Analog Input/Output System

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Overview of Analog Input Signals

- Analog input modules are used in applications where the field device's signal is continuous.
- Unlike discrete signals, which possess only two states (ON and OFF), **analog signals** have an infinite number of states.
  - Temperature, for example, is an analog signal because it continuously changes by infinitesimal amounts.

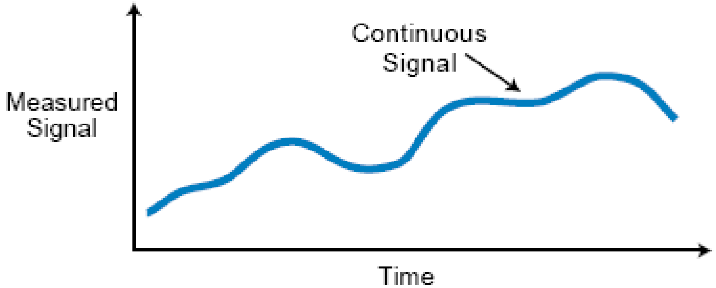


Figure 7-2. Representation of a continuous analog signal.

Figure 7-1. Analog input modules.

Overview of Analog Input Signals

- **Analog input interfaces** translate continuous analog signals into discrete values that can be interpreted by PLC processors.

- 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.

Instructions for Analog Input Modules

- Analog input modules digitize analog input signals, thereby bringing analog information into the PLC.
- The modules store this multi-bit information in register locations inside the PLC.
- The analog instructions used with analog input modules are similar to the instructions used with multi-bit discrete inputs.

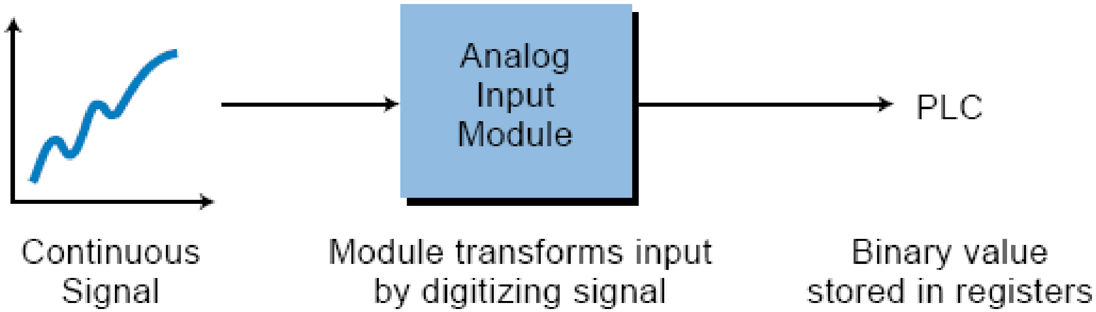
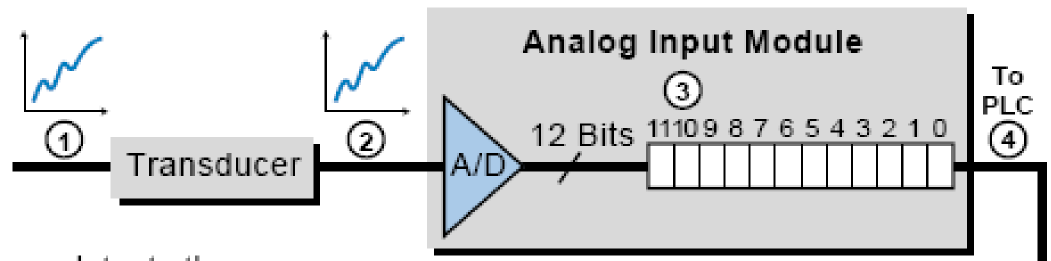


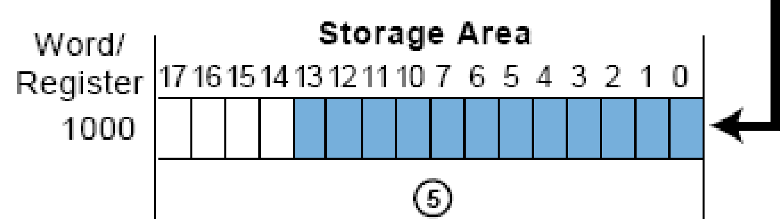
Figure 7-3. Digitization of an analog signal.

Instructions for Analog Inputs



① The transducer detects the process signal (e.g., temperature).

② The transducer transforms the process signal into an electrical signal that the analog input can recognize.



③ The analog input transforms the signal into a 12-bit value proportional to the electrical input to the module.

④ A block transfer in instruction, or another analog input instruction, transfers the 12-bit value to the PLC.

⑤ The PLC stores the 12-bit digital value in a memory location for future use.

Figure 7-4. Steps in converting an analog signal to binary format.

Instructions for Analog Inputs

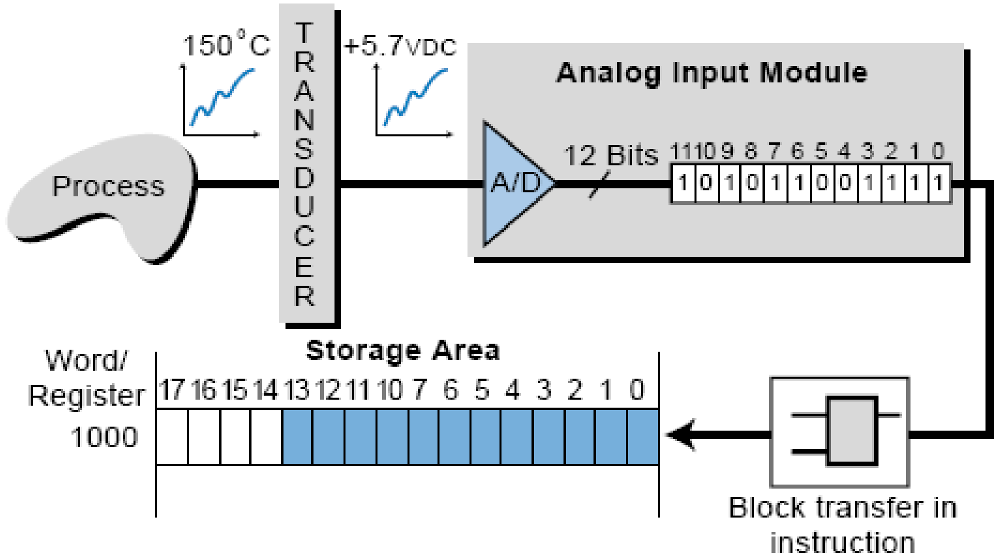


Figure 7-5. Multibit instruction.

- After the instruction is executed, the contents of register 1000 will be: 0000 1010 1100 1111
- Since the value is represented in 12 bits, the preceding bits are filled with 0s.

Analog Input Data Representation

- Analog field devices are usually connected to transmitters.
- A **transducer** converts a field device's variable (i.e., pressure, temperature, etc.) into a very low-level electrical signal (current or voltage) that can be amplified by a
- The **transmitter** amplifies **the signal** and then input into the analog interface.

