Input & Output Data Flow

Block Objective

- Introduce the concept of system input and outputs.
- The different types of points
  - binary (digital),
  - multi-state,
  - analog,
  - accumulating
- Parameters associated with each point type
- For analog points the mathematical concepts associated with scaling will be fully developed.
- Concept that provides for network wide sharing of information.

Points

- A generic term used to describe data storage locations in a DDC controller.
- Points may be classified by:
  - Data Type
  - Data Flow
  - Source of Data
- Each data storage location within a DDC system has a unique means of identification.
- “Variable”, “network variable”, or “Object” are sometimes used in lieu of the term points.

Data Types: Binary, Analog

- Binary / Boolean / Digital / Discrete Data
  - Different words, same meaning
  - Value of the data is an integer

    Strictly speaking: Binary data is 1 or 0; ON or OFF
  - When new data is stored, the previous value is discarded.
  - BACnet uses Binary ….. I agree….
- Analog Data
  - Value of the data is numeric, a decimal number
  - When new data is stored, the previous data is discarded.

Data Types: Multi-state

- Value of the data is a small integer
- Represents one of several options
- Occupancy is a prime example:
  - OCCUPIED
  - UNOCCUPIED
  - STANDBY
  - WARMUP/COOLDOWN
- Internally, these “State Descriptors” are represented by a number.
- System “modes” are another example

Data Types: Accumulating

- Value of the data is numeric, a decimal number
- New data is added to existing data; the resulting sum is then stored.

Data Source: Hardware I/O

- Data is received from a hardware device (input point) or will be sent to a hardware device (output point).
- A hardware point may also be referred to as an external point.
- Hardware points may be binary, analog or accumulating, and they may be input or output.

Data Source: Internal

- Data is created by a mathematical program in the controller.
- These points may be binary, analog, or accumulating.
- Other terms:
  - Values (BACnet has Analog/Binary Values)
  - Virtual points
  - Calculated points
  - Numeric points
  - Data points

Data Source: Network

- Point data is transmitted to the network for use by other controllers.
- Point data is received from another controller through the communication network.
- Binary, analog, or accumulating points may be associated with the movement of data to or from the network.

Binary Input Points

- Binary input points (BI, sometimes DI) or variables are data storage locations which:
  - Contain binary (integer) data
  - Internally, represented by a “1” or “0”
  - Typically will provide input information to the control logic
- Intent / meaning of 1 or 0 is not obvious
  - Operators need something ***meaningful***

0 = Noflow
1 = Flow

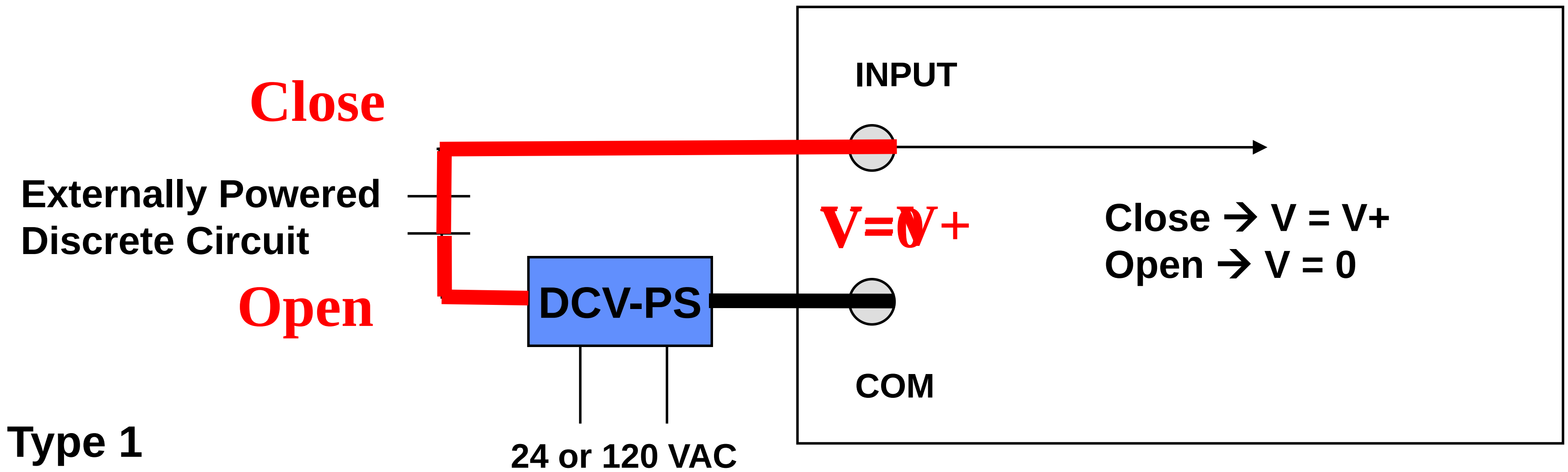
0 = Open
1 = Closed

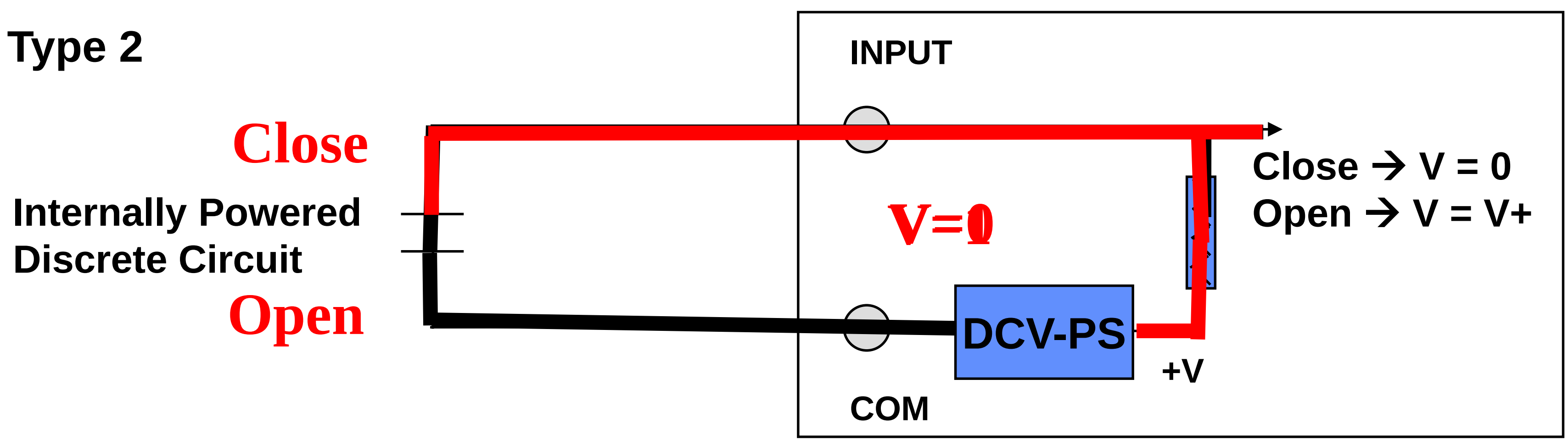
0 = Alarm
1 = Normal

External Binary Inputs

- External Binary Inputs are established by placing a set of contacts in a voltage/resistance circuit.
- The opening and closing of the contacts will open or close the circuit sending a voltage or no voltage to the controller.
- We’ll draw detailed circuits – with modern controllers, these wiring details will be taken care of for you.

Circuit Diagrams



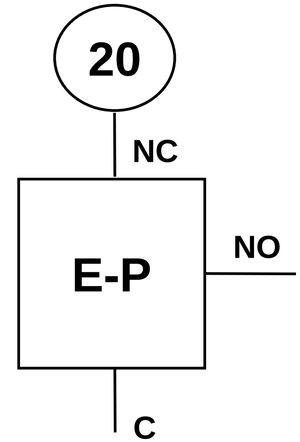


Binary Output Points

- Written as BO (sometimes DO)
- A binary point with a value of 0 or 1.
- 1 = energize output circuit
- 0 = de-energize output circuit
- State descriptors are used to report the value on the point to the GUI / user.
- Analyze the wiring of the external device to determine the relationship between the BO state and the end device state

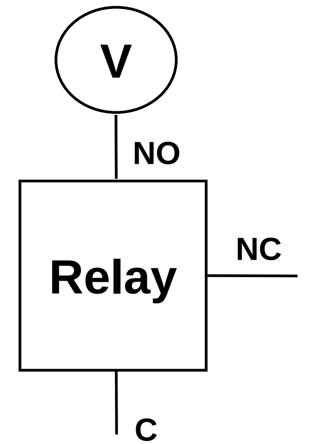
“Normal” positions

- Pneumatic switch has Normally Open (NO) and Normally Closed (NC) positions.
- Pneumatic “Open” means there’s a connection: air passes between the ports
- The NO port allows air to pass when the power is off and blocks air when energized
- The NC port blocks air when the power is off and passes air when energized
- As shown, main air is applied to Common when energized



"Normal" positions

- Relay also has NO and NC positions.
- Electric "Closed" means there's a connection between terminals
- The NO connection is "open circuit" – it blocks current when the power is off and passes current when energized
- The NC connection is "close circuit" – it passes current when the power is off and blocks current when energized
- As shown, power is applied to Common when energized
- Note this is reversed from the pneumatic terms

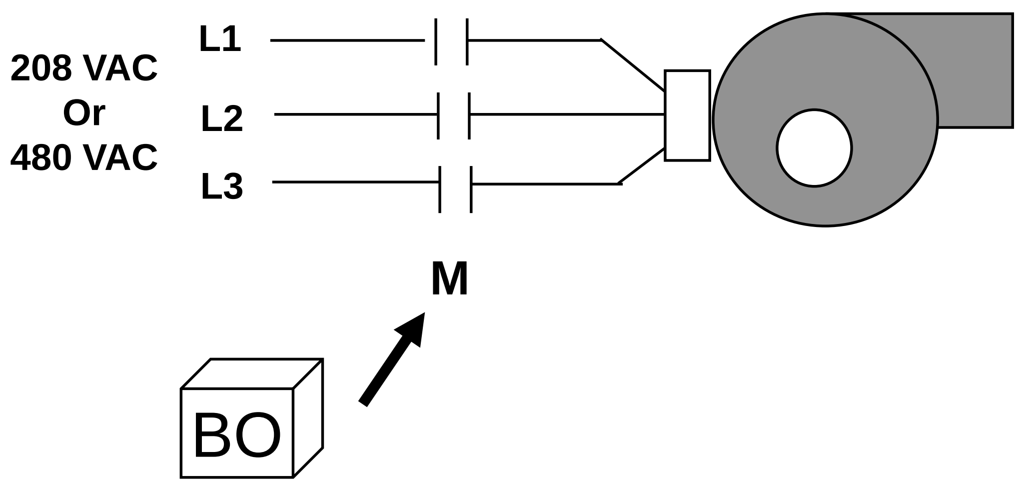


“Normal” vs “Failed”

- “Normal” technically means:
  - The position of the output when power is removed
- Is often confused with:
  - The position the output is “normally” in
  - A normally closed valve may “normally be open”
- Use term “failed” instead
  - Failed Open
  - Failed Closed
  - Fail in Last Position (FILP)
    - Many electric actuators without spring returns
- (and don’t forget electric vs pneumatic “open”)

Binary Outputs

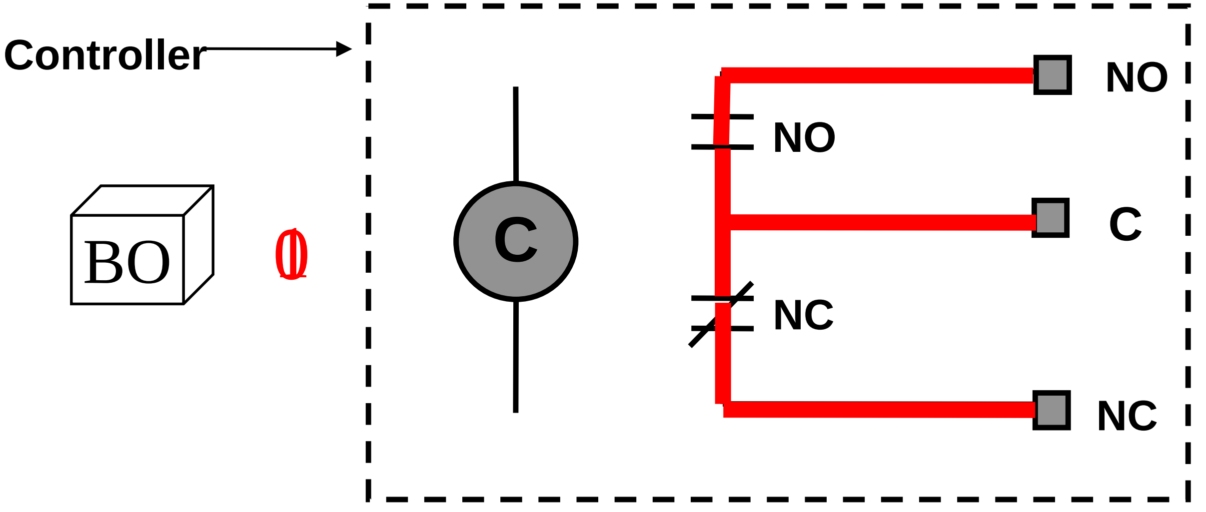
- The typical objective of a binary output is to control a set of contacts that will control the power to a device such as a fan. The contacts are controlled by a relay usually powered by 24 VAC or 120 VAC.



