A14 - BASIC ELECTRONICS FOR FIELD MEASUREMENT

Written by Dale Gary Edited by Geoff Shiblom

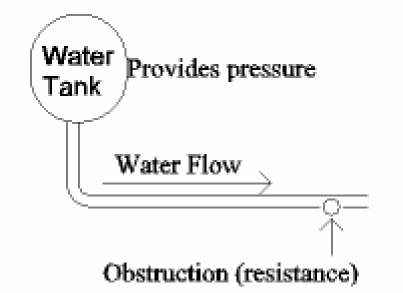
ABB, Totalflow Products
7051 Industrial Boulevard, Bartlesville, Oklahoma 74006

INTRODUCTION

This paper is written with the idea of presenting basic electronic principles and how to apply these to common applications in the oil and gas industry.

Basics

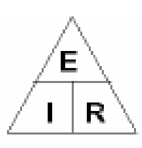
The three basic laws we will discuss are Ohm's law, Kirchhoff's voltage law, and Kirchhoff's current law. The main terms used are voltage (units are Volts), current (units are Amps or milliamps), and resistance (units are ohms). These terms by themselves are meaningless unless a relationship can be established. An analogy that we can use to visualize the relationship between voltage, current and resistance is water flowing through a pipe. In the water analogy, pressure that pushes the water would correspond to voltage. The water flowing through the pipe would correspond to current. Any obstruction in the pipe restricting the flow would correspond to resistance.



This relationship could be expressed mathematically as the flow (current) is equal to the pressure (Volts) divided by the resistance to flow (ohms). This is Ohm's law.

Ohm's Law

Ohms law may be expressed as follows. The triangle is a good way to remember the relationship without memorizing any formulas.

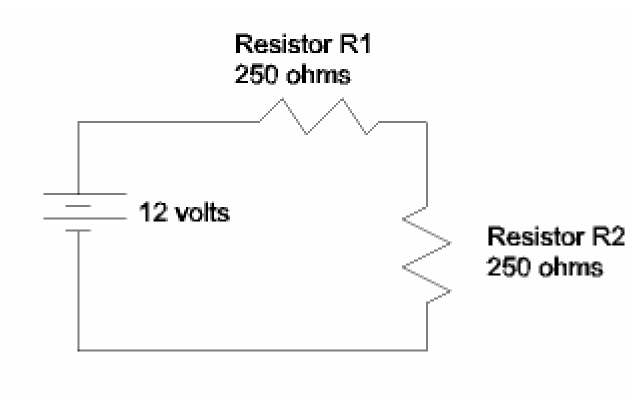


E = I * R	E = Voltage (volts)
I = E / R	I = Current (amps)
R = E / I	R = Resistance (ohms)

Voltage equals the current times the resistance. Current equals the voltage divided by the resistance and resistance equals to the voltage divided by the current. One of the important things to remember is the relationship between current and resistance. It is an **inverse** relationship. What this means is as resistance goes up the current goes down.

Kirchhoff's Voltage Law

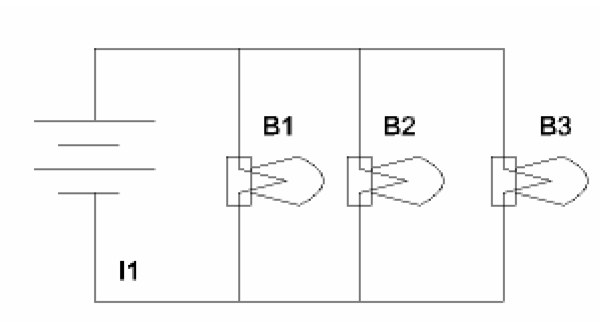
Kirchhoff's voltage law says, **The sum of all the voltage drops equals the source voltage** This law is important for what it implies as much as what it says. What it implies is that when you have resistive elements that are in line with each other, their values can be added together to obtain the total resistance of a circuit. Another thing to note is that the current is the same anywhere you check in a series circuit. See the following example.



