Vehicle Main Fuse 40 AMP with a bad fuse, also switch out the main cab electrical relay with a bad one. Ensure that the students have all appropriate material and PPE before starting the practical exercise. Pass out Performance Checklist to students have the students fill out the top and look at the checklist, ask them if they have any questions and tell them to begin.

1. Safety Brief: Ensure that the students have all appropriate material and PPE before starting the practical exercise.

2.Supervision and Guidance: Instructor is moving around the equipment, assisting students, and answering questions as they arise.

3.Debrief: N/A

(ON SLIDE #191)

TRANSITION: During the prac ap we covered Trouble shooting electrical on an engineer piece of gear. Do you have any questions? If not, I have some for you and then let’s take a ten minute break.

____

____

____

(Q1) What is the first step a mechanic should take when he/she suspects failure of a battery?
(A1) Perform a simple visual inspection of the battery.

(Q2) What are two types of integrated circuits?
(A2) Analog and Digital.

(Q3) What is the purpose of a circuit protection device?
(A3) To protect the rest of the circuit when a component within that circuit exceeds a predetermined level of current.

(BREAK - 10 Min)

TRANSITION: During the break did anyone come up with any questions? If not, we have discussed electrical components, protection devices, and gauges. We also used these skills to troubleshoot a piece of engineer equipment using the knowledge obtained throughout the class. Are there any questions, if not let's discuss the starting system.

(ON SLIDE #192)

5. **STARTING SYSTEM OPERATION/TROUBLEHSHOOTING**. **(1 Hr 30 Min)**

(ON SLIDE #193)

INSTRUCTOR NOTE
Movie starting systems .28 minutes.

a. **Starting Motor and Drive**.

(1) Purpose. The starter drives the engine through a pinion gear attached to the starter armature shaft. The gear is brought together with the teeth cut on the rim of the flywheel or flex plate. The drive must be equipped with an overrunning clutch or some other means of quick disengagement. Owing to limitations of size and capacity of the battery, a high-speed starter with a high gear reduction is used to obtain the necessary torque. The great speed reduction required is affected in the majority of cases by utilizing the flywheel as a driven gear. The gear may be bolted, cut, or heat shrunk to the rim of the flywheel itself. The starter is mounted on the flywheel housing.

(ON SLIDE #194)

(2) Construction and Operation. Electrical starting motors for heavy duty applications vary from manufacturer to manufacturer; however, there are many similar components that will be found on most motors.

(ON SLIDE #195)

(a) Armature.

1. The armature contains multiple loops of heavy copper. These coils pass through a laminated core of iron to increase the permeability of the armature. The commutator(The slotted copper segments at the end of the armature on an electric motor, which transfers the current from the brushes to the coils wound on the armature segments) are made of heavy copper bars that are set into mica or epoxy resins. The armature rotates on bronze bushings.

2. In use, the motor armature has many armature coils equally spaced around the entire circumference of the armature. Each of these coils carries current and consequently exerts a force to rotate the armature as it passes the pole pieces. The switching of the armature coils to the brushes is handled by a segmented commutation. The result is a comparatively high turning power (or torque) that is sufficient to crank the engine if it is applied through suitable gear reductions.

(ON SLIDE #196)

(b) Field Coils. The field coils electrically create the magnetic field that causes armature rotation. They are constructed of heavy copper wire that is usually rectangular in cross section. An insulating material is placed within the windings to insulate the coils from each other. The coils then are insulated on the outside by either wrapping them in paper or sealing them in rubber. The field coils are secured to the field frame by the pole shoes.

(ON SLIDE #197)

(c) Pole shoes. The pole shoes serve as a core for the field coils to increase permeability. They are made of high magnetic permeability material to help concentrate and direct the lines of force in the field assembly.

(ON SLIDE #198)

(3) In all starter designs the rotary motion is transmitted via an Overrunning Clutch. The overrunning clutch allows the pinion to be driven by the armature shaft however it breaks the connection between the pinion and the armature shaft as soon as the accelerating engine spins the pinion faster than the starter.

(a) The shell and sleeve assembly of the clutch is driven by the starter armature shaft. The inner portion, rotor, is connected to the pinion, which meshes with the teeth on the engine flywheel.

(b) Steel rollers are located in wedge-shaped spaces between the rotor and the shell. Springs and plungers normally hold the rollers in position within the wedge spaces. When the starter armature shaft turns, the rollers are jammed between the wedge-shaped surfaces, causing both the inner and the outer members to rotate as a unit and crank the engine.

(ON SLIDE #199)

INSTRUCTOR NOTE

Have students read the paragraphs (4),(4a-4c). Follow along with slide.

(4) Starter Solenoid. Shifting the overrunning clutch pinion gear in mesh with the flywheel gear is made automatic on a good proportion of modern equipment by the use of the starter solenoid.

(a) The solenoid shift unit is mounted rigidly on the starter field frame. Inside the solenoid coil is a heavy plunger connected to the shift lever. The two larger terminal posts on the shift unit are connected in series with the starter. The smaller terminal that leads to the solenoid is connected to the control circuit.

(b) When the circuit is closed and current flows to the solenoid, current is directed to the pull-in and hold-in windings. Because it requires a large amount of current to create a magnetic field strong enough to pull the core in, both windings are usually energized to create a combined magnetic field. Once the core is moved, the current required to hold the core is reduced. This prevents overheating of the solenoid and allows the current that was used to move the core to be used elsewhere in the electrical system (such as powering the starting motor).

(c) When the control circuit is closed to supply current to the solenoid coil, the solenoid exerts a pull on the shift plunger, which shifts the pinion to engage with the flywheel teeth. After the pinion shift lever has moved the distance required for engaging the pinion gear, the pointed end of the shift plunger presses against the end of a contact plunger. This action pushes a contact disk on the contact plunger across the switch contacts to operate the starter.

(ON SLIDE #200)

INTERIM TRANSITION: We've just discussed the components of a starter, are there any questions? If not, let's talk about the different classifications of starters.

(ON SLIDE #201)

b. **Starter Classifications**. Starter motors for heavy duty applications must provide high power at low starter speeds at all temperatures and at the speed required for the engine to start (more than 250 R.P.M.). Electric starting motors are classified according to the internal connections. The method used will determine the motor's power producing characteristics. The following are the most popular.

(ON SLIDE #202)

(1) Parallel. The wiring of field coils in parallel will increase their field strength because they each receive full voltage Note that additional pole shoes are used. Though they have no windings, their presence will further strengthen the magnetic field.

(ON SLIDE #203)

(2) Series-Parallel. The wiring of field coils in a series-parallel combination will create a much stronger magnetic field than the parallel coil configuration described above.

(ON SLIDE #204)

(3) Series. The wiring of field coils in series will provide a large amount of low-speed starting torque, which is a very necessary characteristic of some starting motors. An undesirable characteristic of series-wound motors is that they

will build up excessive speed if allowed to run free to the point where they will destroy themselves.

