Section 1

Essential Electrical Concepts

Introduction

Modern vehicles incorporate many electrical and electronic components and systems:

- Audio
- Lights
- Navigation
- Engine control
- Transmission control
- Braking and traction control

You need to know essential electrical concepts to effectively troubleshoot these and other electrical circuits.

Electrical and electronic system troubleshooting can be straightforward if …

- You know what to look for.
- You know how to select and use the appropriate tools and test equipment.

With the knowledge and techniques you will learn in this course, you will be able to …

- Diagnose and repair electrical and electronic problems correctly on the first attempt.
- Reduce diagnostic and repair time.
- Increase customer satisfaction.

Meters

Different meters are used to measure voltage, current, and resistance:

- Voltmeter - to measure voltage
- Ammeter - to measure current
- Ohmmeter - to measure resistance

These three metering functions are combined into a single tester called a “multimeter.” Nearly all automotive technicians use multimeters.

A multimeter is often called a “volt-ohmmeter,” even though most multimeters also measure amperes (current).

A multimeter can be one of two types:

1. Analog - display uses a needle to point to a measured value on a scale.
2. Digital - display shows measured value in actual numbers (digits).

Metering Functions

Three metering functions are combined in a typical digital multimeter.

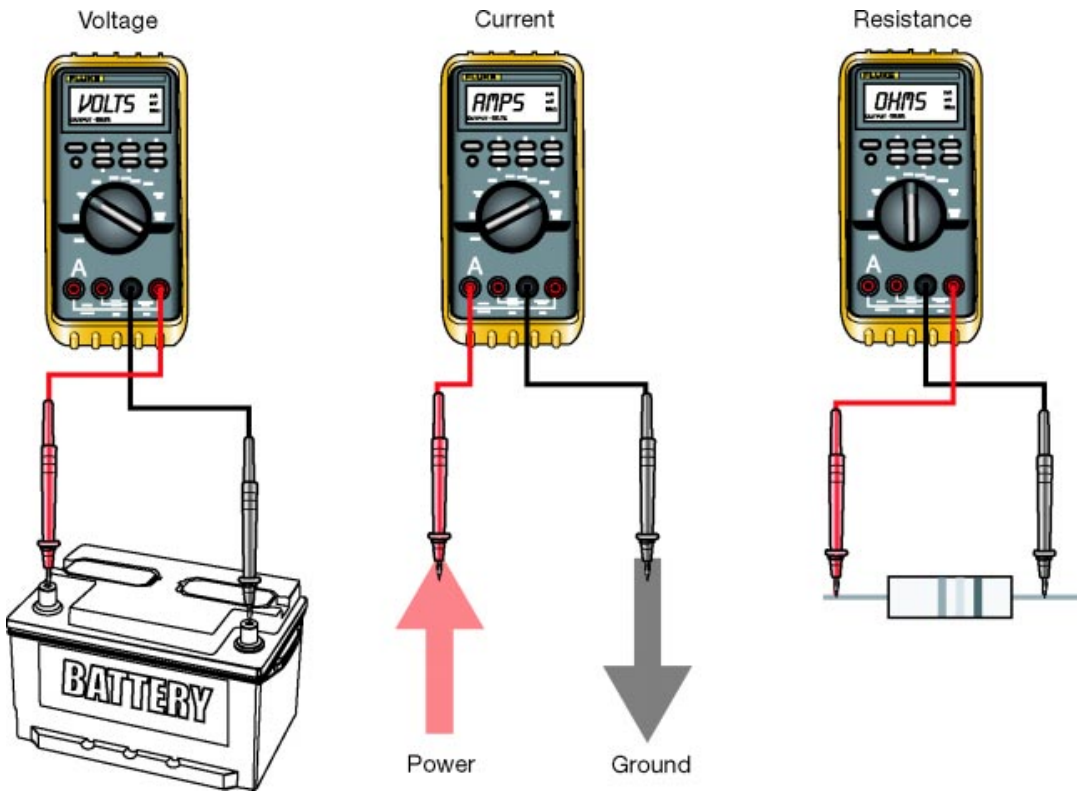


Fig. 1-01
TL623f100c

Analog Multimeters

Analog multimeters …

- Use a mechanical movement to drive a pointer.
- Display a measured value where the pointer intersects a calibrated scale.
- Are not suitable for measurements in circuits with sensitive electronic components (such as ECUs).
- Are more susceptible to damage from mechanical shock than are digital multimeters.

Typical Analog Multimeter

Analog meters use a mechanical movement and are not suitable for measurements in circuits with sensitive electronic components.

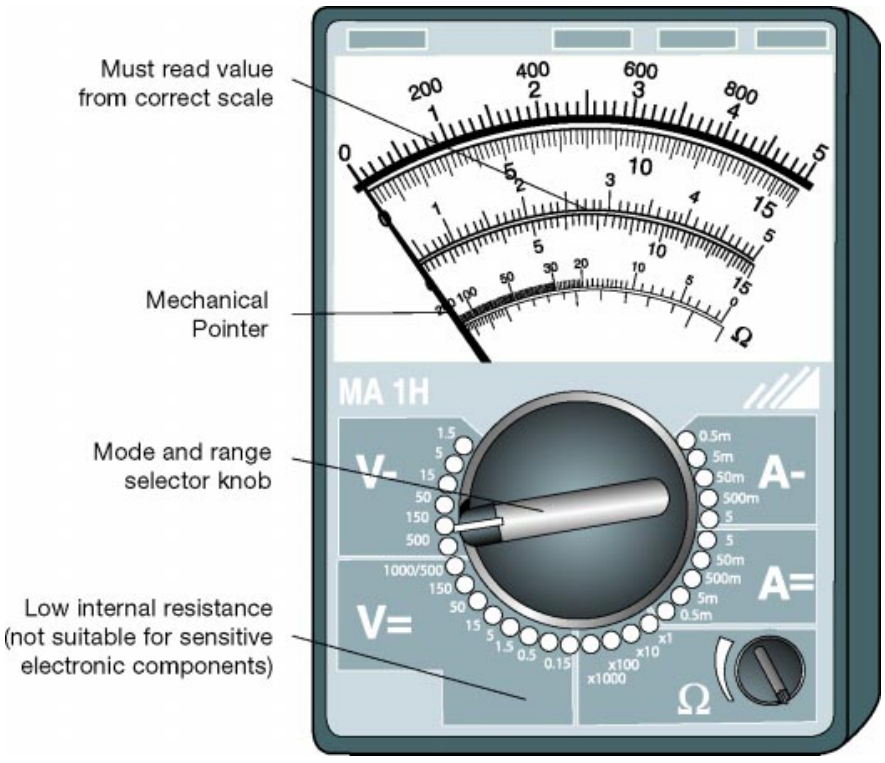


Fig. 1-02
TL623f102

Digital Multimeters

Digital multimeters …

- Use a digital display.
- Display a measured value in actual numbers.
- Are suitable for measurements in circuits with sensitive electronic components (such as ECUs).
- Are less susceptible to damage from mechanical shock than are analog multimeters.
- Have a longer battery life.
- Have a higher internal resistance.

Typical Digital Multimeter

Digital multimeters display the actual measured value and are suitable for measurements in circuits with sensitive electronic components.

Fig. 1-03
TL623f103c

DMM Components

The main components found on the front panel of a typical digital multimeter (DMM) are …

- Digital display
- Range selector
- Mode selector
- Input jacks

DMM Components

This figure shows the main components of a typical digital multimeter.