The resistance “seen” by the 12-Volt battery is 500 ohms . The total resistance is the sum of the resistors R1 and R2. Each resistor will drop a calculable amount of voltage. This voltage is given by Ohm's Law. The way to calculate this is to figure the amount of current going through the whole circuit. To calculate the current we divide 12 Volts by the resistance (500 ohms). 12/500= .024 Amps or 24 milli-amps. The voltage drop across one resistor can be calculated by the equation -
E (voltage) = I (current) * R (resistance)
or .024 amps * 250 ohms. This equals 6 Volts. So the voltage drop across R1 (6 Volts) + the voltage drop across R2 (6 Volts) equals 12 Volts or the source voltage according to Kirchhoff’s Law!

Kirchhoff's Current Law

Kirchhoffs current law states that **currents in parallel are additive**. An example would be the light bulbs in your house. The voltage across each light bulb is the same. The current supplied by the source is the sum of the current through each light bulb.



Light bulbs in Parallel

So the sums of currents B1 + B2 + B3 give us I1.

PRACTICAL APPLICATIONS

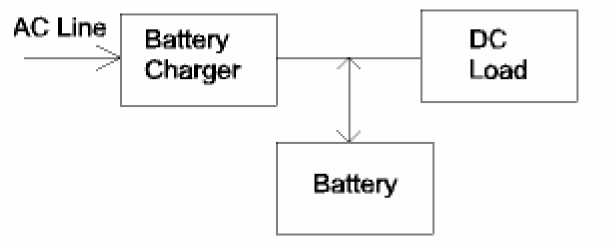
Power Sources

Batteries

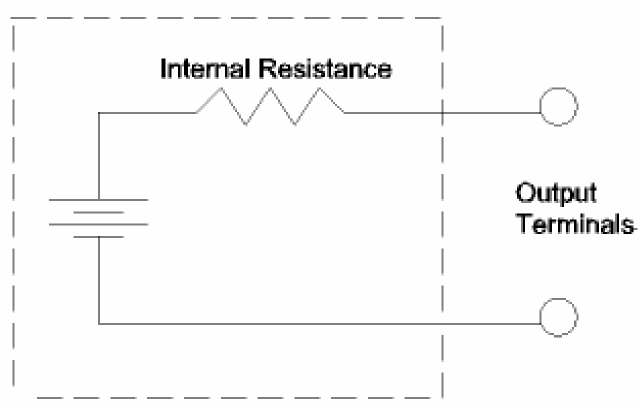
Lets look at a battery in terms of the laws above. The most common battery is the wet cell. This is what is used in your car. What is used in equipment out in the field is generally a lead acid gel cell. This is a battery where the water and acid mixture has been replaced by an acid paste or gel. Each battery is made up of individual cells (the name comes from a battery of cells). These cells are wired in series. The voltages of these individual cells are added together give the output voltage of the battery. Individual lead acid cells have a nominal output voltage of 2.1 Volts. So a 12-Volt battery will have six cells and an output voltage of 12.6 Volts.

The capacity of a battery is rated in discharge current for a specific period of time. As an example a typical battery might be rated at 8 amp hours. This means that this battery should be able to deliver one amp for 8 hours. The battery can supply more current for less time or less current for a longer time. The ratings for lead-acid batteries are usually specified for a temperature of 77 to 80 degrees F. A temperature outside of this range effects battery life and capacity. Higher temperatures reduce internal resistance (an effect we will discuss later). Too high of a temperature (generally above 110 degrees) will reduce battery life. Low temperatures reduce the voltage and capacity. The amp-hour capacity is reduced by .75% for each degree F below the rated temperature. This means that at 0 degrees F only 60% of your batteries capacity is available. In colder climates people sometimes will turn their lights on for a few minutes before starting their car, discharging some current warms the battery up and returns some of the lost capacity due to low temperature.