(ON SLIDE #205)

INSTRUCTOR NOTE
Movie starting system circuits 4.49 minutes.

c. **Electrical Circuits of the Starting System**. Any internal combustion engine must be cranked manually to start it running on its own. Early equipment was started by the driver through the use of a hand crank. A system of cranking the engine with an electric motor was developed as technology progressed. The modern electric starting system has reduced the task of starting an internal combustion engine to the turn of a key or the pushing of a button. To accomplish this task electrically, a typical starting system consists of the start and control circuits.

(ON SLIDE #206)

(1) Start circuit. The circuit that delivers the heavy current required to crank the engine with sufficient torque and speed to overcome the mechanical forces of friction and compression include:

(a) A power source such as a battery or batteries capable of supplying the necessary electrical energy.

(b) A starter motor able to change the electrical energy into the mechanical horsepower and torque required to start the engine.

(c) A solenoid that closes the circuit between the motor and power source and shifts the drive mechanism into mesh with the starter ring gear on the flywheel or flex plate.

(d) Heavy gauge wire to transmit the electrical energy between the power source, solenoid, and motor.

(ON SLIDE #207)

(2) Control circuit. One method of controlling the starter engagement is by a pushbutton on the instrument panel. Pushing the button closes the control circuit so that current can be supplied to the solenoid coil. Current practice, however,

is to eliminate a separate pushbutton switch by incorporating a start position into the key switch. A relay is frequently used in the control circuit to supply current to the solenoid coils. Only a low-current control circuit to the instrument panel is then necessary. The relay will close the circuit through the solenoid coil, which carries the larger current. The circuit that controls the operation of the starting motor includes:

(a) An ignition switch that allows the operator manual control over the starting system by means of "opening" or "closing" the circuit.

(b) Small gauge wiring: provides a pathway for the current within the control circuit.

(c) Electrically controlled relay to provide additional control over the larger current flow to the starter motor.

(d) Fuses or circuit breakers to protect the starting system against a possible current overload by opening the circuit, thus stopping the current flow.

(ON SLIDE #208)

(3) Starting Safety Switches. There are as many different types of safety switches to help prevent job related injuries and equipment mishaps as there are manufactures and models. However they have a common purpose, to prevent unintended equipment operation without human intervention. The most common is the "*Neutral Start Switch*":

(a) An item of equipment with an automatic transmission requires a means of preventing the engine from starting while the transmission is in gear. Without this feature, the equipment would lunge forward or backward once it was started, causing personal injury or property damage. The normally open neutral safety switch is connected in series in the starting system control circuit and is usually operated by the shift lever. When in the "PARK" or "NEUTRAL" position, the switch is closed, allowing current to flow to the starter circuit.

(b) Actual location of the neutral safety switch depends on the kind of transmission and the location of the shift lever. Some manufactures place the switch in the transmission, while others place the switch on the transmission housing, and still others incorporate the switch into the selector lever.

(ON SLIDE #209)

d. **<u>Common Causes of Starting System Failure</u>**. The proper operation of the starting system depends on a good battery, good cables, good wiring connections, and a good starting motor. Because a starting problem can be caused by a defective component anywhere in the starting circuit, it is important to check for the proper operation of each part of the circuit to diagnose and repair the problem.

(ON SLIDE #210)

(1) An under charged or malfunctioning battery will not deliver the proper electrical energy to the starting system in order to crank the engine at the speed required for starting.

(2) Corrosion, loose connections, burnt contacts, and frayed terminals will cause a resistance to the flow of electrical current, and “rob” the starting system of electrical voltage needed to create mechanical power.

(3) An open circuit, usually an unconnected ground or blown circuit protection device, will interrupt the flow of electricity to the starting system components.

(4) Mechanical failure due to binding will cause excessive current flow as the load component works harder than its intended design or electrical circuitry allows.

(5) Mechanical failure due to excessive wear or catastrophic failure will prevent proper engagement of the starter drive and engine driven gears with suitable transfer of torque between the two.

(6) Excessively low temperatures have the effect of lowering battery discharge capacity, reducing cylinder compression temperatures, and increasing the viscosity of engine fluids (oil and fuel). All these affect engine start-up and may prevent an already strained starting system from cranking the engine fast enough for starting the engine.

(ON SLIDE #211)

INSTRUCTOR NOTE

Movie starter solenoid voltage drop 1.15 minutes. Movie starter current draw 1.26 minutes. Movie diagnosing starter binding, .23 minutes. Movie starting and charging testing min max 1.31 minutes.

(ON SLIDE #212)

INTERIM TRANSITION: During the past 1 hour and 30 min we've covered Starting System Operation and Troubleshooting. Do you have any questions? If not you will take a quiz and then a ten min break before the practical application.

____
____
____

QUIZ (30 MIN)

Hand out electrical starting system and troubleshooting quiz.

(BREAK – 10 MIN)

(ON SLIDE #213)

INTERIM TRANSITION: Do you have any more questions before the practical application?

____
____
____

(ON SLIDE #214)

INSTRUCTOR NOTE

Perform the following practical application. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION. (12 HRS) This is a Practical Application for any piece of engineer equipment. The purpose of this practical application is to get the students to follow troubleshooting steps in the manual, locate and fix any faults observed. Normal class size is 25. There is one instructor required for this evolution

STUDENT'S ROLE: The students should find the troubleshooting steps in the appropriate electronic technical manual and follow the steps to fix any faults displayed by Vehicle Automated Diagnostics System (VADS).

INSTRUCTOR ROLE: You as the instructor will create a starter fault on a piece of engineer equipment. Ensure that the students have all appropriate material and PPE before starting the practical exercise. Pass out Performance Checklist to students have the students fill out the top and look at the checklist, ask them if they have any questions and tell them to begin.

1. Safety Brief: Ensure that the students have all appropriate material and PPE before starting the practical exercise.

2.Supervision and Guidance: Instructor is moving around the equipment, assisting students, and answering questions as they arise.

3.Debrief: N/A

(ON SLIDE #215)

(BREAK – 10 MIN)

(ON SLIDE #216)

TRANSITION: Before the break we have covered the electrical starting systems, are there any questions, if not, I have a couple for you.

(Q1) What does a typical starting system consists of?
(A1) The start and control circuits.

(Q2) Which of the two circuits requires a start switch or push button to close the circuit?
(A2) Control circuit.

If there are no more questions we will talk about the Charging system.

____
____
____

(ON SLIDE #217)

6. **CHARGING SYSTEM OPERATION/TROUBLESHOOTING**. **(1 Hr)**

(ON SLIDE #218)

a. **General**. The charging system is a mechanism in which the principle of electromagnetic induction is used to convert mechanical energy into electrical energy. It restores the current used in cranking the engine to the battery. It also supplies, up to the limit of its capacity, current to carry the electrical load of the lights and accessories.

(ON SLIDE #219)

b. The heart of the charging system is the alternator and uses many of the same electrical principles as a motor; however, their operation is opposite. In the alternator, mechanical motion is converted into electrical energy. In the motor, electrical energy is converted into mechanical motion.