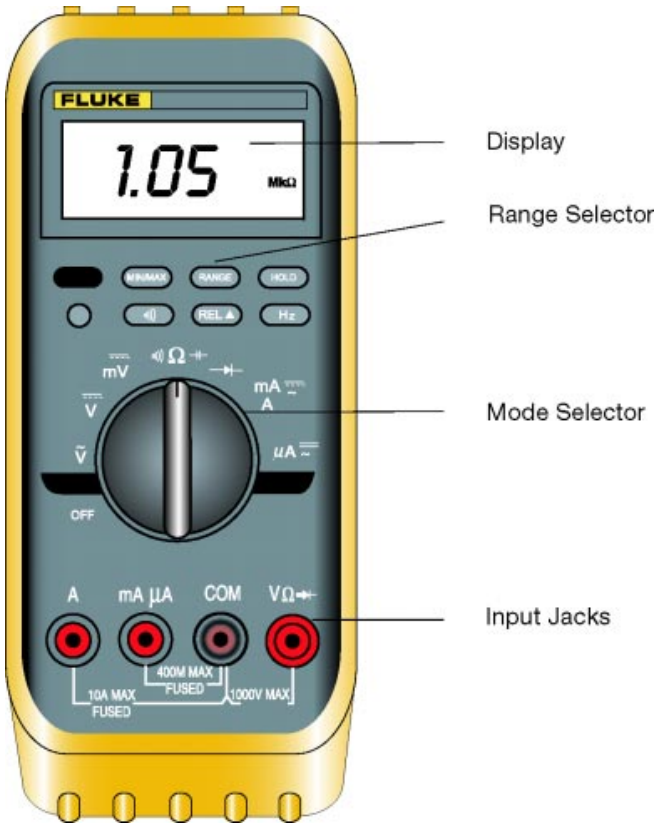


Fig. 1-04
TL623f104c

DMM Mode Selector

Use the mode selector to set the meter for the type of test to be performed. These are the modes available on a Fluke 87 DMM:

- **Off -** Turns the meter off. Turning the mode selector to any other setting turns the meter on.
- **Volts AC -** Use to measure voltage in alternating current (AC) circuits.
- **Volts DC -** Use to measure voltage in direct current (DC) circuits.
- **Millivolts DC (mV) DC -** Use to measure very low voltage in direct current (DC) circuits.
- **Resistance/Continuity (ohms) -** Use to measure resistance and check continuity.
- **Diode Check -** Use to check the operation of a diode (meter sends a small current through the diode).
- **Amps or Milliamps AC/DC -** Use to measure current in a circuit.
- **Microamps (AC/DC) -** Use to measure very small current in a circuit.

DMM Mode Selector

The mode selector knob lets you set the meter for the type of test you want to perform.

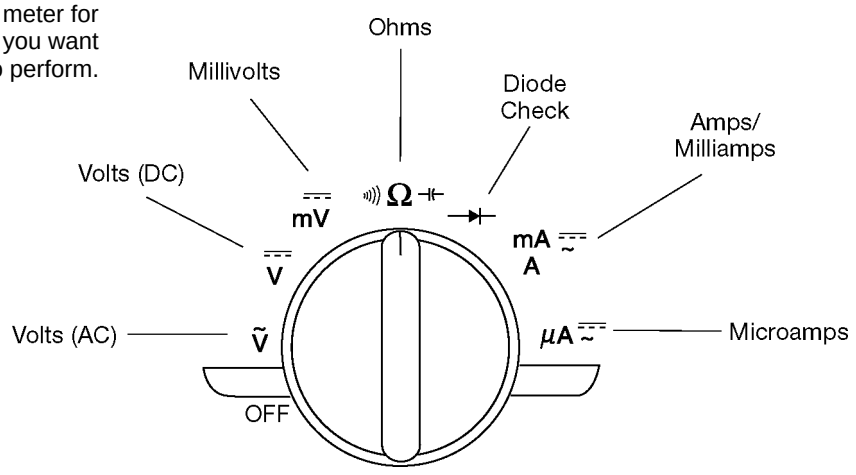


Fig. 1-05
TL623f105

DMM Display

DMMs display information that must be properly interpreted to get the correct measured value.

Interpreting DMM Displays

The digital display gives a direct readout in actual numbers. However, you still must properly interpret the display to get the correct measurement value.

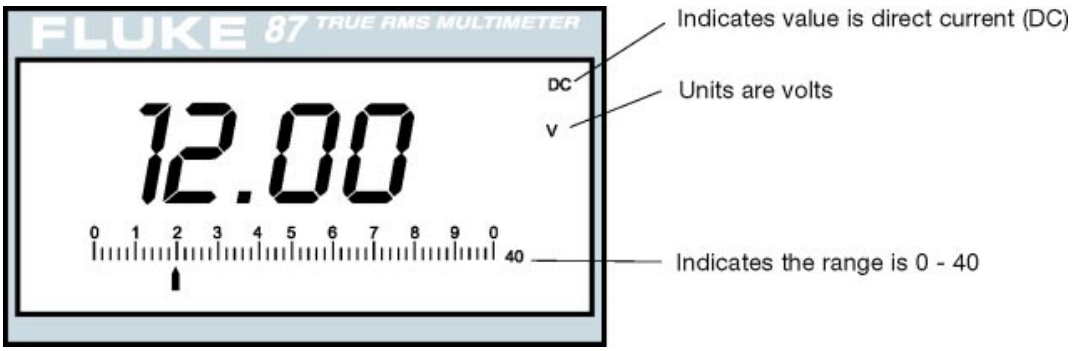


Fig. 1-06
TL623f106

Voltage type - The DMM shows the voltage type (AC or DC) in the upper right hand corner of the display.

Measured value - The large digits in the center of the display represent the measured value. Typically, the total value will contain four or five digits with a decimal point.

Units - To the right of the measured value number, the display shows letters that represent units:

V volts
A amperes
Ω ohms

Range - The DMM displays the measurement range in the lower right hand corner of the display, just to the right of the bar graph.

Unit modifiers - The letters m, k, μ, and M modify unit values:

Volts -

mV	millivolts	volts x 0.001
kV	kilovolts	volts x 1,000

Amperes -

mA	milliamps	amps x 0.001
μA	microamps	amps x 0.000001

NOTE Automotive technicians rarely use readings at the microamp level.

Ohms -

Ω	ohms	
kΩ	kilo-ohms	ohms x 1,000
MΩ	megohms	ohms x 1,000,000

DMM Over-Limit Display

The "O.L" or "over-limit" display appears whenever the test produces a value that exceeds the selected range. For resistance, that typically indicates an open circuit.

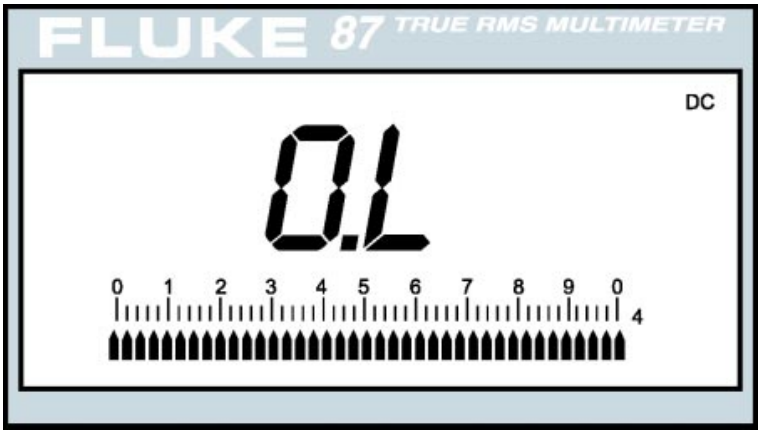


Fig. 1-07
TL623f107

Over-Limit Measurement - Most DMMs display an over-limit sign when the meter is measuring voltage or current that exceeds the selected or available range.

