PLCs, like other digital computers, are discrete systems that only understand 1s and 0s. Therefore, they cannot interpret analog signals in their continuous form. **Analog input interfaces** translate continuous analog signals into discrete values that can be interpreted by PLC processors. These discrete values are subsequently used in the control program. Table 7-1 lists some devices that are typically interfaced with analog input modules.

Analog Inputs
Flow transducers
Humidity transducers
Load cell transducers
Potentiometers
Pressure transducers
Vibration transducers
Temperature transducers

Table 7-1. Devices used with analog input interfaces.

Analog input modules digitize analog input signals, thereby bringing analog information into the PLC (see Figure 7-3). The modules store this multibit information in register locations inside the PLC. The analog instructions used with analog input modules are similar to, if not the same as, the instructions used with multibit discrete inputs. The only difference between them is that analog multibit instructions are the result of a digital transformation of the analog signal, while discrete multibit instructions are the result of many multibit devices (or separate signals) connected to the same number of discrete input connections.

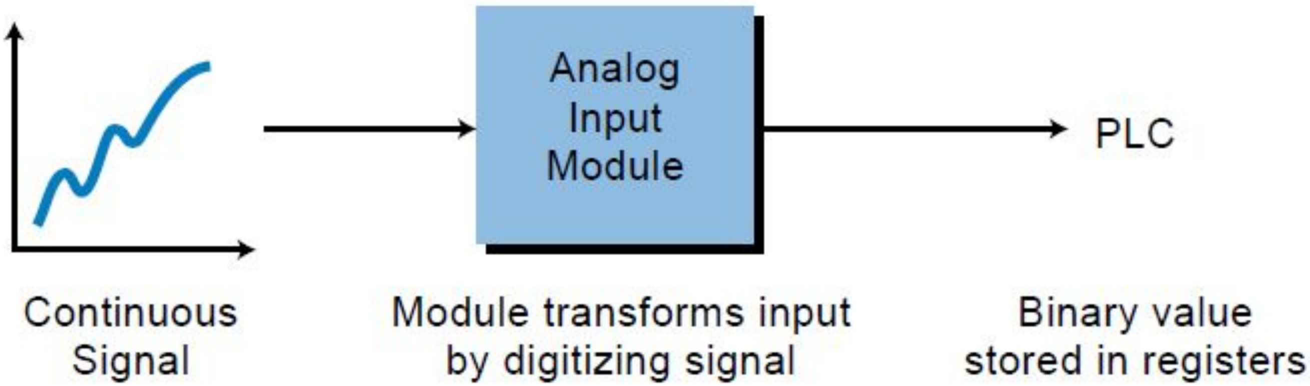
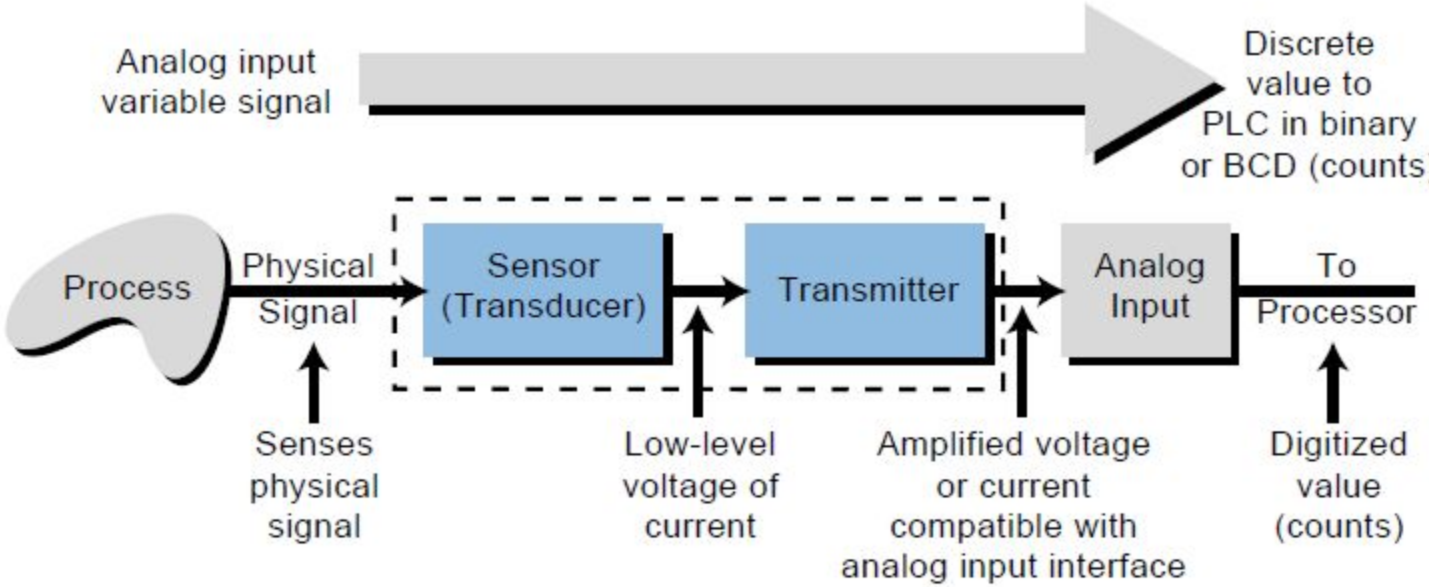