Hardware Types

- Controllers are equipped with one of three (four) types of binary outputs.
  - Form-C, SPDT, Relay Contacts
  - Triac, NO, internal AC power (Voltage Sourcing Triac)
  - Triac, NO, external AC power
  - Legacy Only: Open collector transistor, Normally Open (NO), external DC power

Form-C, SPDT Relay



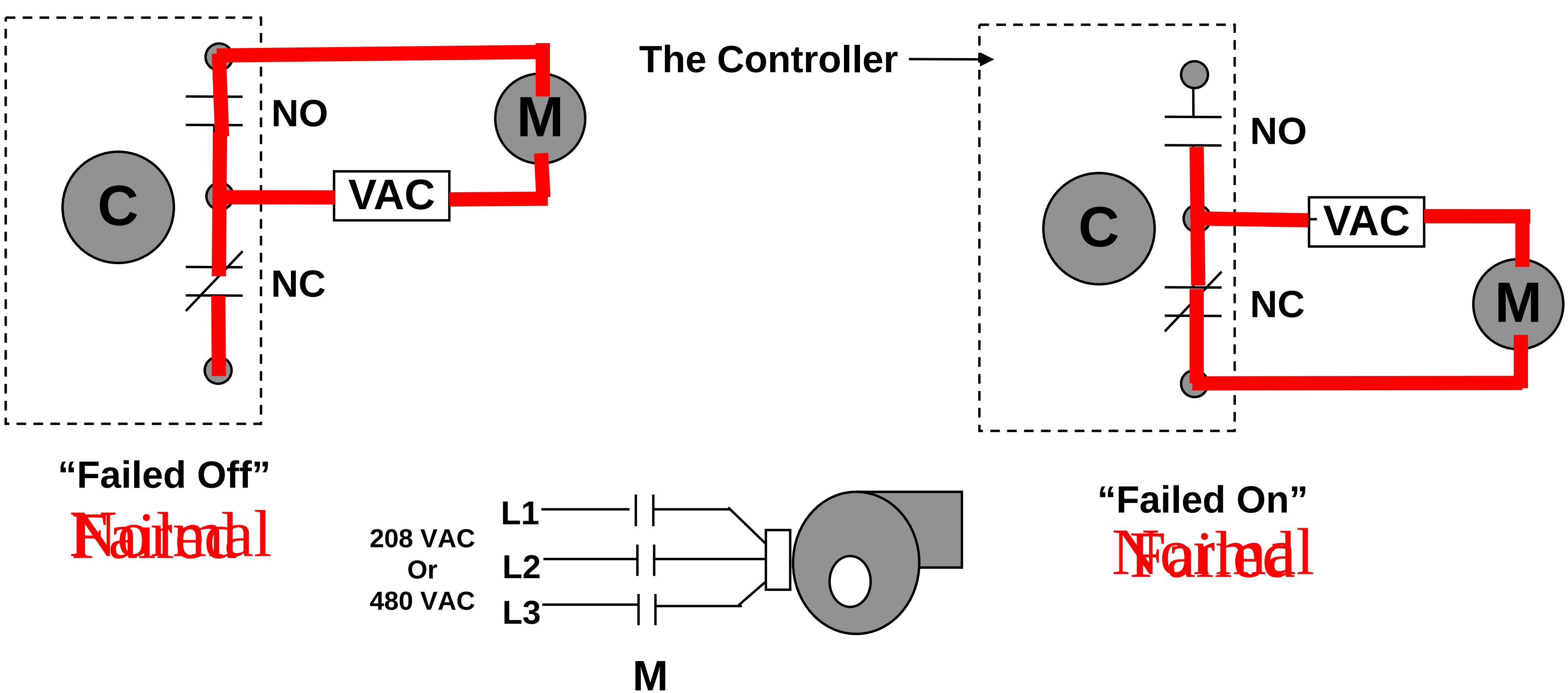
When a value of 0 is sent to the BO point , the relay will be de-energized and terminal NC will be electrically connected to terminal C.

When a value of 1 is sent to the BO point, the relay will be energized and terminal NO will be electrically connected to terminal C.

Relay Outputs

Start	Command = 1
Stop	Command = 0

Start	Command = 0
Stop	Command = 1



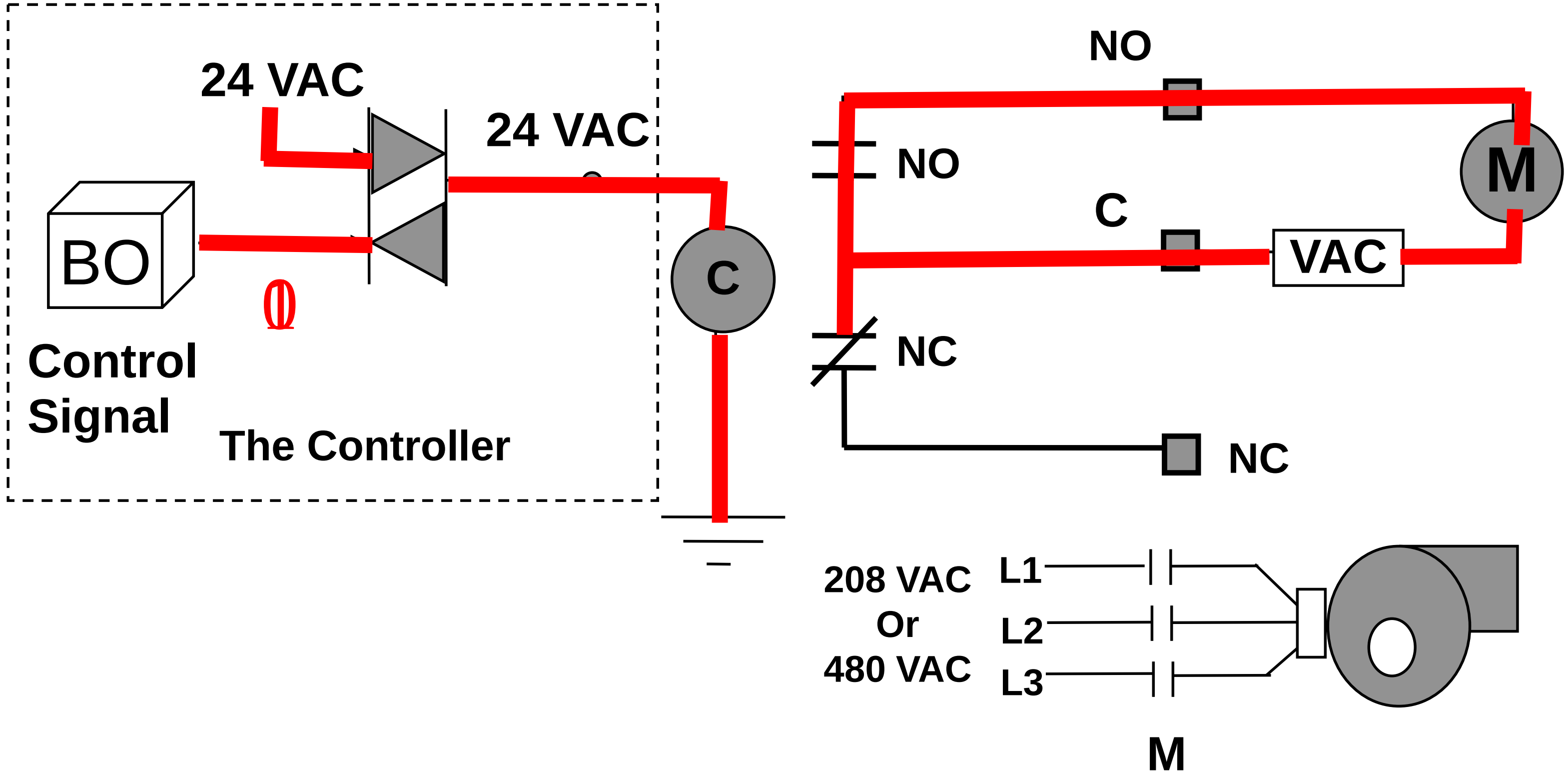
"Failed Off"

Normal
Failed

"Failed On"

Normal
Failed

Voltage-Sourcing Triac

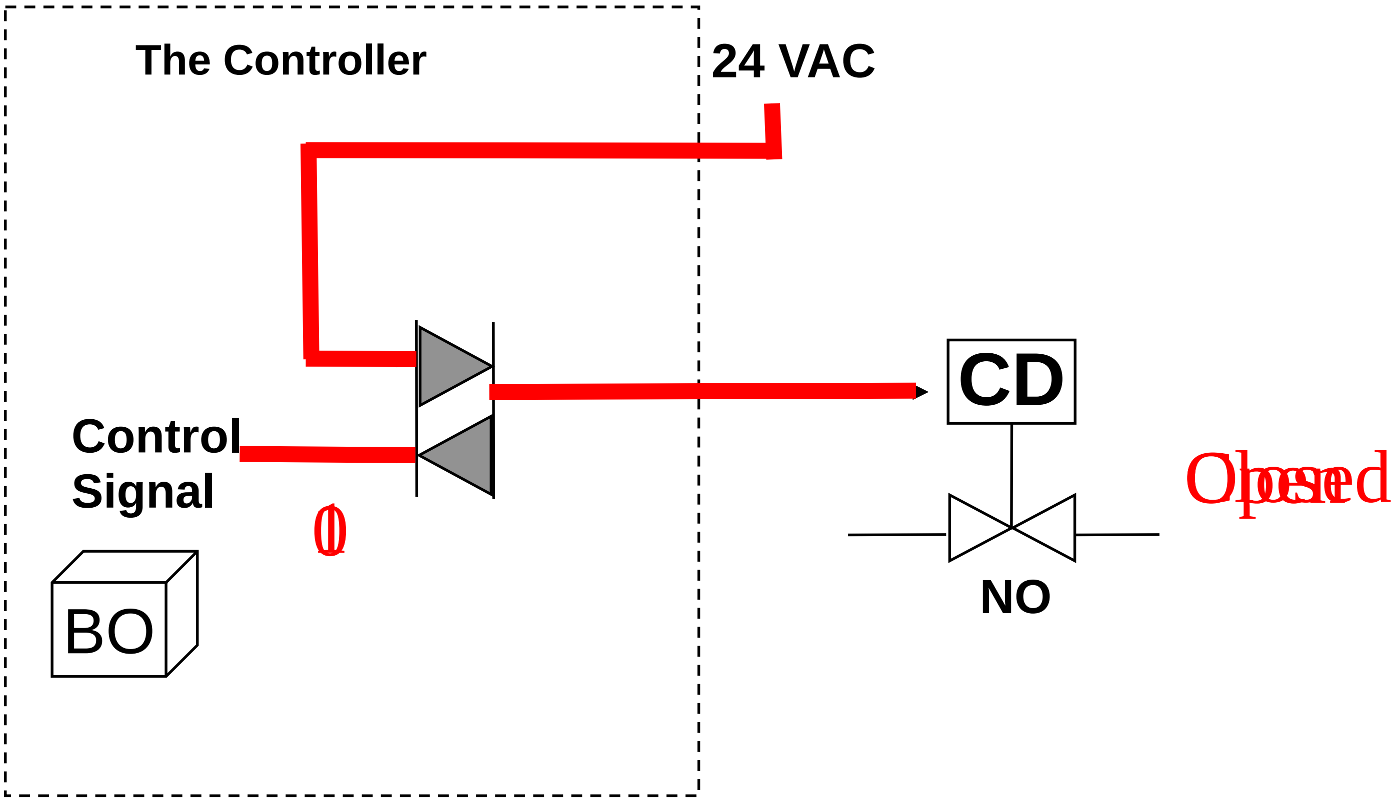


- Generally requires an external relay
- Otherwise is identical in usage to the relay output

