Basic Electronics for the Field Technician
Class # 3060

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Introduction

Electronics is the branch of physics, science, engineering, and technology dealing with electrical circuits that are controlled by electrical means rather than mechanical means. The main purpose of electronics is the processing and communication of information and signals. Vacuum tubes were one of the earliest electronic components when electronics technology was known only as radio technology due to the primary application. Today, electronics is driven by micro-sized devices such as transistors and diodes to form the integrated circuit. In comparison, about 400 X 10^{17} transistors could fit into the space occupied by a single original vacuum tube. The microscopic size of electronic components make today's complex and powerful devices handheld realities. Device size is now limited by power and input/output interfaces rather than logic and computational electronics.

As electronics are in almost every currently manufactured electrical device, electronics are certainly a critical element of measurement devices and systems. As technology changes at an ever increasing rate, the need for a technician to understand electronics also rapidly increases with time. Regardless of the size and application of electronics all electronic components are electrical devices and operate according to the basic laws of electricity discovered long ago. This paper briefly discusses electrical safety, some electronic basics, and how electronics is applied to the field of hydrocarbon measurement.

Electrical Safety

Safety first! Working with electricity is extremely dangerous when the proper precautions are not taken. "Every day in America, 12 people go to work and never come home. Every year in America, 3.3 million people suffer a workplace injury from which they may never recover. These are preventable tragedies that disable our workers, devastate our families, and damage our economy.", stated Secretary of Labor Hilda Solis on Apr 28, 2011.[1]

Over a four year period, worker contact with electric current in some shape or form was responsible for 1,213 fatal workplace accidents and, 13,150 workers were so severely injured from these electrical contacts that their injuries required time off from work. While contact with overhead power lines is the leading categroy of electrical fatality, the second leading category is coming into contact with wiring, transformers, or other electrical components, which is the type of accident that occurs more often to an electrical worker. The third leading category of electrical fatalities involves workers coming into contact with electric current from machines, tools, appliances, light fixtures, etc.[2]

Because electricity has long been recognized and proven to be a serious workplace hazard, standards, such as OSHA and NFPA standards, exist to protect those exposed to dangers such as electrical shock, electrocution, fires, and explosions. For example, OSHA 29 CFR 1910 Subpart S addresses electrical safety requirements that are necessary for the practical safeguarding of employees in their workplaces. NFPA 70 is the National Electric Code that defines requirements for practical safeguarding of persons and property from hazards arising from the use of electricity. NFPA 70E is the Standard for Electrical Safety in the Workplace that defines requirements related to provision of a safe working area for employees relative to the hazards arising from the use of electricity. NFPA 70E details requirements for labeling and minimum boundaries of electrical equipment, personal protective equipment when working on energized equipment, etc.

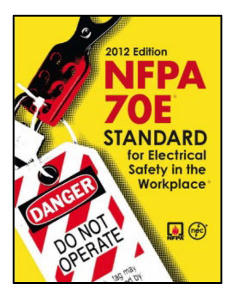

Figure 1. NFPA 70E

Whenever possible, work on electrical equipment in a de-energized state and perform a lockout/tagout according to company or site procedure to help guarantee your safety. Verify absence of electrical energy by first verifying your voltage meter is able to detect voltage at a known source, then using the meter to verify absence at the equipment on which work will be performed. Working with energized parts should only be done when absolutely necessary and requires both the appropriate personal protective equipment and the appropriate training.

Figure 2. Arc Flash

Electricity, in all voltages, must be respected! Ventricular fibrillation, which is uncoordinated heart muscle contraction and can cause death, can occur at any voltage at a current as low as 50 mA (0.05 A) and will occur from 100 to 200 mA (0.1 to 0.2 A). Above 200 mA (0.2 A), muscular contractions can become severe enough that chest muscles clamp and stop the heart for the duration of the shock.[3]

Electrical Laws

The fundamentals of electricity and electronics are found in some basic electrical laws. The law of the conservation of energy states that energy, including electrical energy, cannot be created or destroyed. As energy can be transformed from one type to another, electrical energy can be generated from other forms of energy and forced to move in certain paths or circuits to transmit power. For example, a generator such as a windmill converts mechanical energy into electrical energy. Ohm's Law, Joule's Power Law, and Kirchhoff's Circuit Laws are some of the laws that govern the flow or transmission of electrical energy and aid in basic linear circuit analysis.