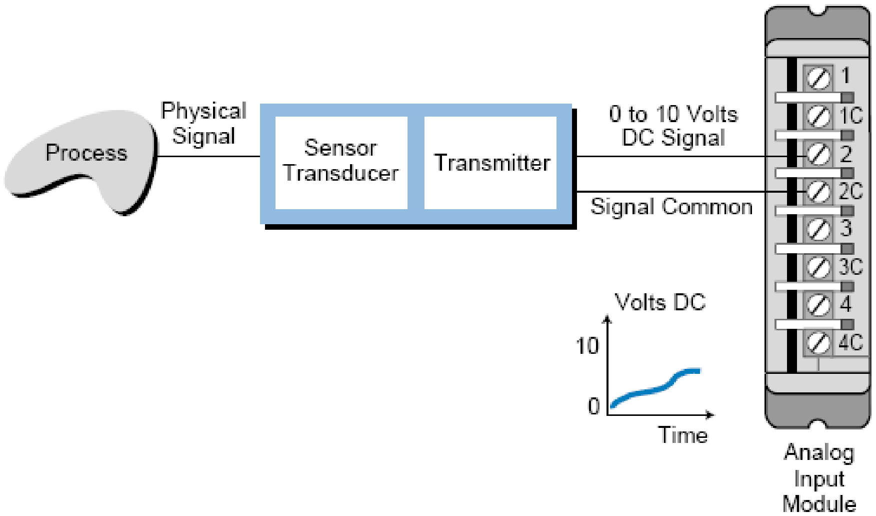


Figure 7-6. Conversion of an analog signal by a transmitter and transducer.

Analog Input Data Representation

- Analog input modules have several standard electrical input ratings as shown in Table

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 Data Representation

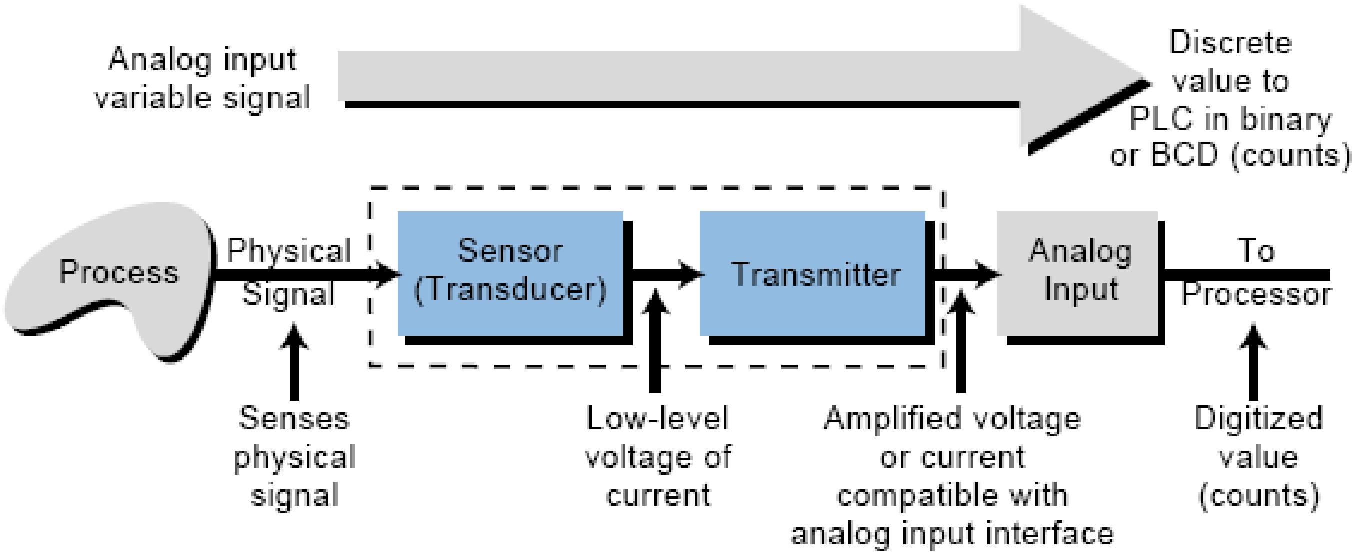


Figure 7-7. Transformation of an analog signal into a binary or BCD value.

Analog Input Data Representation

- An **analog-to-digital converter (A/D or ADC)** performs the signal conversion in an analog input module.

- The **resolution** of the module is given as a function of how many bits the A/D uses during conversion.

  - For example, if an A/D breaks down an input signal using 12 bits or 4096 parts (i.e., $2^{12} = 4096$), it has a 12-bit resolution

  - In this case, the manufacturer could then use the remaining bits (bits 14–17) as status monitoring bits, representing module conditions such as *active*, *OK*, *channel operating*, etc.

Analog Input Data Representation

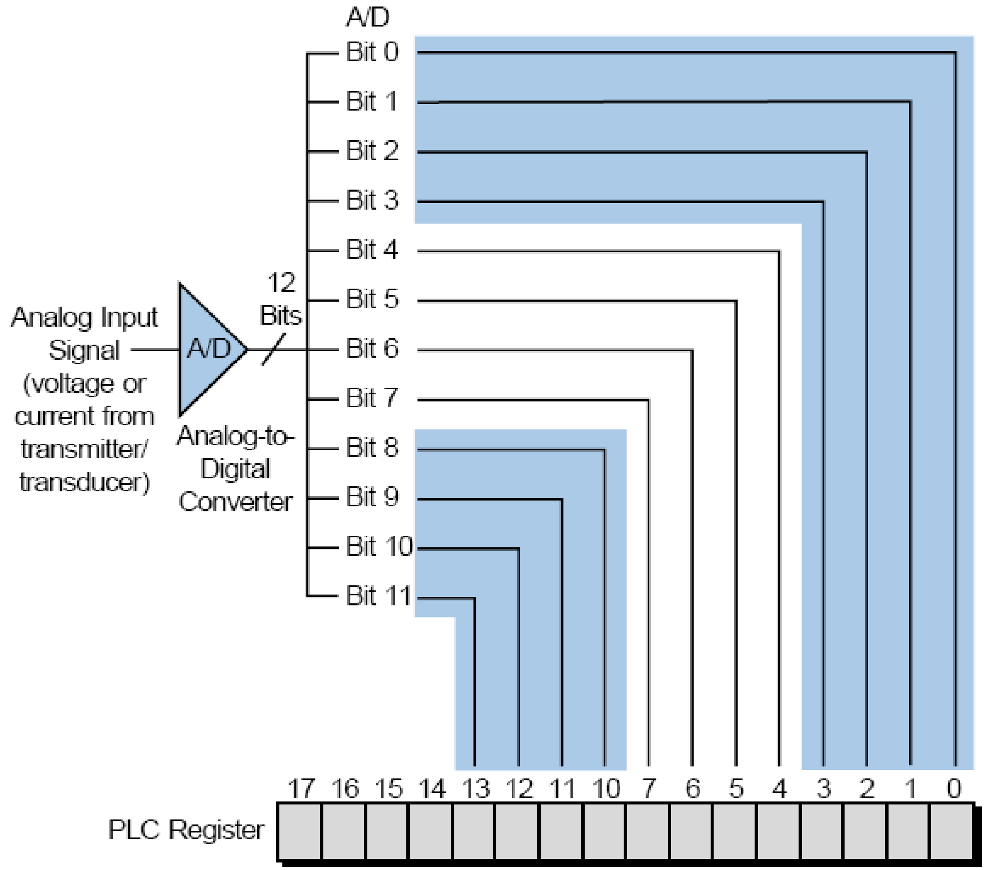


Figure 7-8. An analog-to-digital converter with 12-bit resolution.

Analog Input Data Representation

Pressure psi	Analog Voltage Input	Digital Representation Eng Engr. Units ts 0000-9999	Digital Representation Decimal Scale 0-4095
0	0V	0000	0
50	1V	1000	410
100	2V	2000	819
150	3V	3000	1229
200	4V	4000	1638
250	5V	5000	2047
300	6V	6000	2457
350	7V	7000	2866
400	8V	8000	3276
450	9V	9000	3685
500	10V	9999	4095

Table 7-3. Psi values translated into decimal equivalents and engineering units.

