Chapter 13

Signal Conditioning for Controls

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Signal conditioning is the process of acquiring the signals from the field and converting them into a form that is acceptable by the digitization and machine-control hardware. Signal conditioning plays important role in protecting the control hardware against high frequency coupling and also in personal safety by protecting against dangerous voltages. Aspects of signal conditioning will be discussed here.

13.1. Introduction

Signal conditioning is required to convert different types of electrical signal from the field to a form acceptable by control hardware. For example we might have used pressure sensors, temperature sensors of different types and voltage probes and current sensors. The output from these sensors may be current or voltage of different ranges. If the overall signal count is high we can employ one or more modules for each type of signals. However in our systems the signal count is very less and all the signal shall be connected to one or 2 modules. In this case signal conditioning is necessary. Additional advantage of signal conditioning is isolation. Signal conditioning may involve one or more than one of the following processes: a. Amplification b. Filtering c. Linearization d. Isolation.

13.2. Processes Involved in Signal Conditioning

Signal conditioning is an assembly of multiple signal refinement processes. Following processes are involved in a typical signal conditioning,

13.2.1. Amplification/Attenuation

Amplification increases signal amplitude to the level acceptable by the control hardware. Attenuation reduces signal to the level acceptable by the control hardware. Whether a signal requires attenuation or amplification is governed by the magnitude of the signal and acceptability threshold and minimum threshold at the input port of the receptor.

13.2.2. Filtering

Filtering is the process of blocking unwanted signal in the incoming signal. The source of these unwanted signals may be arising from external noise sources. The range of signals that are blocked depends on the filter cut-off frequency and type of filter used. Unwanted signals can be bypassed or blocked by using Zener diodes, MOVs, GSDs, current limiting resistors and fuses.

13.2.3. Linearization

Linearization is the mapping of sensor's signal value and measured physical quantity in such a way that an incremental change in the physical quantity corresponds to a similar incremental change in the output electrical signal.

13.2.4. Excitation

Excitation is required for many types of transducers. This excitation is provided by the signal conditioning / measurement device.

13.2.5. Isolation

Isolation is a method of physically and electrically separating two distinct parts of an instrument. If two systems or subsystems or instruments electrically isolated means that current does not flow between them.Voltage signals outside the range of ADC not only damages the measurement system, it can also harm the operator. When two subsystems operate at very different voltage ranges, implementing isolation protects the low voltage subsystem from overvoltage damage. Electrical isolation breaks the galvanic path between the input and output signal. First the input electrical signal is converted to an optical or magnetic signal then it is transmitted and reconstructed at the output using suitable hardware. In this process there will be no electrical connection between input and output i.e. input and output are galvanically isolated. Hence unwanted signals on the input line are prevented from passing through to the output. There is need for isolation when there is no common ground between input and outputs or one of the systems is ungrounded/ floating.

13.3. Isolation Techniques

Isolating power sources and sensor signal is the most effective way of eliminating undesirable ground loop currents and induced electrical noise. Isolation can be achieved by using following techniques, (a) Linear Optical Isolation, (b) Magnetic Coupling, (c) Isolation Amplifier and (d) Switching to Digital Mode.

13.3.1. Linear Optical Isolation

Linear Optical Isolation is a technique which uses an electronic component or device in its linear range of characteristics. Optical isolators for digital signals are widely used and easily available; they use analog parts such as LED and a phototransistor. If an optical isolator is used in the current domain, the output of the transistor has a linear relationship to the input current of the LED. The disadvantage of using opto-isolators for linear isolation is that opto-isolators has very narrow linear region. They need operational amplifiers to convert current into voltage signal and vice versa. This linear region will change for the same device opto-isolators with change in family/batch /manufacturer. So we need to recalibrate every time we change any of the devices.