(ON SLIDE #220)

c. **Simple Single-Loop Generator**.

(1) If a single loop of wire (generating part) is rotated in the magnetic field between a north and a south pole (field part), there will be an electrical pressure produced in the two sides of the loop. The voltage and current produced will relate to the direction of the magnetic field (north to south) and the direction of rotation.

(2) If each end of the loop is connected to a metal segment of a commutator on which brushes rest, this electrical pressure will cause a current to flow through any external circuit that may be connected across the two brushes.

(ON SLIDE #221)

(3) If the loop is rotated through a complete revolution, sides 1 (white) and 2 (black) will cut magnetic lines of force in first one direction and then in the other. This will produce current in each side of the loop, first in one direction and then in the other. That is, in side 1, current will flow in one direction when it is passing the North Pole and in the other direction when it is passing the South Pole. However, because the commutator segments also rotate with the

loop, the current always will leave the right-hand brush and enter the left-hand brush according to the electron theory.

d. **Multiple-Loop Generator**.

(1) In the simple, single-loop generator, the current produced in each side of the loop reaches a maximum when the sides are cutting the lines of force in a perpendicular direction. (This is the position in which the loop is shown.) As the loop moves away from this position, it cuts fewer and fewer lines of force and less and less current is produced. By the time the loop has turned 90 degrees the sides are moving parallel to the lines of force and are cutting no lines, therefore no current is being produced.

(ON SLIDE #222)

(2) Many loops, or turns, of wire are required in the conductor in order for the generator to produce an appreciable amount and even flow of current. The rotating member that contains the wire loops and the commutator is called an armature (much like a starter).

(3) The windings are assembled in a soft iron core because iron is more magnetically permeable than other substances that could be used. The windings are connected to each other and to the commutator segments in such a way that the current impulses overlap and produce a smooth flow of current. This could be compared to the overlapping of power impulses in an 8- or 12-cylinder engine.

(ON SLIDE #223)

e. **The Basic Alternator**. Most military equipment is now equipped with an A/C charging system. The reason for changing to the A/C system is that an alternator is capable of producing a higher voltage at idle speed, whereas a D/C generator produces very little voltage at idle speed. Many of the military vehicles are equipped with radios, firing devices, and other high-current drawing equipment. When this equipment is in operation and the vehicle's engine is at a low rpm, a D/C generator would not produce the required current and voltage to keep the batteries charged and to supply the current required to operate the accessories properly.

(ON SLIDE #224)

(1) Construction. In the alternator, it is the field (rotor) that moves and the generating part (stator) is stationary. The purpose of the alternator is to produce more power and operate over a wider speed range than that of a generator. Because of this, its construction is different.

(ON SLIDE #225)

(2) Rotor Design. The rotor is designed with two pole pieces that sandwich the field winding on the shaft. Each pole piece has finger-like projections. When the rotor is assembled, the projections interlock with each other. The pole pieces form north and south magnetic poles. The core of the rotor contains the axially wound field winding which is made of varnish-insulated copper wire. Each end of the field winding is connected to an individual slip ring.

(ON SLIDE #226)

(3) Stator Design. The stator is the section in which the current is induced. It is made of a slotted laminated ring with the conductors placed in the slots. The current generated in the windings is transferred to the rest of the system through three stationary terminals. The stator is designed with three separate windings so that it produces three separate A/C currents. This is known as three-phase output. Each winding is in the form of loops that are spaced at intervals on the frame. The windings then are arranged so that they are offset from each other. There are two types of connections for the windings:

(a) The three windings are connected in series and are all tied together in the middle to form what is known as a "Y" (wye) wound stator. It is the most common.

(b) The three windings are connected in parallel and are all tied together at one end to form what is known as a "D" (delta) wound stator. The advantage of a "D" wound stator is a higher current output due to parallel arrangement of the stator connections.

(ON SLIDE #227)

(4) Rotor-to-Stator Relationship. The rotor is synchronized to the stator; that is, when one north pole projection is aligned with one of the loops of one-phase winding loop, the other north pole projections will also align with the

other loops of that phase winding. This sequence of alignment between the rotor projections is necessary for operation.

(ON SLIDE #228)

(5) <u>Rectifier Bridge</u>. The alternator produces alternating current at its output, and this is unacceptable for a D/C electrical system.

(a) The alternator is fitted with a rectifier bridge to convert the output from A/C to D/C. If the output wires of a basic A/C circuit are each fitted with diodes, the alternating current can be given one direction and thus be changed to direct current.

(b) Because most alternators have three outputs (three-phase stator), the rectifier bridge will consist of six diodes (three positive and three negative). The diodes will be connected so that they combine the three A/C outputs of the alternator into one D/C output.

(ON SLIDE #229)

(6) <u>Solid-State Voltage Regulator</u>. A solid-state voltage regulator is a static unit that is totally electronic in operation. In this configuration, the rotor field is turned on and off by zener diodes. The zener diodes produce a signal to the base of a transistor whenever the electrical system voltage reaches the desired level. This signal to the base of the transistor reduces or shuts off field current to reduce or stop alternator output.

(a) When the system voltage drops again, the transistor again will allow alternator output. This cycle will repeat itself as much as 2000 times per second. Some applications utilize a rheostat to adjust the resistance of the field current, thereby regulating alternator output.

(b) The solid-state regulator has virtually replaced the mechanical units in all currently produced equipment due to the extreme reliability and low manufacturing costs of solid-state components. Another desirable feature of a solid-state regulator is that it can be made small enough to be built into the alternator.

(ON SLIDE #230)

(7) Diode trio. There is another circuit in the alternator to control the charging system warning lamp that is on the dash. Part of that circuit is another set of diodes mounted inside the alternator called the diode trio. The diode trio takes current coming from the three stator windings and passes a small amount through three diodes so that only the positive voltage comes through. After the diodes, the wires are joined into one wire and sent out of the alternator. It then goes to one side of the dash warning lamp that is used to tell you when there is a problem with the charging system. The other side of the lamp is connected to the run side of the ignition switch. If both sides of the warning lamp have equal positive voltage, the lamp will not light. Remove voltage from one side and the lamp comes on to let you know there is a problem.

(ON SLIDE #231)

f. **Cooling Alternators**. Air cooling is the most common method of heat removal from alternators. The usual arrangement consists of a fan that forces air through the alternator to cool the rotor, stator, and rectifier. The major advantage of air cooling is that it is self-contained, drawing air from the environment. However, another factor is that, unless it is filtered, cooling air can deliver abrasive particles, water, or other substances to the interior. Furthermore, rotor and stator design must permit unrestricted passage of air through the alternator. This can be accomplished by designing passages through the rotor and stator.

(ON SLIDE #232)

INSTRUCTOR NOTE
Movie charging system components 1.39 minute.

(ON SLIDE #233)

f. **Accessory Items**.