Example 1: Temperature Sensor

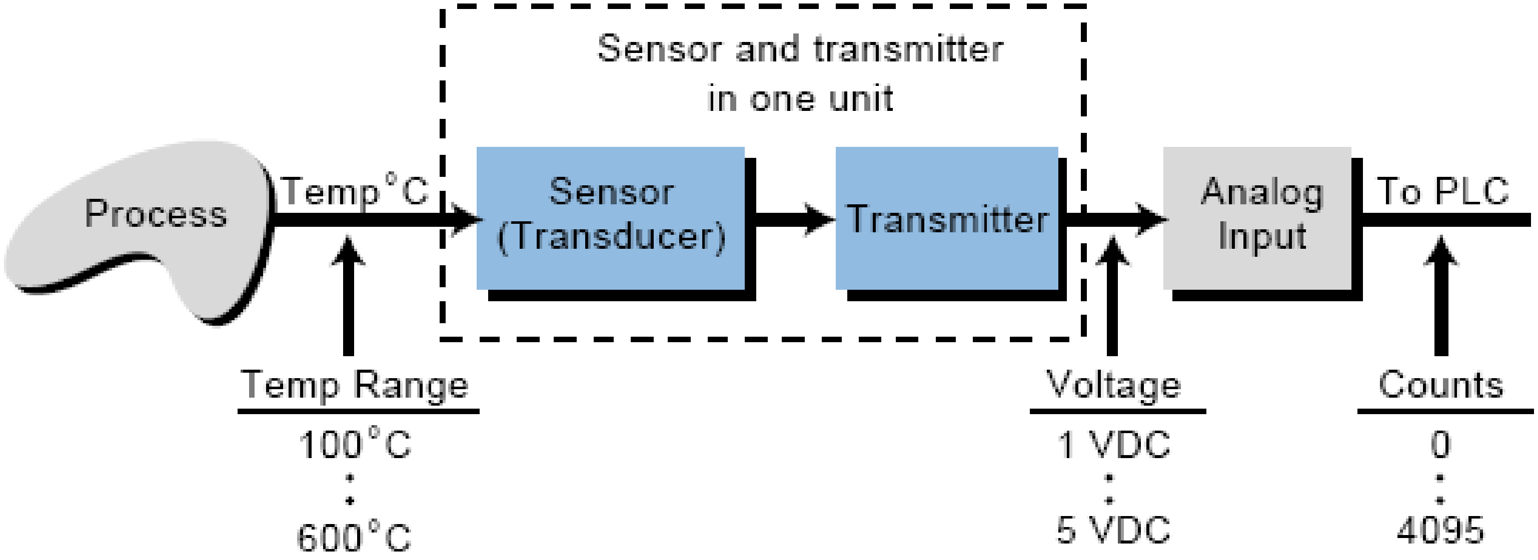


Figure 7-9. An A/D and an analog input module connected to a temperature-sensing device.

Example 1: Temperature Sensor

- The changes (Δ) in temperature, voltage, and input counts are 500°C, 4 VDC, and 4095 counts.
- The voltage change for a 1°C temperature change is:

Δ 500 ° C	=	Δ 4 VDC
1° C	=	4 VDC / 500 = 8.0 m VDC

Example 1: Temperature Sensor

- The change in voltage for each input count:

Δ 4095 counts	=	Δ 4 VDC
1 count	=	4 VDC / 4095 = 0.9678 mVDC

- The corresponding number of counts per degree Celsius:

Δ 500 ° C	=	Δ 4095 Counts
1 ° C	=	4095 / 500 = 8.19 counts

Example 2

- A temperature transducer/transmitter 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.

Example 2

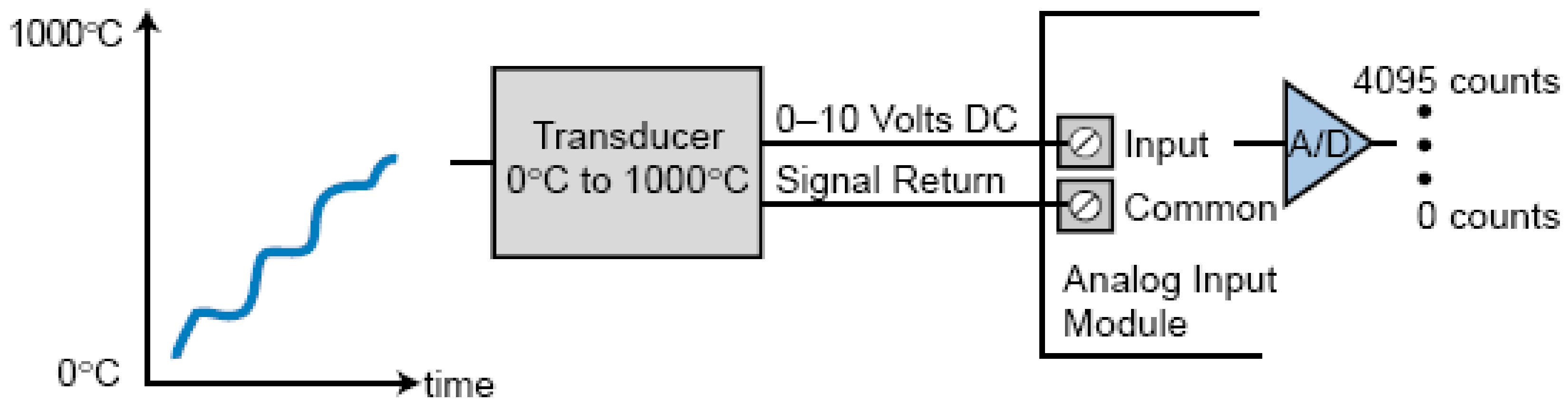


Figure 7-10. Temperature transducer/transmitter connected to an input module.