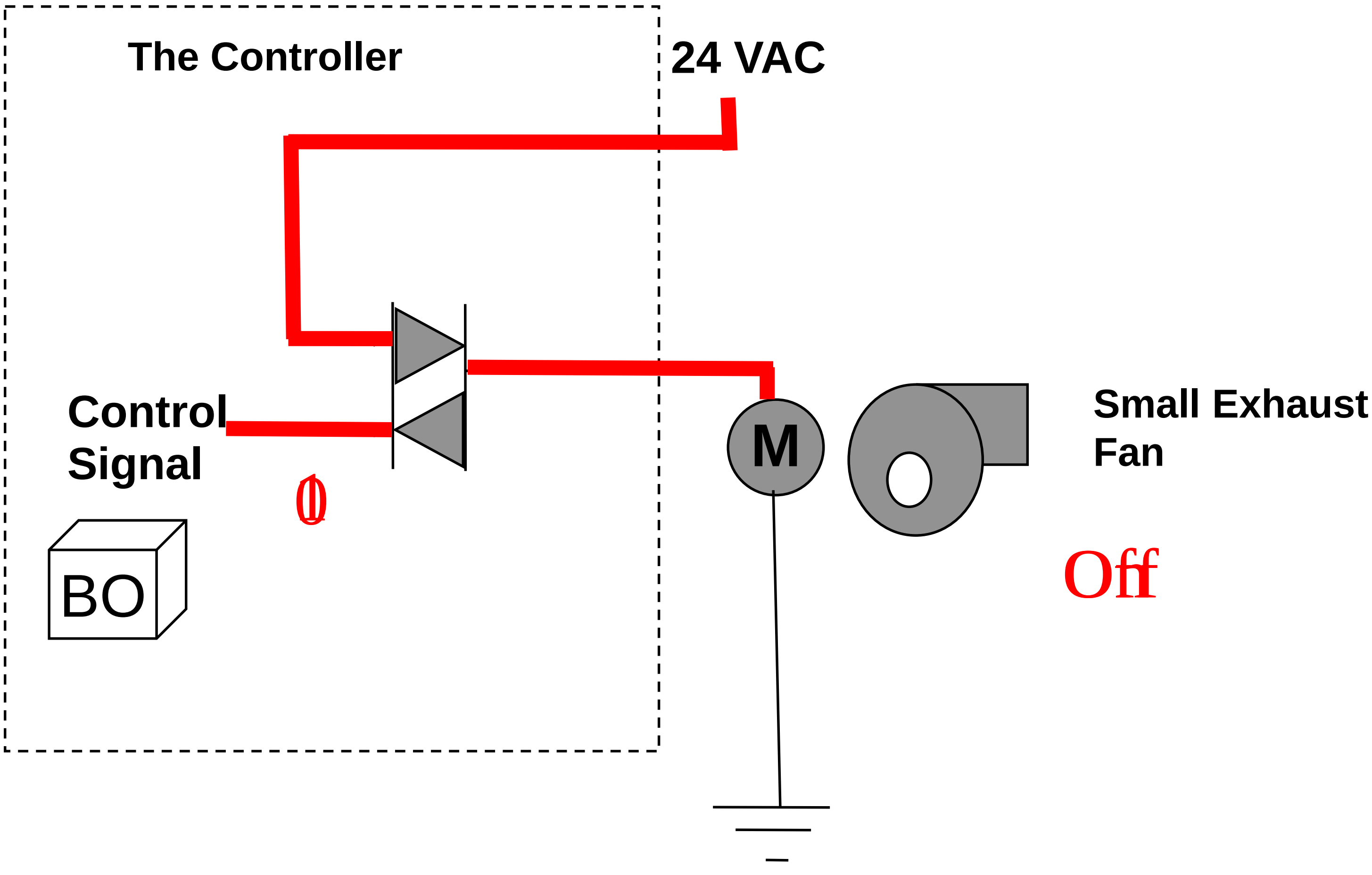
External Voltage Triac

- The triac is just a switch – a substitute for a relay
  - Cheaper
  - More reliable
  - Less power handling (usually limited to 2 A or less)
  - May not be electrically isolated
  - Cannot be used to switch DC loads!
- Common external voltages: 24 VAC, 120 VAC
- Can – if needed – connect to external relay
- Useful for direct connection to low-power loads
  - Small fans, 2-position valves and dampers, etc.

External Voltage Triac



External Voltage Triac



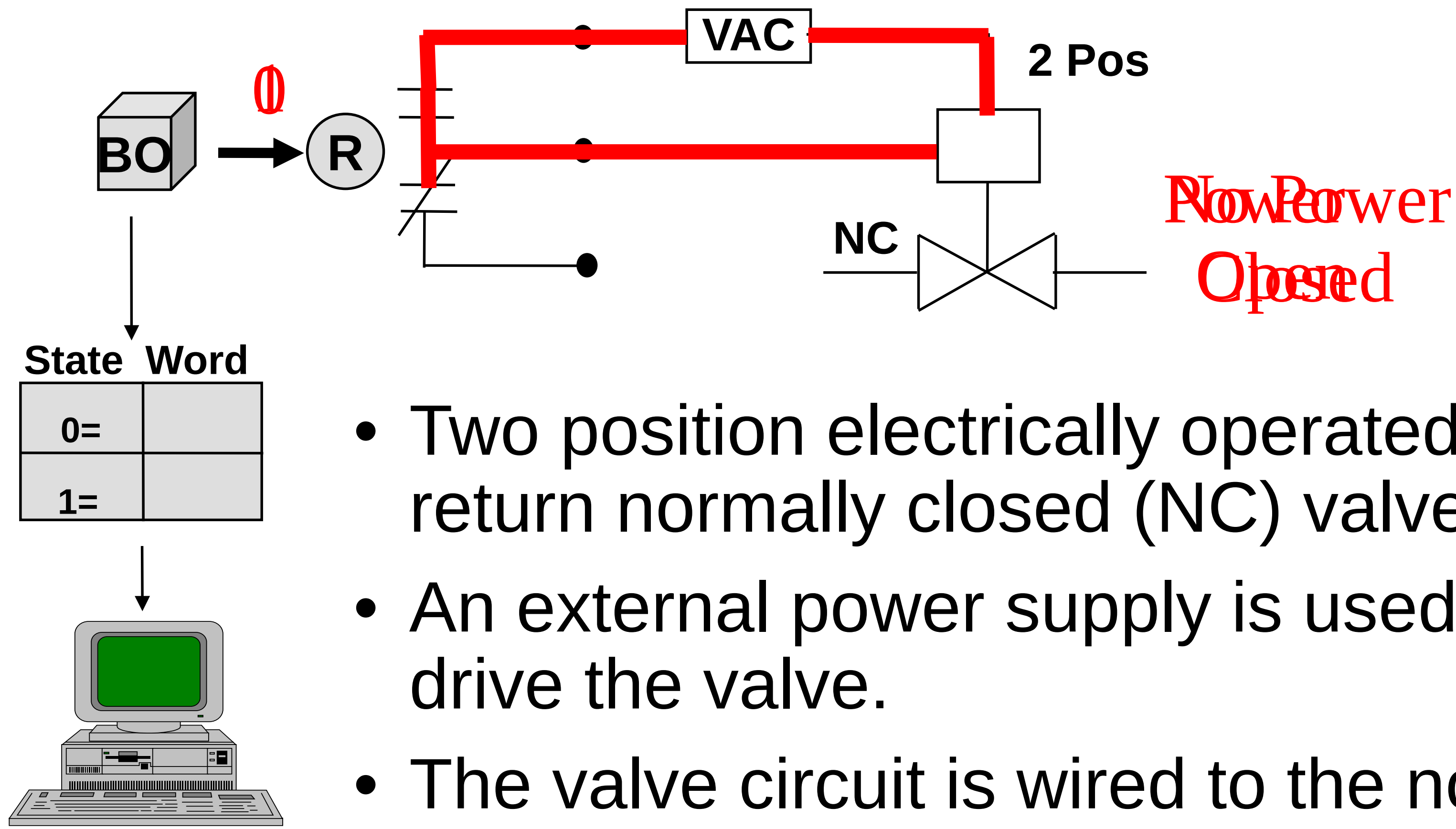
Hardware Types

- From a programming standpoint, through the use of interposing relays, all four types of hardware can be set up to provide a “Normally On” controlled device or a “Normally Off” controlled device.

Example BO set up

- Determine the electrical circuit for the device
- Establish all normals (failed states), both electrical and mechanical
- Sketch and label the circuit on the diagram.
- Define the state descriptors by evaluating the impact of a 0 on the point and a 1 on the point.
- Note any software or hardware inversions of the basic relationships between the integer command and the status of the relay.

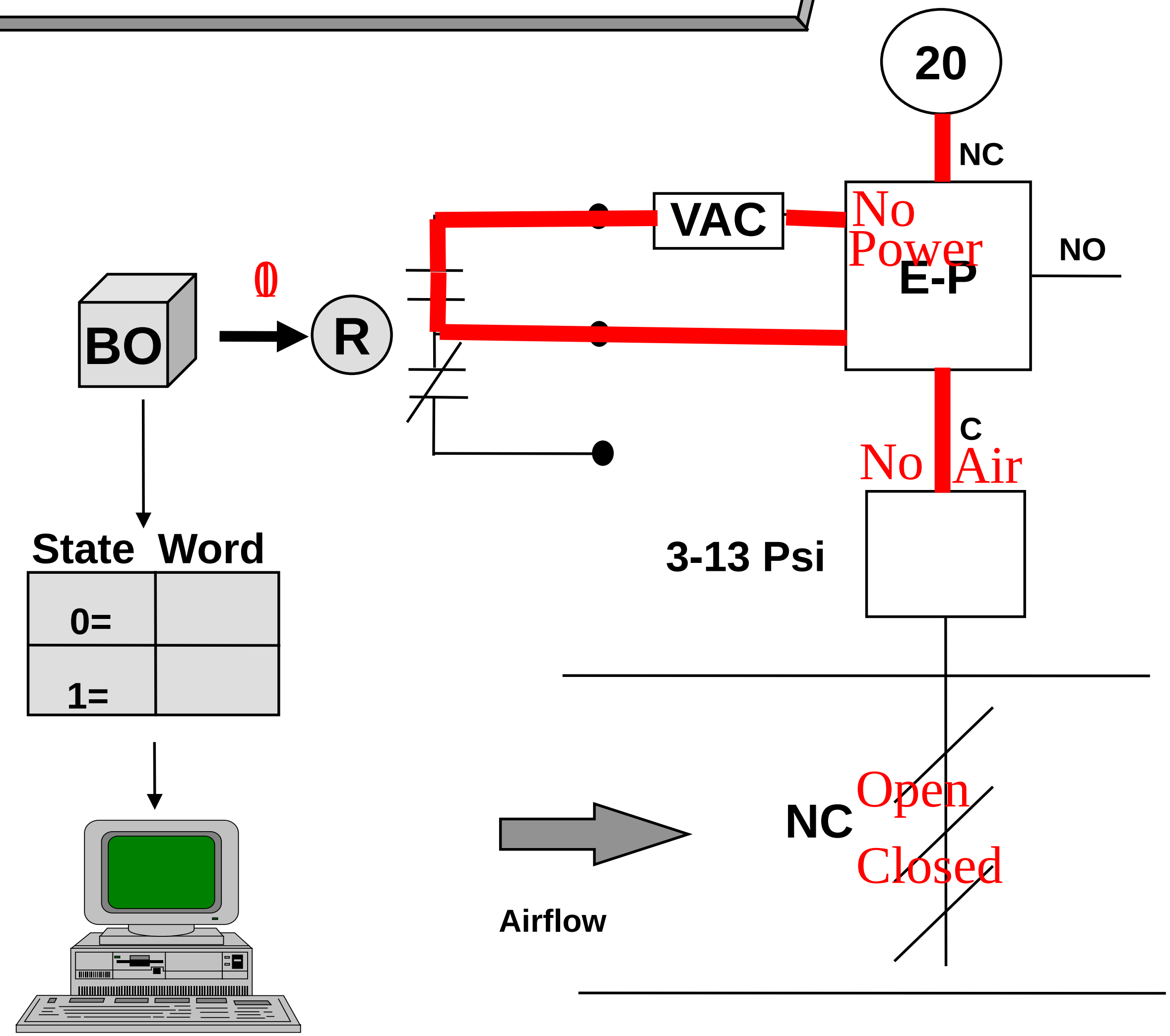
Example Wiring Diagram



- Two position electrically operated spring return normally closed (NC) valve.
- An external power supply is used to drive the valve.
- The valve circuit is wired to the normally open contact on the BO.

Example Wiring Diagram

- NC damper with 3 – 13 psi actuator.
- E-P switch connected to NO relay contact.
- 20 psi main air is connected to the NC port on the E-P switch.