Figure 7-3. Digitization of an analog signal.

Due to the many types of transducers available, analog input modules have several standard electrical input ratings. Table 7-2 lists the standard current and voltage ratings for analog interfaces. Note that analog interfaces can be either *unipolar* (positive voltage only—i.e., 0 to +5 VDC) or *bipolar* (negative and positive voltages—i.e., –5 to +5 VDC).

Input Interfaces
4–20 mA
0 to +1 volts DC
0 to +5 volts DC
0 to +10 volts DC
1 to +5 volts DC
± 5 volts DC
± 10 volts DC

Table 7-2. Typical analog input interface ratings.


Analog input
variable signal
Discrete
value to
PLC in binary
or BCD (counts)
Process
Physical
Signal
Sensor
(Transducer)
Transmitter
Analog
Input
To
Processor
Senses
physical
signal
Low-level
voltage of
current
Amplified voltage
or current
compatible with
analog input interface
Digitized
value
(counts)

Specifying an Analog Input

There are basically three characteristics that need to be considered when selecting an analog input. They are as follows.

Unipolar (positive only) or bipolar (plus and minus)

This is a simple decision. If the voltage being measured cannot be negative, then a unipolar input is the best choice. It is not economical to purchase a bipolar input to measure a unipolar signal.

Input range

This is relatively simple also. For this specification, you will need to know the type of output from the sensor, system, or transducer being measured. If you expect a signal greater then 10 volts, purchase a 10 volt input and divide the voltage to be measured using a simple resistive voltage divider (keep in mind that, if necessary, you can restore the value in software by a simple multiplication operation). If you know the measured voltage will never exceed 5 volts, avoid purchasing a 10 volt converter because you will be paying extra for the unused additional range.

Number of Bits of Resolution

The resolution of an A/D operation determines the number of digital values that the converter is capable of discerning over its range. As an example, consider an analog input with 4 bits of resolution and a 0-10 volt range. With 4 bits, we will have 16 voltage steps, Example Problem:

A temperature sensor outputs 0-10 volts DC for a temperature span of 0-100 degrees C. What is the bit resolution of a PLC analog input that will digitize a temperature variation of 0.1 degree C?

Solution:

Since, for the sensor, 10 volts corresponds to 100 degrees, the sensors outputs 10V / 100 degrees = 0.1 volt/degree C. Therefore, a temperature variation of 0.1 degree would correspond to 0.01 volt, or 10 millivolts from the sensor. Using our rule of thumb, we would need an analog input with a voltage resolution of 10 mV x 25% = 2.5 mV (or less) and an input range of 0-10 volts. This means the converter will need to divide its 0-10 volt range into 10 V / 2.5 mV = 4000 steps. To find the bit resolution we find the smallest value of n that solves the inequality $2^n > 4000$. The smallest value of n that will satisfy this inequality is n=12, where $2^n = 4096$. Therefore, we would need a 12-bit 10 volt analog input. Now we can find the actual resolution by solving for a 12-bit 10 volt converter. The resolution would be 10v / 2^{12} = 2.44 mV. This voltage step would correspond to a temperature variation of 0.0244 degree. This means that the digitized value will be within plus or minus 0.144 degree of the actual temperature.