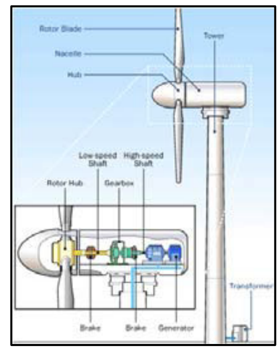

Figure 3. Windmill Generator

Ohm's Law

George Ohm, a German physicist, published a description of measuring applied voltage and current through simple electric circuits along with experimental results in 1827. He presented a slightly more complex equation than the current version of Ohm's Law to explain or model his experimental results.[4] A voltage is required to force a current through a circuit against the resistance caused by elements and conductor materials. Ohm's law defines the mathematical relationship between voltage, current, and resistance and is stated as $\mathbf{V} = \mathbf{I} \times \mathbf{R}$, where V is voltage (volts), I is current (amps), and R is resistance (ohms). Ohm's law is also often expressed as $\mathbf{E} = \mathbf{I} \times \mathbf{R}$, because electromotive force (E) is a synonym for voltage.

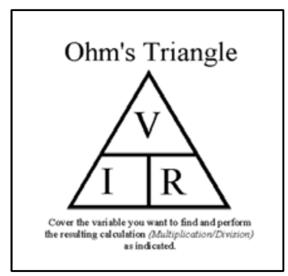

Figure 4. Ohm's Triangle

Ohm's law is merely a restatement in electrical terms of the general law that applies to all physical phenomena. The result is directly proportional to the effort or cause and inversely proportional to the opposition. In this case, current is the result, voltage id the cause, and resistance is the opposition.

Figure 4 is the Ohm's Law Triangle that is often used as a visual representation of the mathematical relationship. One would cover the sought value and perform the remaining visual operation. Figure 5 is an example simple circuit with which Ohm's law can be applied to solve for loop current.

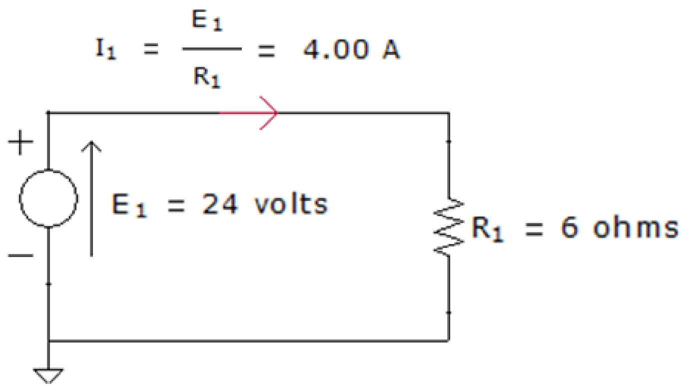

Figure 5. Ohm's Law Example

Joule's Power Law

James Prescott Joule (1818-1889) was an English physicist and brewer. As a manager of the family brewery, he scientifically explored the feasibility of replacing the steam engines with the recently invented electric motor. In his comparison, Joule developed a common standard of economical duty defined as the ability to raise one pound by a height of one foot, termed the foot-pound. He later speculated about the convertibility of energy and focused on the nature of heat and discovered its relationship to mechanical work, which led to the theory of the conservation of energy which electrical laws are based.[5]

Joule's first law states that the power dissipated in a resistive component can be expressed in terms of current through and resistance of the component. This law is expressed as $\mathbf{P} = \mathbf{I}^2 \times \mathbf{R}$, where P is power (watts), I is current (amps), and R is resistance (ohms). Algebraically combining Joule's Law $\mathbf{P} = \mathbf{I}^2 \times \mathbf{R}$ and Ohm's Law $\mathbf{V} = \mathbf{I} \times \mathbf{R}$ yields the generally more applicable Power Law $\mathbf{P} = \mathbf{I} \times \mathbf{V}$ or $\mathbf{P} = \mathbf{I} \times \mathbf{E}$

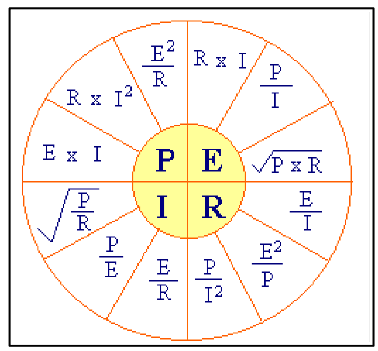

Figure 6. Ohm's & Power Law Wheel

Electric Circuit Analogy

Because electrical parameters are not visible, the electrical parameters within a circuit are often conceptually compared to the mechanical parameters of a liquid piping system. Table 1 lists analogous parameters for these two types of systems.