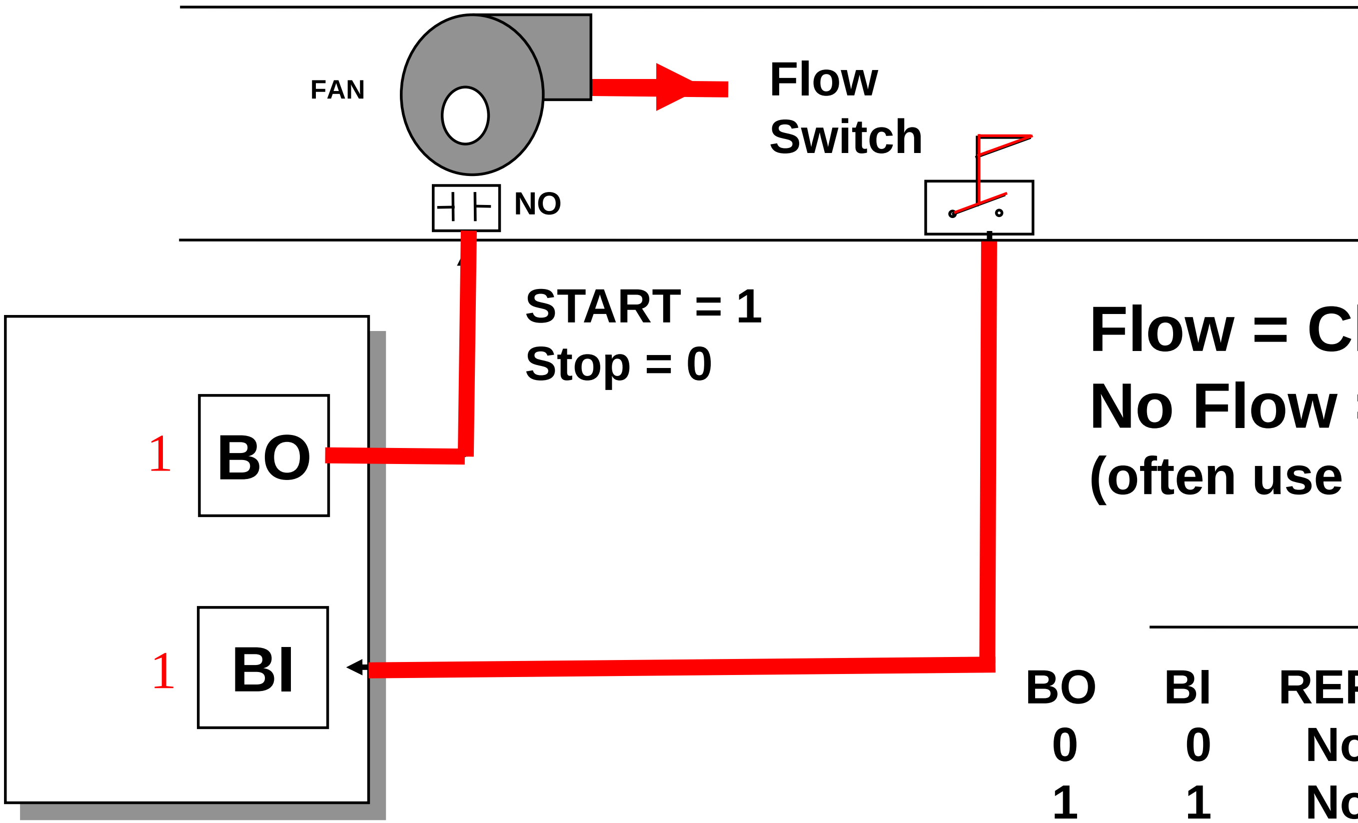
BO Programming Issues

- Consider the following when programming logic for a BO point:
  - “Normal” (Failed) positions
  - Minimum ON time
  - Minimum OFF time
  - How should the BO react to the first cycle of the program after a power cycle?
- We will discuss these issues in the applications blocks.

BO Application: Proof

- Proofing: the concept of associating a binary sensor (BI) with a binary output (BO) to verify (feedback) the performance of the end device.
- Used to ensure a controlled device started and has not failed.

The Concept



Flow = Closed = 1
No Flow = Open = 0
(often use CT)

BO	BI	REPORT
0	0	Normal
1	1	Normal
0	1	Alarm (Optional)
1	0	Alarm

Often, failure of Proof will shut off the fan BO

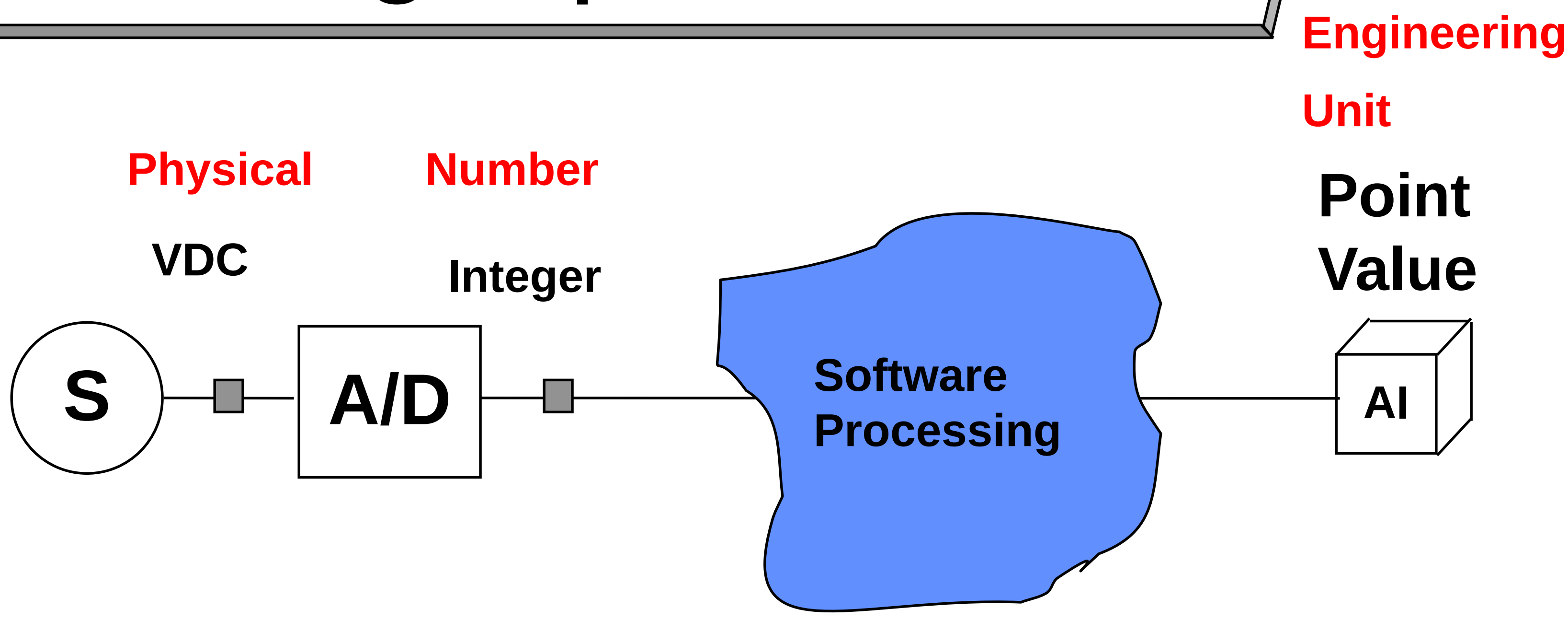
Analog Points

- Hardware Analog Input Points
- Internal Analog Input Points
- Hardware Analog Output Points
- Internal Analog Output Points

Hardware AI Points

- Hardware AI points store the value measured by an electrical input to the DDC controller.
- Several issues are important
  - Sensor range, resolution, and accuracy
  - A/D converter resolution
  - Controller accuracy
  - Overall AI resolution
  - Software processing of the electrical data
  - Calibration concepts

Analog Input Points



A/D: Analog to Digital Converter

AI Data Flow

- The sensor measures a real physical quantity
- Input circuitry generates a DC Voltage signal.
- The A/D converter converts the DC Voltage signal into an integer.
- The integer is processed mathematically by one or more software algorithms.
- The output of the software processing is the calibrated value of the process variable measured by the sensor.

The Sensor

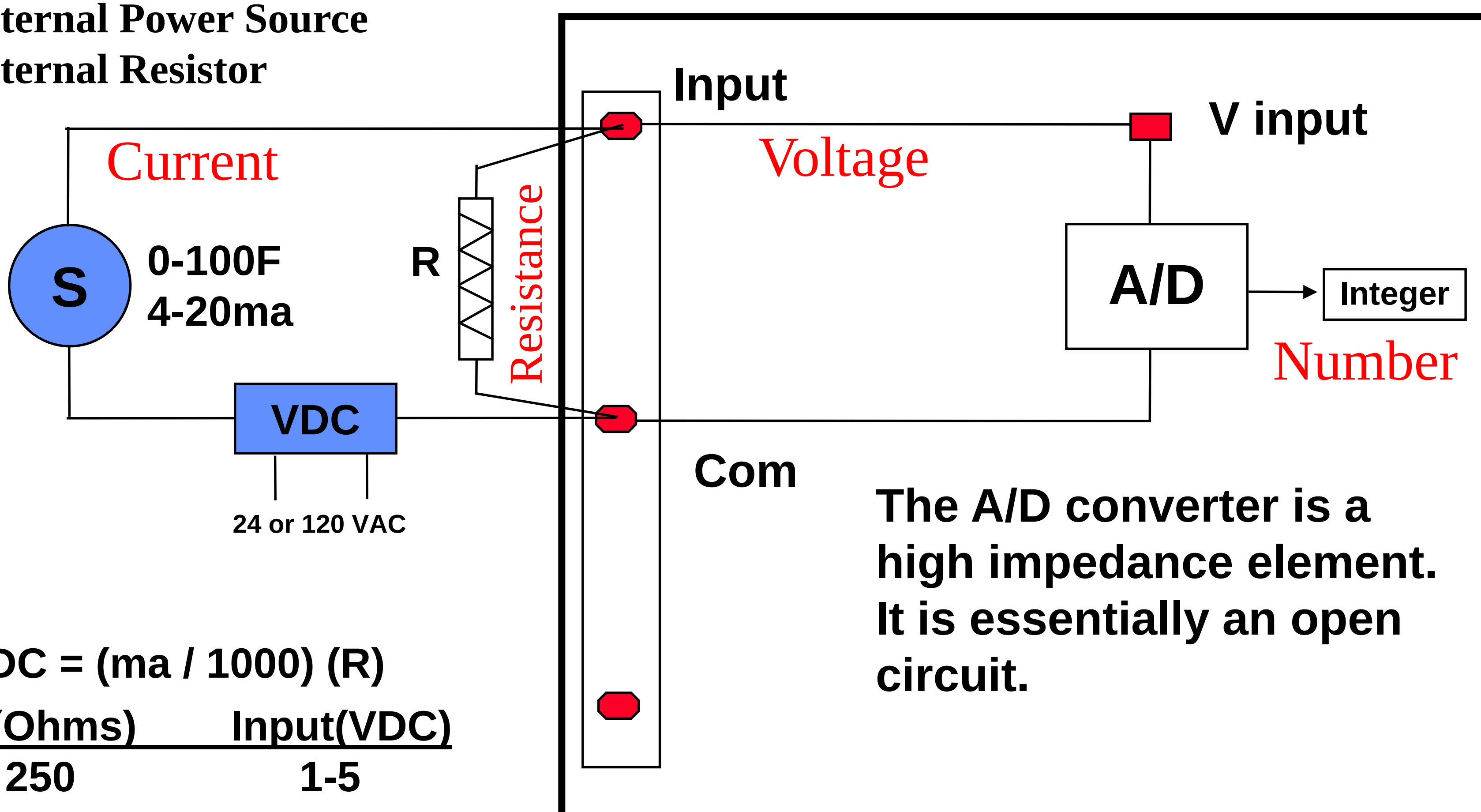
- The A/D converter ***only*** reads DC volts.
- The voltage range of the A/D converter is limited and will vary with different controllers.
- If the sensor does not output DC Volts, the circuit will need to be modified to produce volts.
- If a sensor does not produce a signal in DC Volts that matches the voltage range of the A/D converter, the circuit will need to be modified.
- If the sensor output voltage range is larger than the input range of the A/D converter, the entire range of the sensor will not be "read".

AI Configuration

- The required physical modification will involve the installation of resistors on an input by input basis.
- The resistor size and installation details will depend on the type of sensor and "Universal Input" characteristics of the DDC controller.
- For most modern DDC Hardware, actual configuration will be via software – you'll change a configuration screen and the software will add/remove resistors "under the hood".

Example Circuit

External Power Source
External Resistor



The A/D converter is a high impedance element. It is essentially an open circuit.