Example 2

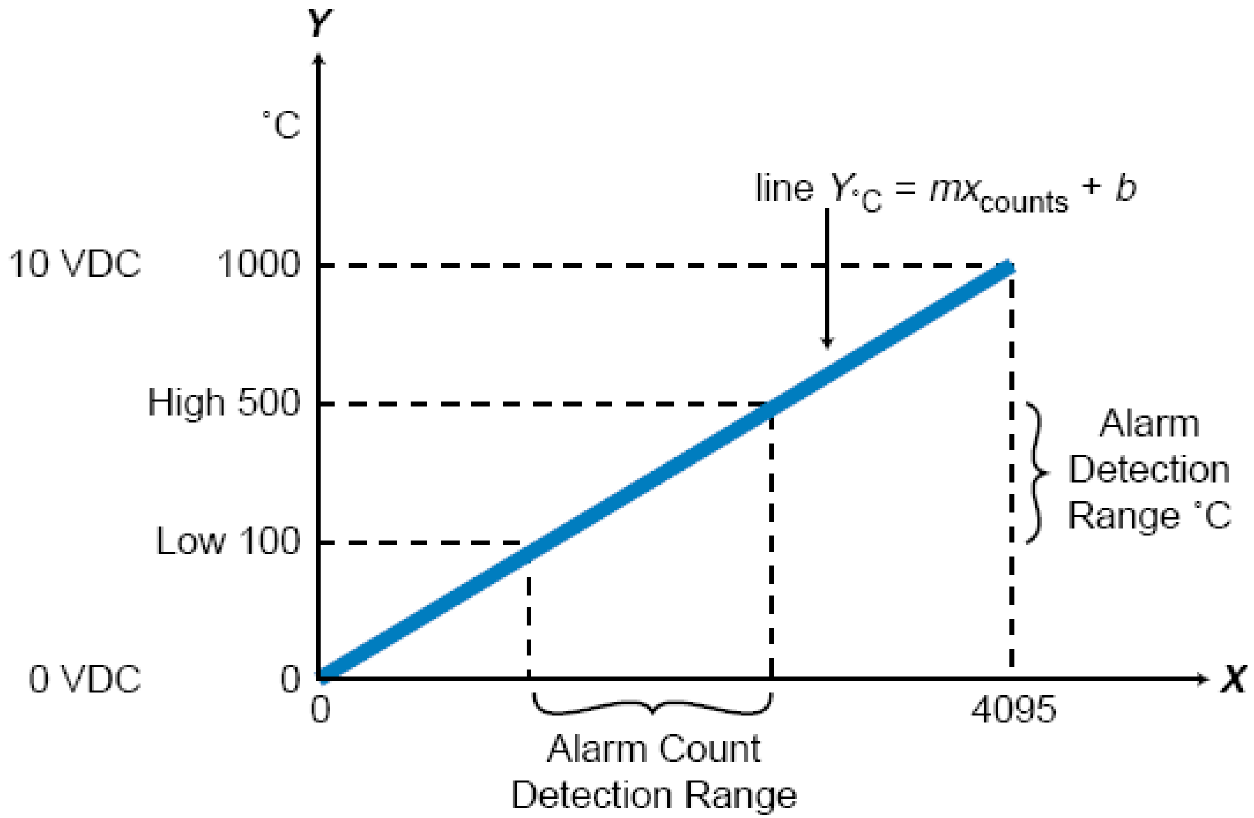


Figure 7-11. Relationship between counts and input signal.

Example 2

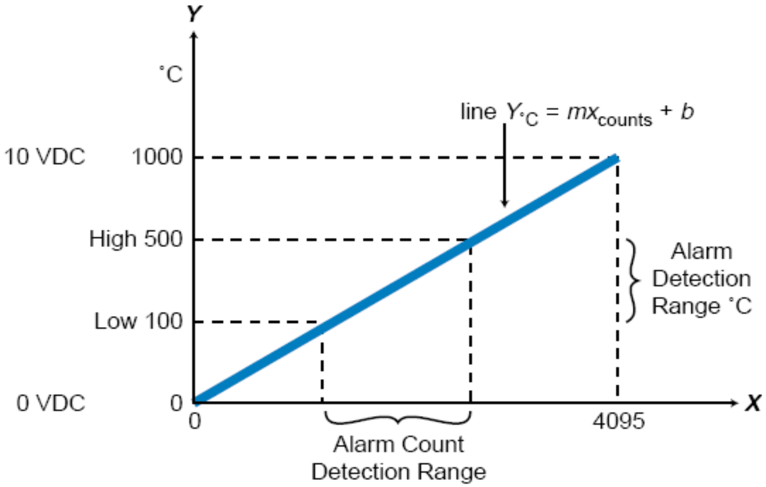


Figure 7-11. Relationship between counts and input signal.

$$m = \frac{Y_2 - Y_1}{X_2 - X_1} = \frac{°C_2 - °C_1}{\text{count }2 - \text{count }1} = \frac{1000 - 0}{4095 - 0} = \frac{1000}{4095}$$

$$Y = mX + b$$

$$Y_{°C} = \frac{1000}{4095} X_{\text{counts}} + 0$$

$$= \frac{1000}{4095} X_{\text{counts}}$$

$$X_{\text{counts at }100°C} = \frac{4095(100)}{1000} = 409.5 \text{ counts}$$

$$X_{\text{counts at }500°C} = \frac{4095(500)}{1000} = 2047.5 \text{ counts}$$

Example 2

- Another method for solving this problem is to determine the number of counts that are equivalent to 1°C.

$$(4095 - 0) / (1000 - 0) = 4.095$$

- The count value for 500°C would be (500)(4.095) = 2047.5 and for 100°C would be (100)(4.095) = 409.5.

- Rounding off these values yields 2048 and 410 counts

- If the counts had not started at 0, an offset count addition would have been necessary for computing the number of counts per degree.

Analog Input Handling

- During the input reading section of the scan, the processor reads the value from the module and transfers the information to a location (i.e. word or register) specified by the user.

- Most analog modules provide more than one **channel**, or input, per interface.

- A processor can determine whether or not the module inserted in the enclosure is analog.
  - If the module is analog, the processor will read the available data in groups of 16 bits, with 12 bits (depending on the resolution) displaying the analog value in binary or BCD.

Analog Input Handling

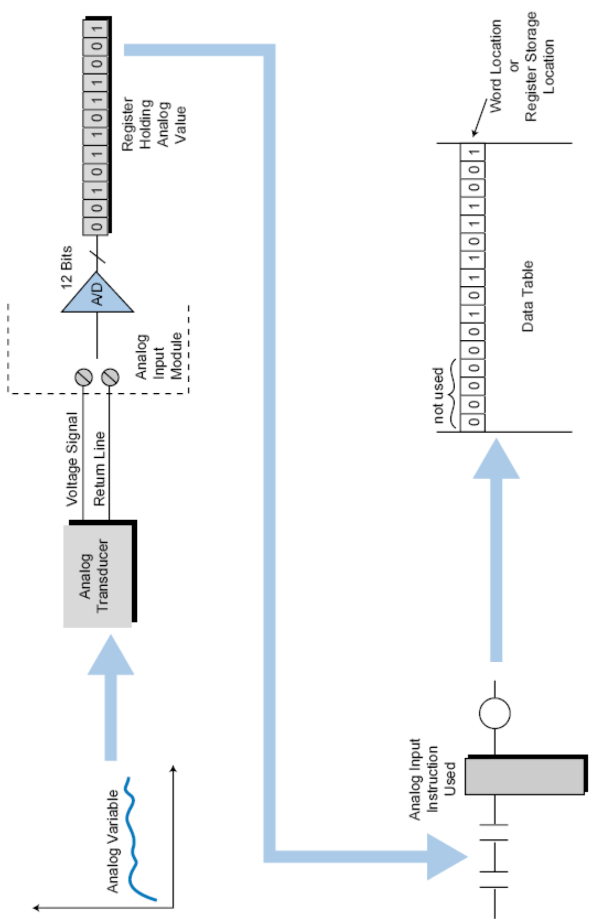


Figure 7-12. Process for inputting analog data to a word location.

