Resistors control current flow in a circuit and are rated by their resistance value and power rating. Only the resistance value is marked. The resistor’s power rating is determined by its size.

Resistors are identified by four or five colored bands, each of which represents a number value.

In a series circuit, current flows to each component in turn, on one path, with all the electrons flowing at the same rate. Current is the same everywhere. In a series circuit containing resistors, the total resistance is the sum of all of the individual resistances.

In a circuit with three resistors (each of 4 ohms) powered by a 12-volt battery, total resistance is 12 ohms. There is 1 ampere of current flowing through the whole circuit.

The electromotive force or pressure drops from a potential difference of 12 volts (as it leaves the battery) to virtually no difference (no voltage at all) as it returns.

The pressure lost in driving the current through the resistor causes voltage drop.

The voltage drop across each resistor can be found by subtracting the voltage after a resistor from the voltage before it (or the difference can be measured).

Ohm’s law can be used in series circuits to calculate voltage, resistance, and current.

In a series circuit, components are connected like links in a chain. If any link fails, current to all the components is cut off.

In a parallel circuit, all components are connected directly to the voltage supply. If any connection or component fails, current continues to flow through the rest.

Since all components connect directly to the battery terminals, the metal of the vehicle’s body can become one of the conductors. One terminal of the battery and one of each component can be connected anywhere on the body or chassis to complete the circuit. This is called an earth, or ground, connection.

In parallel circuits, the voltage across each component is the same as the battery voltage. No matter how many components are added or removed, the voltage across them (and the battery) will be the same.

The current flowing in each branch is determined by that branch’s resistance. If the resistors are the same, the current flowing in each branch is also the same. The sum of the individual currents equals the total current in the circuit.

When the resistances are not equal, the current divides in accordance with the value of each resistance, but the total current flow is still the sum of the currents flowing in each branch.

Total resistance of a parallel circuit is found by turning all the resistances upside down, making fractions called reciprocals.

Selecting too small a gauge wire for an application will cause voltage drop and poor performance, or, in extreme cases, the cable will get hot enough to melt the insulation. Selecting too large a gauge increases costs and weight.

The resistance of a cable, determined by its length and diameter, affects how much current it can carry. The longer the cable and the smaller the diameter, the higher the resistance. The shorter the cable and the larger the diameter, the lower the resistance.

Manufacturers and standards bodies use cable gauge charts to define how much current each cable gauge can carry safely and effectively. The primary wire gauges are the metric wire gauge and the American wire gauge (AWG).

Sensors are integrated into a common wiring harness by combining all the individual systems, where possible, into a multiplexed serial communications network in which they can share the information.

Fewer connections and less wire mean less chance of dirty connections causing faults. This system is referred to as a controller area network bus (CAN-bus), and it uses two thin wires to connect, or multiplex, all the control units and their sensors to each other. The output devices are referred to as nodes.

Multiplex networks enable a decreased number of dedicated wires for each function, leading to a reduced number of wires in the wiring harness; reduced system cost and weight; and improved reliability, serviceability, and installation.

Common sensor data, such as vehicle speed and engine temperature, are available on the network; thus data can be shared, reducing the number of sensors.
Functions can be added or modified through software changes. Other control units can be added to the system by simply connecting them to the network. A diagnostic tool can be connected to the CAN-bus to assist in diagnosis and fault finding.

Fiber optics are long strands of glass, about the diameter of a human hair. They can be arranged in bundles and are called optical cables. Light signals can be transmitted along the cable over long distances.

Light is transmitted along the cable, bouncing from wall to wall along the way. The inner wall of the optical fiber has a mirror finish, so the light continues to travel along the cable even when it bends around corners.

Optical fiber transmits digital data for computers and lights up dash gauges.

Optical fiber is especially suited to transmit a large amount of digital data reliably. Optical fiber cables could be used to replace copper data bus systems.

Optical fiber is less expensive and thinner than other technology, it can carry much more data than copper cables can, and it has less signal degradation over length and less interference. Light in one fiber does not interfere with light in another fiber. Optical fiber is nonflammable, lightweight, and flexible.