DMM Auto-Ranging

Many DMMs offer a feature called “auto-ranging.” Meters with this feature allow you to disable it when you want to select ranges manually. When the meter is set to auto-range, it automatically selects the range most appropriate for the measurement being performed.

EXAMPLE Auto-ranging is convenient for making most measurements. It is especially helpful when you do not know what value to expect. A resistance measurement provides a good example.

A typical DMM has these ranges available for resistance measurements:

- 400 Ω
- 4 k./40 kΩ/400 kΩ
- 4 M./40 MΩ

If the DMM is connected to a component with an internal resistance of about 700 ohms, the meter can automatically select the 4 k. range. Without auto-ranging, you might scan through several ranges before determining that the 4 kΩ range is most appropriate for this measurement.

DMM Auto-Ranging

Digital multimeters with auto-ranging will automatically select the appropriate scale for a test measurement.

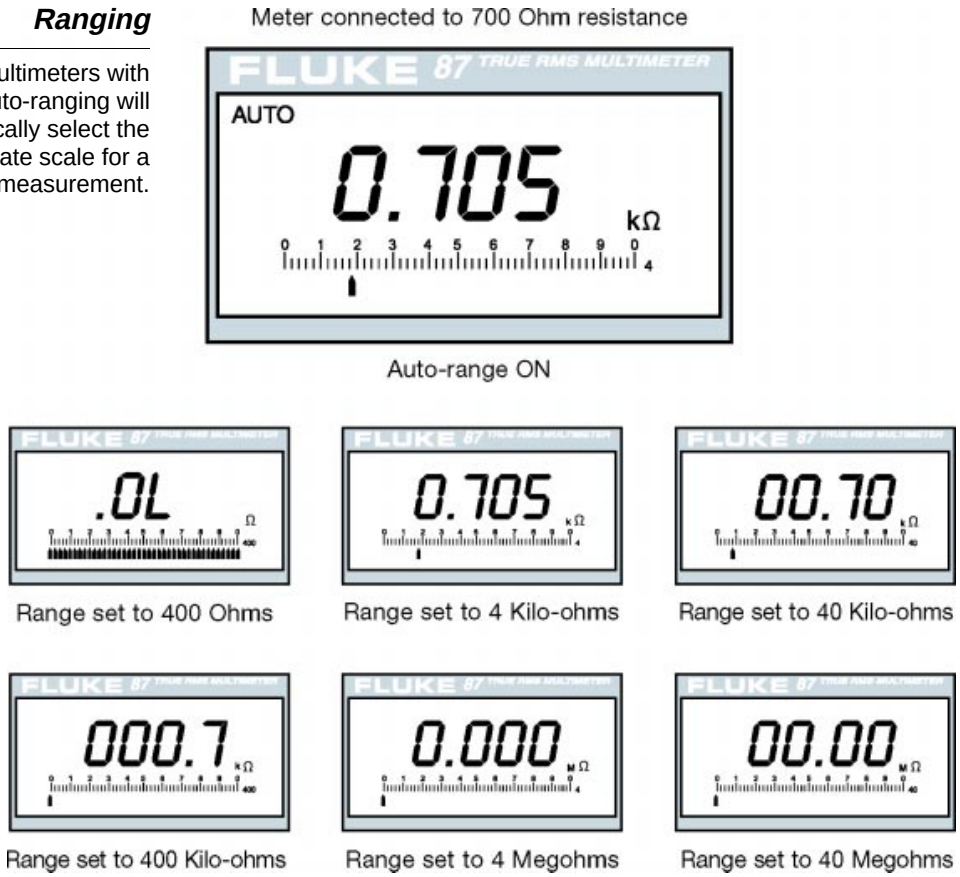


Fig. 1-08
TL623f108

DMM Test Leads and Input Jacks

The typical DMM has two test leads and four input jacks. The leads plug in as follows:

- BLACK - always plugs into the COM input jack.
- RED - plugs into one of the three remaining jacks, depending on what measurement is being performed.
  - V/Ω/diode input for measuring resistance, conductance, and capacitance, as well as checking diodes (Voltage).
  - A input for measuring current up to 10 amps.
  - µA/mA input for measuring current up to 400mA.

DMM Input Jacks

The meter leads must be plugged into the proper input jack for different tests (voltage and resistance or two ranges of current).

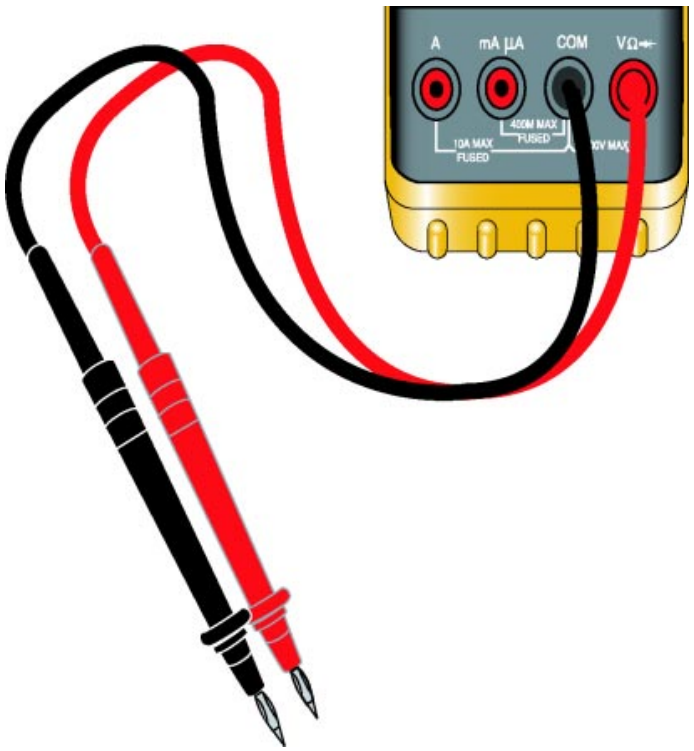


Fig. 1-09
TL623f109c

Voltage

Voltage is the electromotive force between two points in a circuit.

EXAMPLE When you place the probes of a DMM on the terminals of a battery, you are measuring the electromotive force, or voltage, between the positive and negative battery plates.

Overview

This meter is connected to measure battery voltage.