(1) Fuel Pressure Field Switch. The fuel pressure field switch is a device that is used on high output alternators to prevent the alternator from placing a load on the engine until it is running. The alternator field circuit opens until the fuel pressure reaches the normal operational range.

(2) Field Relay (Cut out relay). The field relay is used in two basic applications:

(a) It can be used to isolate the field circuit from the battery whenever the ignition switch is turned off. In this application, the magnetic coil is energized with the ignition switch. The contact points then pull together, completing the field circuit.

(b) It also can be used to operate an alternator no-charge warning light; the magnetic coil is energized by one of the stator windings. This will cause the contact points to be pulled together whenever the alternator produces sufficient current to sustain operational voltage.

(ON SLIDE #234)

g. **Charging System Gauges and Indicators**.

(1) Ammeter. The ammeter is used to indicate the amount of current flowing to and from the battery. It does not give an indication of total alternator output because other units in the electrical system, besides the battery, are supplied by the alternator. Current flowing from the storage battery to the starting motor is never sent through the ammeter, because the great quantities used (200 to 600 amperes) cannot be measured on an instrument of such limited capacity.

(ON SLIDE #235)

(2) Voltmeter. Voltmeters are a common instrument panel battery condition indicator. This is because the electrical system voltage is a more accurate indication of the condition of the electrical system than the amperage and is easier to interpret by the operator. During equipment operation, the voltage indicated on the voltmeter is considered to be normal in a range of 13.2 to 14.5 volts for a 12-volt electrical system. As long as the system voltage remains in this range, the operator can assume that no problem exists. This contrasts with an ammeter, which gives the operator no Indication of problems such as an improperly calibrated voltage regulator, which could allow the battery to be drained by regulating system voltage to a level that is below normal.

(ON SLIDE #236)

(3) Low-Voltage Warning Light. The indicator lamp can be set-up to warn the operator whenever the electrical system voltage has dropped below the normal operational range. The lamp

is operated by a calibrated relay that opens the circuit to it whenever electrical system voltage is in the normal range (13.2 to 14.5 volts for a 12-volt system). Whenever the voltage falls below the normal range, the magnetic field becomes insufficient to overcome the force of the relay spring, which pulls the contact points closed. This closes the circuit to the indicator lamp.

(ON SLIDE #237)

(4) <u>No-Charge Indicator</u>. The indicator lamp can also be set-up to indicate whenever the alternator is not producing current. The circuitry that operates a no-charge indicator lamp is usually incorporated in the voltage regulator.

(a) In a system equipped with a no-charge indicator lamp a resistor is matched with the resistance of the indicator lamp so that their parallel arrangement will produce a zero-voltage drop when the alternator is producing current.

(b) When the ignition switch is closed, before the engine is started, current flows through the resistor and the indicator lamp to the alternator field, causing the indicator lamp to light.

(c) After the engine is started, the alternator begins to produce current, energizing the field from the stator. This results in a zero potential across the indicator lamp, causing it to go out (opposing voltage).

INSTRUCTOR NOTE
Refer back to Kirchoff's Voltage Law and Watt's Law for further explanation.

(ON SLIDE #238)

h. **<u>Common Causes of Charging System Failure</u>**.

(1) An under charged or malfunctioning battery will cause the charging system to work harder under all conditions by trying to recharge the battery while supplying electrical system requirements.

(2) Corrosion, loose connections, burnt contacts, and frayed terminals will cause high resistance to the flow of

electrical current, and cause the voltage regulator to remain on longer than its intended design causing overheating.

(3) Loose or improperly aligned drive belts can cause pulley slippage under heavy current demand, or mechanical failure from excessive bearing wear.

(4) Polarity reversal of the electricity used to energize the rotor field circuit can destroy the fine electronic circuitry of the voltage regulator or cause catastrophic failure of the alternator.

(ON SLIDE #239)

INSTRUCTOR NOTE
Movie starting and charging system testing 2.21 minutes. Movie alternator output test 1.42 minutes.

(ON SLIDE #240)

INTERIM TRANSITION: During the past hour we've covered Charging System Operation and Troubleshooting. Do you have any questions? If not let's take a break and then get into troubleshooting the charging system practical application.

(BREAK – 10 MIN)

INTERIM TRANSITION: Any more questions before the charging system practical application.

INSTRUCTOR NOTE
Perform the following practical application. **Allow students to take breaks as required or as instructed**.

(ON SLIDE #241)

PRACTICAL APPLICATION. (12 HRS) This is a Practical Application for any piece of engineer equipment. The purpose of this practical application is to get the students to follow troubleshooting steps in the manual, locate and fix any faults observed. Normal class size is 25. There is one instructor required for this evolution

STUDENT'S ROLE: The students should find the troubleshooting steps in the appropriate electronic technical manual and follow the steps to fix any faults displayed by Vehicle Automated Diagnostics System (VADS).

INSTRUCTOR ROLE: You as the instructor will create a charging system malfunction on a piece of engineer equipment. Ensure that the students have all appropriate material and PPE before starting the practical exercise. Pass out Performance Checklist to students have the students fill out the top and look at the checklist, ask them if they have any questions and tell them to begin.

1. Safety Brief: Ensure that the students have all appropriate material and PPE before starting the practical exercise.

2.Supervision and Guidance: Instructor is moving around the equipment, assisting students, and answering questions as they arise.

3.Debrief: N/A

(ON SLIDE #242)

TRANSITION: During the past hour we've covered Charging System Operation and Troubleshooting. Do you have any questions? If not, I have a couple for you.

(Q1) What is the reason for changing A/C to D/C system on our Marine Corps gear?
(A1) An alternator is capable of producing a higher voltage at idle speed, whereas a D/C generator produces very little voltage at idle speed. When this equipment is in operation and the vehicle's engine is at a low rpm, a D/C generator would not produce the required current and voltage to keep the batteries charged and to supply the current required to operate the accessories properly.

(Q2) What changes Alternating current to Direct Current?
(A2) A Rectifier Bridge (Diode Trio).

Take a 10 min break and we'll take a quiz and then move into Electrical Wiring Repair and Electrical Schematic Interpretation.

____
____
____

(ON SLIDE #243)

(BREAK – 10 MIN)

(ON SLIDE #244)

QUIZ (30 MIN)

After coming off the break handout charging system operation and troubleshooting quiz.

TRANSITION: Do you have any more questions? If not, lets talk about Electrical Wiring Repair and Electrical Schematic Interpretation.

(ON SLIDE #245)

7. **WIRING REPAIR AND SCHEMATIC INTERPRETATION. (2 Hrs)**

(ON SLIDE #246)

a. Power Distribution Designs. Electrical power and control signals must be delivered to electrical devices reliably and safely so that the electrical system functions are not impaired or converted to hazards (Appendix 4). This goal is accomplished through careful circuit design, prudent component selection, and practical equipment location.

(1) The list of common equipment used to fulfill power distribution requirements in military equipment includes:

(a) Single-conductor wires.

(b) Multi-conductor harnesses.

(c) Bus bars.

(d) Terminal blocks.