Controller

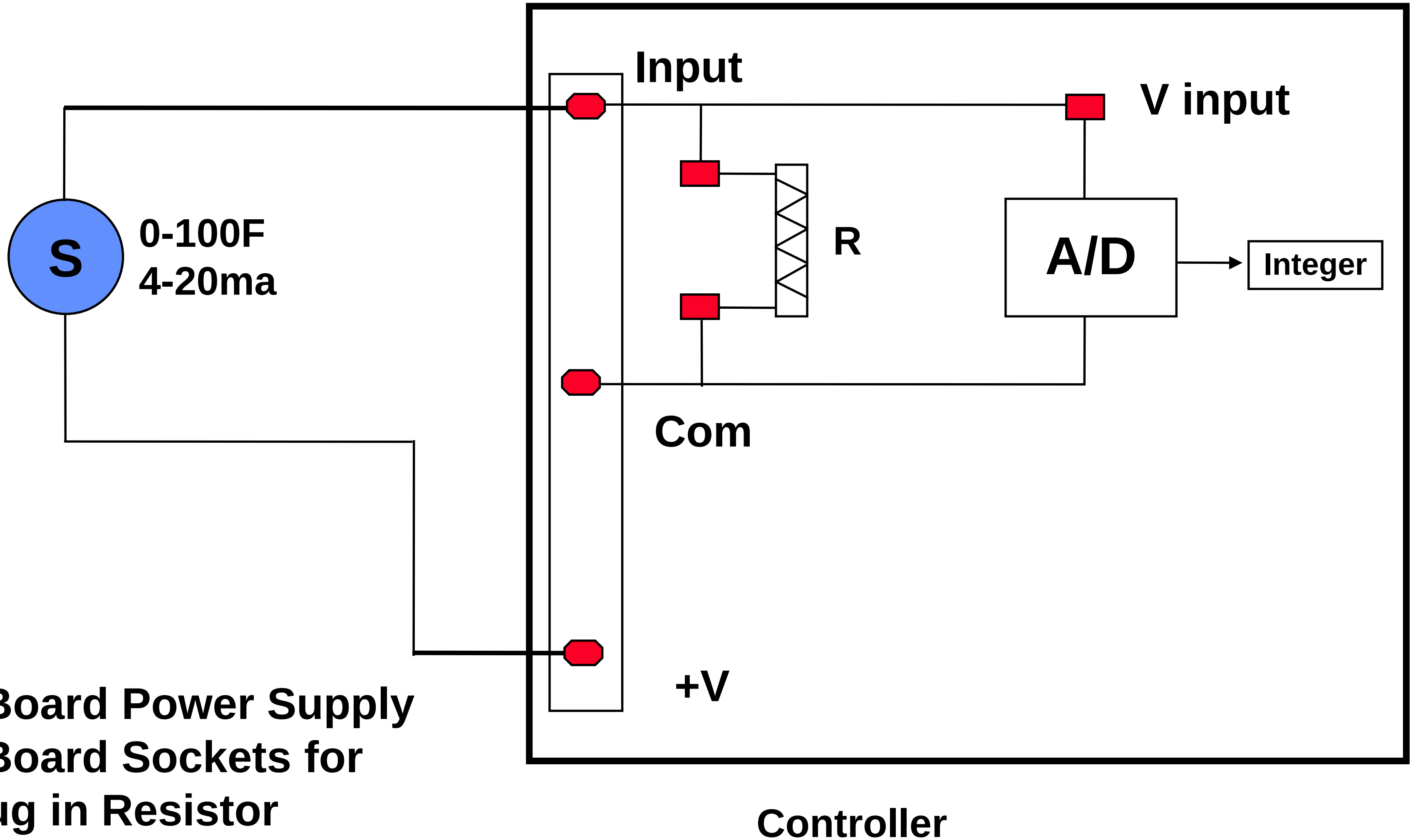
VDC = (ma / 1000) (R)

R(Ohms)	Input(VDC)
250	1-5
500	2-10
600	2.4-12

The Circuit

- Sensor provided current, not volts
- Resistor converts current to volts.
- Resistor value depends on the design voltage range of the A/D converter.
- In this circuit, the sensor required a external DCV power source.
- The A/D has a very high impedance (open circuit) and does not affect the circuit that it is measuring.

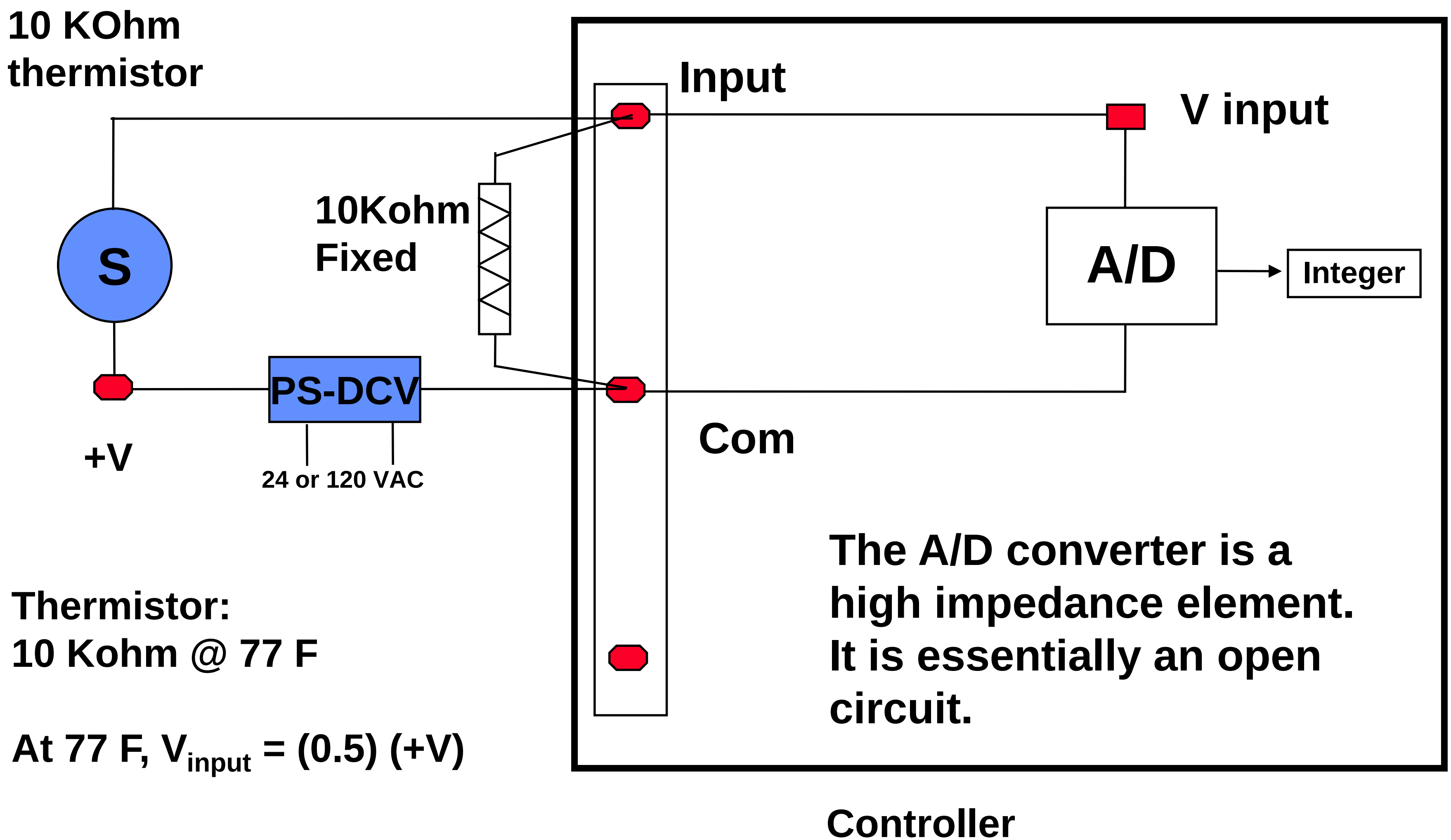
Alternate Circuit



On Board Power Supply

On Board Sockets for plug in Resistor

Example Circuit



The A/D converter is a high impedance element. It is essentially an open circuit.

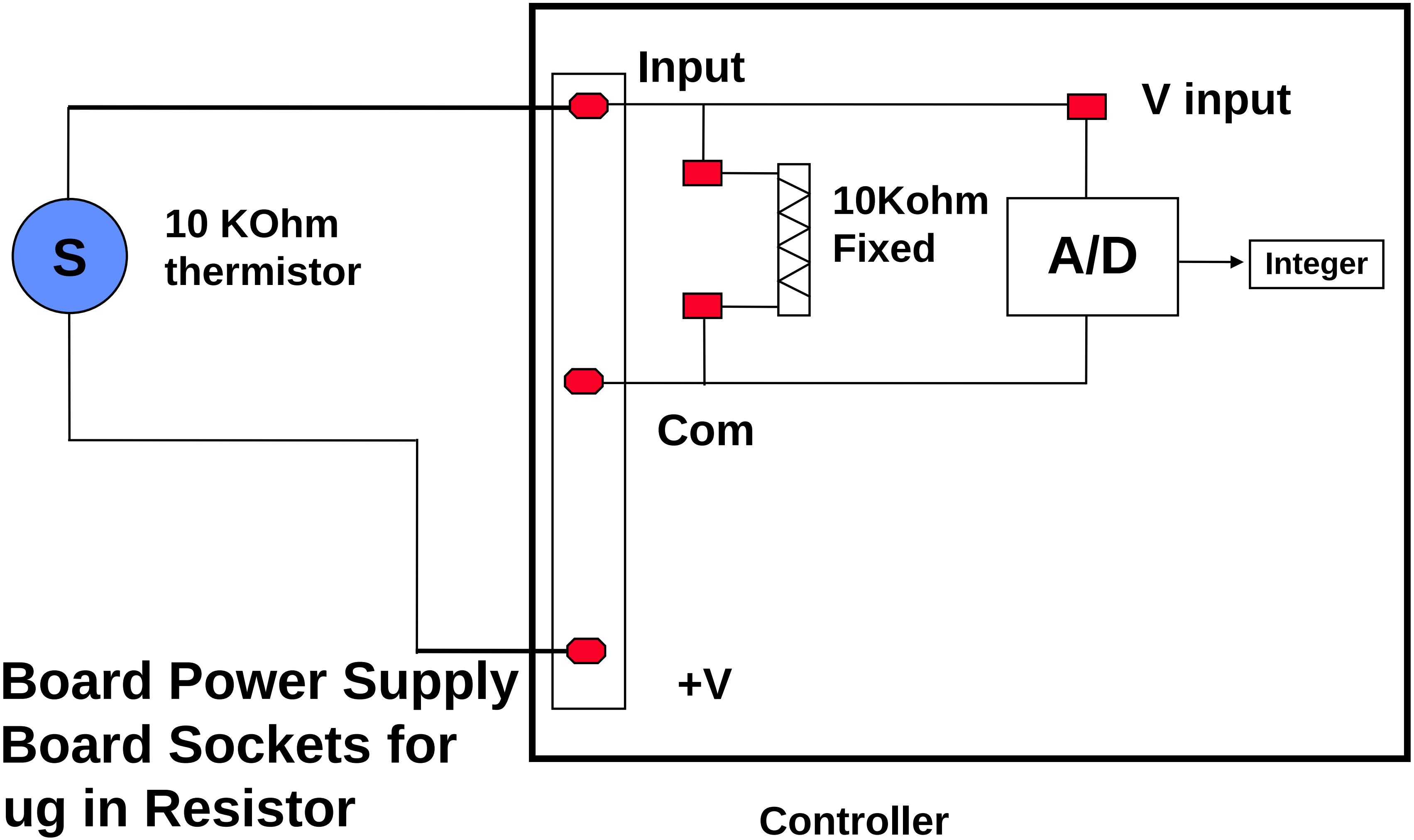
Thermistor:
10 Kohm @ 77 F

At 77 F, $V_{input} = (0.5)\ (+V)$

The Circuit

- Sensor is a 10K ohm temperature dependent resistor. At the temperature rises the resistance falls in a highly non-linear fashion.
- Sensor provides resistance, not voltage.
- 10 Kohm resistor creates a voltage divider: at the rated temperature (typically 77 F), the voltage input will be one half of the power supply voltage.
- As the temperature rises, the thermistor resistance will drop and the voltage input will rise (in a non-linear fashion).