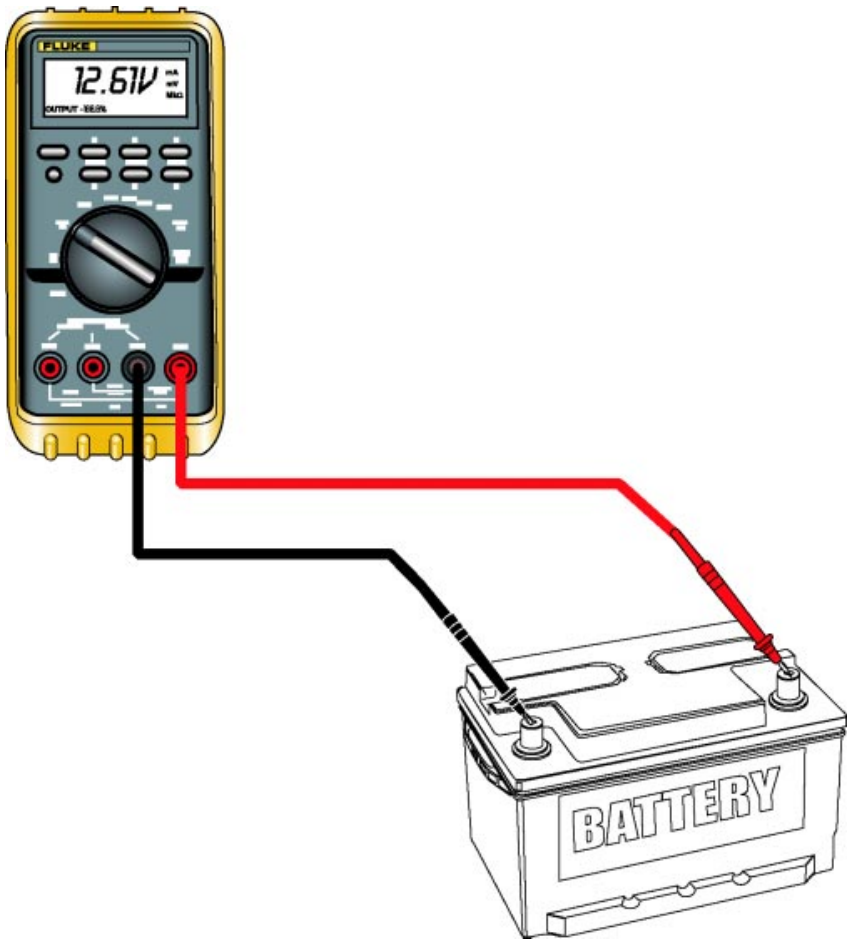


Fig. 1-10
TL623f110c

Applications of voltage - Technicians are concerned with voltage in different applications:

- Source voltage
- Available voltage
- Voltage drop

Source voltage - the battery supplies source voltage in most automotive electrical systems.

Measuring voltage - use the DMM to measure voltage. Note that voltage measurements are made by placing the voltage leads in a parallel circuit to the circuit you are testing. (Parallel circuits are covered in Section 2.)

Available voltage - is the voltage in a circuit available to operate the load.

Voltage drop - most parts of an electrical circuit offers some resistance to current. Every element that has resistance causes a voltage drop. Voltage drop increases as resistance increases.

Measuring Voltage

The meter leads in this figure show three different ways to measure voltage.

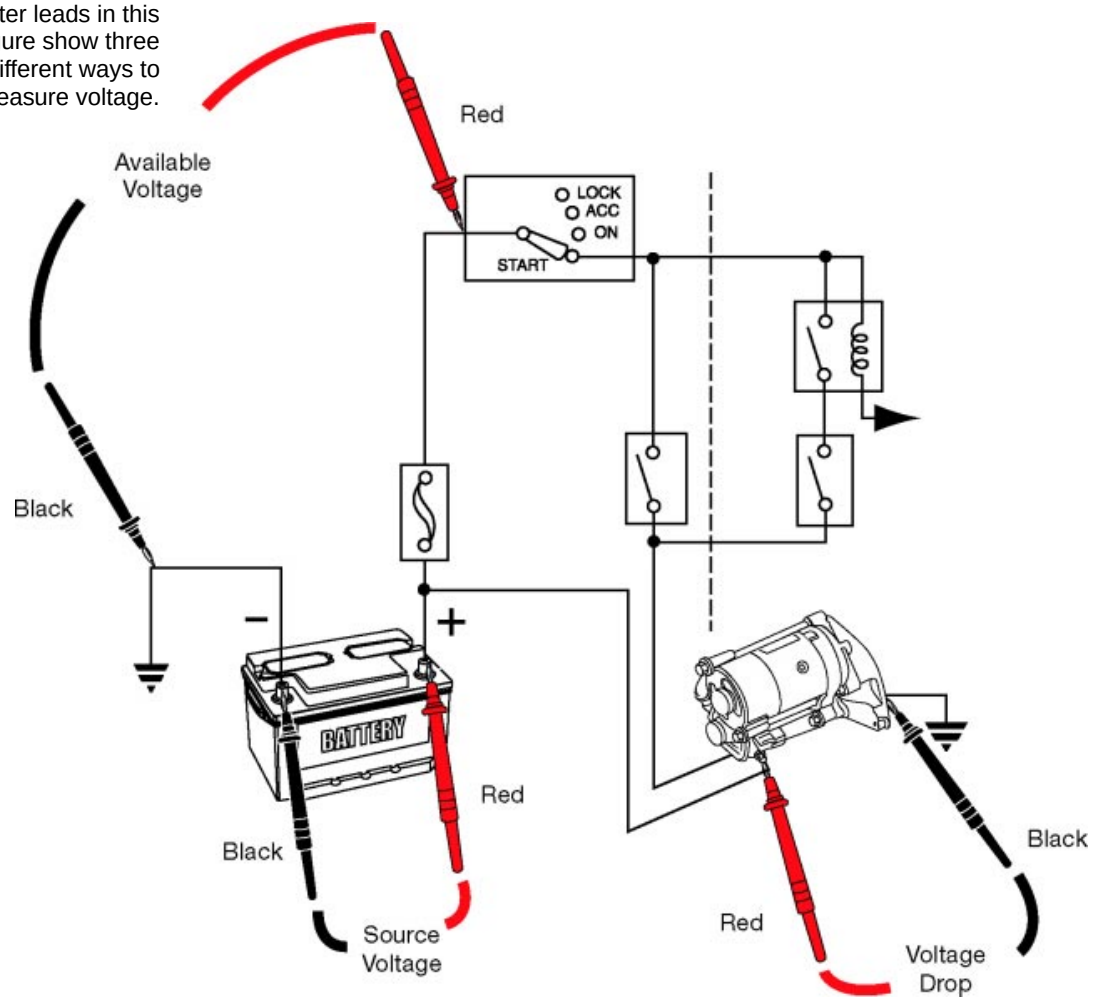


Fig. 1-11
TL623f111c

You can measure voltage …

- Between any two points in a circuit
- Between any point in a circuit and ground
- Across any component in the circuit
  - Switches
  - Relay contacts and coils
  - Connectors
  - Wires
  - Cables

Available Voltage

The meter probes are placed to test the available voltage at the switch.

