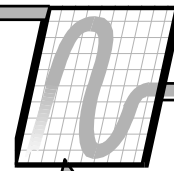
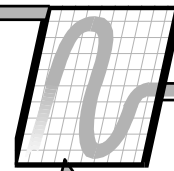


# Fundamentals of DDC



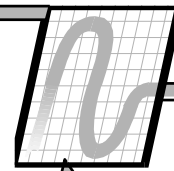
## **Input & Output Data Flow**

# 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
  - 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

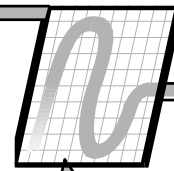
- BACnet uses Binary ..... I agree....

- Analog Data

- Value of the data is numeric, a decimal number
  - e.g 327.56
  - Does the data come with engineering units?

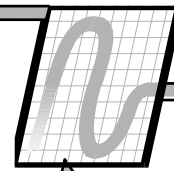
327.56 ..... CFM? ..... LPS?..... GPM?

# Data Types: Multi-state



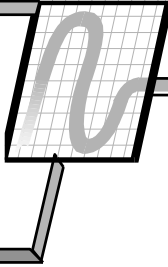
- Value of the data is a small integer
- Represents one of several options
- Occupancy is a prime example:
  - OCCUPIED
  - UNOCCUPIED
  - STANDBY
  - WARMUP/COOLDOWN
- Internally, these “State Descriptors” are represented by a number.
- System “modes” are another example

# 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.

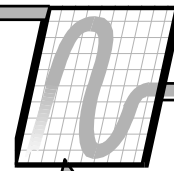
# Data Source: Internal



- 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

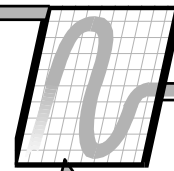


# Data Source: Network



- 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

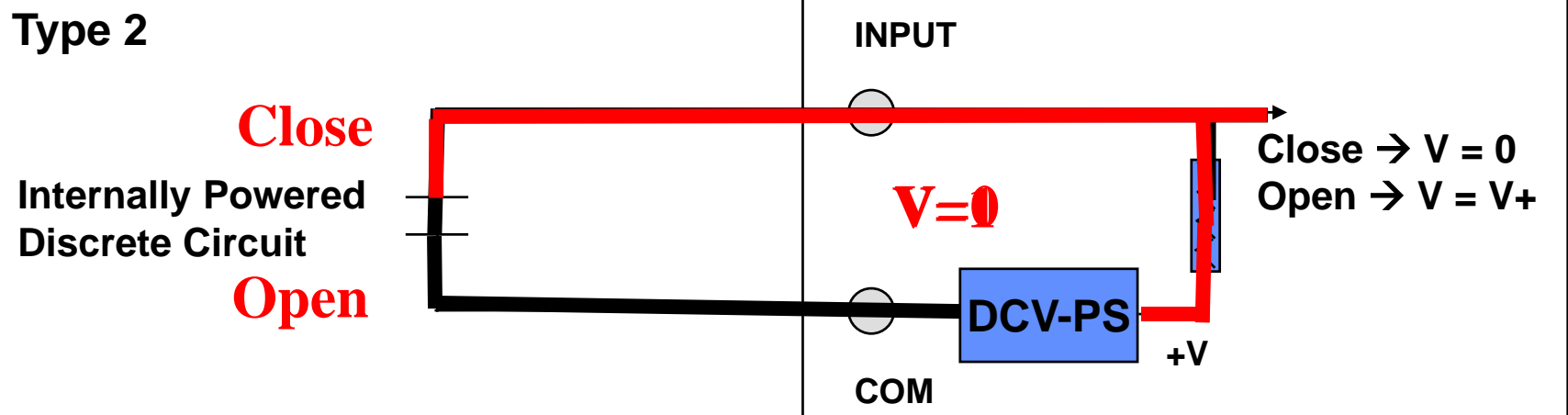
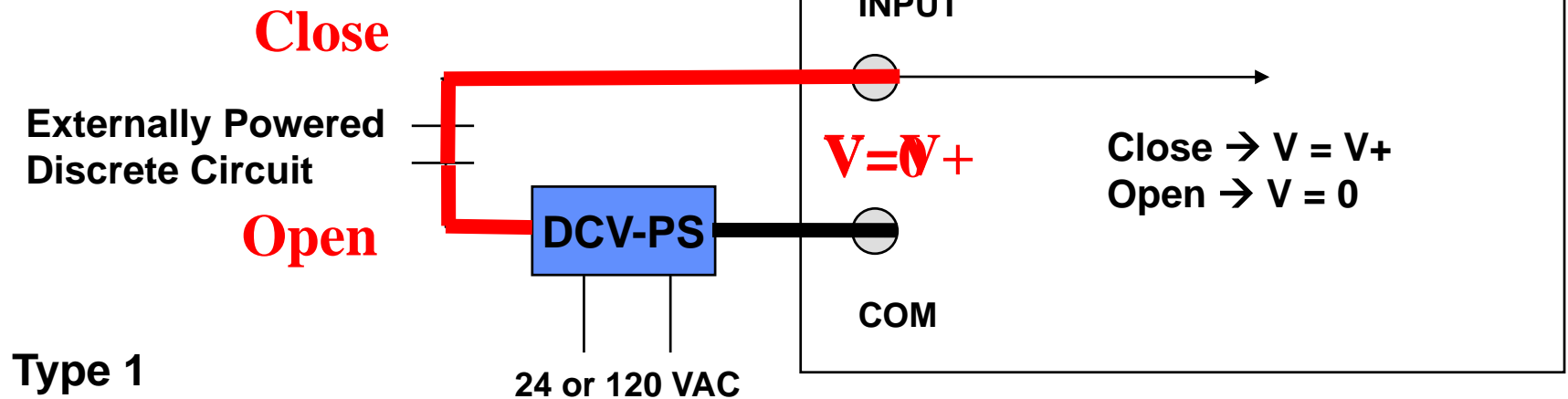
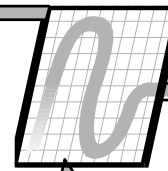
0 = Alarm  
1 = Normal