Table 1. Analogy of Liquid Piping System & Electric Circuit

Liquid Piping System	Linear Electric Circuit
Horsepower	Watts
Pressure	Voltage
Flow	Current
Obstruction (Valve, Blockage)	Resistor
Pipe Friction	Wire Resistance
Differential Pressure Gauge	Voltage Meter
Flow Meter	Ammeter

Figure 7 illustrates the similarities between systems and governing laws.

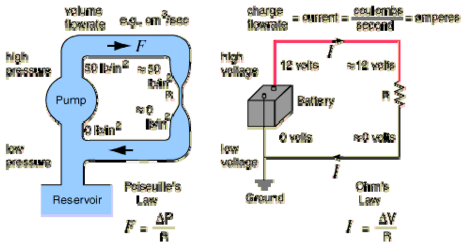

Figure 7. Fluid System & Electric Circuit Analogy

<u>Circuit Analysis: Kirchhoff's Current Law</u>

Gustav Robert Kirchhoff (1824 – 1887) was a German physicist who defined several laws of electrical circuits, spectroscopy, and thermochemistry. While a 21 year old student, Kirchhoff formulated his circuit laws as part of a seminar exercise, which later became his doctoral dissertation.[6] These circuit laws are the foundation of circuit analysis.

Kirchhoff's Current Law (KCL) is his first circuit law and is based on the conservation of electric charge. The Current Law states that at any node (junction) in a circuit, the sum of the currents flowing into the node is equal to the sum of the currents flowing out of that node. In other words, because a node does not generate or absorb energy, what goes in must come out. Nodal analysis is circuit analysis that examines a single junction in a circuit using calculations based on Kirchhoff's Current Law.

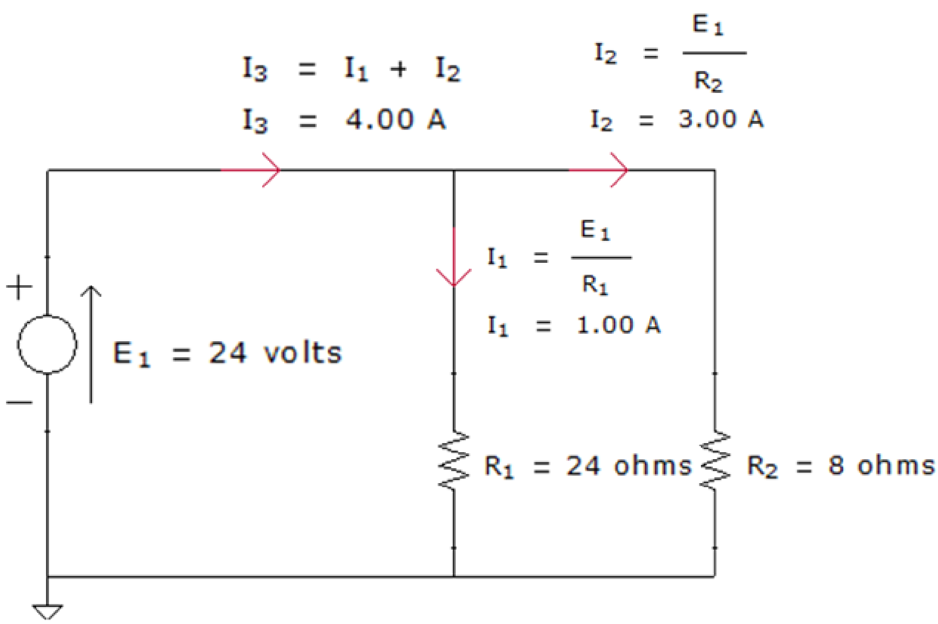

Figure 8. Nodal Analysis – Summing of Currents

<u>Circuit Analysis: Kirchhoff's Voltage Law</u>

Kirchhoff's Voltage Law (KVL) is his second circuit law and is also based on the conservation of energy. The Voltage Law states that the sum of the electrical potential differences (voltages) around any closed circuit is zero. In other words, the sum of the voltage sources in a closed loop system is equal to the sum of the voltage drops in the same system. Loop or mesh analysis is circuit analysis that examines a single loop in a circuit using calculations based on Kirchhoff's Voltage Law.