A *unipolar quantizer* deals with analog signals ranging from 0 volt to a positive reference voltage, and a *bipolar quantizer* has an analog signal range from a negative reference to a positive reference. The notations and general rules for quantization are:

$$\Delta = \frac{(x_{\max} - x_{\min})}{L}$$

$$L = 2^m$$

$$i = round\left(\frac{x - x_{\min}}{\Delta}\right)$$

$$x_q = x_{\min} + i\Delta, \text{ for } i = 0,\ 1, \ldots,\ L - 1,$$

Example Problem:

A 10-bit bipolar analog input has an input range of -5 to +5 volts. If the converter outputs the binary number 0110111101_2 what is the voltage being read?

EXAMPLE 7-3

A temperature transducer/transmitter (see Figure 7-10) provides a 0–10 VDC voltage signal that is proportional to the temperature variable being measured. The temperature measurement ranges between 0 and 1000°C. The analog input module accepts a 0–10 VDC unipolar signal range and converts it to a range of 0–4095 counts. The process application where this signal is being used detects low and high alarms at 100°C and 500°C, respectively.

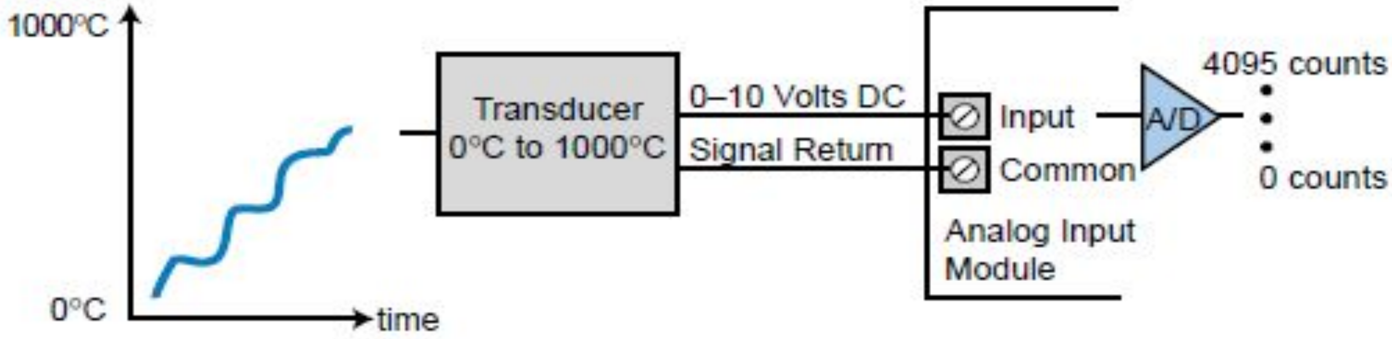


Figure 7-10. Temperature transducer/transmitter connected to an input module.

Find **(a)** the relationship (i.e., equation of the line) between the input variable signal (temperature) and the counts being measured by the PLC module and **(b)** the equivalent number of counts for each of the alarm temperatures specified.

(a) Figure 7-11 shows the relationship between counts and the input signal in volts and degrees Celsius. Line *Y* describes the numerical relationship between the input signal and the number of counts (assuming a linear relationship).