Lead acid batteries are the most forgiving for charging. The type of charging system most commonly used is called Float Charging. This means the charger, battery, and loads are tied together and the voltage floats. The cars charging system is of this type. To charge a battery, a voltage source larger than the battery must be connected. The polarity must match. This means connect the positive to positive and negative to negative. How much voltage to use for the charging voltage is determined by the number of cells in the battery. The charging source should put out approx. 2.5 Volts per cell. This means on a 12 Volt battery (6 cells) the charging voltage should be 6 cells * 2.5 Volts or approximately 15 Volts.

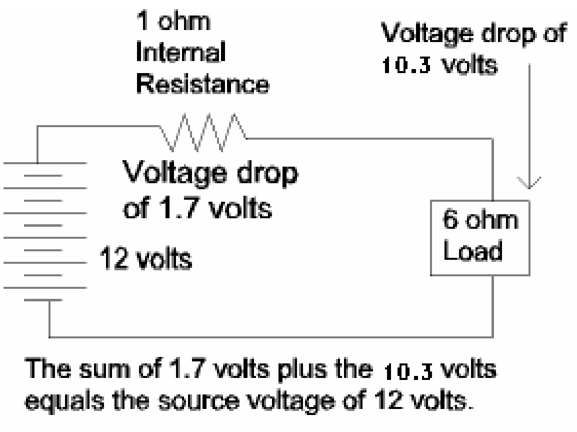


All devices that produce voltage have what is called internal resistance. This means that all of the current expected is not delivered to the load. This also means there is a corresponding voltage drop inside the battery.



Let’s put some easy numbers together to see what this really means. In a battery of 12 Volts with an internal resistance of 1 ohm and a load of 6 ohms the current expected at the load would be 2 amps. The **actual** current is 12-Volts / 7 Ohms equals 1.7 Amps. Also (remember the voltage law) the source voltage is equal to all the voltage drops around the circuit. The current 1.7 amps multiplied by the internal resistance of 1 ohm drops 1.7 Volts. The voltage delivered to the load is now 12 Volts (source) minus internal resistance voltage drop of 1.7

Volts equals 10.3 Volts. This could be a problem for a device that requires 12 Volts at 2 amps.

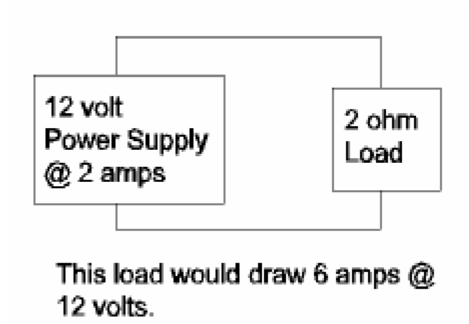


This is a real world occurrence. As batteries age (the electrolyte gets weak, corrosion on the plates, etc.) the internal resistance becomes larger. This is why a battery can read charged with a voltmeter but sometimes won't run the equipment. For example; a car battery reads 13 Volts with a voltmeter but won't start a car. If you place a voltmeter on the battery while trying to start the car, you will see the voltage drop dramatically but return to 13 Volts when the load is removed. Suspect batteries should always be tested under load.

Power supplies

Power supplies have some of the same characteristics as batteries but for different reasons. Power supplies have some internal resistance by how the circuitry is designed. As components age this internal resistance can increase, decreasing the amount of current it can deliver. All power supplies have rated capacities. This is usually expressed as a rated voltage at a given current (i.e. 12 Volts at 6 Amps.) Also power supplies have different regulation ratings. It is common to get a 12 Volt power supply that when read with a voltmeter shows higher output. As the load current approaches the rated output of the supply, the voltage output will drop to the rated voltage. Most equipment you encounter should have an internal regulator that drops the voltage supplied by the power supply to what it needs to operate.