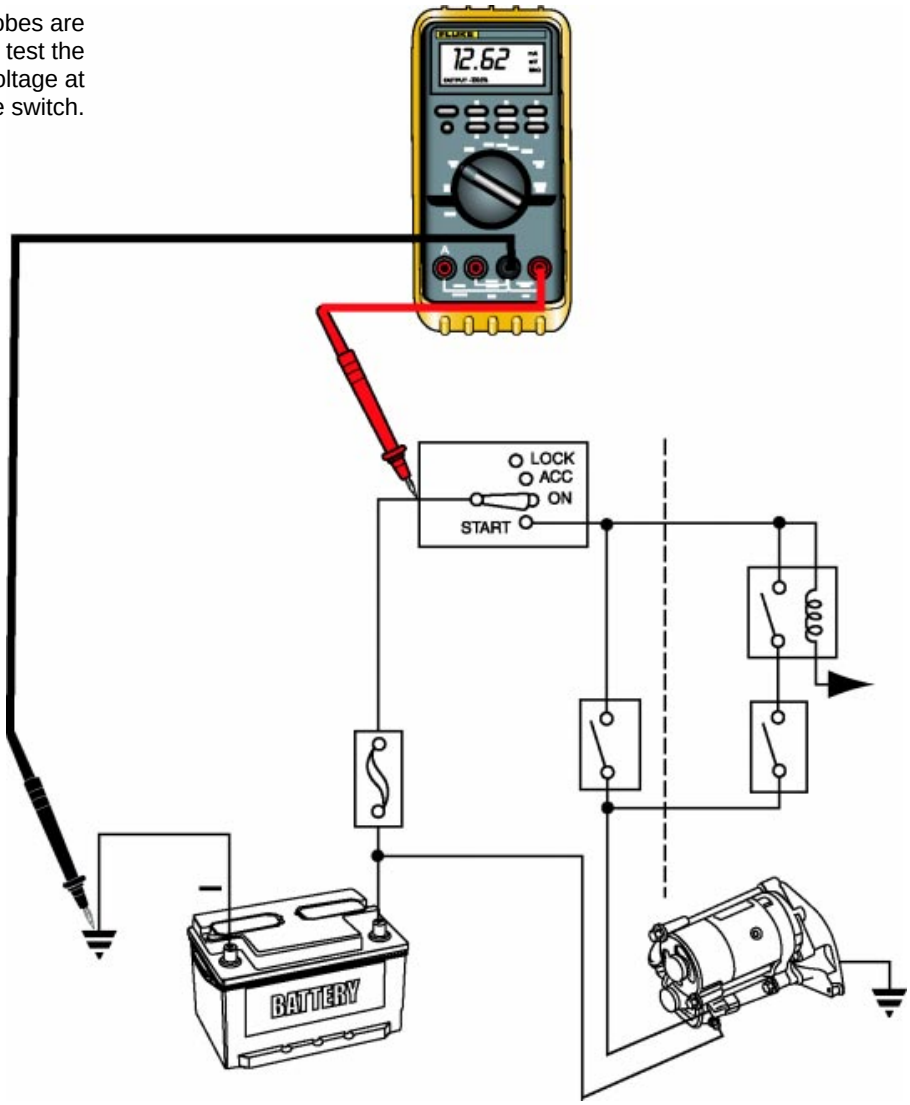


Fig. 1-12
TL623f112c

Available Voltage

Measure available voltage using a digital multimeter with these steps:

1. Set the mode selector switch to Volts DC.
2. Select the Auto-Range function or manually set the range.
   - Because the battery supplies available voltage in automotive circuits, you will typically measure voltages between zero and 12 to 14 volts.
   - For Fluke Series 80 DMMs, set the range to 40.
   - For other DMMs, set the range to the value closest to and higher than 12 volts.
3. Connect the voltmeter leads in parallel with the circuit element to be tested.
   - Red lead closest to the battery (connect first).
   - Black lead to a good ground.
4. Read measurement on DMM display.
   - Note polarity.
   - Correctly apply units.

NOTE The meter leads are most likely reversed if the DMM display indicates negative polarity. It could also mean there is a fault in the circuit.

Voltage Drop

Voltage Drop

Voltage drop indicates the voltage being used in that section of the circuit.

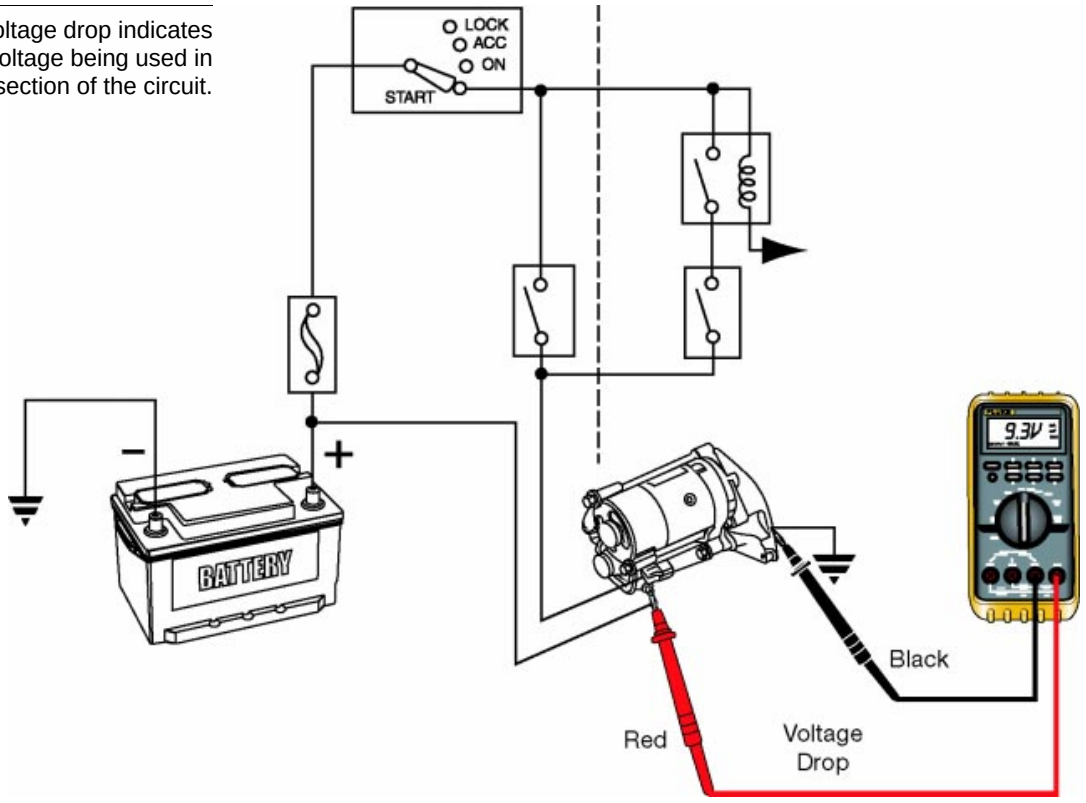


Fig. 1-13
TL623f113c

Voltage drop is one of the most useful tests you can perform. A voltage drop test isolates voltage used in the portion of the circuit being tested. A voltage drop test is done as follows:

1. Place the positive lead in the most positive section of the circuit you are testing.
2. Place the ground lead on the most negative section of the circuit you are testing.
3. Operate the circuit with the meter leads in place and note the reading.

Typical voltage drops are as follows:

- Across a switch, relay contacts or connector: Less than 200 mV (< 0.2 V).
- Across a section of the harness: Less than 200 mV (< 0.2 V).
- Across the load: Approximately source voltage (> 12.4 V).

The sum of all voltage drops in a circuit equals the source voltage. A voltage drop that exceeds normal limits indicates excessive resistance (an unwanted load) in that portion of the circuit.

A voltage drop test can quickly isolate excessive resistance in a circuit that may not be detected using a resistance test. The Ohmmeter only passes a small current through the portion of the circuit you are testing. A voltage drop test is done with circuit operating at normal current levels. A loose pin in a connector or a damaged wire may show continuity with the Ohmmeter but under load show a voltage drop due to the increased resistance during normal current levels.

Converting Voltage Values

To convert volts to millivolts (and vice versa) just move the decimal point three places.

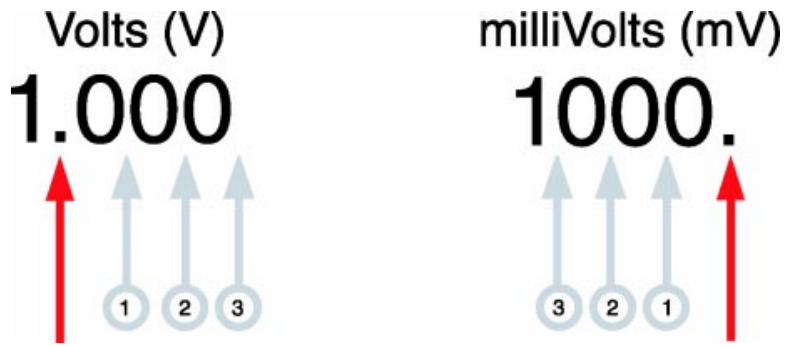


Fig. 1-14
TL623f114c

Converting Voltage Values - Automotive voltage values vary from around 14 volts to very small values under 50 mV.

CAUTION Hybrid vehicles such as the Prius use circuits with high voltage and current (over 100 volts). Follow all safety precautions and service procedures when working on high voltage circuits.

Values under 1 volt are often expressed as millivolts. 1 volt is equal to 1,000 millivolts.