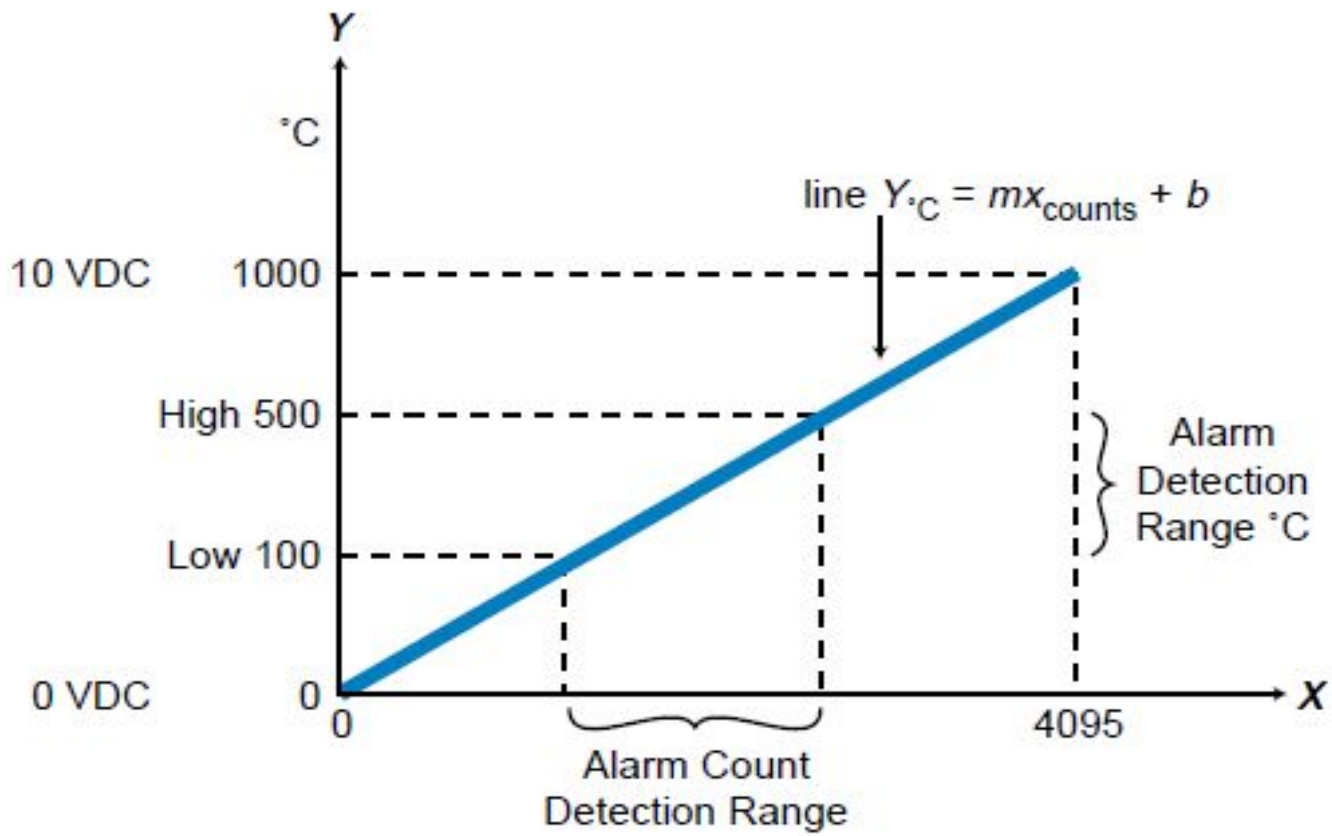


Figure 7-11. Relationship between counts and input signal.

Analog (D/A) Output

When selecting an analog output for a PLC, most of the same design considerations are used as is done with the analog input. Most analog outputs are available in unipolar 0 to 5 V and 0 to 10 V, and in bipolar -5 to +5 V and -10 to +10 V systems. The methods for calculating bit resolution and voltage resolution is the same as for analog inputs, so the selection process is very similar.

However, one additional design consideration that must be investigated when applying an analog output is load impedance. Most D/A converters use operational amplifiers as their output amplifiers. Therefore, the maximum current capability of the converter is the same as the output current capability of the operational amplifier, typically about 25 mA. In most cases, a simple ohm's law calculation will indicate the lowest impedance value that the D/A converter is capable of accurately driving.

Example Problem:

A 12-bit 10 volt bipolar analog output has a maximum output current capability of 20 mA. It is connected to a load that has a resistance of 330 ohms. Will this system work correctly?

Solution:

If the converter were to output it's highest magnitude of voltage, which is -10 volts, the current would be 10 V / 330 ohms = 30.3 mA. Therefore, in this application, the converter would go into current limiting mode for any output voltage greater than 20 mA x 330 ohms = 6.6 V (of either polarity).