# External Binary Inputs

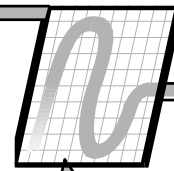


- External Binary Inputs are established by placing a set of contacts in a voltage/resistance circuit.
- The opening and closing of the contacts will open or close the circuit sending a voltage or no voltage to the controller.
- We'll draw detailed circuits – with modern controllers, these wiring details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

# Circuit Diagrams



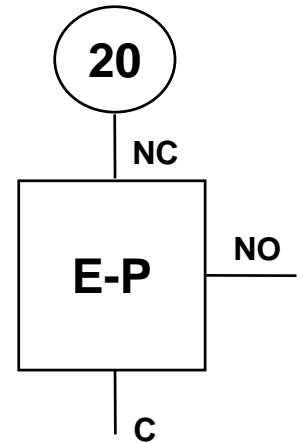
# Binary Output Points



- 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

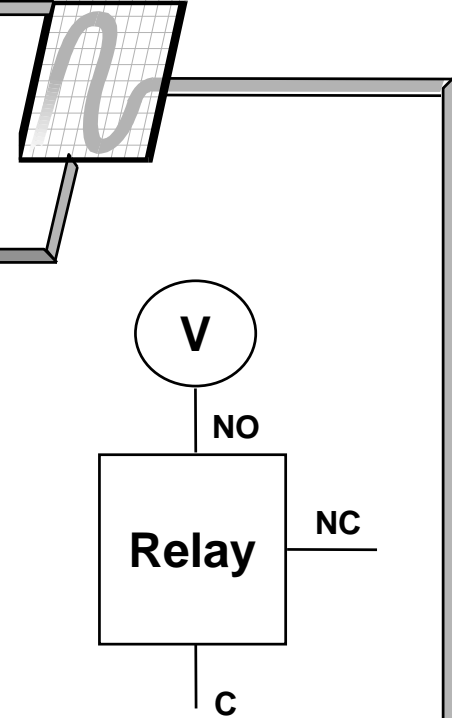
# “Normal” positions

- 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

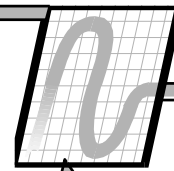


# “Normal” positions

- 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**



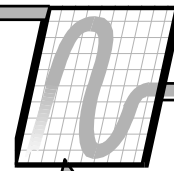
# “Normal” vs “Failed”



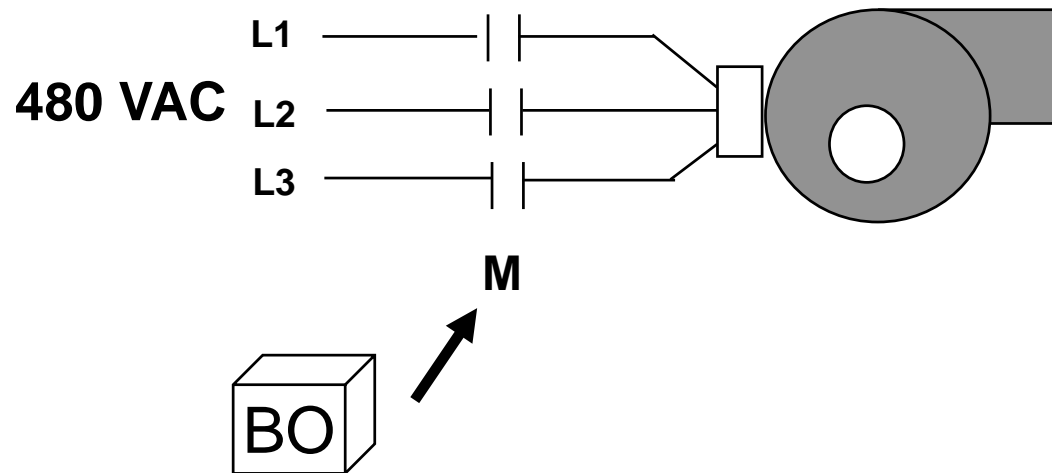
- “Normal” technically means:
  - The position of the output when power is removed
- Is often confused with:
  - The position the output is “normally” in
  - A normally closed valve may “normally be open”
- Use term “failed” instead
  - Failed Open
  - Failed Closed
  - Fail in Last Position (FILP)
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



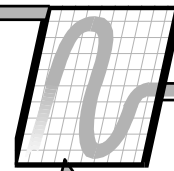
# Binary Outputs



- 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.