Analog Input Handling

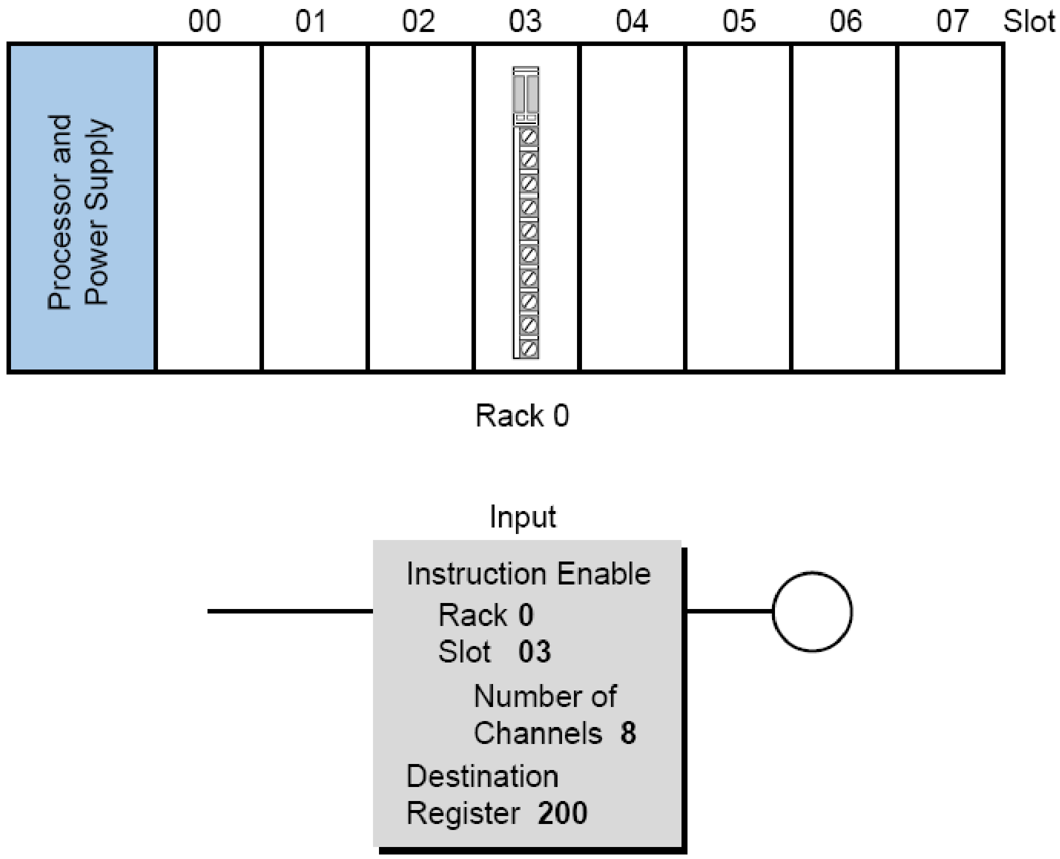


Figure 7-13. An addressed analog module.

Analog Input Handling

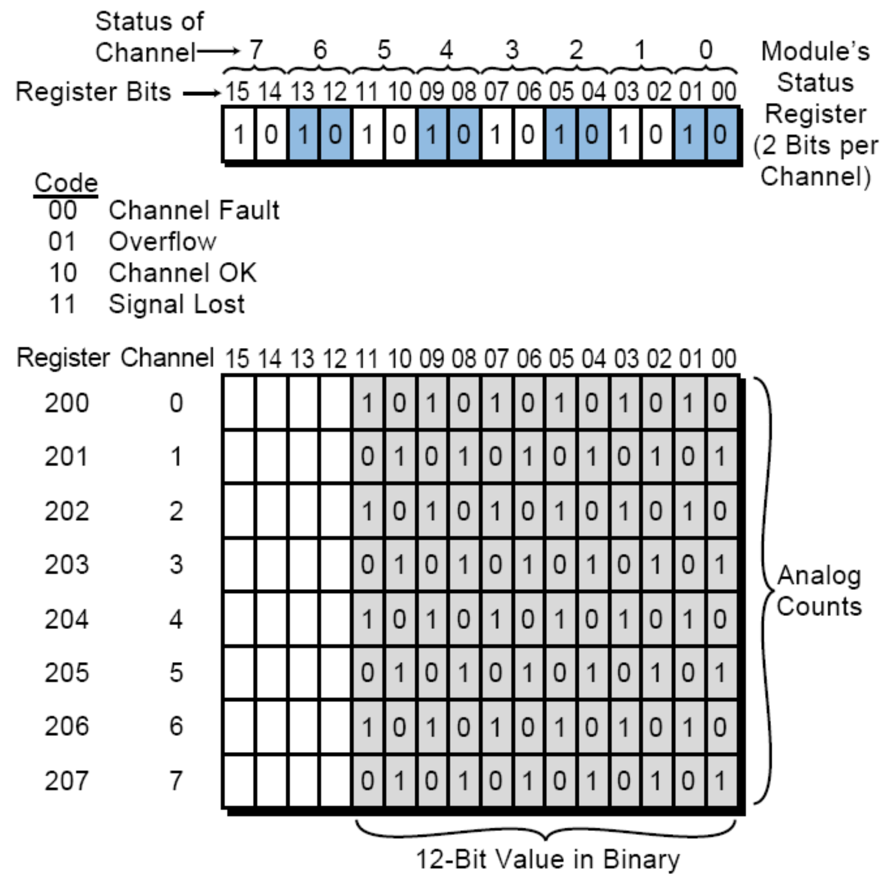
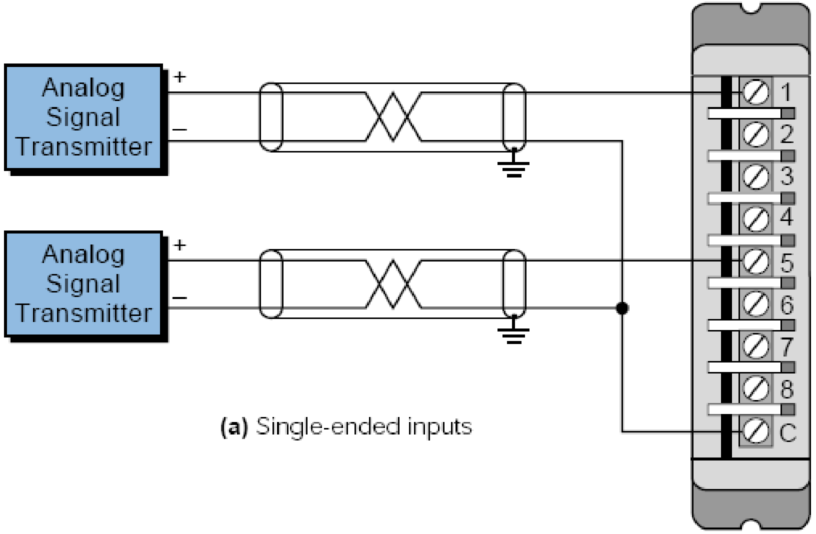


Figure 7-14. Bits within a register indicating the status of each channel.

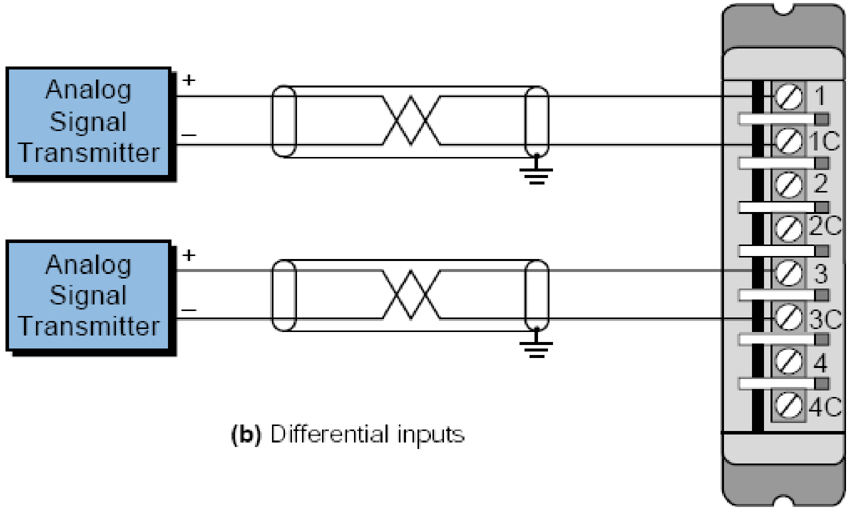
Analog Input Connections

- Analog input interfaces can receive either **single-ended** or **differential** inputs.
- Each channel in an analog interface provides signal filtering and isolation circuits to protect the module from noise.
- Shielded conductor cables should be used to connect both the input module and the transducer.
- Analog input interfaces seldom require external power supply sources because they receive their required power from the back plane of the rack or enclosure.