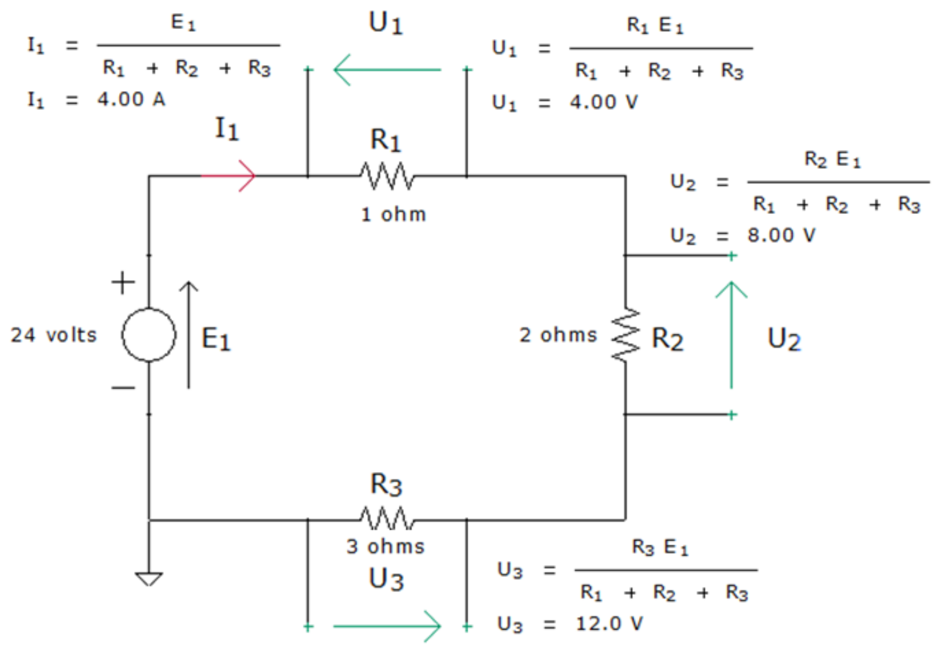

Figure 9. Loop or Mesh Analysis - Summing of Voltages

Basic Electronics

Electrical technology has the general purpose of generation, distribution, switching, storage, and conversion of electrical energy using devices such as motors, generators, batteries, transformers, switches, relays, resistors, and capacitors. Electronics technology has the general purpose of information and signal processing using electrical components such as vacuum tubes, transistors, diodes, inductors, and capacitors. All electronic devices are electrical (use or produce electric energy) and operate according to the same electrical laws; however, the flow of electricity in electronic devices is controlled by electrical means rather than mechanical means. Electronics technology was termed radio technology until 1950 because the primary development and usage focused on the design and theory of radio transmitters, receivers, and vacuum tubes.[7]

Electronic devices include electronic circuits to achieve a specific function, such as amplifier, radio receiver, or oscillator, that are connected together (usually on a printed circuit board) to achieve the overall device function, such as process and transmit a temperature input. Electronic components are often classified as active (e.g. transistors) or passive (e.g. resistors and capacitors) and can be packaged individually or as integrated circuits.

Electronic circuits can be analog or digital. Analog, derived from the Greek word analogos meaning proportional, is a circuit type that has a continuously variable signal. Electronic signals are communicated by changing voltage, current, frequency, or total charge. For example, AM radio transmits signal by varying or modulating voltage amplitude while FM radio transmits signal by varying or modulating frequency. Digital circuits represent signal by discrete bands rather than by a continuous analog range. Because all signals within an analog band represent the same digital signal, digital signals are less susceptible to noise or attenuation.

Digital signals have states 0 (reference voltage) and 1 (supply voltage) controlled by logic gates (arrangement of electrically controlled switches known as transistors), so communicating signals more complex than two “off/on” states, such as an analog process signal) requires pulsing the digital signal and/or combining several digital signals into a digital circuit. A series of numerical values can be used to represent a continuously varying quantity. For example, Table 2 illustrates how 3 digital signals (bits in computer language) can be used in combination to represent 8 (2^3) discrete values. Therefore, 16 individual signals or bits could be used to represent 65536 (2^{16})

different values. A 16-bit temperature device ranged from 0 to 150 deg F would have a resolution of 0.0023 deg F (150 deg F span / 65536).