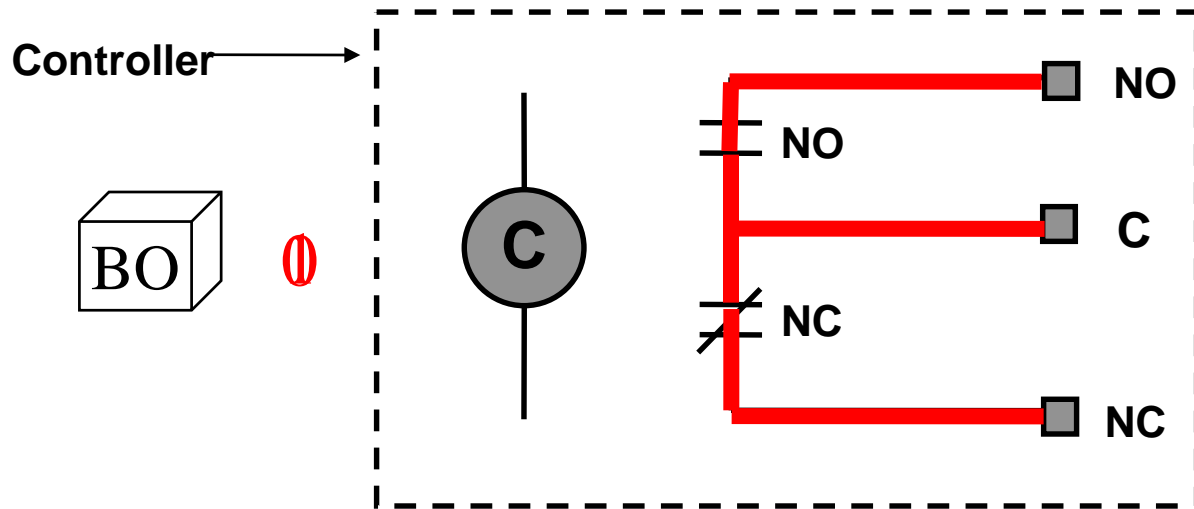


# Hardware Types



- 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



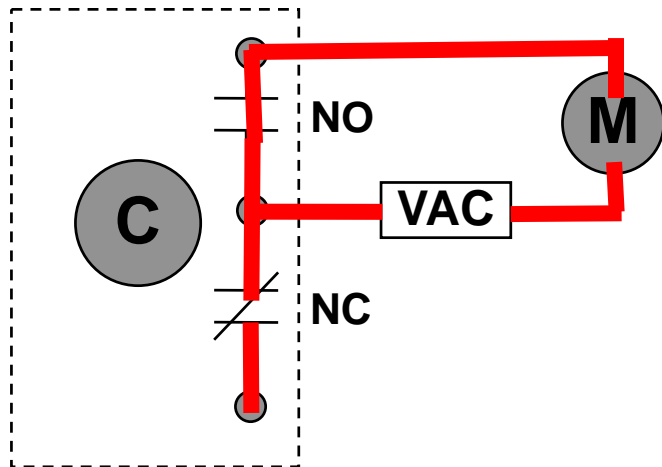
When a value of 0 is sent to the BO point , the relay will be de-energized and terminal NC will be electrically connected to terminal C.

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

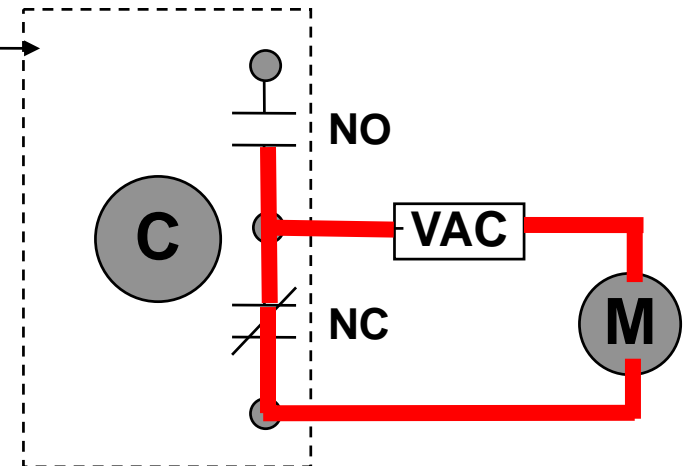
Start	Command = 0
Stop	Command = 1



“Failed Off”

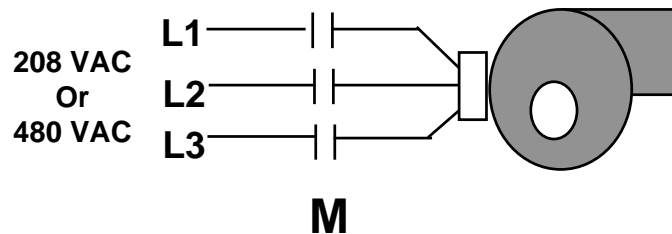
~~Normal~~

The Controller →



“Failed On”