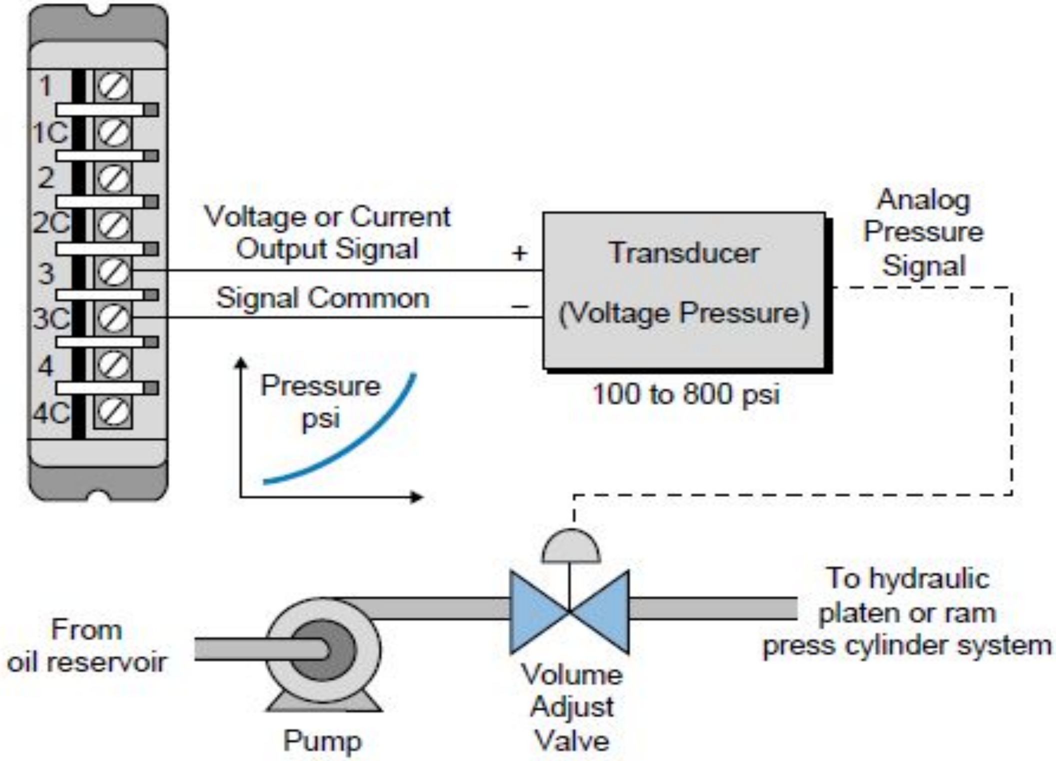


Figure 7-16. Representation of a volume adjust valve.

Analog Outputs
Analog valves
Actuators
Chart recorders
Electric motor drives
Analog meters
Pressure transducers

Table 7-4. Typical analog output field devices.

Output Interfaces
4–20 mA
10–50 mA
0 to +5 volts DC
0 to +10 volts DC
± 2.5 volts DC
± 5 volts DC
± 10 volts DC

EXAMPLE 7-5

A transducer connects an analog output module with a flow control valve capable of opening from 0 to 100% of total flow. The percentage of opening is proportional to a –10 to +10 VDC signal at the transducer's input. Tabulate the relationship between percentage opening, output voltage, and counts for the output module in increments of 10% (i.e., 10%, 20%, etc.). The bipolar output module has a 12-bit D/A (binary) with an additional sign bit that provides polarity to the output swing.

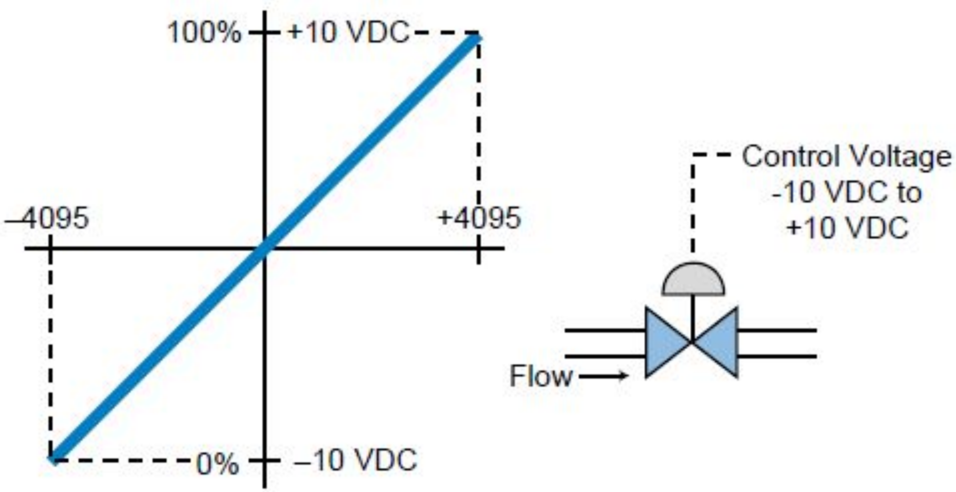


Figure 7-22. Relationship between counts, voltage, and percentage.

Percentage Opening	Output Voltage	Counts
0%	–10 VDC	–4095
10	–8	–3276
20	–6	–2457
30	–4	–1638
40	–2	–819
50	0	0
60	+2	+819
70	+4	+1638
80	+6	+2457
90	+8	+3276
100	+10	+4095

Table 7-7. Equivalent counts, voltages, and percentages.