(e) Terminals.

(f) Connectors.

(ON SLIDE #247)

(2) In order to optimize performance, economy, and safety in electrical system design, guidelines for the design of main power distribution circuits, conductor selection, routing practices, and wiring and cable assembly requirements include:

(a) Human factors.

(b) Environmental factors.

(c) Circuit protection factors.

(d) Circuit identification techniques.

(ON SLIDE #248)

b. **Wiring Harness Assemblies**.

(1) Wiring assemblies consist of wires and cables of definitely prescribed length, assembled together to form a subassembly that will interconnect with specific electrical components and/or equipment. There are two basic types of wiring assemblies:

(a) Cable Assembly. The cable assembly consists of a stranded conductor with insulation or a combination of insulated conductors enclosed in a covering or jacket from end to end. Terminating connections seal around the outer jacket so that the inner conductors are isolated completely from the environment experienced by the outer jacket. Cable assemblies may have two or more ends.

(b) Wiring Harness. Wiring harness assemblies contain two or more individual conductors laid parallel or twisted together and wrapped with binding materials such as tape, lacing cord, or wiring ties. The binding materials do not isolate the conductors from the environment completely, and conductor terminations may or may not be sealed. Wiring harnesses may also have two or more ends.

(ON SLIDE #249)

(2) Wiring Harness Bindings. Several methods are employed to bind the wire bundles together in wiring harness assemblies. Each method has an intended or preferred application in military equipment.

(a) Tape Binding. This binding is intended for equipment interior wiring applications where wires are unprotected, and an additional measure of snag protection and abrasion resistance is required. Wires are bound together with one-half overlapping turns of tape.

(b) Spaced Bindings – Tapped. This binding is intended for interior wiring in protected locations, or in junction and control box applications. Wires are bound together with one-half overlapping turns of tape in spaced intervals. Tape should form 2- to 2.25-in. wrap lengths spaced at 8- to 12-in. intervals.

(c) Spaced Bindings – Heat-Shrinkable Tubing. One alternative method for spaced binding uses sleeving in lieu of tape. The cables are bound together with 0.75- to 1.25-in. lengths of the heat-shrinkable sleeving spaced at 8- to 12-in. intervals

(ON SLIDE #250)

(d) Spaced Bindings – Cable Ties. Another alternative spaced-binding method uses wire ties or straps. Cables are bound together with straps spaced at 8- to 12-in. intervals.

(e) High-Temperature Bindings. This binding method is intended for harnesses used on engines, transmissions, or other systems where additional protection against high temperature is required. Wires are covered, or bound together with insulating sleeving. Sleeving ends and junctions are bound to cables with one-half overlapping turns of tape. Tape endings must overlap fully.

(ON SLIDE #251)

c. **Wiring Harness Identification**. Wires in an electrical system should be identified by a number, color, or code to facilitate tracing circuits during assembly, troubleshooting, or rewiring operations.

(1) This identification should appear on wiring schematics and diagrams and whenever practical on the individual wire. The assigned identification for a continuous electrical connection should be retained on a schematic diagram until the circuit characteristic is altered by a switching point or active component.

(2) An extension of this system involves the use of suffix letters on wiring diagrams and wiring assemblies to identify the segments of wires between terminals and connector contacts. The use of suffix letters is advantageous when it is necessary to identify several individual wires of a common circuit that are bound in the same harness.

(ON SLIDE #252)

(3) Different manufactures use different methods to mark their wiring assemblies. There are several practical methods used to apply wire identification characters on wiring assemblies. Four of the commonly employed methods are:

(a) Lettering may be hot stamped or printed directly on the wire or cable insulation using white letters on dark backgrounds or black letters on light backgrounds.

(b) Lettering may be hot stamped or printed on heat-shrinkable sleeving, length and diameter as required, assembled over the wire insulation.

(c) Lettering may be indented or embossed style and length as required.

(d) Metal marker bands with indented or embossed characters are the most durable and they remain legible even if painted over.

(ON SLIDE #253)

INTERIM TRANSITION: Are there any questions over wiring harness identification? If not, let’s talk about wire terminal connections.

(ON SLIDE #254)

d. **<u>Wire Terminal Connections</u>**. Wire lug terminals are divided into two major classes: the solder type; and the solderless type, which also are called the pressure or crimp type. The solder type has a cup in which the wire is held by solder permanently, whereas the solderless type is connected to the wire by special tools that deform the barrel of the terminal and exert pressure on the wire to form a strong mechanical bond and electrical connection. Solderless-type terminals gradually have replaced solder-type terminals in military equipment.

(ON SLIDE #255)

(1) <u>Solderless Terminals</u>. Solderless terminals come in a variety of designs. Some of the more common recommended terminals are the ring-tongue, rectangular-tongue, and flag types. The inside diameter of the sleeve is slightly larger than the outside diameter of the wire insulation. In the crimping operation, when the barrel is fastened to the end of the wire, the insulation supporting sleeve is fastened around the insulation.

(ON SLIDE #256)

(a) One of the major sources of trouble when a terminal is connected to a wire has always been the breakage of the wire near its junction with the terminal. Wire failures have been decreased by adding a sleeve to the basic terminal. This additional support prevents excessive bending of the wire at the point where it enters the barrel of the terminal, and also prevents fraying of the insulation or braid that is over the wire.

(b) A special water seal terminal, designed to prevent water from reaching the conductor is also available. This terminal should be used wherever interconnecting wire is terminated in an area subject to bilge water, road splash, or corrosive spills. If water seal terminals are not used in such circumstances, the stranded conductor will absorb moisture, and rapid corrosion of the individual strands will occur.

(ON SLIDE #257)

(2) <u>Solder-Type Terminals</u>. Solder-type terminals come in most of the configurations. Although they are considered to

make more positive, permanent connections, they are not used as widely as solderless connectors because of the difficulty involved with installing them. However, in modern equipment with multiple computer controlled circuits, most manufactures require wire repairs to be soldered or solder-type connectors to be used.

(ON SLIDE #258)

INSTRUCTOR NOTE
Movie wire repair 3.30 minutes.

(ON SLIDE #259)

e. <u>Wiring Harness Connectors</u>. Harness connectors have evolved to facilitate the coupling and uncoupling of electrical equipment for replacement or service. The typical connectors used on military equipment permit the elements of a system to be fabricated and serviced as individual assemblies or components so that the final system configuration is built and maintained more easily. The interconnection generally is accomplished using multiconductor or single conductor cable assemblies or wiring harnesses, which permit convenient placement of the system components. Connectors and receptacles are also attached directly to individual components to permit the easy removal of items that are connected to mating parts without the use of interconnecting cables (circuit boards and relays). A compatible connection system consists of a pin assembly, a mating receptacle assembly, and the wires or cables leading to them.

(ON SLIDE #260)

Connector assemblies exist in a variety of configurations, each of which is intended for a particular environmental and/or mounting condition.