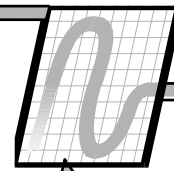
~~Normal~~



M

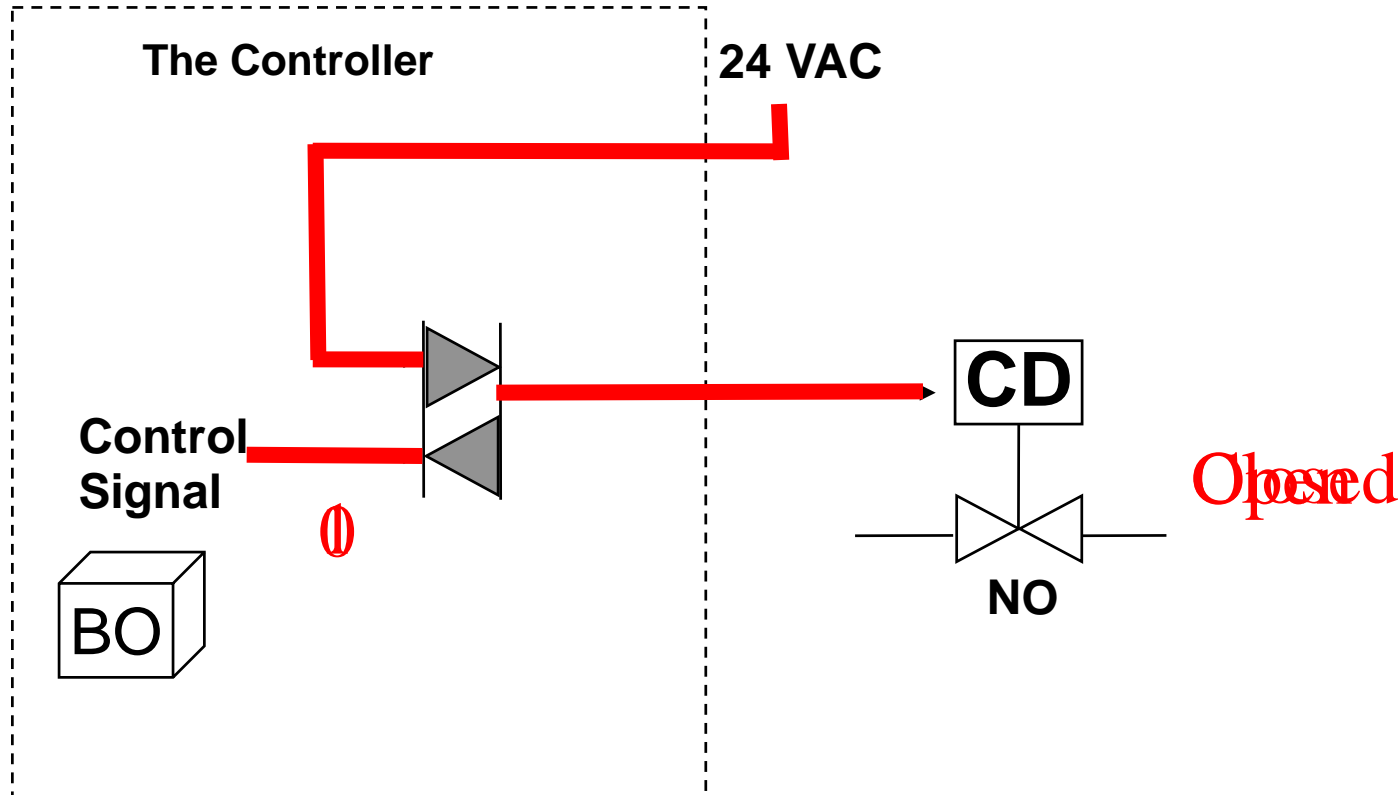
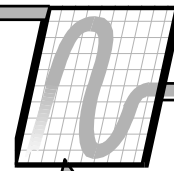