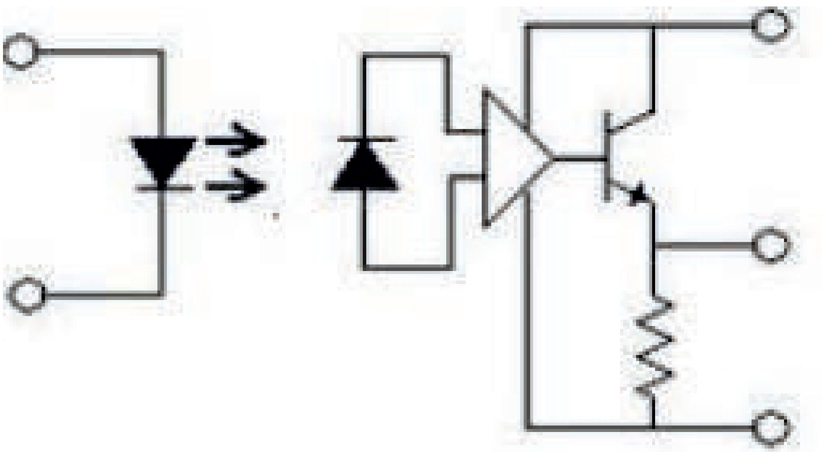

Figure. 13.1. Linear Optical Isolation.

13.3.2. Magnetic Coupling (Isolation Transformers)

Transformer can be used to isolate electrical signals. Two coils of the transformer that are magnetically coupled can transfer energy to each other due to change in magnetic field. Even though both the coils are electrically isolated, magnetic isolation has some issues. Since transformers acts as a low pass filter because of its high inductance, it can block sudden energy spikes from electrostatic discharge. However it may not block mains surges.

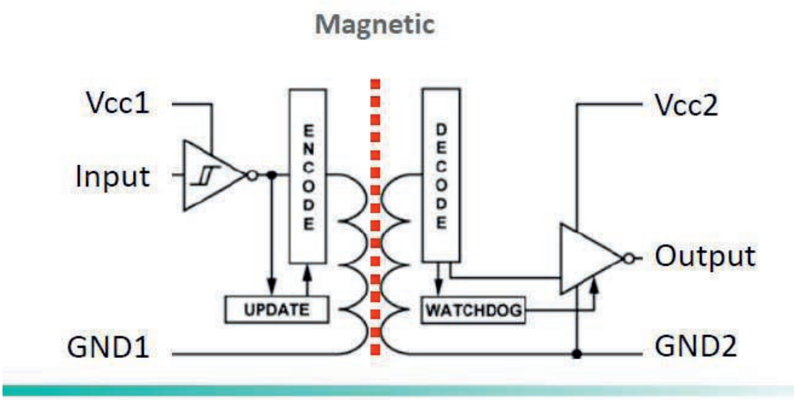

Figure 13.2. Magnetic Coupling.

Since energy transfer occurs only when there is a change in magnetic field, this technique can't be used to isolate DC analog voltages and there is always a limitation on the input signal frequency as the material and design of the transformer changes with the operating frequency. To use magnetic coupling for isolation, analog signals has to be converted into time varying signals of known frequency. This makes them impractical to measure unknown frequency signals.

13.3.3. Isolation Amplifier

Isolation Amplifiers are integrated circuits that may use one of the isolation techniques discussed above to perform analog isolation. Isolation amplifier is the first choice of engineers for analog isolation. The reason for using this chip over a customized solution is that the manufacturer has incorporated the circuitry that is required for amplification, linearization and isolation in a single chip. Isolation amplifiers may use an internal inductive, capacitive or optical means for analog isolation. In inductive or optical method, isolation is achieved by using a PWM/ any other modulation technique to convert an incoming analog signal to a carrier wave with a specific frequency, passing modulated signal across an internal transformer or opto-coupler and then re-generating the carrier wave into the analog signal using PWM/Frequency-to-Voltage Converter/demodulator or some other technique.