Alternate Circuit



On Board Power Supply

On Board Sockets for plug in Resistor

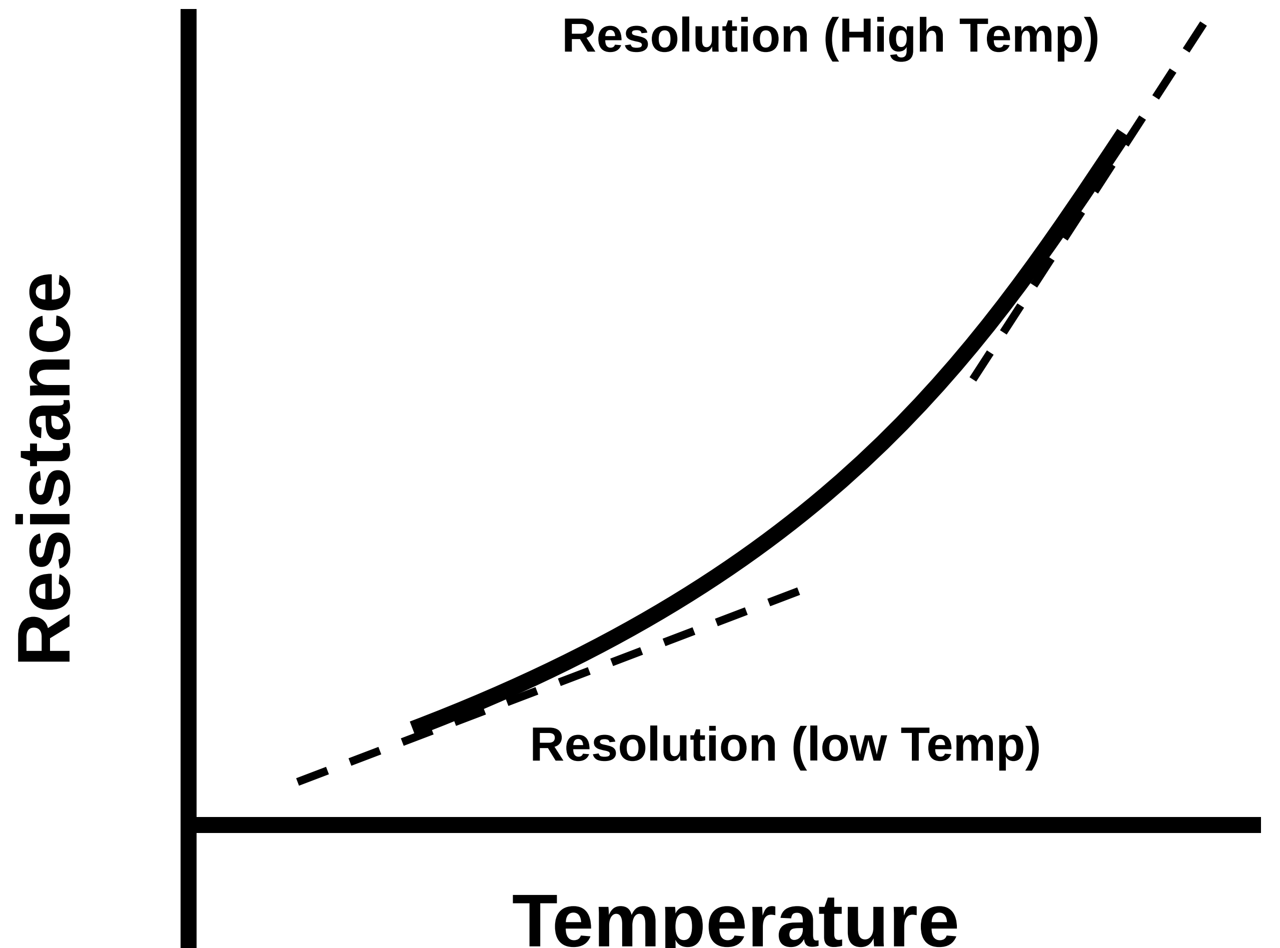
Sensor Resolution

- The sensor resolution is defined as the engineering units per volt.
- Example: A temperature sensor rated 0 to 150 F, 0 to 10 VDC has a resolution of 15 F per volt.
- A temperature sensor rated 50 – 90 F, 0 - 10 VDC has a resolution of 4 F per volt.
  - Careful when writing specs: Is “higher” resolution better?
- Example: A relative humidity transmitter with a 500 ohm dropping resistor is rated 0 to 100%, 2 to 10 VDC. This yields a resolution of 12.5 % per volt.

Sensor Resolution

- With the non-linear thermistor input circuit, the sensor resolution will not be fixed.
- It will vary over the range of the sensor.
- In this case it will be necessary to describe the anticipated operating range and define the worst resolution within that range.

Resolution example



Thermistors

- A sensing element where the resistance falls in a highly nonlinear fashion as the temperature rises.
- Very high resistance which allows for two-wire connection with no transmitter. (Unlike 1000 ohm or 100 ohm RTDs, it can be used in a simple voltage divider circuit.)
- Inexpensive
- Accurate over typical HVAC temperature ranges

Typical Thermistor

- Rated at 10K ohms at 75 ^{o}F.
- Between 32 and 160 ^{o}F a conformity of plus or minus 0.5 ^{o}F. (Accuracy = .3%)
- A look up table is required in the first software processing to linearize the input.
- DDC vendors will usually standardize on specific thermistors and they will provide the look up tables.

The A/D Converter

- Defined by their resolution and voltage range.
- Resolution

  8-bit: 2^8 = possible values are 0 to 255

  10-bit: 2^{10} = possible values are 0 to 1023

  12-bit: 2^{12} = possible values are 0 to 4095

  16-bit: 2^{16} = possible values are 0 to 65535
- Voltage Ranges (Vary by controller model)

0 - 5 VDC	1 - 5 VDC	0 - 12 VDC
0 - 10 VDC	2 - 4 VDC	

Software Processing

- Calibration via Gain and Offset parameters
  - Point Value = Gain x Integer + Offset
- Converts the calibrated value into the appropriate engineering units.
  - Curve fit equation
  - Look up table
  - Square root function

Calibrating AI Inputs

- Controls contractor often say they install calibrated sensors and calibration is not required.
- Do not accept this statement!!
- Adjustment in the processing of the input signal such that the reported value matches the measured value from a test instrument.
- Many field factors introduce error and calibration is a mandatory step in installing a quality system.

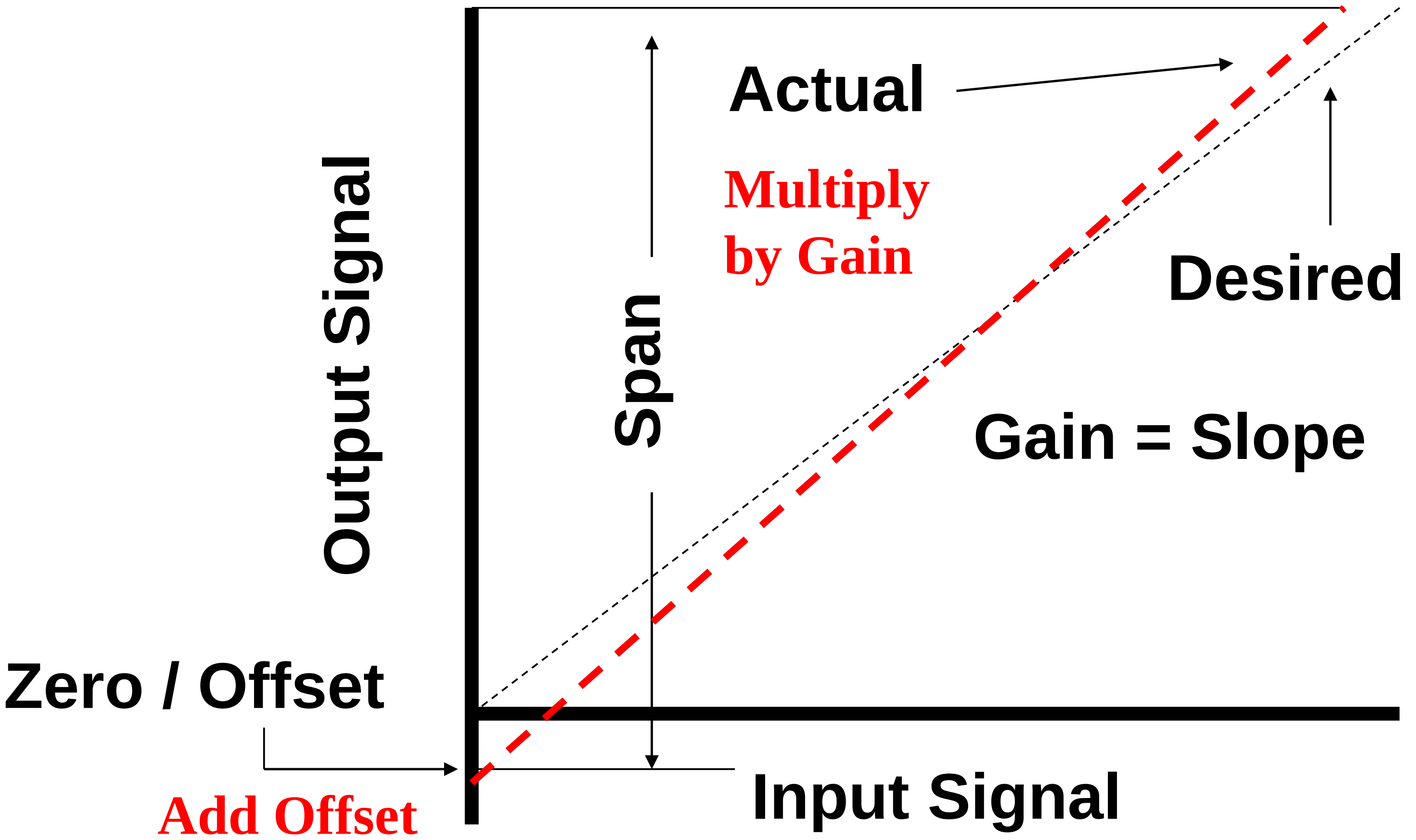
Calibrating AI Inputs

- Calibration software varies from vendor to vendor.
- Require each vendor to clearly state how you can adjust the software processing.
- Some Concepts:
  - Built in offsets within the point template
  - Adjustable ranges
  - Programmed within the logic

Calibration Example

- Temperature sensor: 40 – 90 F gives 0 – 10 Volts
- When measured, 40 F = -.2 V, 90 F = 10.4 V
- Zero offset = .-2 V
- Span (desired) = 10 V, (actual) = 10.6 V
- Gain (desired) = .2 V/F, (actual) = .212 V/F
- Input parameters (zero, span, gain) to correct actual readings to desired.

Calibration Example



RTDs

- Resistance Temperature Detectors
  - 100 ohm platinum
  - 1000 ohm platinum
  - 1000 ohm nickel
  - 1000 ohm balco
- RTDs require special circuits to give accurate and consistent results.
- Not all DDC vendors support the use of RTDs.

RTDs

- Special Circuits
  - Two wire wheatstone bridge circuit
  - Three wire wheatstone bridge circuit
- Vendor will provide the temperature versus resistance performance.
- Four wire, current source circuit.
- RTD in a simple voltage divider will usually result in poor resolution and potential “drift” as the voltage source drifts.

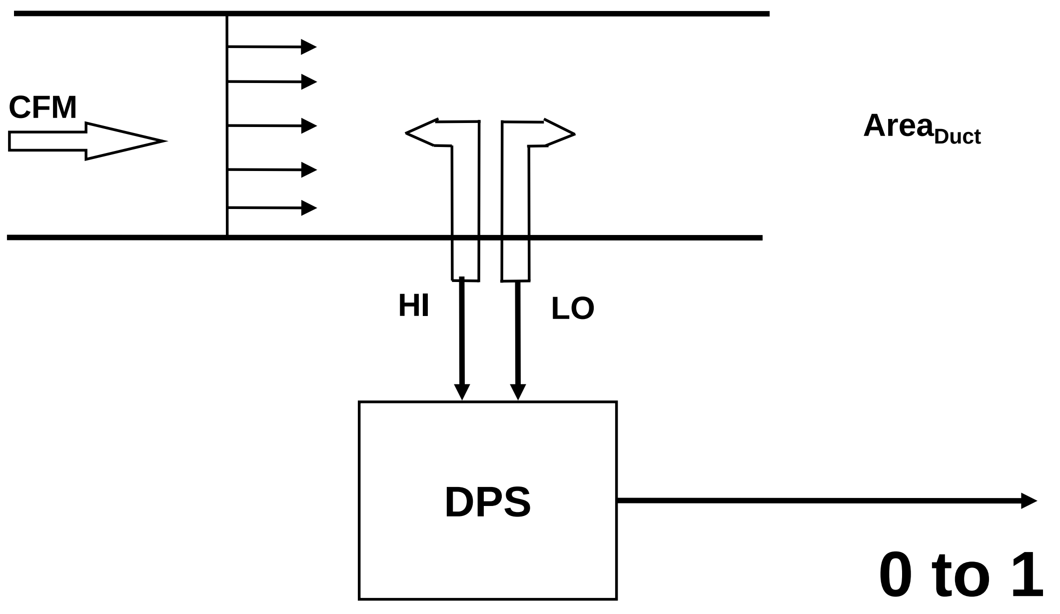
Measuring Air Flow

- The pressure energy is “omni-directional”.
- The motion energy has a very defined direction.
- The combination of the pressure energy and the motion energy is called the “total energy”

Measuring Air Flow

- A probe facing 90 degrees or downstream to the direction of flow measures the pressure and is referred to as the “Static Pressure” (SP).
- A probe facing upstream, looking directly into the flow, measures the total pressure and is referred to as the “Total Pressure” (TP).
- If we subtract the Static Pressure from the Total Pressure, we get the “Velocity Pressure”.
- VP = TP - SP

Air Flow Basics



0 to 1 inches
4 to 20 ma

Air Flow Measurement

VEL = (Flow Coeff) (SQRT(VP))

CFM = (AREA) (Flow Coeff) (SQRT(VP))

- The software processing of the electrical input will include a square root function to linearize the input.
- Flow coefficient will be a number between 2000 and 4000 (4005 is “theoretical limit”).
- We will determine this number from sensor performance data.