# External Voltage Triac

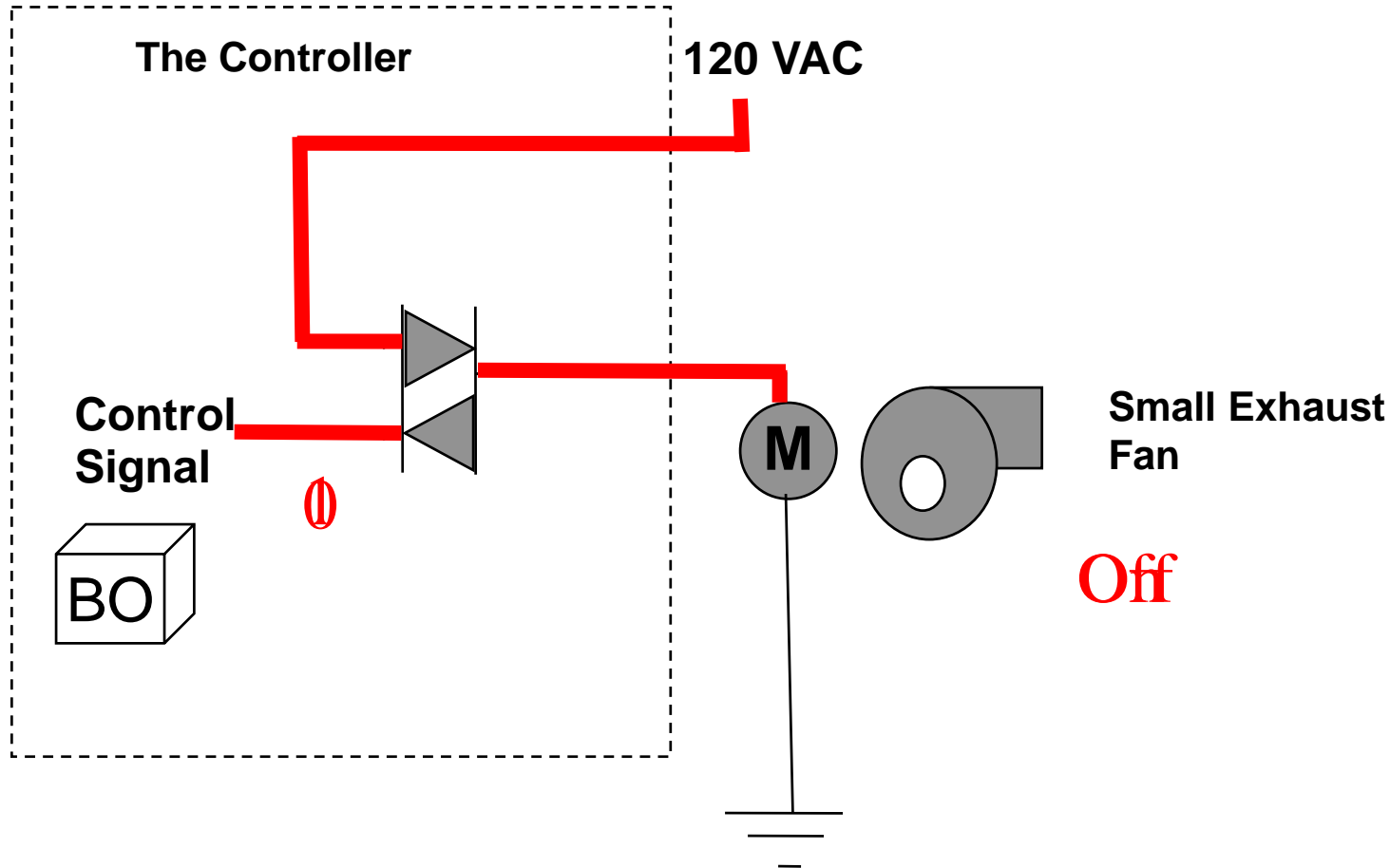
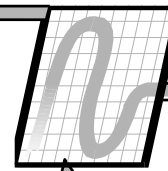


- The triac is just a switch – a substitute for a relay
  - Cheaper
  - More reliable
  - Less power handling (usually limited to 2 A or less)
  - May not be electrically isolated
  - Cannot be used to switch DC loads!
- Common external voltages: 24 VAC, 120 VAC
- Can – if needed – connect to external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