Convert the values as follows:

- Volts to millivolts, move the decimal point 3 places to the right. (example: 1.34 V = 1,340 mV)
- millivolts to volts, move the decimal point 3 places to the left. (example: 289 mV = .289 V)

Practice - Convert the following voltage values:

50 mV = _____ V

3,233 mV = _____ V

9.48 V = _____ mV

.27 V = _____ mV

Current

Current is measured in amperes or "amps." Current is sometimes called *amperage*.

Current is present in a circuit when …

- There is sufficient available voltage.
- There is a continuous path from the source, through the load, to ground.

You will not use current measurements as often as voltage measurements. Most diagnostic specifications for automotive circuits specify voltage or resistance.

You will measure current to diagnose …

- Faults in starting and charging systems.
- Parasitic load faults.

A parasitic load is an unwanted load that draws current when the ignition switch is turned to OFF. This problem is typically reported as "battery drains while vehicle is parked overnight."

Measuring Current

A convenient place to measure current is at the fuse holder. When you remove the fuse to measure current, always use a fused jumper wire or leads as shown.

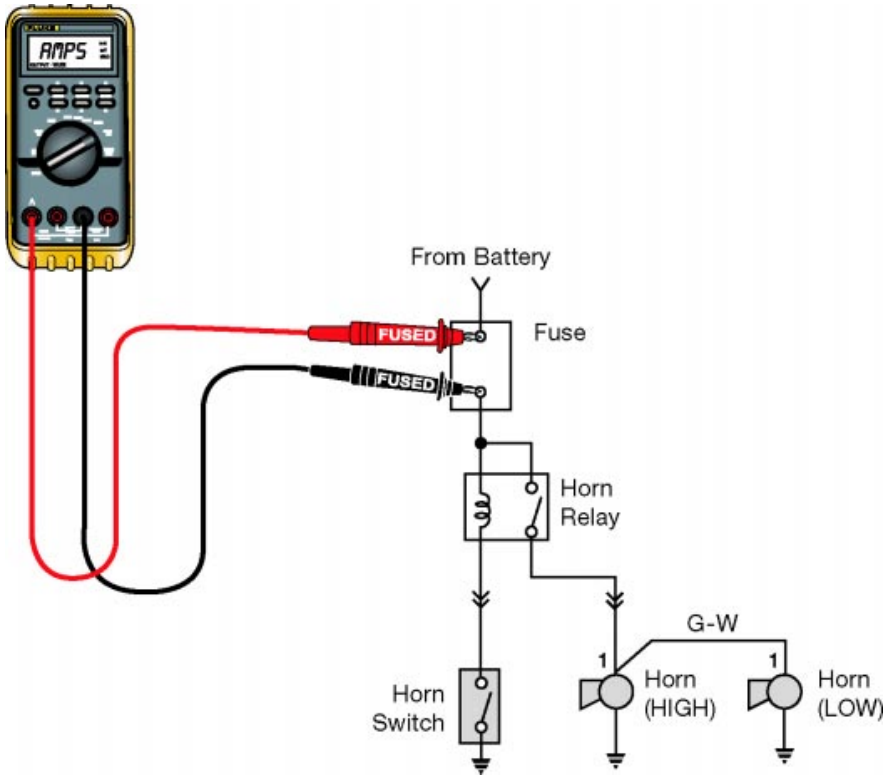


Fig. 1-15
TL623f115c

DMM connections - A DMM is connected differently for measuring current than it is for measuring voltage:

- Voltage - meter connected in parallel with circuit element.
- Current - meter connected in series with circuit (current actually flows through the meter).

Maximum current capacity - It is important to observe the maximum current capacity of the DMM you are using. To determine the maximum current capacity:

- Read the rating printed next to the DMM input jacks.
- Check the rating of the meter's fuse (maximum current capacity is typically the same as the fuse rating).

NOTE Use only fuses of the correct type and rating for each meter. Substituting an incorrect fuse could cause damage to the meter.

If you suspect that a measurement will have a current higher than the meter's maximum rating, use an optional inductive pickup. Some specific testers, such as the Sun VAT series, have built in ammeters with high current ratings for testing starting and charging systems.

Measure current with a DMM using these steps:

1. Turn the circuit to be tested off.
   - Make sure leads are in correct jacks on DMM.
2. Set the DMM mode selector to the appropriate current function (typically amps or milliamps).
3. Select the Auto-range function or manually select the range for the expected current value.
4. Open the circuit at a point where the meter can be inserted in series.
   - A fuse holder makes a convenient point to open a circuit.
   - Use a jumper wire (with a fuse of the same rating in the circuit) to connect one of the meter leads.
5. Turn the circuit to be tested on.
6. Note the measured value on the DMM display.
   - Apply the correct units.
   - Convert units as needed to match diagnostic specifications.

Converting Current Values

To convert amperes to milliamps (and vice versa) just move the decimal point three places.

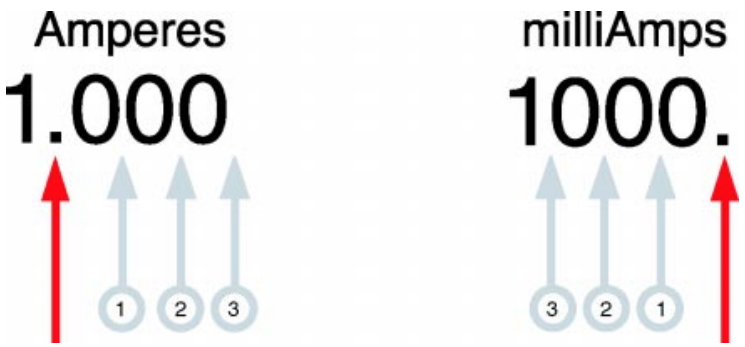


Fig. 1-16
TL623f116c

NOTE Make sure that current values are expressed in the same units when comparing measured current values to diagnostic specifications.

Current should match the specifications in the service information.

- If current is too high, check for a short circuit or a faulty component.
- If current is too low, check for excessive resistance (with resistance and voltage drop measurements).

Converting amperage values - Automotive system currents vary from large to small:

- Large currents (up to 100 A) - charging and starting system.
- Small currents (less than an amp) - electronic control circuits.

Large current values typically display in amperes. Smaller current values may be expressed as milliamps. To convert from one to the other, simply move the decimal point three places:

- Amperes to milliamps - decimal point moves 3 places to the right.

  1.000 ampere = 1,000 milliamps

- Milliamps to amperes - decimal point moves 3 places to the left.

  0.001 ampere = 1.000 milliamp

Practice - Convert the following amperage values:

90 mA = _____ A

9,416 mA = _____ A

6.30 A = _____ mA

.78 A = _____ mA

Inductive current probes - These are also called “current clamps.” They are …

- An optional accessory for DMMs.
- Convenient (no need to open the circuit being tested).
- Safe.

Current probes work by sensing the magnetic field generated in a wire by the current.

NOTE The following procedure applies to most Fluke DMMs and current probes. Some meters may operate differently. Check the operator’s manual for your equipment to confirm.

Measure current with a clamp-on current probe using these steps:

1. Set DMM mode selector to millivolts (mV).
2. Connect probe to meter.
3. Turn probe on.
4. Use the zero adjust knob (if equipped) to zero the DMM display (with jaws empty).
5. Clamp probe around wire in circuit to be tested.
6. Orient the arrow on the clamp in the proper direction (in the direction of current flow).
7. Note the voltage reading on the DMM display.
8. Convert the voltage reading to amperes (1 mV = 1 ampere).

EXAMPLE If the reading is 1 mV (millivolt), then the current is 1 ampere. If the reading is 15 mV, then the current is 15 amperes.

Current Clamp

Attach an accessory current clamp to a digital multimeter to measure current without breaking the circuit.