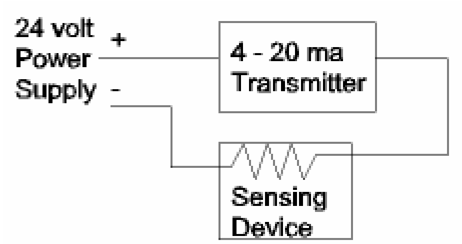
So what happens when the load exceeds the ratings of the power supply? This will depend on the power supply. The cheaper supplies will have a fuse that blows. Better power supplies will have over current protection circuits that produce an effect called fold over. The voltage will drop to a safe level (for the power supply). When the excess load is removed the supply returns to its original voltage levels.



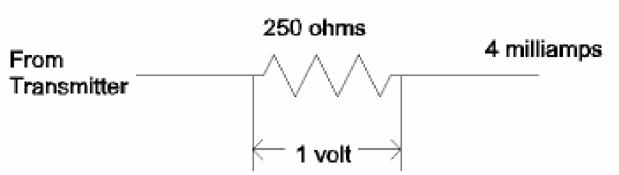
This would create an over current condition that would cause the power supply fold over. Probably the supply voltage would drop to less than a Volt.

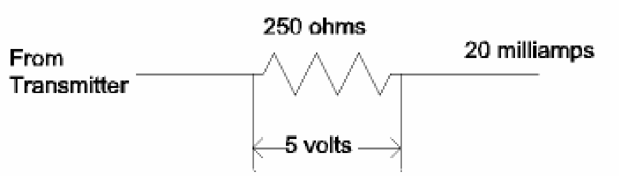
MILLIAMP LOOPS OR MIL LOOPS

A series circuit can provide a means of transferring information to multiple receivers. This method uses the principle that the current is the same everywhere in a series circuit. This method of transferring information is called a current loop and is commonly implemented as a 4 to 20 milliamp loop. A transmitter will supply a current that can be sensed by other devices. This system has the advantage of providing a common method of transferring information between devices independent of supply voltages and loads. This last statement will require some clarification. The instrument will have power requirements that will include a supply voltage. The most common is 24 Volts but 12 Volts is not uncommon.

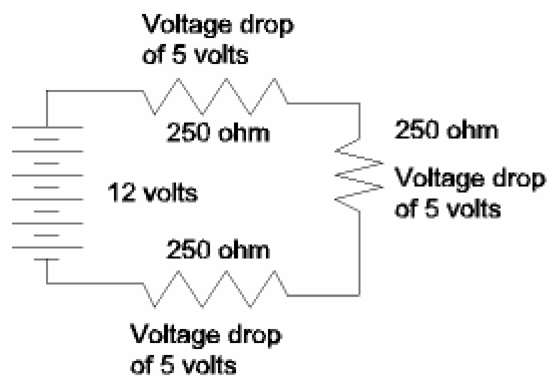


The supply voltage will determine the number of loads. A brief explanation is in order here. The most common load is 250 ohms. The reason is most receivers actually read the information as 1 to 5 Volts. This works by a method that can be explained by ohms law. The formula we are interested in here is E (Volts) = I (current) * R (resistance). The current 4 milliamps (.004 Amps) * 250 ohms equals 1 Volt. The top end of 20 milliamps (.020 Amps) * 250 ohms equals 5 Volts.

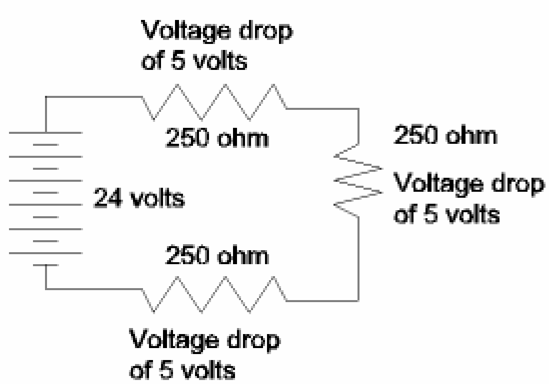




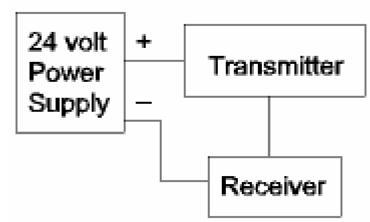
The question would be raised here of what does that have to do with the supply voltage. Remember Kirchhoff's voltage law. It states that the sum of the voltage drops around a series circuit must equal the supply voltage. This becomes very important in this application. This sample application will use 12 Volts as the supply and three loads of 250 ohms each.