**Schematics**

**READY FOR REVIEW**

- Electrical schematics (diagrams) use abstract graphical symbols to represent and provide information about the components in an electrical circuit, how they link to other components, the wiring and connectors, and where they are located on the vehicle.
- Users must be able to interpret the graphical symbols in the diagrams and to relate them to real-world components and systems on vehicles.
- Manufacturers provide information to help users read schematics.
- Many abbreviations and symbols are standardized, but variations will occur. Grid references are on the actual schematic pages.
- The wire code configuration conveys important information about individual wires.
- Page codes for each electrical schematic are stamped on each wire related to that page, as well as a number from 1 to 99.
- The wire code configuration contains information about the color of the wire.
- Wire colors are usually assigned to particular circuits to help identify each wire in both schematics and on the vehicle. Grid references can identify a particular location or circuit on a schematic.
- Fuses and circuit breakers are shown on schematics.
- Schematics usually contain information about ground locations, which can be identified by the locator next to the component on the schematic.
- The schematic legend provides information to decode the ground locations.
- Modern schematic diagrams contain many complex circuits. Sometimes circuits are continued on other pages.
- When a wire continues to another page, an arrow is drawn at the end of the wire with a description of where the wire continues.
- Connectors and terminal strips are shown on schematic diagrams. Manufacturers label them with codes that can be read in the legends.
- Bus bar connectors are shown in schematic diagrams and are coded so they can be found in the schematics.
- Harness drawing pages provide information on the location of the following:
  - Electrical harnesses run in the vehicle
  - Electrical components
  - Electrical connectors
  - Devices not easily found in the schematics
- Power cable drawings indicate the location and routing of individual cables; often individual part numbers are shown on the schematics.

**Electronic Components**

**READY FOR REVIEW**

- By restricting the direction of movement of charge carriers, a diode allows an electrical current to flow in one direction but blocks it in the opposite direction.
- A semiconductor diode has a single pn junction. If it is connected to a current source, with the p region connected to a negative pole and the n region to a positive pole, the holes will be attracted toward the negative pole and the electrons to the positive pole. This enlarges the depletion layer, stopping current flow across the junction.
If the current source is reversed, lots of holes flow across the junction toward the negative pole, and electrons travel toward the positive pole. The pn junction floods with charge carriers and the depletion layer (along with the insulator effect) disappears.

Using conventional current flow, a diode lets a low-voltage current flow from its p side to its n side, but the diode stops current flowing from its n side to its p side.

A Zener diode is designed to block current flow through it, but if the voltage of the current source is large enough, it can force current to flow through the diode without damage. This is called breakdown.

Because Zener diodes respond to certain voltage changes like switches, they are used in voltage regulators.

Light-emitting diodes (LEDs), emit light when they are connected in a forward direction.

Resistors are electrical components that resist a current running through them.

Putting a resistor in a circuit causes a drop in voltage across the resistor. Resistors are used to control the voltage that reaches various components.

Each electrical component also has a resistance of its own.

Most resistors that can carry large currents contain a coil of high-resistance wire wound around a ceramic former to dissipate heat.

Resistance is measured in ohms; thus resistors are rated in ohms, indicating how strongly they will oppose any current flowing through them.

Because resistors work by converting some of the electrical energy passing through them into heat, they have a wattage rating.

Some types of resistors include fixed resistors, variable resistors, thermistors, and metal oxide varistors.

The three types of variable resistors are rheostats, potentiometers, and thermistors. Variable resistors can be linear (resistance value varies proportionally with movement or temperature change) or nonlinear (resistance change is not proportional with movement).

A rheostat is a mechanical variable resistor with two connections. Rheostats alter the current flow in a circuit.

Potentiometers are mechanical variable resistors with three connections: two fixed and one moveable. They act as voltage dividers, altering the voltage in a circuit.

Thermistors are conductors whose resistance value is affected by temperature. There are two types: negative temperature coefficient thermistors (NTC) and positive temperature coefficient thermistors (PTC).

Thermistors are semiconductor resistors whose electrical resistance varies according to temperature.

NTC resistors have lower resistance at high temperatures and therefore conduct current more readily when they are hot.

PTC resistors have higher resistance at high temperature and therefore conduct current less readily when they are hot, making them useful as current-limiting protective devices in circuits, instead of fuses.

Transistors are semiconductor devices used as switches and to amplify currents.

There are two kinds of transistors: npn and pnp. The npn transistor has a p-type semiconductor between two n-type semiconductors. A pnp transistor has an n-type between two p-types.

In a circuit, npn transistors can act as a switch. If the control switch is open, the depletion layer at one pn junction is blocking current from flowing through the transistor and driving the load.

If the control switch is closed, a small current flows through the emitter-base pn junction. Extra charge carriers flow across the emitter-collector pn junction, letting current operate the load. The transistor is then said to be turned on.