Analog Input Connections



(a) Single-ended inputs



(b) Differential inputs

Overview of Output Signals

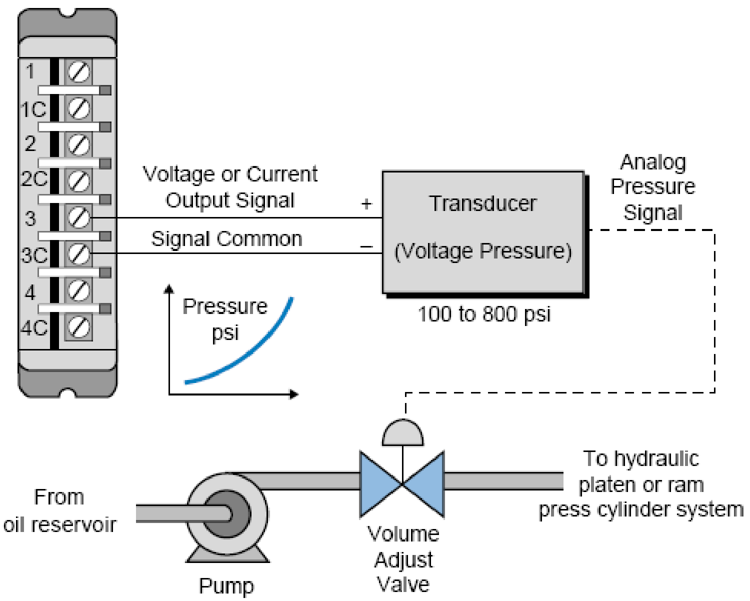


Figure 7-16. Representation of a volume adjust valve.

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

Table 7-4. Typical analog output field devices.

Instructions for Output Modules

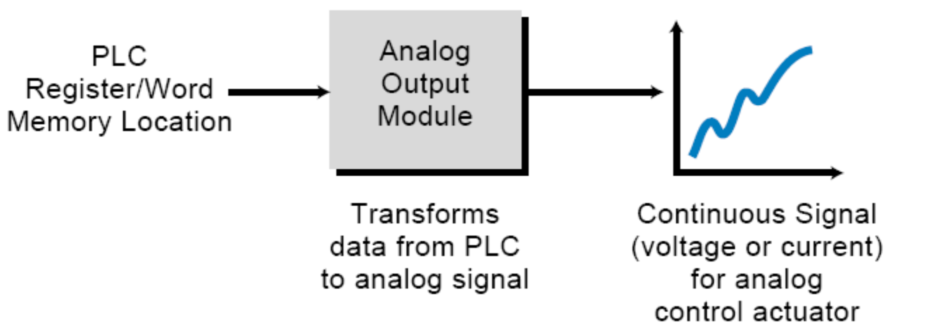


Figure 7-17. Conversion of register data to an analog signal.

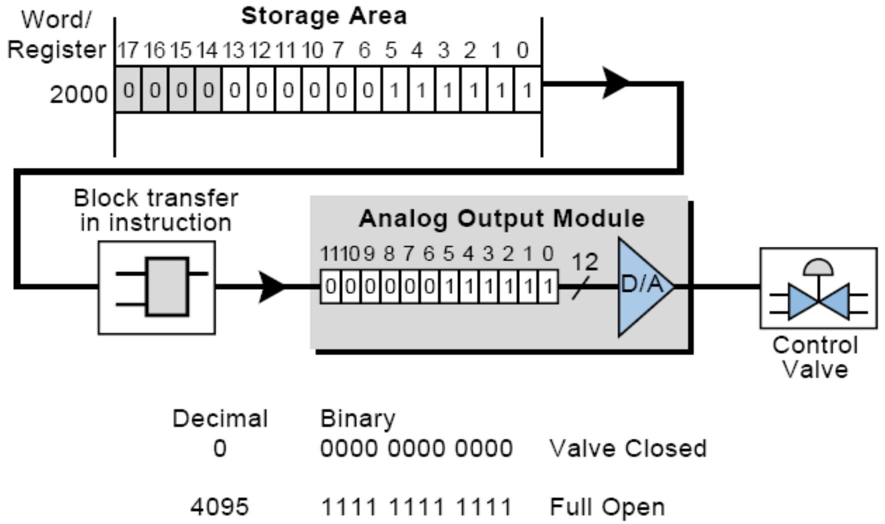


Figure 7-19. Block transfer of register contents to an analog output module.

Analog Output Representation

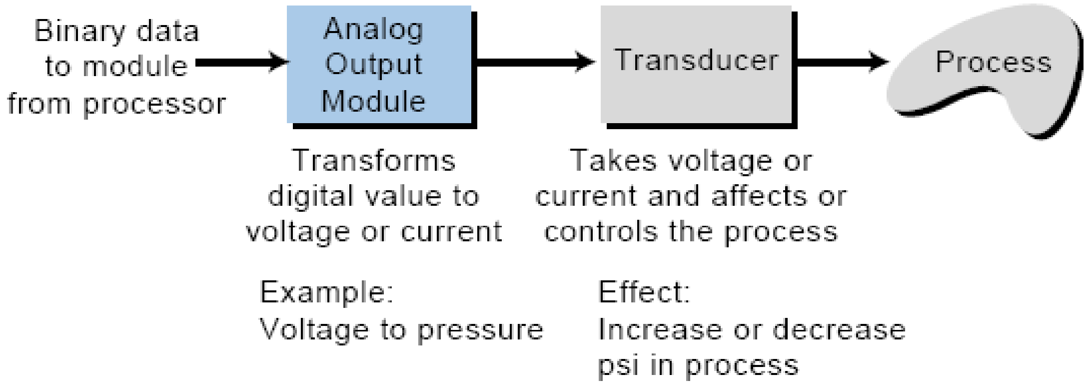


Figure 7-20. Analog output device connected to a transducer.

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

Table 7-5. Analog ouput ratings.

Analog Output Representation

PLC Register		Output		Pressure
Decimal	Binary	0–10 VDC	4–20 mA	(psi)
0	0000 0000 0000 0000	0 VDC	4 mA	0 psi
2047	0000 0111 1111 1111	5 VDC	12 mA	1000 psi
4095	0000 1111 1111 1111	10 VDC	20 mA	2000 psi

Table 7-6. Output values for a 12-bit analog output module.

Example

- 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.

Example

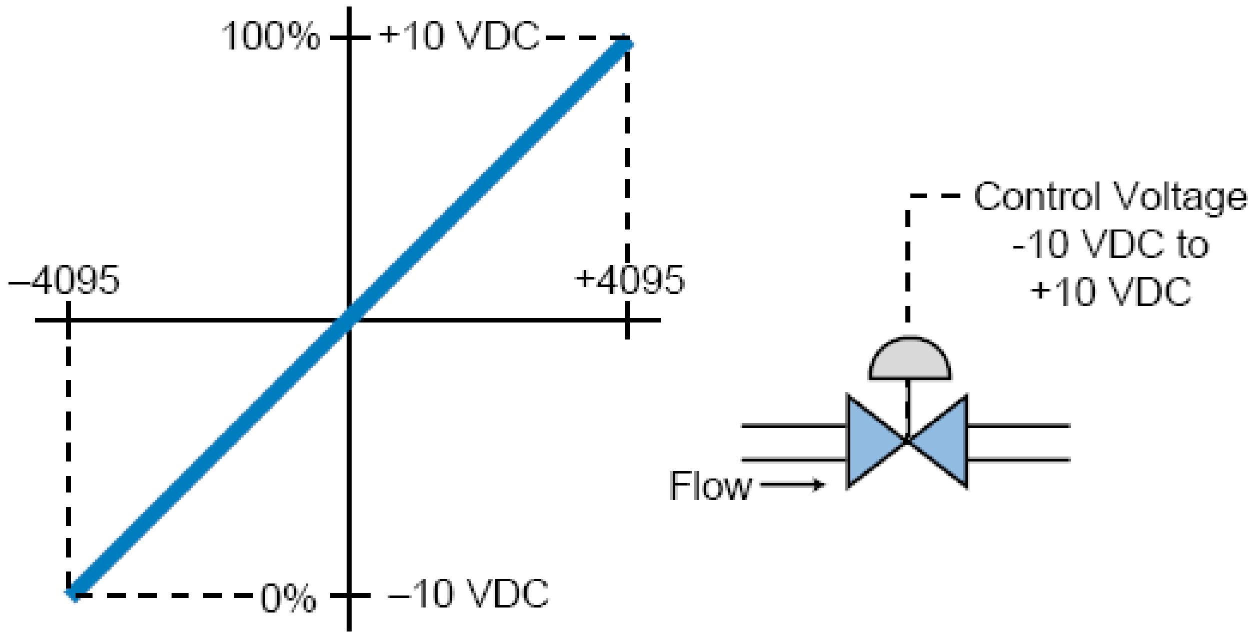


Figure 7-22. Relationship between counts, voltage, and percentage.