# External Voltage Triac



# External Voltage Triac



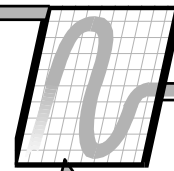


# Hardware Types



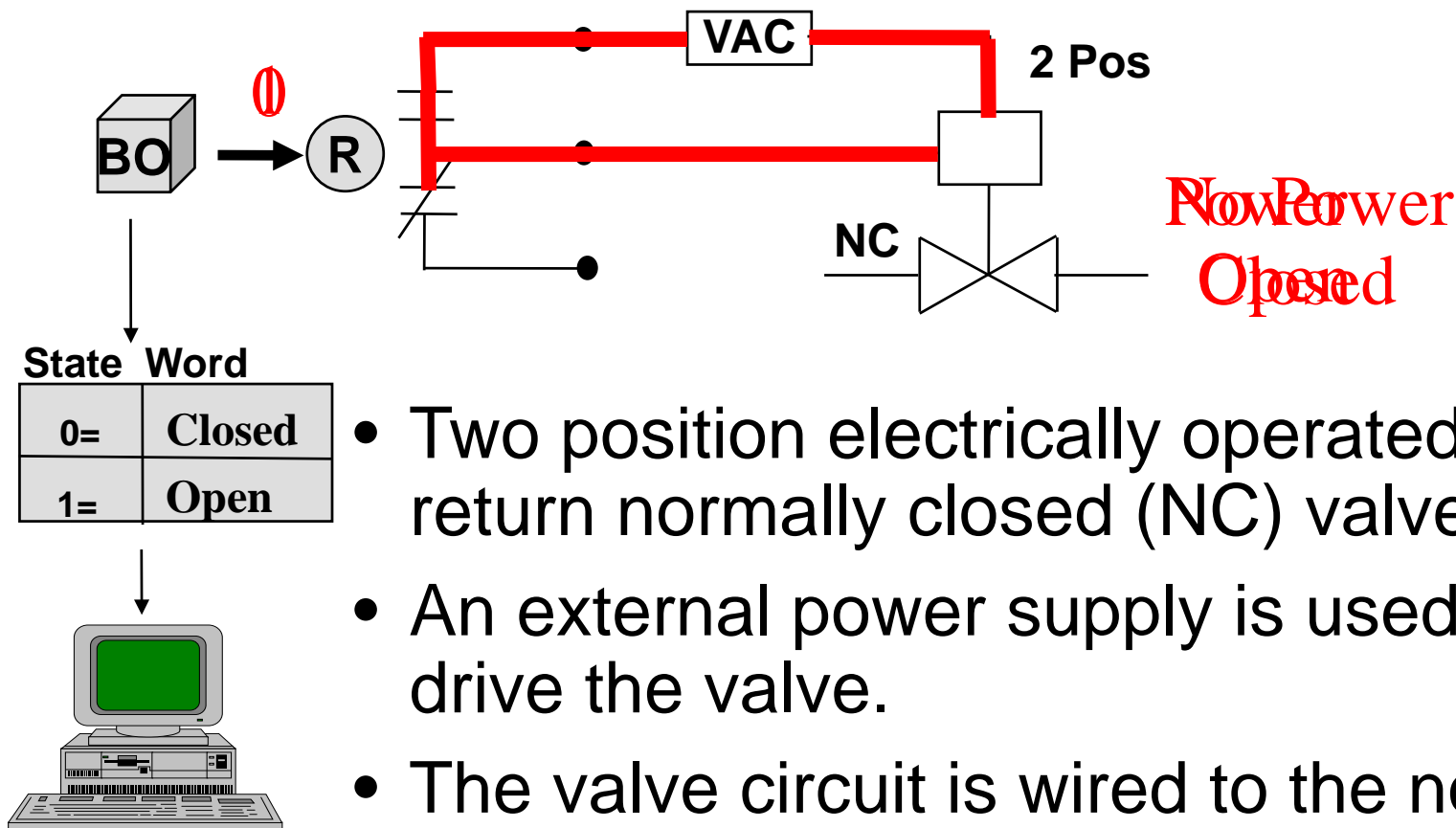
- From a programming standpoint, through the use of interposing relays, all four types of hardware can be set up to provide a “Normally On”(failed ON) controlled device or a “Normally Off” (failed OFF) controlled device.