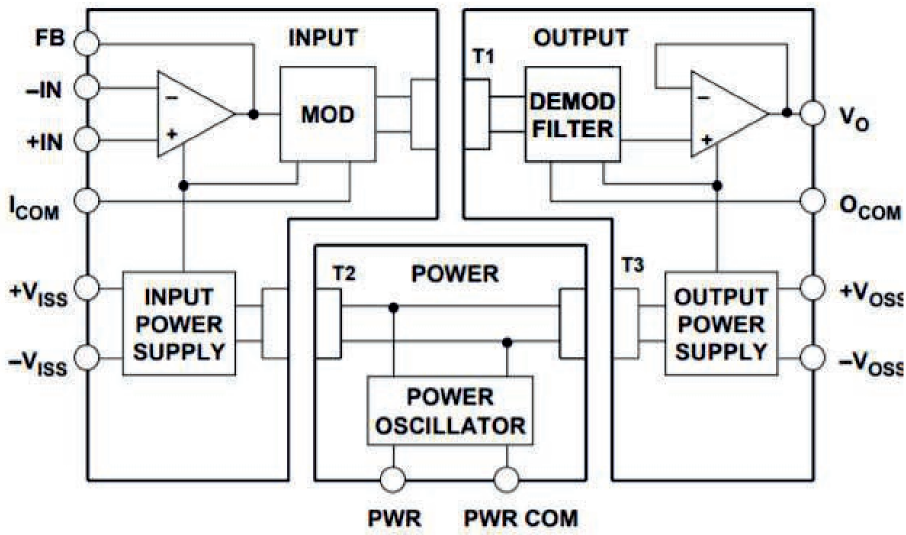

Figure 13.3. Three-Port Isolation.

13.3.4. Switching to Digital Mode

Digital signal can be isolated easily by using a pair of LED and photo transistor with suitable circuitry. This suitable pair is available in single devices as optical isolator. If we convert the analog signals in to digital signals optical isolator can be used for isolation of analog signals. An analog signal is first converted into a digital pulse using Voltage to Frequency Converter (or PWM). These digital output pulses are converted into light signals using LED/IR LEDs. These light signals then transmitted over optical fiber.

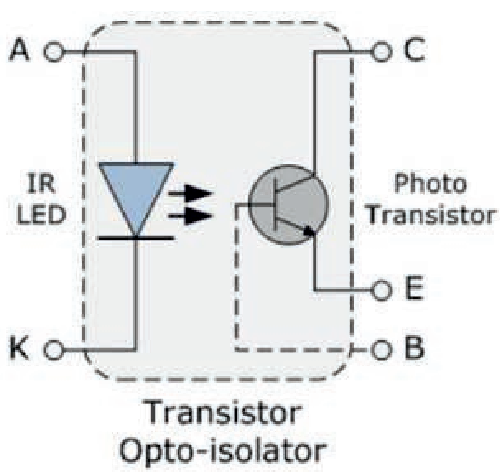

Figure 13.4. Optical Isolator.

At the receiver end these light pulses are converted in to electrical signals (digital pulses) using photo transistors. As there is no electrical connection between field devices or measurement systems and control hardware. This method not only provides protection from electrical surges and ESDs but also basic characteristics of DC signals, thereby making it a more ideal choice over a magnetic isolation. If we use only analog circuitry for conversion, then there will be infinite range of possible values and output will be a true replica of original signal. But if we use VFC or PWM, the analog signal will be quantized. This quantization means that the output of the analog isolator will not be a true replica of the input signal. The output analog signal will be an approximation of input signal and have a finite resolution with some quantization error. This quantization error depends on the step size. The major disadvantage of this technique is that the device used to measure the physical parameters and devices used in ADCs are still exposed to ESD and other high energy sources.

13.4. Summary

Isolating measurement and control signals protects the equipment and ensures personal safety by blocking dangerous voltages and degrading effects of noise and other hazards present in HV systems.

References

[1] Dataforth corporation, Application Note-116 titled "Why Use Isolated Signal Conditioners".

[2] Arrow Application Notes on "Analog Isolation Techniques for Circuit Protection".