Example

ΔPercentage	ΔVoltage $(-10 \text{ to } +10)$	ΔCounts $(-4095 \text{ to } +4095)$
100	20	8190

$$1\% \text{ change as function of voltage} = \frac{20 \text{ VDC}}{100} = 0.2 \text{ VDC}$$

$$1\% \text{ change as function of counts} = \frac{8190}{100} = 81.90 \text{ counts}$$

$$\text{Percentage as function of voltage} = (0.2 \times P) - 10 \text{ VDC}$$

$$\text{Percentage as function of counts} = (81.9 \times P) - 4095 \text{ counts}$$

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.

Analog Output Handling

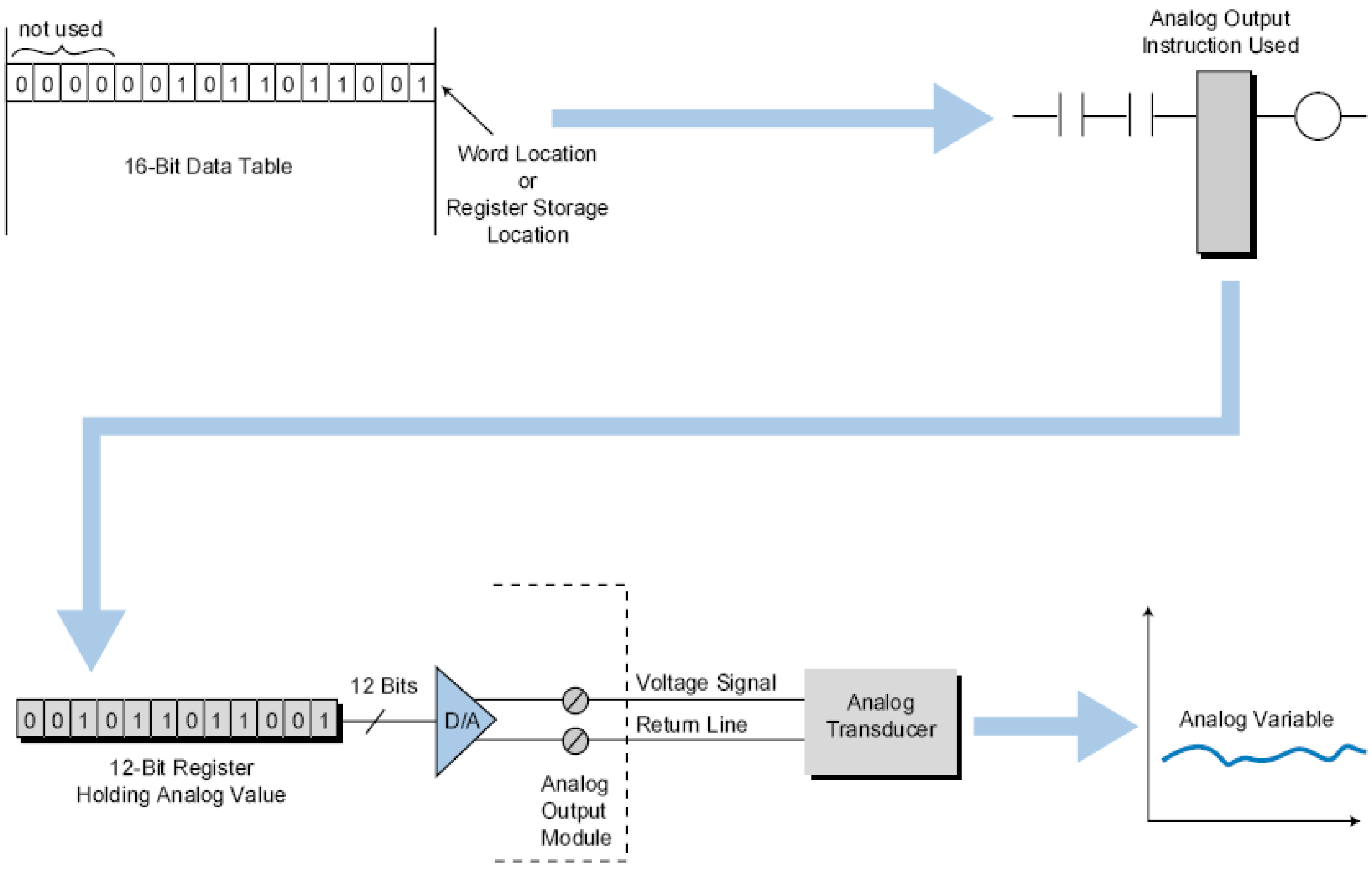
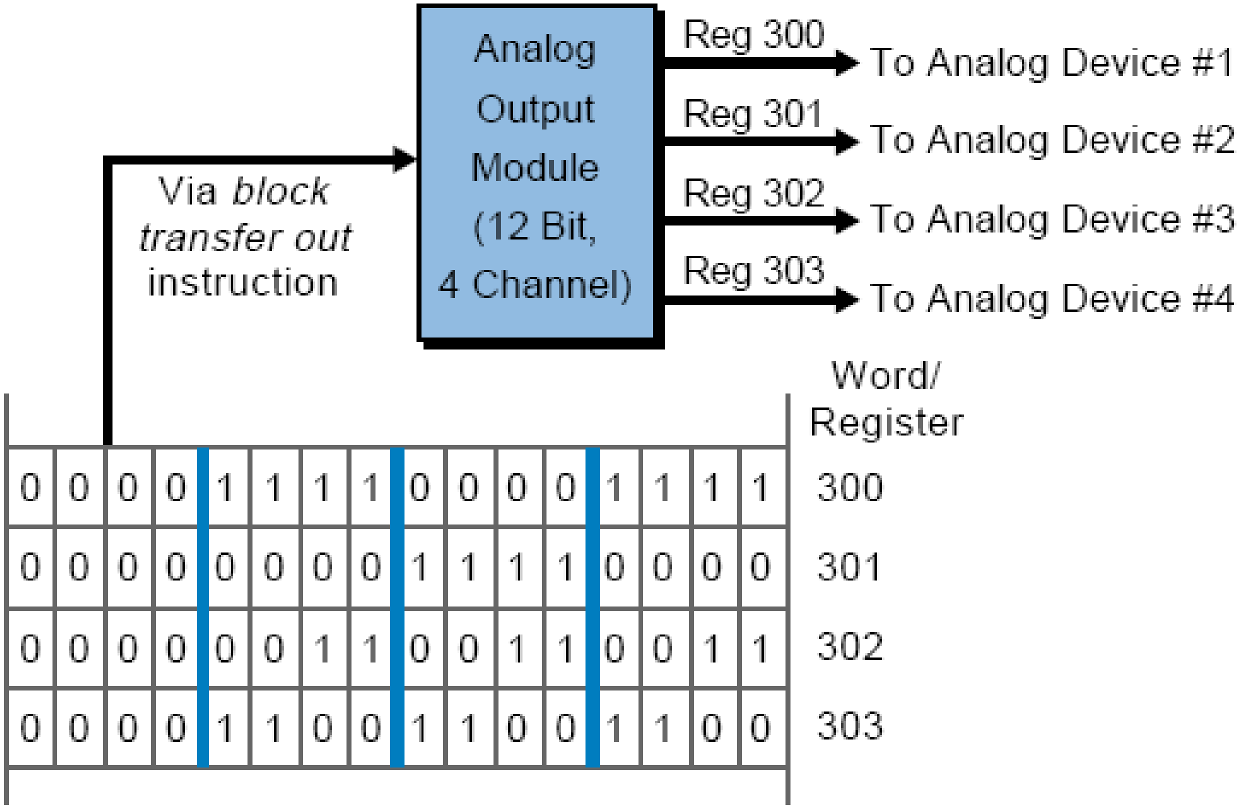