# 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.

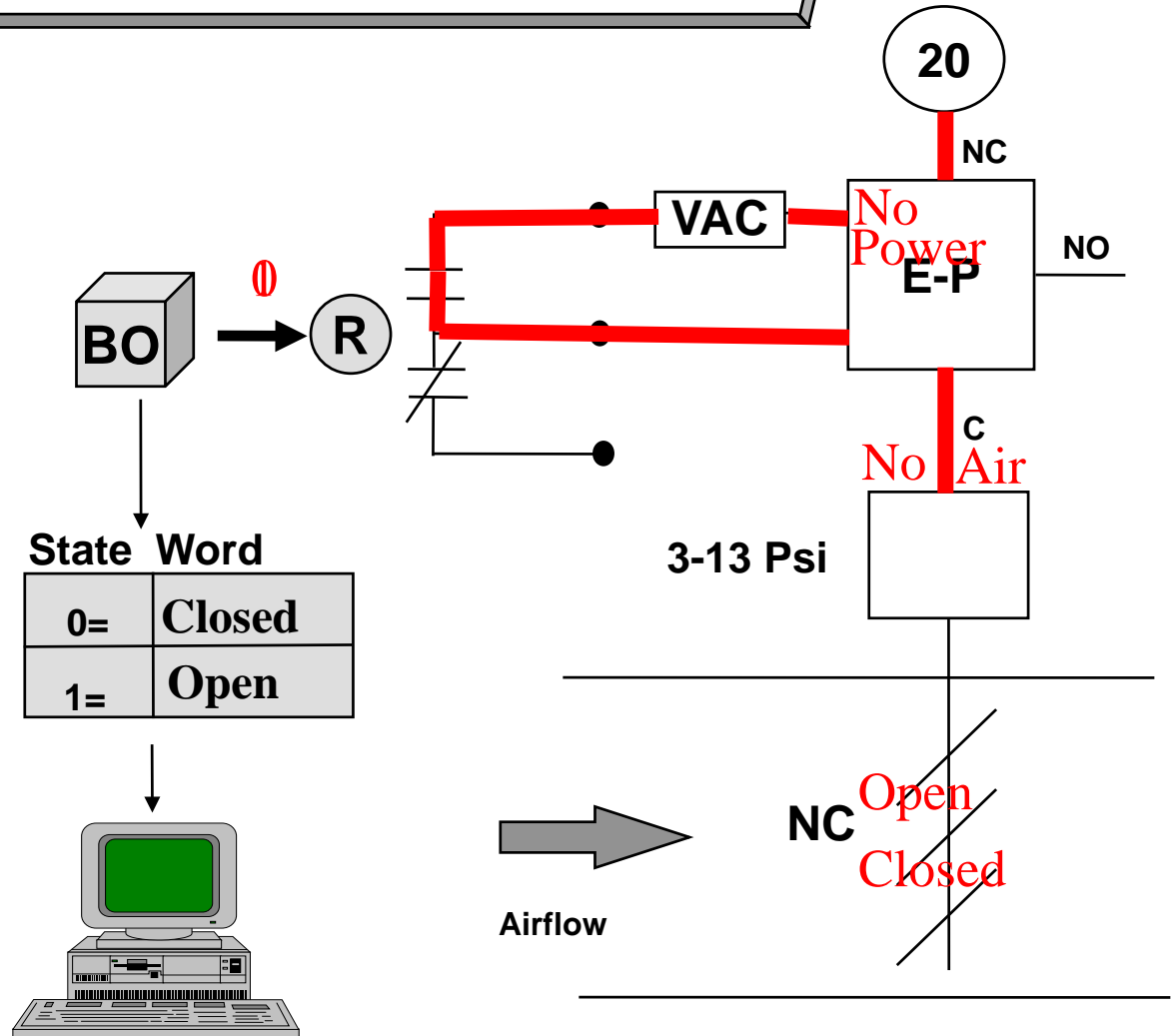
# Example Wiring Diagram



- 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.

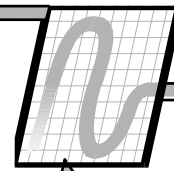


# BO Programming Issues



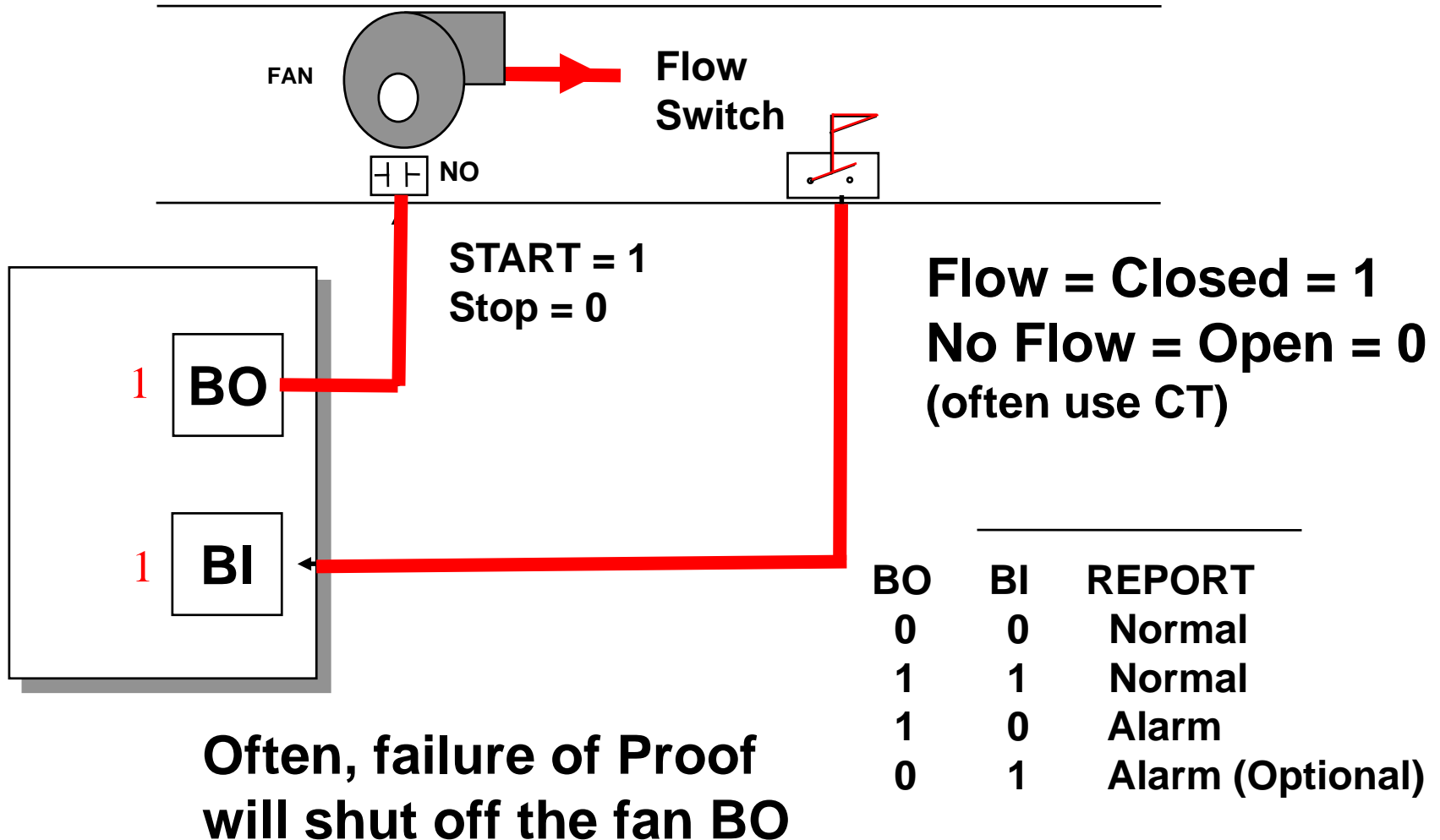
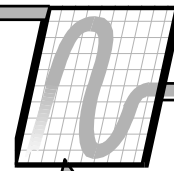
- Consider the following when programming logic for a BO point:
  - “Normal” (Failed) positions
  - Minimum ON time
  - Minimum OFF time
  - How should the BO react to the first cycle of the program after a power cycle?
    - May be issues with motor inrush currents.
- We will discuss these issues in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