Analog Output Points

- External Analog Output points
- Connected to external hardware
- Control logic will produce a signal over the range of 0 to 100%.

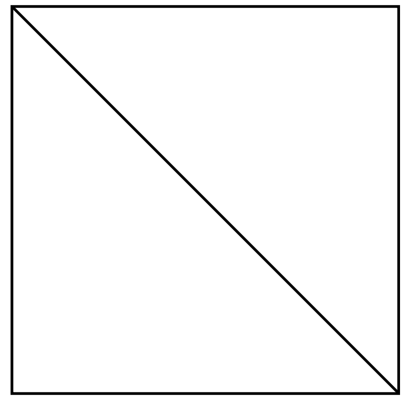
Percent Travel

- Do not confuse *percent travel* with *percent open*, *percent closed*, *percent heat* or *percent cool*.
- ***Percent travel*** refers to the stroke of the actuator on a controlled device.
- If a valve is normally open, it will be 100% open at 0% travel and 0% open at 100% travel.
- Just the opposite will occur with a normally closed valve.
- Again have the “normal” ambiguity

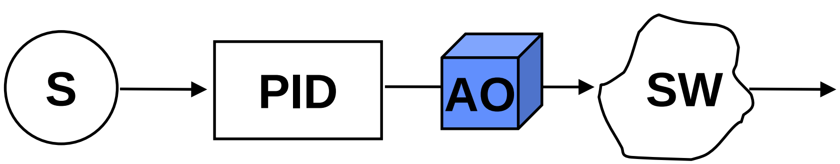
The Term “Percent”

Proportional

Heating control



Assume heating is NO valve

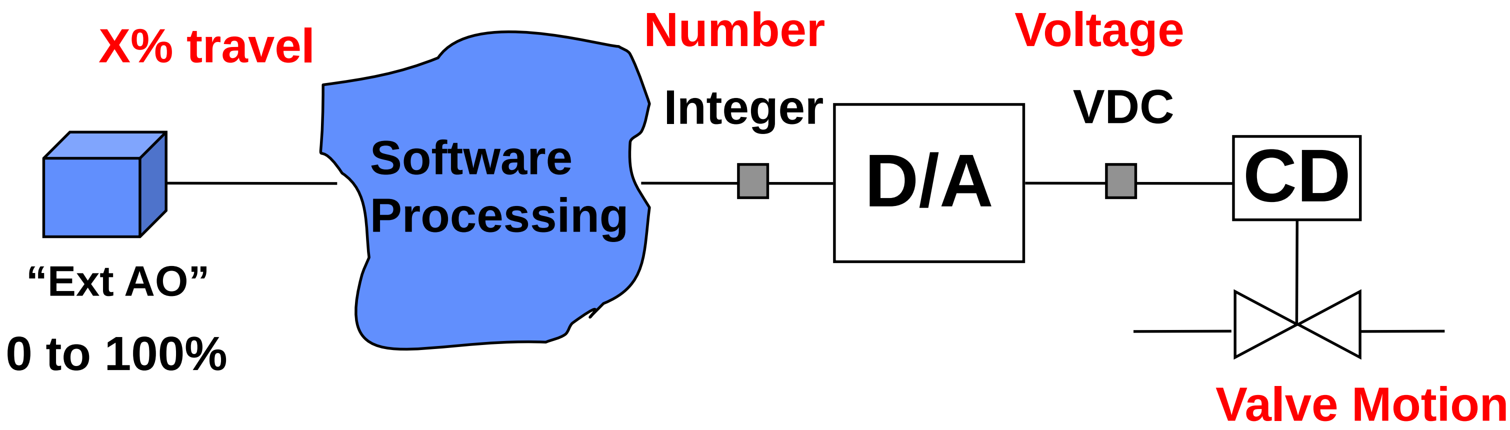


SW configuration of AO inverts 0%-100% to 100%-0%

Analog Outputs

- AO, Direct Connect
  - 4 - 20 ma, no transducer
  - 0 - 10 VDC, no transducer
- AO, with transducer
  - 4 - 20 ma, 3 - 18 psi transducer
  - 0 - 10 VDC, 3 - 18 psi transducer

AO Data Flow



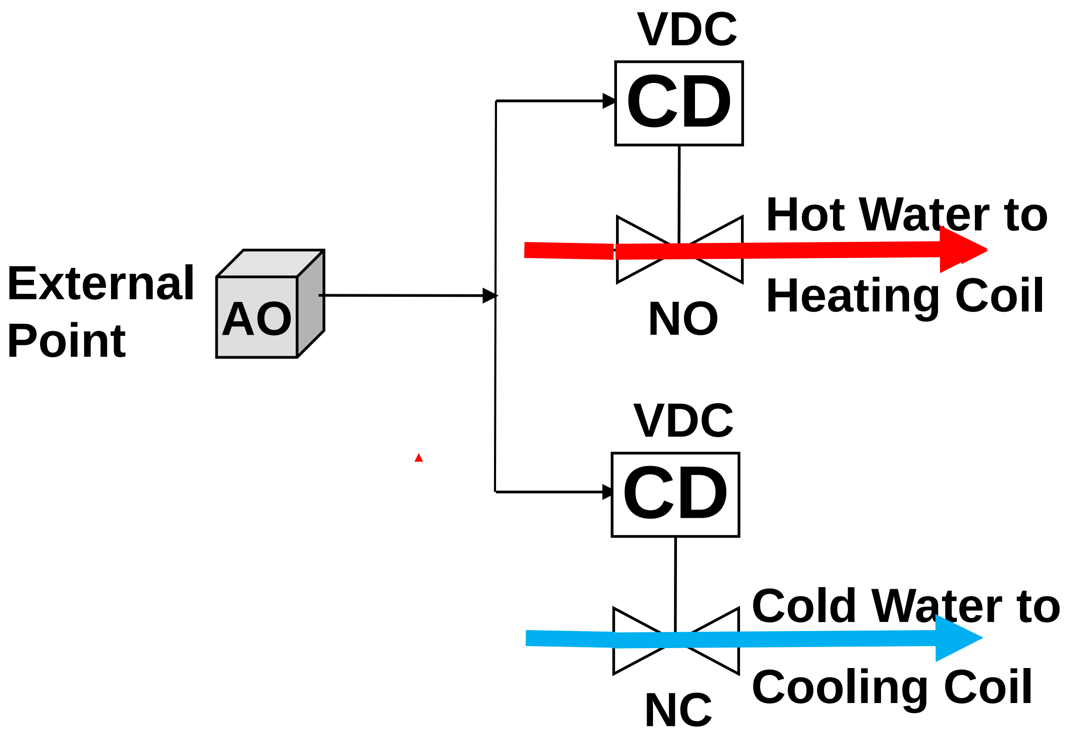
The value in AO point is converted to an integer by firmware (under the hood).

The D/A converter converts the integer to volts.

Output Device Range

- What is the operating range of the controlled device?
  - 0 to 10 VDC
  - 4 to 20 mA
  - 5 to 10 psi
  - 6 to 9 VDC
      - Perhaps sequenced valves

Sequenced Valves



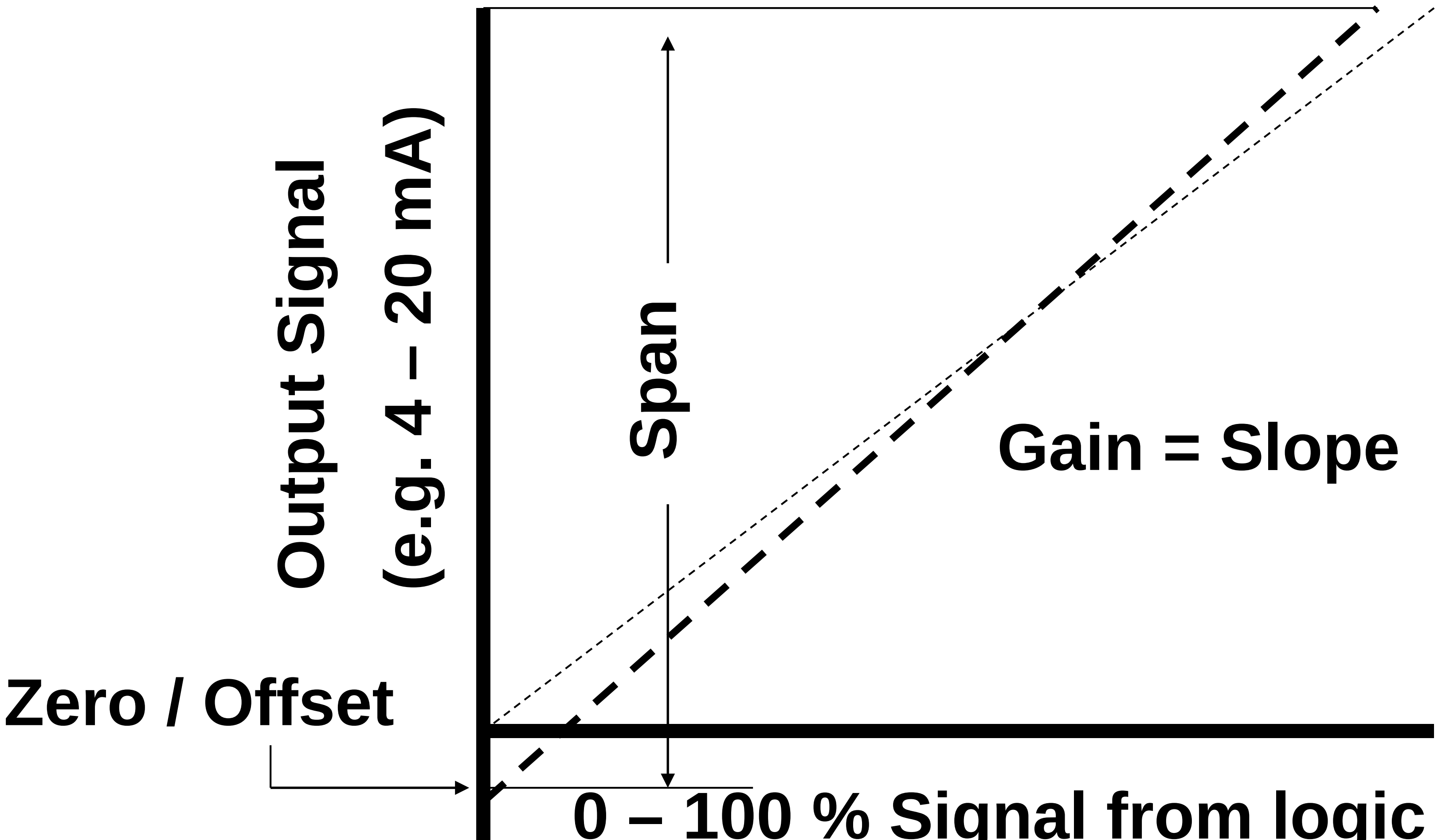
As output goes from 0% to 100%:

1) **Heating valve full open, Cooling valve full closed.**
2) **Heating valve partially open**
3) **Heating valve full closed**
4) **Cooling valve partially open**
5) **Cooling valve full open.**

Calibrating AOs

- Calibration software varies from vendor to vendor.
- Require vendor to clearly state how you can adjust the software processing.
- Some Concepts:
  - Built in offsets within the point template
  - Adjustable ranges
  - Programmed within the logic