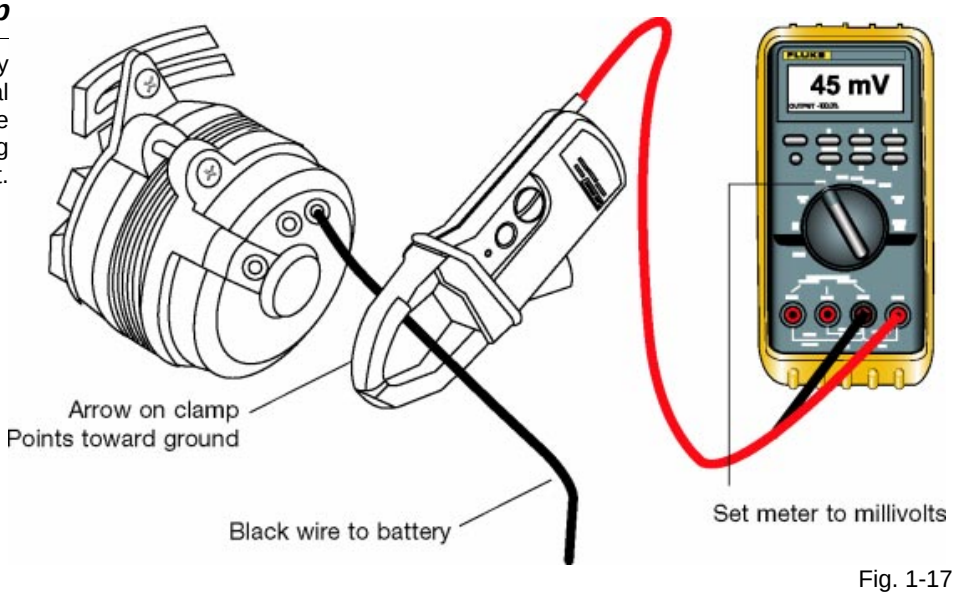


Fig. 1-17
TL623f117c

Resistance

Circuit load - The load has the highest resistance in a typical circuit. Other circuit elements may be used to control current by providing additional resistance.

EXAMPLES Resistance used to control current:

- Instrument panel lighting controlled by dimmer switch.
- Blower speed controlled by blower motor resistors.

Excessive resistance - Excessive resistance in a circuit can prevent it from operating normally. Loose, damaged, or dirty connections are a common source of excessive resistance.

Resistance

To get accurate resistance measurements, isolate the circuit or component and make sure it is not connected to a power source.

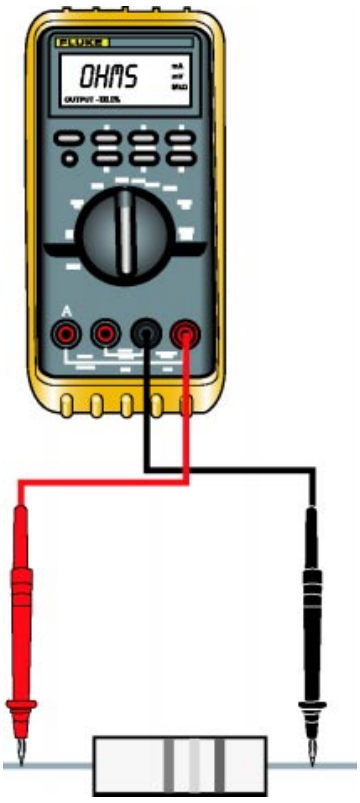


Fig. 1-18
TL623f118c

Measure resistance with a DMM using the following steps:

1. Make sure the circuit or component to be tested is isolated and not connected to any power source.

CAUTION Some meters may be damaged if you apply voltage to the meter leads when the mode selector is set to measure resistance.

2. Set the DMM mode selector to measure resistance.
3. Select the Auto-range feature or manually select a range appropriate for the test.
4. Confirm the meter calibration by touching the meter's two probes together.
   - For a typical DMM, resistance of the leads should be 0.2 ohms or less.
5. Connect the meter leads across the component or circuit segment to be tested.
6. Read the measured value on the DMM display.
   - Note the units.

Other Ohmmeter Functions - The ohmmeter function of a DMM can also be used for other tests and measurements:

- Circuit continuity (with audible beep to confirm continuity)
- Conductance (very high resistance)
- Diode test (some DMM's cannot test)
- Capacitance (some DMM's cannot test)

Circuit continuity tests verify a path for current exists. The DMM may beep to indicate continuity and display a very low ohm reading. An open circuit is indicated by a very high reading or OL (out of limits - infinite resistance).

Measuring Resistance

This meter is connected to measure the resistance across the switch. Notice the fuse and relay have been removed to isolate the component being tested.

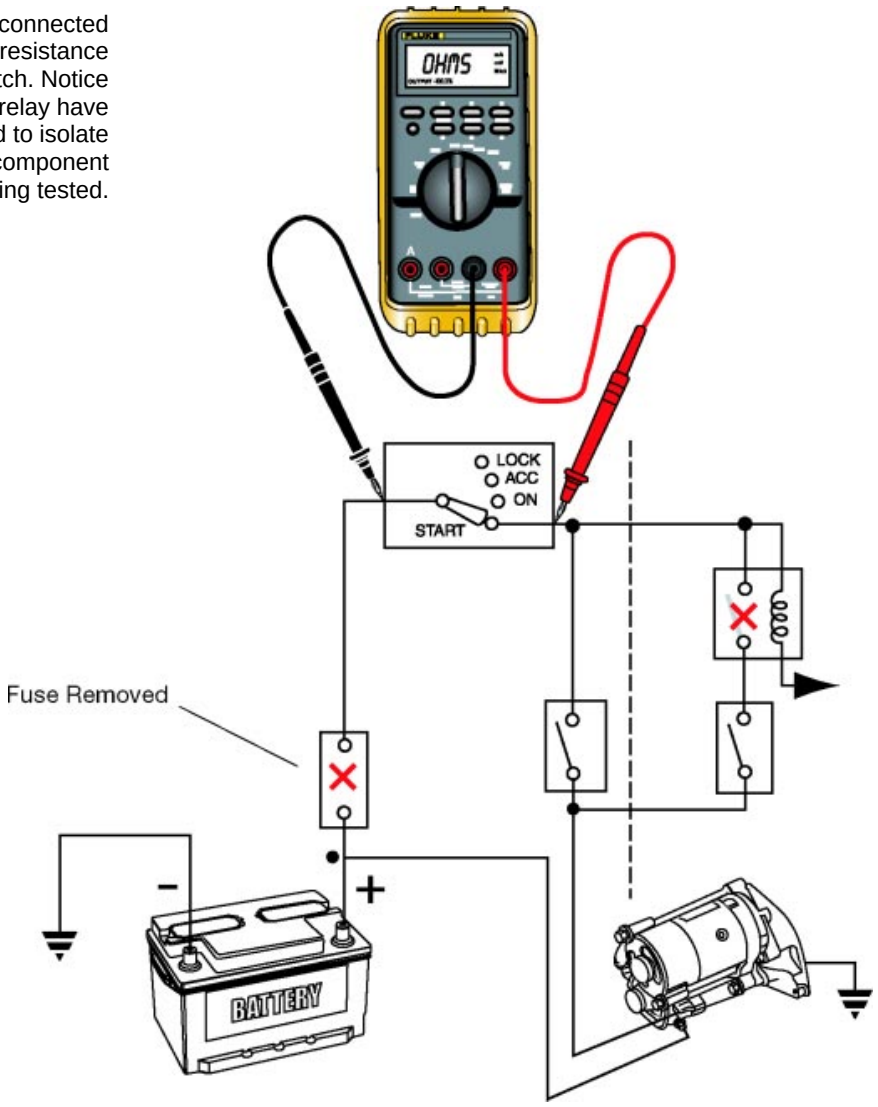


Fig. 1-19
TL623f119c

NOTE Make sure that resistance values are expressed in the same units when comparing measured resistance values to diagnostic specifications.