(ON SLIDE #261)

(1) The mating halves are available with either pin-type or receptacle-type contacts (male or female contacts). The placement of one in preference to the other is based on a "general rule" prescribing that receptacle (female) is used on the power side of a connection. This arrangement is intended to prevent accidental shorting of the power side of the connection, which could injure personnel or damage equipment. Connectors are designed specifically for high or low voltage applications.

(ON SLIDE #262)

(2) There is a variety of connector plug assemblies used on military equipment, and the primary physical difference between them is the back shell configuration. The back shell is used to direct the connecting wire or cable either axially or in angles up to 90 degrees from the axis of the connector, as well as to provide a water seal and strain relief for the cable or wire.

(a) The Circular Plastic Connector™ - Pin-type Contacts will accommodate many different arrangements of pin contacts. Not all pin cavities in the connector have to be used; however, the corresponding cavities must be matched because the mating halves will only fit one way.

(ON SLIDE #263)

(b) The Sure-Seal™ connector and pin contacts also have provisions for accurate mating between the two halves. But instead of using guide keys and key ways, the connector bodies are molded such that they will not mate incorrectly.

(ON SLIDE #264)

(c) The Metrimate™ connector and pin contacts also have a safeguard so that it can be mated only one way. The locking mechanism consists of clips, and to separate the connector halves, the clips must be depressed while pulling them apart.

(ON SLIDE #265)

(d) The Mate-N-Lok™ connector and pin contacts have provisions for six pin contacts. The locking mechanism engages as the connector halves are mated. To disengage, the locking clips on the male connector half must be depressed as the two connector halves are pulled apart.

(ON SLIDE #266)

(e) The Deutsch™ connector is circular like the Circular Plastic Connector™, but it is made from metal rather than plastic. It also has soft rubber around the cavity holes to seal out moisture, dust, or any other type of contaminate. This connector is available in different sizes to accommodate varying numbers of pin contacts, and some models will take two different sizes of pins.

(ON SLIDE #267)

(f) The Weather Pack™ connector has a molded self-lubricating silicone seal that comes assembled to the pin connector half. When the two connector halves are mated, the seal creates an effective environmental seal between the connector halves. To keep moisture and other contaminates from entering the connector at the wire leads, cable seals are used on each wire lead.

(ON SLIDE #268)

(g) The molded type connector usually has one to four wires that are molded into a one piece component. Although the connector halves separate, the connector itself cannot be taken apart.

(ON SLIDE #269)

INSTRUCTOR NOTE
Movie CAT connector repair - small 1.47 minutes. Movie CAT connector repair - medium 1.44 minutes. Movie CAT connector repair - large .46 minutes.

(ON SLIDE #270)

INSTRUCTOR NOTE
Have students or a student read paragraphs 3, 3a-3d.

(3) <u>Harness connector requirements</u>. Electrical connectors must be capable of withstanding the effects of the military environment. Protection against damage due to temperature extremes, water, oil, and physical abuse is mandatory.

(a) In order to conduct current safely through each contact, the circuit amperage is determined prior to installation. The contact size is then established with a safety factor sufficient to provide safe operation under conditions of temporary overload.

(b) Another important safety factor is mechanical strength. In many applications, oversized contacts are used even though a smaller contact may be called for because the mechanical strength of the oversized contact is needed.

(c) Great care must be exercised in the selection of connectors to make certain that they will meet mechanical strains placed upon them in practical application. Some equipment connector housings may be used as personnel steps if they happen to be in the right location, and it is not an uncommon sight to see military equipment lifted or carried by one or more of its connectors even though connectors or thin housings are not intended for these purposes.

(d) The selected connector is designed to prevent incorrect mating built into it. This may be done through dissimilar-size guide pins, a nonsymmetrical arrangement of contact barriers, or the design of the connector shell housing. Contact pins should never be used for alignment or polarization.

(e) Most connectors (except for molded connectors) are designed so that an individual pin or receptacle contact can be removed and replaced should it become bent or broken. The locking mechanism that retains the individual wires, pins, and receptacles varies from connector to connector, however they are available through the supply system and come disassembled when ordered.

(ON SLIDE #271)

INSTRUCTOR NOTE
Picture of connectors.

(ON SLIDE #272)

f. **<u>Negative Grounded Circuits versus Positive Grounded Circuits</u>**.

(1) The body and chassis equipment is made of steel. This feature is utilized to eliminate one of the wires from all of the electrical circuits. By attaching one of the battery terminals to the body and chassis you ground the battery. Any electrical component can be connected by hooking up one side, by wire, to the battery and the other side to the body. The

practice of connecting one side of the battery to the body is called grounding (also called earth).

(ON SLIDE #273)

Most equipment manufacturers ground the negative side of the battery. This is referred to as an electrical system with a negative ground.

(ON SLIDE #274)

INSTRUCTOR NOTE
Movie negative ground corrosion .46 minutes.

(2) Some manufactures use positive ground electrical systems to eliminate corrosion or electrolysis affecting the electrical systems. When a negative grounded vehicle is exposed to moisture, the potential is there for electrolysis to take place because of the steel structural parts of the equipment and copper wires, terminals, and electrical components. The voltage differential between the steel and copper parts is significant.

(3) By exposing the equipment to moisture combined with salt, a condition similar to copper plating results. The copper in this electrolyte bath is ionized and is attracted to the negative steel, resulting in electrical system deterioration. On a positively grounded system the action is reversed. With the large mass of structural steel compared to the small amount of electrically charged copper in the electrical system, the effect of deterioration is minor.

(ON SLIDE #275)

INTERIM TRANSITION: During the past 2 hours we've covered Wiring Repair and Schematic Interpretation. Do you have any questions? If not, let's take a break and then we will move into our practical application for repairing wires.

____
____
____

(BREAK – 10 MIN)

INTERIM TRANSITION: Are there any more questions before our practical application for repairing wires.

____

INSTRUCTOR NOTE
Perform the following practical application. **Allow students to take breaks as required or as instructed.**

(ON SLIDE #276)

PRACTICAL APPLICATION. (2 Hrs) This is a Practical Application conducted in the bay at the work stations. The purpose of this practical application is to get the students familiar with repairing open circuits. Normal class size is 25. There is one instructor required for this evolution.

STUDENT ROLE: The students will repair a simulated open circuit by soldering two loose ends together and then selecting a method of protection against outside elements.

INSTRUCTOR ROLE: You as the instructor will supervise and assist any student who may have difficulty repairing the wire and answer any questions that may arise.

1. Safety Brief: Ensure that the students have all appropriate material and PPE before starting the practical exercise.

2.Supervision and Guidance: Instructor is moving around the work stations, assisting students, and answering questions as they arise.

3.Debrief: N/A

(ON SLIDE #277-278)

TRANSITION: We have just completed repairing a simulated open circuit, do I have any questions? If not, I have a couple for you.

(Q1) What are some of the common equipment used to fulfill power distribution requirements in military equipment?
(A1) Single-conductor wires, Multi-conductor harnesses, Bus bars, Terminal blocks, Terminals, Connectors.