The loads drop 5 Volts each. Three loads times 250 ohms would equal 15 Volts. This exceeds the supply voltage. Clearly this application would not work. The application using 24 Volts as the supply voltage would work since 24 Volts – 15 Volts equals 9 Volts left.



This is a quick rule of thumb. The actual loads would include the power (i.e. voltage drop) of the transmitter and the resistance of the wire. This assumes a two-wire transmitter. The resistance of the wire can be calculated from the manufacture data sheet, a table from a National Electrical code book, or just read with an ohmmeter. If calculated from a data sheet or table, remember to multiply this resistance by two. This is because of the two legs (out to and back from the transmitter).



Ensure the distance of both legs is used.

Always remember to read the data sheets for the receiver. The most common load is 250 ohms however this isn't the only load size. There are receivers that have fractional loads. It is possible that the receiver could require the input to be scaled to something other that 1 to 5 Volts.

DIGITAL INPUTS AND OUTPUTS

Very common in the oil and gas industry is the use of digital signaling to indicate an alarm condition as well as for control of equipment. Digital control is normally accomplished by one of the following methods.

Mechanical contact switching is common in large-scale equipment where there is plenty of power to activate a mechanical switch by motor operated cam or by energizing a coil on a relay. For signaling or control, the making or breaking of a mechanical switch interrupts one leg of a circuit supplying power to a device. Testing a circuit like this is simply a matter of measuring the resistance across the switch during activation when the load and power source are disconnected. A normally open switch will show infinite resistance before activation and low resistance after activation. A normally closed switch will be just the opposite and break contact on activation.

Mechanical switches can switch a large variety of loads. Mechanical "dry contact" switches exhibit a phenomenon called switch bounce. This is a situation where the mechanical contacts make multiple connections for each opening and closing operation. This may not be a concern in some applications like turning on lights or resistance heaters.

Transistor control is very common in today's low power computer controlled equipment. This type of control uses a solid state device to switch a small amount of current. This is ideal for connecting to other computer equipment but may not be sufficient for directly controlling a pump or motor. In this case, transistor control can be use activate mechanical switches (relays) or other solid state devices.

A technician cannot rely on being able to use a multi-meter measuring resistance to test the cycling of a transistor digital output. Transistors require power on their load side to operate. The best way to test a transistor circuit is to apply a voltage to the circuit and measure the voltage as the circuit is switched on and off. An ammeter may be used also to measure current flow as the circuit is switched.

Digital input circuits can either accept contact closures, dry contact (mechanical switches) or they may require a voltage to be applied. It is important to know what your equipment requires when working with a control or monitoring system. Many devices today can accept both types of inputs, however wiring requirements may be different. There are even single devices that can be wired either as digital inputs or outputs.

Switch bounce is a concern when connecting a mechanical switch to a digital input. For signaling, multiple contacts may indicate multiple events. This is of particular concern if you are trying to count the pulses from a device for measurement. Software or hardware designs must take switch bounce into account. There are schemes of hardware filtering and software filtering. Each of these methods will reduce the maximum frequency input of the system. Some computer-controlled devices have an option built in that will enable or disable software filtering for switch bounce. This is many times called a "de-bounce" feature.

CONCLUSION

This paper is a very fast and not very deep presentation of the electronics used in the oil field. If a person were interested, courses in dc electronics and general instrumentation would cover this same material. These courses could be found at most junior colleges.

REFERENCES

Grob, Bernard 1986. DIRECT AND ALTERNATING CURRENT CIRCUITS. McGraw-Hill Book Company