Figure 7-23. Transformation of binary storage table data into an analog signal.

Analog Output Handling



																Word/ Register
0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	300
0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	301
0	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1	302
0	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	303

Figure 7-25. Transfer of data from a source register.

Example

- A programmable controller uses a bipolar –10 to +10 VDC signal to control the flow of material being pumped into a reactor vessel.
- The flow control valve has a range of opening from 0 to 100% to allow the chemical ingredient to flow into the reactor tank.
- The processor computes the required flow (the percentage of valve opening) through a predefined algorithm.
- Analog flow meters send feedback information to the processor about other chemicals being mixed.
- A register stores the computed value for percentage opening, ranging from 0000 to 9999 BCD (0 to 99.99%).

Example

- **(a)** Find the equation of the line defining the relationship between the analog output signal (in counts) and the analog output transformation from –4095 to +4095 counts. The module has a 12-bit resolution and includes a sign bit as a function of voltage output and percentage opening.

- **(b)** Illustrate the relationship of outputs in counts to the computed percentage opening as stored in the PLC register (0000 to 9999). Also, find the equation that describes the relationship between the required counts and the available calculated value stored in the register.

Example

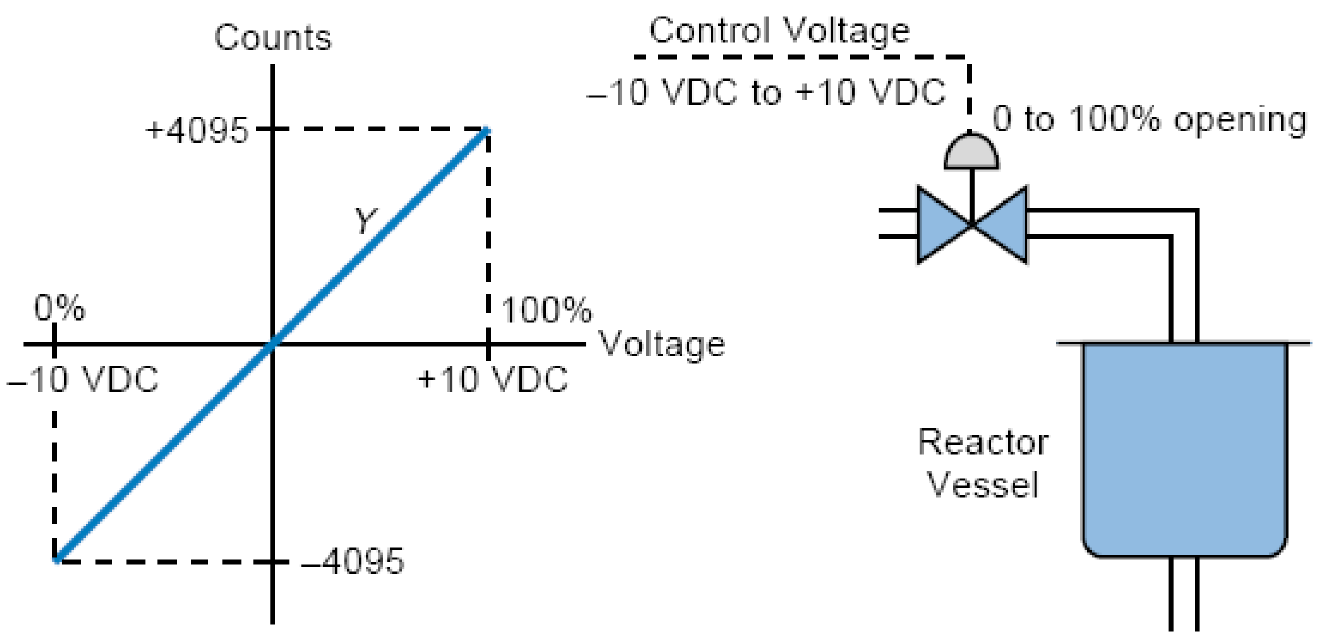
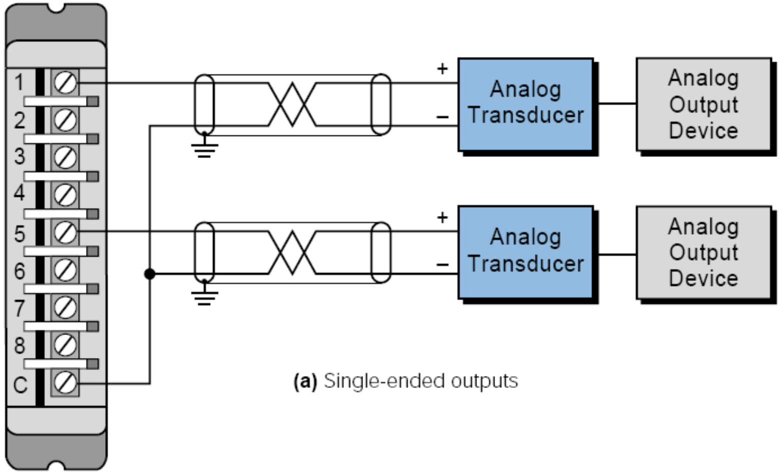
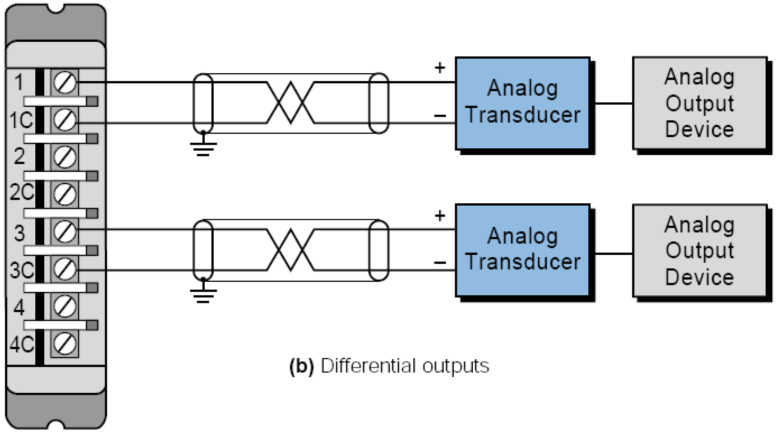


Figure 7-26. Representation of percentage opening and analog output counts.

Analog Output Connection



(a) Single-ended outputs



(b) Differential outputs

Reference: Programmable Controllers: Theory and Implementation by Bryan and Bryan