(Q2) What are two basic types of wiring assemblies?
(A2) Cable Assembly and Wiring Harness.

Take a 10 min break and we'll move into On-Board Diagnostic Systems Operation and Troubleshooting.
Before the break we have covered Wiring Repair and Schematic Interpretation. Now let's talk about On-Board Diagnostic Systems Operation and Troubleshooting.

____

____

____

(BREAK – 10 MIN)

TRANSITION: Now let's talk about On-Board Diagnostic Systems Operation and Troubleshooting.

(ON SLIDE #279)

8. **ON-BOARD DIAGNOSTIC SYSTEMS OPERATION/TROUBLESHOOTING.**
(3Hrs)

INSTRUCTOR NOTE
Movie introduction to ECM 3.17 minutes.

(ON SLIDE #280)

a. General.

(1) The purpose of integrating computers into equipment systems is to optimize performance, increase reliability, and improve operator efficiency. The use of computers on equipment has expanded to include control and operation of several functions, including engine management, braking, suspension, transmission, and load lifting. Some of these functions are

controlled or monitored by what is commonly known as the Electronic Control Module (ECM).

(ON SLIDE #281)

(2) The ECM processes the physical conditions that represent information (data).

(ON SLIDE #282)

The operation of the ECM is divided into four basic functions input, processing, storage, and output. Understanding these four functions will help the mechanic to organize the troubleshooting process.

(ON SLIDE #283)

When a system is tested, the mechanic will be attempting to isolate the problem to one of these functions.

(ON SLIDE #284)

b. Inputs. Voltage signals are sent from input devices to the ECM. The ECM receives the inputs that it checks with programmed values.

(ON SLIDE #285)

Depending on the input, the computer will control the output(s) until the programmed results are obtained. The inputs can come from other computers, switches, the mechanic, or through a variety of sensors.

(ON SLIDE #286)

(1) Sensors are used as inputs to computer management systems to monitor various conditions during equipment operation. There are many different designs of sensors. Some are nothing more than a switch that completes the circuit. Others are complex chemical reaction devices that generate their own voltage under different conditions. Repeatability, accuracy, operating range, and linearity are all requirements of a sensor. (Linearity refers to the sensor signal being proportional to the measured value.)

(ON SLIDE #287)

(2) A thermistor contains a thermal resistor. It's used to sense engine coolant or ambient air temperatures. By monitoring the thermistor's resistance value, the computer is capable of observing very small changes in temperature. The computer sends a reference voltage to the thermistor (usually 5 volts) through a fixed resistor. As the current flows through the thermistor resistance to ground, a voltage sensing circuit measures the voltage drop. Using its programmed values, the computer is able to translate the voltage drop into a temperature value.

(ON SLIDE #288)

(3) A piezoresistive sensor changes its resistance value according to the amount of pressure that is applied to it. A voltage regulator supplies a constant voltage to the sensor. Since the amount of voltage dropped by the sensor will change with the change in resistance, the computer can determine the amount of pressure on the crystal by measuring the voltage drop across the sensor.

(ON SLIDE #289)

INSTRUCTOR NOTE
Movie testing a "TP" sensor. 4.38 minutes.

(4) The potentiometer usually consists of a wire wound resistor with a moveable center wiper. A constant voltage value (normally 5 volts) is applied to "A". If the wiper is located close to this terminal, there will be represented by high voltage signal back to the computer through terminal "B". As the wiper is moved toward the "C" terminal, the sensor signal voltage to terminal "B" decreases. The computer interprets the different voltage values into different positions of the wiper.

(ON SLIDE #290)

(5) <u>Magnetic pulse generator</u>.

(a) <u>Application</u>. Magnetic pulse generators are commonly used to send data to the computer about the speed of the monitored component. This data provides information about equipment speed and engine speed. The signals from the speed sensors are used for computer-driven gauges, gear shifting in automatic transmissions, and automatic ride control systems.

(ON SLIDE #291)

(b) A timing disc is attached to the rotating shaft and is used to conduct the lines of magnetic force. The teeth on the timing disc will cause a voltage generation that is constant per revolution of the shaft and is relational to the amount of distance that is traveled by the equipment.

(ON SLIDE #292)

INSTRUCTOR NOTE
Clip Magnetic pulse generator

(c) The pick-up coil may consist of a permanent or electromagnet. As a tooth on the timing disk approaches and passes the pick-up coil, it distorts the magnetic field around the magnet causing the field to move in relation to the coil. This relative motion creates an alternating current in the coil that is sent to the computer.

(ON SLIDE #293)

INSTRUCTOR NOTE
Movie testing a wheel speed sensor 3.10 minutes.

The computer calculates how fast the equipment is going based on the frequency of the signal.

(ON SLIDE #294)

(6) Feedback signals. Data concerning the effects of the computer's commands may be fed back to the computer as an input signal. When an actuator is operated by the computer, the feedback signal will confirm the operation of the device. Changing states of the actuator will result in a predictable change in the computer's voltage sensing circuit.

(ON SLIDE #295)

INTERIM TRANSITION: Are there any questions over magnetic pulse generators? If not, let's talk about processing.

(ON SLIDE #296)

c. **Processing**.

(1) A computer is capable of reading only voltage signals. The programs used by the computer are "programmed" using a series of numbers (binary "1s" and "0s"). These numbers represent various voltages that the computer can understand. The voltage signals to the computer can be either analog or digital.

(ON SLIDE #297)

(2) The computer uses this input information and compares it to programmed instructions. The logic circuits (composed of transistorized gates) process the input signals into output demands.

(ON SLIDE #298)

d. **Storage**. The program instructions are stored in an electronic memory. The input signals may also be stored for later processing. Some of the different types of memory include:

(1) Read only memory (ROM). Memory that is stored as permanent information. This information is used to instruct the computer on what to do in response to input data. It can be read, but cannot be written to or changed.

(2) Programmable read only memory (PROM). Read only memory that contains specific data that pertains to the exact equipment in which the computer is installed. Can only be programmed once.

(3) Electronically Erasable programmable read only memory (EEPROM). This is memory that allows for changing the information through diagnostic tools. Can be erased and reprogrammed

(ON SLIDE #299)

(4) Random access memory (RAM). Memory that is information temporarily stored that can be read from or written to by the computer. It helps to enhance the computers performance.

(5) Nonvolatile random access memory (NVRAM). Memory that is not erased when it is disconnected from the power source. NVRAM is a combination of RAM and EEPROM.

(ON SLIDE #300-304)

e. **Outputs**. After the computer has processed the sensory inputs and checked its programmed instructions, it will put out control commands to various output devices. These output devices may be electric relays, solenoids, or motors. The output of one computer can also be used as an input to another computer.

(ON SLIDE #302)

INSTRUCTOR NOTE
Movie electronic transmission shifting 5.50 minutes.

(ON SLIDE #305-306)

f. **Multiplexing (MUX) Concepts**.