Table 2. Digital Signal Representation

Input Signal A	Input Signal B	Input Signal C	Output Value
0	0	0	**0**
0	0	1	**1**
0	1	0	**2**
0	1	1	**3**
1	0	0	**4**
1	0	1	**5**
1	1	0	**6**
1	1	1	**7**

Electronics in Measurement

In hydrocarbon measurement, electronics are primarily utilized to process and communicate signals for the purpose of volume determination. Electronic devices include flow meter pickup coils, flow meter frequency signal amplifiers, secondary process transmitters (temperature, pressure, density, etc), logic controllers, and flow computers.

Pickup Coils in Metering

In rotary meters, fluid flowing through the meter causes meter rotation and a pickup coil can be used to detect the rotational speed, which is proportional to flow rate. For example, a rotary meter can be equipped with a gear and a pickup coil can be utilized to count the gear teeth as they pass the coil. Pickup coils operate on the principle of electromagnetic induction. As a metallic object, such as a gear tooth, is placed in proximity of a pickup coil, the magnetic field of the permanent magnet inside the coil changes, which induces an electric current in the coil of wire wrapped around the magnet. During rotation of a gear, the coil produces an electric sine wave signal that has the same frequency as the gear teeth frequency (i.e. each gear tooth produces one cycle).

Pre-Amplifiers in Metering

One of the main and most important electronic functions is the amplification of a weak signal. Often, a signal from a pickup coil may be too weak to transmit back to a pulse counter or flow computer. Ideally, a metering signal should also be converted from the sine wave output of a pickup coil to a square wave as close as possible to the flow meter to reduce the effects of signal noise and interference.

In amplifiers, the signal to be amplified is fed into a transistor, a 3-terminal semiconductor device in which one terminal is utilized to control the voltage or current between the other two. With a transistor, a small change in one signal generates a very large change in the output signal. In metering, an amplifier supply voltage can be alternated proportionally with the alternating low voltage produced by a meter pickup coil.

Because the purpose of meter signals is to transmit cycles at a frequency proportional to volume, a square waveform provides less error than a sine waveform. Converting from a sine to a square waveform can be done with rectification, which producing a pulsating DC current from a sine wave AC current. A rectifier utilizes diodes, which are check valve type electronic devices that let current pass only from high potential to low potential. Half-wave rectifiers eliminate the lower half of a sine wave using a single diode as shown in Figure 10 and full-wave rectifiers “flip” the lower half of a sine wave using s combination of diodes and connections as shown in Figure 11.

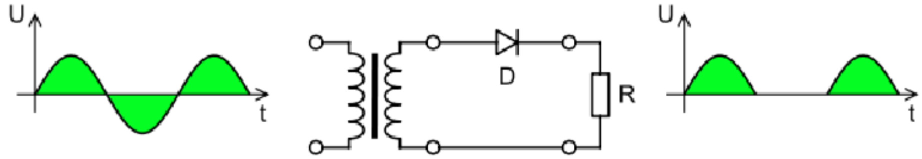

Figure 10. Half-Wave Rectification Using a Diode (Electronic Check Valve)

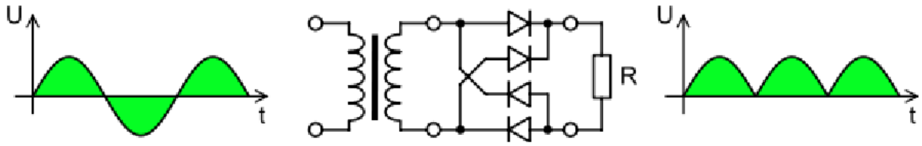

Figure 11. Full-Wave Rectification Using 4 Diodes - Graetz Bridge Rectifier

Electronic filters are electronic devices that can limit or block passage of current when voltage potential is outside a given range. High-pass filters allow current flow above a threshold voltage and low-pass filters allow current flow below a threshold voltage. Electronic filters can be utilized to further smooth the rectified AC waveform into a smooth square wave. Figure 12 demonstrates the parts of the sine waveform that can be limited above a threshold voltage and eliminated below a threshold voltage to produce a more distinct square waveform.