Calibrating AOs



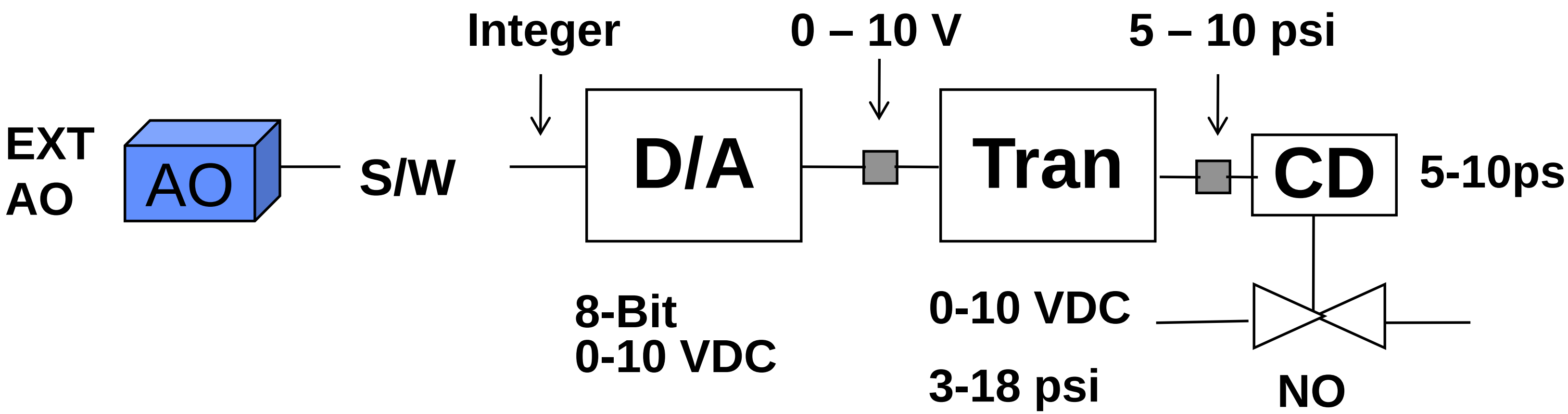
Hardware Transducers

- Transducers are inserted into the data flow between the D/A converter output and the controlled device.
- A typical example is an V-P transducer that will change a 0 to 10 VDC output from an A/D converter to 3 to 18 PSI for a pneumatic valve or damper operator.
- Note that while full range of the output might be 0 – 10 VDC, for a particular application we might not want our output to span the full range of 0 – 10 VDC.

An Example

Calibrate AO so

0% = Closed and 100% = Open



The Transducer converts VDC to PSI.

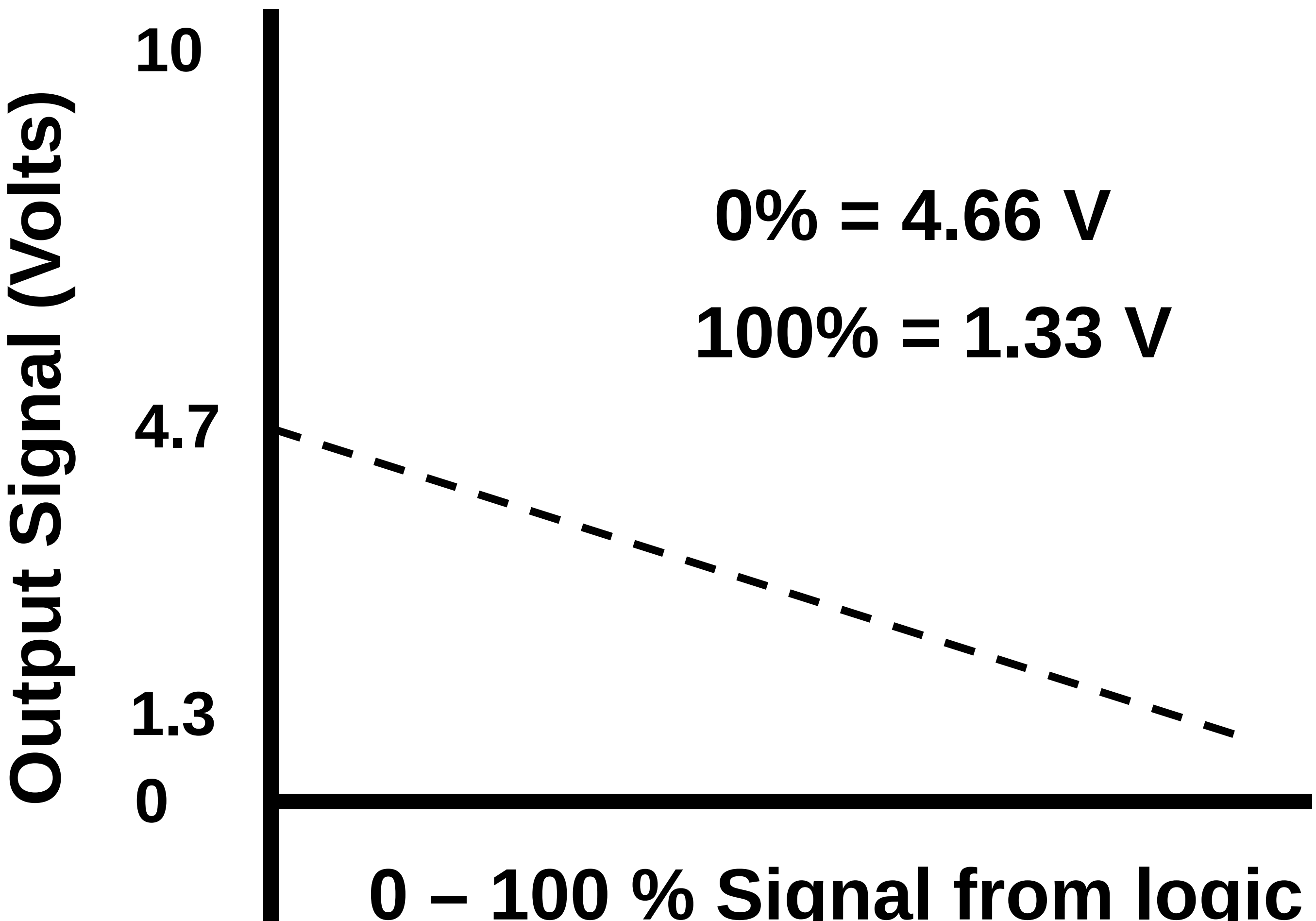
Configuring an AO

- Start with: 5 PSI is Open, 10 PSI is close
- Then for the 0-10 V → 3-18 PSI transducer:

VDC	PSI	
0	3	
1.333	5	“Full Open” for actuator / valve
3.333	8	
4.666	10	“Full Closed” for actuator / valve
6.666	13	
10.00	18	

- Then:
  - 1.333 V = 100% Open
  - 4.666 V = 0 % Open (full Closed)

Calibration Example



The Accumulator Point

- A point where the analog value is equal to the previous value plus an amount to be added during the current scan.
- Typically there are two types of accumulator points structured for different applications:
  - Hardware Pulse Counters
  - Internal

Hardware Accumulator Points

- Hardware pulse counters are connected to external binary pulse sensors.
- Each sample rate of the program the number of pulses accumulated during the sample rate time period are multiplied by the “meter factor” and then added or “accumulated” in a point.
- The count will increase until the data set limit is reached or it is reset to a lower value by a software program.
- Typical units for the meter factor are:
  - KWH per pulse
  - Gallons per pulse
  - CF per pulse

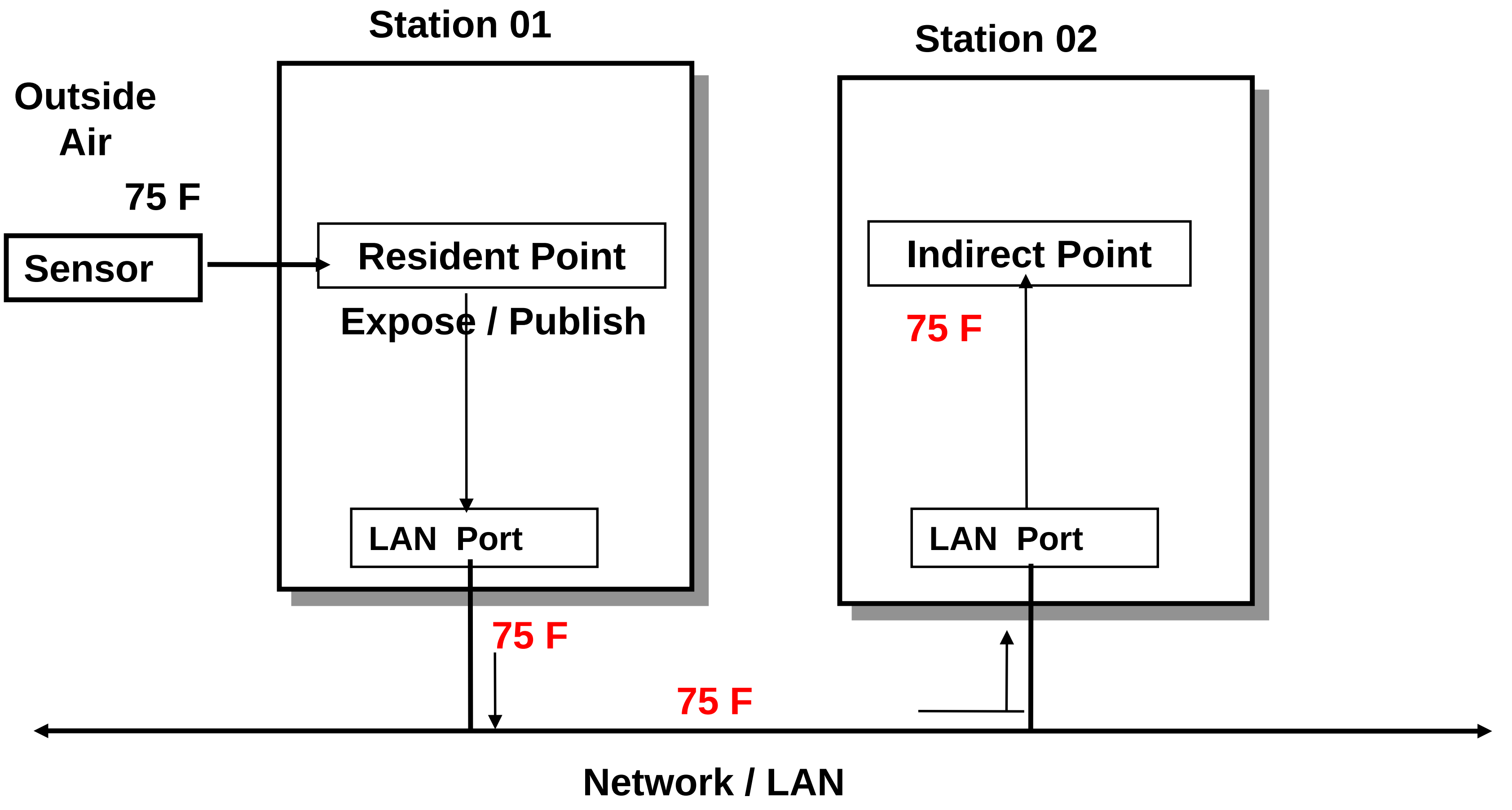
Internal Accumulator Points

- Internal Accumulator points accumulate the value resulting from a calculation.
- When the calculation is executed, the result is added (or subtracted) to the previous analog value stored on the point.
- The analog value will continue to increase (or decrease) until it reaches a limit or it is reset to a different value by a software program.
- Often used by optimization or reset calculations. Duct Static Pressure Reset.

Network Data

- A very powerful feature of networked DDC systems is the ability to move data from one controller to the other.
  - In each controller that is to share data with another controller there must be a point to store the data.
  - The terms “Expose” or “Publish” describes sending point data out onto the network.
  - The term “Indirect Data” describes receiving data from the network.

Example Network Data



Exposed / Indirect Data

- A hardware point in a controller receives data from an external sensor.
- The data from the external sensor can be sent to another controller.
- An input variable in a second controller is programmed to receive the data.
- Be very careful not to overload the network.
- Broadcast updates only as often as necessary.
- Be careful about relying on the network for critical data.

Network Data

- Both proprietary and open protocol systems have the ability to send and receive data to and from the network.
- Defining which data must be on the network is a specification issue – particularly for Open Systems.
- Software concepts will vary from vendor to vendor.
- This is a powerful concept and it must be mastered to achieve the full capability of DDC systems.

“Value” Points

- BACnet also has “Value” Objects:
  - Analog Value
  - Binary Value
  - Multi-State Value
- These are typically used for internal, virtual points.

Conclusion

- The concept of points is fundamental to the operation of DDC systems.
- While the language and terminology varies from vendor to vendor, the basic elements of binary and analog points are universal.
- Your challenge is to master the presentation of the elements for the system you work with.