(1) Purpose. Manufactures use multiplexing systems to allow different control modules to share information. A MUX wiring system uses bus data links that connect each module. Each module can transmit and receive digital codes over the bus data links. This allows the modules to share information. The signal sent from a sensor can go to any of the modules and can be used by the other modules. By sharing this data, the need for separate wires from the sensor to each module is eliminated. The networking of ECM's together can be likened to a MEU operation.

(ON SLIDE #307)

(2) Advantages. In equipment networking provides a multitude of system-level benefits, many of which are only beginning to be realized.

(a) A decreased number of dedicated wires is required for each function, and thus reduces the size of the wiring harness.

(b) System cost, weight, reliability, serviceability, and installation are improved.

(c) Common sensor data, such as vehicle speed, engine temperature, etc. are available on the network, so data can be shared, thus eliminating the need for redundant sensors.

(d) Networking allows greater vehicle content flexibility because functions can be added through software changes. Existing systems require an additional module or additional I/O pins for each function added.

(ON SLIDE #308)

(3) Multiplexing Protocols. Manufacturers and various industry standards organizations (ISO and SAE) have been working for many years to develop standards for networking. Many standards such as VAN, ABUS, CAN, and SAE J1850 have been developed, but SAE J1850 and CAN 2.0 (Controller Area Network) are the predominant standards.

(ON SLIDE #309)

g. **Electromagnetic Interference (EMI) Suppression**. As manufacturers began to increase the number of electronic components and systems in their equipment, the problem of electromagnetic interference (EMI) has to be controlled. The low power integrated circuits used on modern equipment is sensitive to the signals produced as a result of EMI. EMI is produced as current in a conductor is turned on and off. EMI is also caused by static electricity that is created by friction. The friction can be caused by fan belts contacting the pulleys.

(ON SLIDE #310)

(1) EMI can disrupt the equipment’s computer systems by inducing false messages to the computer; the computer requires messages to be sent over circuits in order to communicate with other computers, sensors, and actuators. If any of these signals are disrupted, the equipment may malfunction.

(ON SLIDE #311)

(2) EMI can be suppressed by any one of the following methods:

(a) Adding a resistance to the conductors.

(b) Connecting a capacitor in parallel and a choke coil in series with the circuit.

(c) Shielding the conductor or load components with a metal or metal impregnated plastic.

(ON SLIDE #312)

(d) Increasing the number of paths to ground by using designated ground circuits. This provides a clear path to ground that is very low in resistance.

(e) Adding a clamping diode in parallel to the component.

(f) Adding an isolation diode in series to the component.

(ON SLIDE #313)

g. **Electronic service precautions**. The mechanic must take some precautions before servicing an Electronic Control Module or any of its systems. The ECM is designed to withstand normal current draws associated with normal operation. However, overloading any of the system circuits will result in damage to the computer. Following some simple service precautions will prevent unintentional damage of sensitive electronic components.

(ON SLIDE #314)

(1) Do not ground or apply voltage to any computer controlled circuits unless the service manual instructs you to do so.

(2) Use only a high impedance multimeter (10 megohm or greater) to test the circuits. Never use a test light unless specifically instructed to do so in the service manual.

(3) Make sure the ignition switch is turned off before making or breaking electrical connections to electrical/electronic circuits.

(ON SLIDE #315)

(4) Turn off the ignition switch whenever connecting or disconnecting the battery terminals. Also turn it off when pulling and replacing fuses.

(5) Do not connect any other electrical accessories to the insulated or ground circuits of the computer-controlled system.

(6) Use only manufacture’s specific test and replacement procedures for the equipment being serviced.

(ON SLIDE #316)

(7) Static electricity can destroy or render certain electronic component useless. Some manufactures mark certain components and circuits with a code or symbol to warn mechanics that the units are sensitive to electrostatic discharge.

(ON SLIDE #317)

h. **Trouble codes**. A trouble code is a two to five digit character displayed in the diagnostic display if the testing and failure requirements are both met.

(1) Most ECM's are capable of displaying the stored faults in memory. The method used to retrieve the codes varies greatly; the mechanic must refer to the correct technical manual for the procedure. Depending on the system design, the computer may store codes for long periods of time or lose the code when the ignition switch is turned off.

(ON SLIDE #318)

(2) Systems that do not retain the code when the ignition is turned off require that the mechanic operate the equipment and attempt to duplicate the fault. Once the fault is detected by the computer, the code must be retrieved before the ignition switch is turned off again.

(3) The trouble code does not necessarily indicate the faulty component; it only indicates that circuit of the system that is not operating properly. The fault could be caused by any component (wiring, connections, sensors, switches, actuators, or the ECM) that is a part of that circuit.

(ON SLIDE #319)

(4) Some ECM's will store trouble codes in their memory until they are erased by the mechanic or until a set amount of engine starts have passed. There are two types of trouble codes:

(a) Hard codes. Failures that were present the last time the ECM tested the circuit.

(b) Intermittent codes. Failures that have occurred in the past, but were not present during the last ECM test of the circuit.

(ON SLIDE #320-321)

INSTRUCTOR NOTE
These slides show the students how to read fault codes on the Caterpillar 420 IT Backhoe Loader and on the Omniequip MMV II. Have the students count the number of flashes from the diagnostic indicator in the slides.

(ON SLIDE #322)

INSTRUCTOR NOTE
Movie setting the load indicator on the Terex LCRTF 35 minutes.

(ON SLIDE #323)

TRANSITION: We just covered On-Board Diagnostic Systems Operation and Troubleshooting, are there any questions? If not, I have a couple questions for you.

(Q1) What four basic functions is the ECM divided into?
(A1) Input, Processing, Storage, and Output.

(Q2) What are Magnetic pulse generators are commonly used for?
(A2) This data provides information about equipment speed and engine speed.

____
____
____

(ON SLIDE #324)

SUMMARY **(5 MIN)**

During this period of instruction we've covered Laws and principles of electricity, electrical schematics and wiring diagrams, storage battery operation and troubleshooting, electronic component failure isolation and identification, starting system operation and troubleshooting, charging system operation and troubleshooting, wiring repair and schematic interpretation, on board diagnostic systems operation and troubleshooting. With this knowledge I'm confident that you'll be able to go back to your units and successfully manage your shops, gaining the confidence of your superiors and ultimately getting promoted. Those students with the IRF's go ahead and fill those out, and the rest of you take a ten minute break.

(ON SLIDE #325)

(BREAK - 10 Min)

STUDENT REFERENCES:	**PUBLICATION ID**
624 Loader Repair	TM 11412A-OI/1
624KR LOADER OPERATION AND TEST	TM 11412A-OI
BACKHOE LOADER CATERPILLAR MODLE 420D IT	TM 10996A-OI/A
ELECTRONIC AND ELECTRICAL SYSTEMS	FOS2007NC
FORKLIFT, EXTENDABLE BOOM (EBFL)	TM 10794B-OI/A
FUNDAMENTALS OF ELECTRICITY AND ELECTRONICS	BULLETIN 285-EX ED.2D