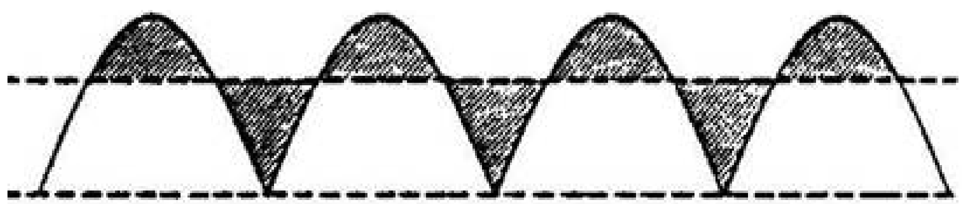

Figure 12. Limiting high amplitude and eliminating low amplitude can convert a sine wave to a square wave.

Process Transmitters

Process transmitters, such as temperature, pressure, and density transmitters, are devices that can measure an input signal, process (convert, amplify, and condition) the signal, and transmit an output signal that represents the measured process condition.

Inspection, verification, and calibration of these devices by the field technician are critical to accurate measurement. Input sensors vary depending on the process condition being measured. For example, temperature transmitter input sensors can be thermocouples that produce a mV signal or resistive thermistor devices (RTD's) that produce an ohm signal. RTD temperature sensors are typically used in measurement applications due to higher accuracy. The temperature corresponding to the resistance of the RTD is a characteristic of the RTD material and reference resistance value. For example, 100-ohm platinum RTD's will measure 100 ohms at 0 deg C and increase 0.385 ohms for every 1.0 deg C increase in temperature.

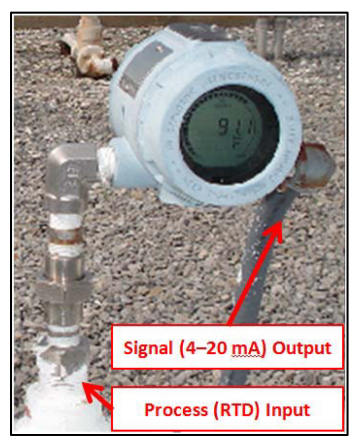

Figure 13. Temperature Transmitter

An analog to digital (A/D) converter measures and converts the analog input signal to a digital value. Figure 13 shows a temperature transmitter displaying a digital value of 91.1 deg F. Transmitter output can be communicated digitally (e.g. modbus serial communication) or in analog form (e.g. 4-20 mA). With analog outputs, a digital to analog (D/A) converter converts the digital value to an analog output signal. From a verification and calibration perspective, it is important that a technician understands the transmitter is made up of both A/D and D/A conversions, both of which requires verification and calibration to ensure a Accurately represented process signal in the calculating device such as a flow computer.

For a measured process condition to be represented accurately at the supervisory or calculating device, the process range must match at both the transmitter and the supervisory device. For example, if a transmitter is configured with a range of 0 – 150 deg F and the supervisory device is mistakenly configured with a range of 0 – 200 deg F, the supervisory equipment will interpret 100 deg F when the process temperature is 75 deg F. This occurs because the supervisory equipment is utilizing a proportion of transmitter output signal to interpret the process condition.

For troubleshooting, a technician must be able to readily understand and calculate conversions between digital process values and electronic process signals. To perform these conversions, the ranges of both the process parameter and the electronic signal must be known. A range is specified as *Lower Engineering Unit (EU)* to *Upper Engineering Unit*. A span is the difference between the Upper EU and the Lower EU. For a 25 to 125 deg F temperature range, 25 deg F is the Lower EU, 125 deg F is the Upper EU, and 100 deg F is the span. The most error-proof way to convert between process signal types (e.g. from digital temperature value to 4-20 mA electronic value) is to first convert from the given value and range to proportion of span, then convert from proportion of span to the desired value within the given range. Figure 14 provides a formula for calculating proportion of span given a reading and range and an example given a reading of 80 deg F and a range of 25 to 125 deg F

$$\text{ProportionOfSpan} = \frac{\text{Reading} - \text{LowerEU}}{\text{Span}} \qquad \frac{80\text{ degF} - 25\text{ degF}}{100\text{ degF}} = 0.55$$

Figure 14. Converting from Reading to Proportion of Span

Figure 15 provides a formula for calculating a reading given a range and a proportion of span and an example given a proportion of span of 0.55 (55%) and a range of 4 to 20 mA.

$$\text{Reading} = (\text{ProprtionOfSpan} \times \text{Span}) + \text{LowerEU} \qquad (0.55 \times 16\text{ mA}) + 4\text{ mA} = 12.8\text{ mA}$$

Figure 15. Converting from Proportion of Span to Reading

Therefore, a temperature transmitter with a range of 25 – 125 deg F should have an output of 12.8 mA at a process temperature of 80.0 deg F. The same conversion methodology works for any linearly proportional signal conversion among ranges of different units (e.g. viscosity to mA, mA to pressure, etc).