Resistance should match the specifications in the service information.

- If resistance is too high, check for an open circuit or a faulty component.
- If resistance is too low, check for a short circuit or faulty component.

Converting Resistance Values

To convert ohms to kilo-ohms (and vice versa) just move the decimal point three places. To convert ohms to megohms (and vice versa) just move the decimal point six places.

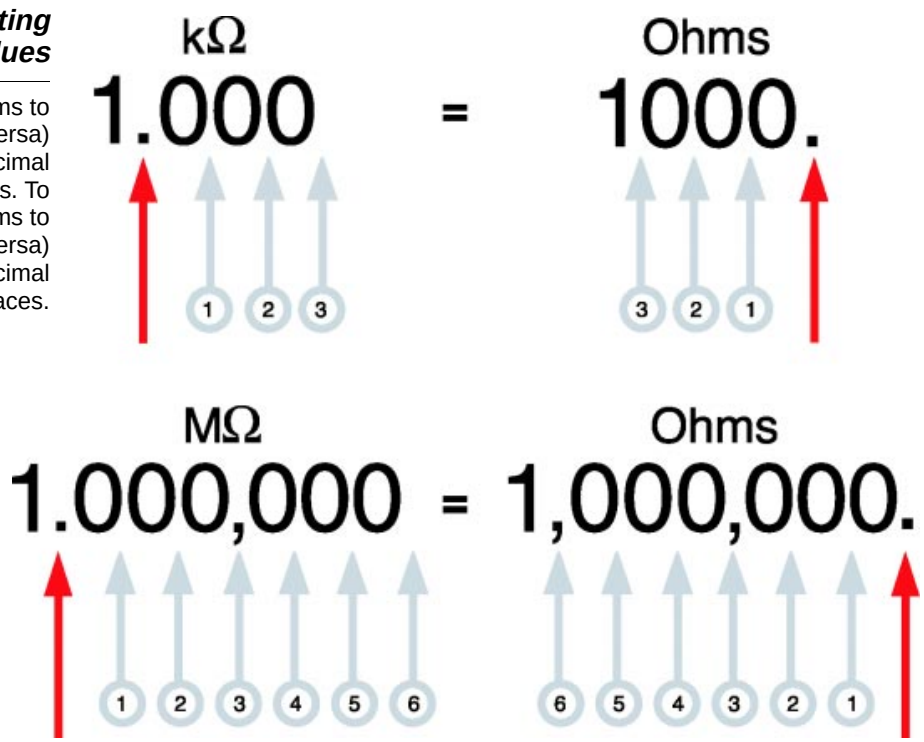


Fig. 1-20
TL623f120c

Converting resistance values - Automotive system resistance values vary from large to small.

Low resistance levels are expressed in ohms. Large resistance values are expressed in kilo-ohms and very large values are expressed in megohms.

- 1 kilo-ohm = 1,000 ohms (1.0 kΩ)
- 1 megohm = 1,000,000 ohms (1.0 MΩ)

Convert ohm readings as follows:

- kilo-ohms to ohms - decimal point moves 3 places to the right.
- ohms to kilo-ohms - decimal point moves 3 places to the left.
- Megohms to ohms - decimal point moves 6 places to the right.
- Ohms to Megohms - decimal point moves 6 places to the left.

Practice - Convert the following resistance values:

2,458 Ω = _____ kΩ

.896 kΩ = _____ Ω

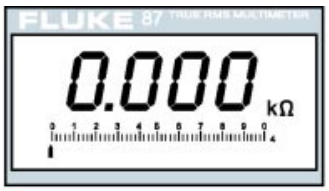
5.87 MΩ = _____ Ω

3,234,000 Ω = _____ MΩ

Common Mistakes

This figure shows similar looking (but very different) values that can easily be mistaken when reading the display.

Display showing over-limit



Display showing zero

Display showing 10 Ohms

Display showing 10 Kilo-ohms

Display showing 10 Megohms

Fig. 1-21
TL623f121

Common mistakes in resistance measuring - There are some common mistakes a technician can make when doing resistance measurements. You can save yourself time and aggravation by avoiding these simple errors:

- Mistaking ZERO OHMS and O.L for over-limit - Take care to note whether the display is showing zero ohms (no resistance) or O.L (resistance higher than selected range or capacity of meter).
- Using the wrong UNITS OF MEASURE - Look for the modifying units on the DMM display. There is a big difference between 10 ohms, 10 kilo-ohms (kΩ), and 10 megohms (MΩ).
- Confusing DECIMAL POINT POSITION - Look for the position of the decimal point. It is important when dealing with large numbers.

Diode Check

To check a diode, use the Diode Check function on the meter and apply both forward and reverse bias.

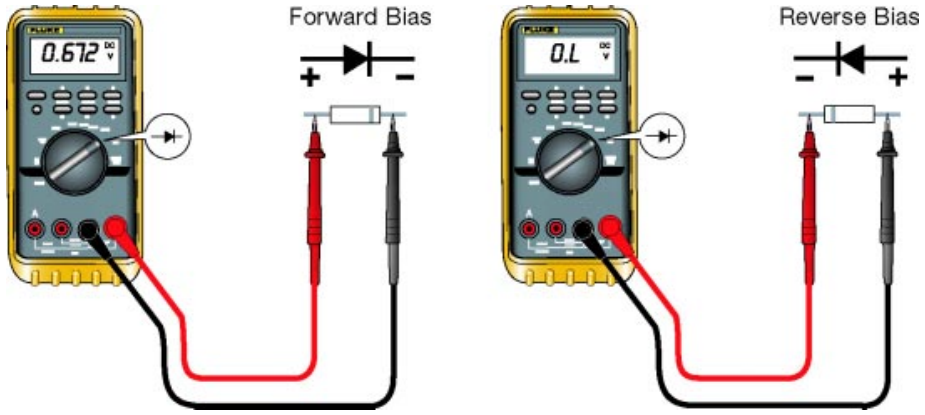


Fig. 1-22
TL623f122c

Diode Check - A diode is like an electronic valve. It allows current to flow in one direction but not in the other.

- The diode conducts current in a circuit when a small voltage is applied in the correct polarity (direction).

Use the diode check function to test a diode with the following steps:

1. Set the DMM mode selector to diode check.
2. Connect the red lead to the anode (the end away from the stripe on the diode).
3. Connect the black test lead to the cathode (end closest to the stripe).
4. Read the DMM display.
   - Forward bias voltage for most diodes in automotive applications is about 0.5 and 0.8 volts.
5. Reverse the test leads to test the diode in reverse bias.
6. The DMM display should show O.L for “over-limit.”

Power

Power is typically calculated, not measured.

Sample Calculation for Power Consumption of Load X:

- Voltage drop across Load X = 12 V
- Current through Load X = 200 mA
- Convert 200 mA to amps (0.2 A)
- Voltage x Current = Power
  12 V x 0.2 A = 2.4 Watts

Fig. 1-23

Power

Definition of power - Power is the amount of work being done by the load in a circuit. Light bulbs are typically rated by voltage and watts.

Equation for power - Power is typically calculated rather than measured. This is the equation for calculating power:

Voltage x Current = Power

Units for power calculations

- Voltage - volts
- Current - amps
- Power - watts

EXAMPLE This example shows the power consumption of Load X:

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- Current through Load X = 200 mA
- Convert 200mA to amps (0.2 A)
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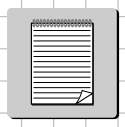

Notes