Technicians can also quickly diagnose incorrect readings as either likely configuration errors or calibration errors according to the magnitude of the error. A large error is likely due to non-identically configured ranges on both ends of a process signal while a small error is likely a calibration error. A calibration error can exist in the A/D converter in the transmitter, the D/A converter in the transmitter, or at the A/D converter in the supervisory or computation equipment. With smart transmitters, a transmitter communicator, such as a HART protocol communicator, will facilitate reading of the digital signal and identification of error in the transmitter A/D converter. An ammeter will facilitate reading of the electronic signal and identification of error in the transmitter D/A converter. A transmitter communicator also facilitates calibration of the A/D and D/A transmitter converters. A calibrated analog source will facilitate identification of an error in the supervisory or computation equipment. Figure 16 shows examples of these common technician tools.

Figure 16. HART Communicator, Digital Multimeter, mA Loop Simulator

Logic Controllers & Flow Computers

From a calculation perspective, measurement-related calculations should be performed in a flow computer. The advantage of a flow computer over other calculating means (e.g. PLC) is that all critical calculations are housed in a single traceable, verifiable, reliable, and secure piece of equipment. Flow meters, temperature devices, pressure devices, and density devices (if applicable) transmit signals to the flow computer for calculation processing. The flow computer should at a minimum produce flow meter proving, product batch, computer configuration, audit trail, daily, and snapshot reports.

Other devices such as product samplers, flow control valves, pressure control valves, may be required to provide accurate measurement from a metering system. These devices could be controlled with a programmable logic controller or, as most flow computers also accommodate some limited logic functions, be controlled with the flow computer utilized for volume calculation purposes.

There are many different brands and types of flow computers and logic controllers, each of which will require specific familiarity and knowledge to program/configure, maintain, and operate. Technicians should ensure they're knowledgeable and skilled in the brands and models utilized in their area of responsibility.

Ideally, companies or geographical can standardize on flow computer and logic controller types to minimize the required technician training and spare parts inventory.

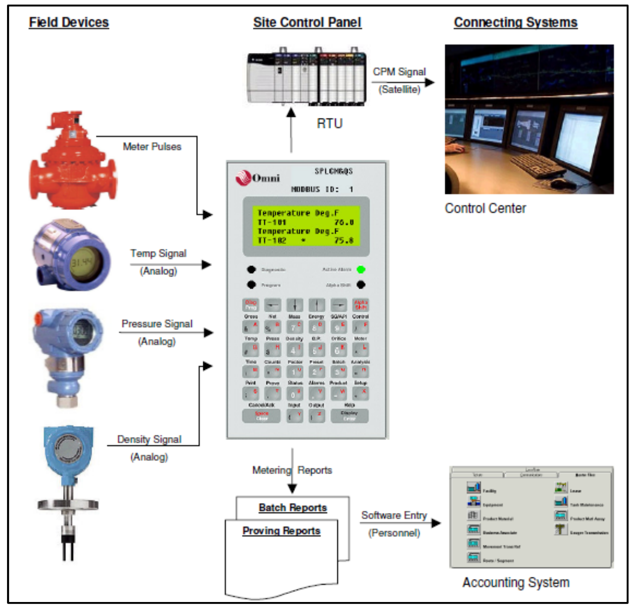

Figure 17. Typical Flow Computer Connections

Conclusion

Some electronic circuitry lies within almost all devices we utilize on a daily basis. Electronics is a field that evolves at an exponentially rapid pace and allows newer and smaller ingenious devices to be continually created. Technicians have the responsibility and challenge to gain knowledge and skills throughout their career at this aggressive pace of technological advancement. Regardless of a device's bells and whistles, the underlying operation of electronic devices is based on electrical laws that have existed for centuries. By understanding some basic electronic devices and their operation, a technician is a more effective troubleshooter and therefore a more skilled worker. Understanding the function of electronic devices and instruments utilized in hydrocarbon measurement facilitates and improves device inspection, verification, and calibration- which is at the heart of accurate hydrocarbon measurement.

Lastly, stay safe by respecting electrical and electronic energy! Proper training and personal protective equipment is required to work with electricity.

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