# BO Application: Proof

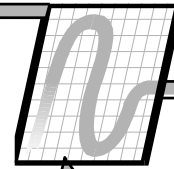


- Proofing: the concept of associating a binary input (BI) with a binary output (BO) to verify (feedback) the performance of the end device.
- Used to ensure a controlled device started and has not failed.
  - Start a fan and monitor via current sensor. Abort sequence if fan does not start.
  - Dampers with end switches to verify operation.

# The Concept



# Analog Points



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

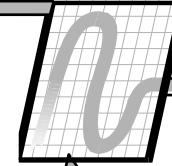


# Hardware AI Points

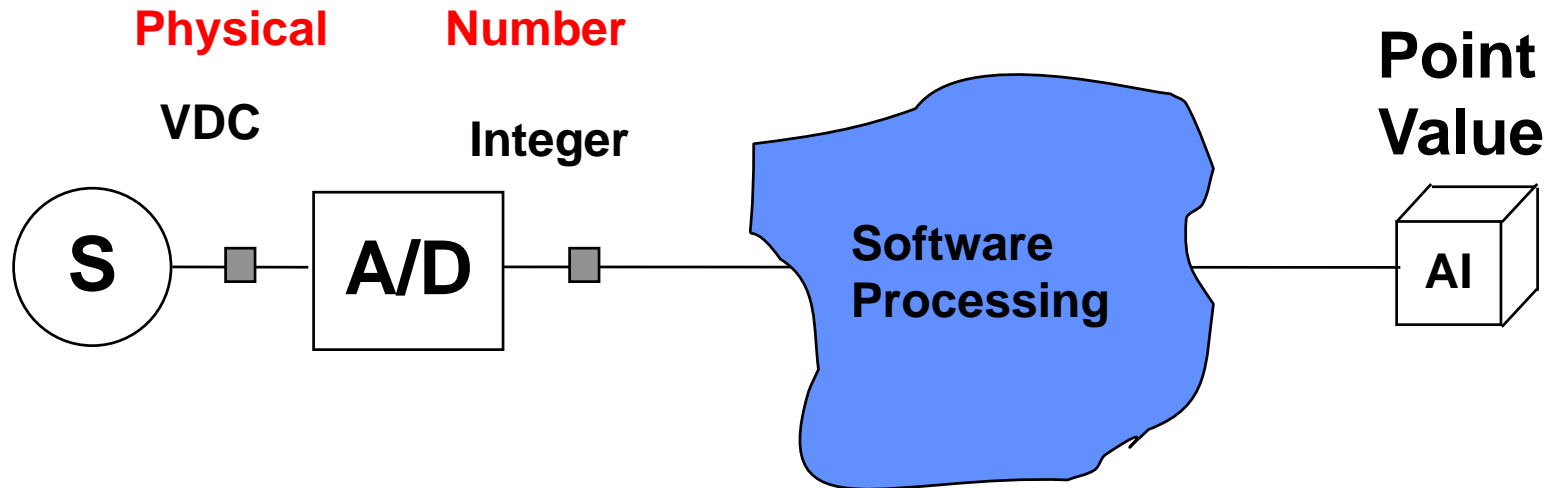


- Hardware AI points store the value measured by an electrical input to the DDC controller.
- Several issues are important
  - Sensor range, resolution, and accuracy
  - A/D converter input range
  - Controller accuracy
  - Overall AI resolution
  - Software processing of the electrical data
  - Calibration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

# Analog Input Points

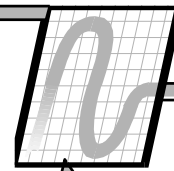


Engineering  
Unit



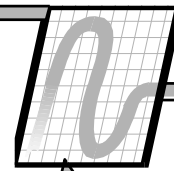
**A/D: Analog to Digital Converter**

# AI Data Flow



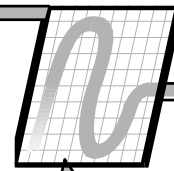
- The sensor measures a real physical quantity
- Input circuitry generates a DC Voltage signal.
- The A/D converter converts the DC Voltage signal into an integer.
- The integer is processed mathematically by one or more software algorithms.
- The output of the software processing is the calibrated value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

# The Sensor



- The A/D converter **only** reads DC volts.
  - Typically 0 – 10 VDC
- 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”.

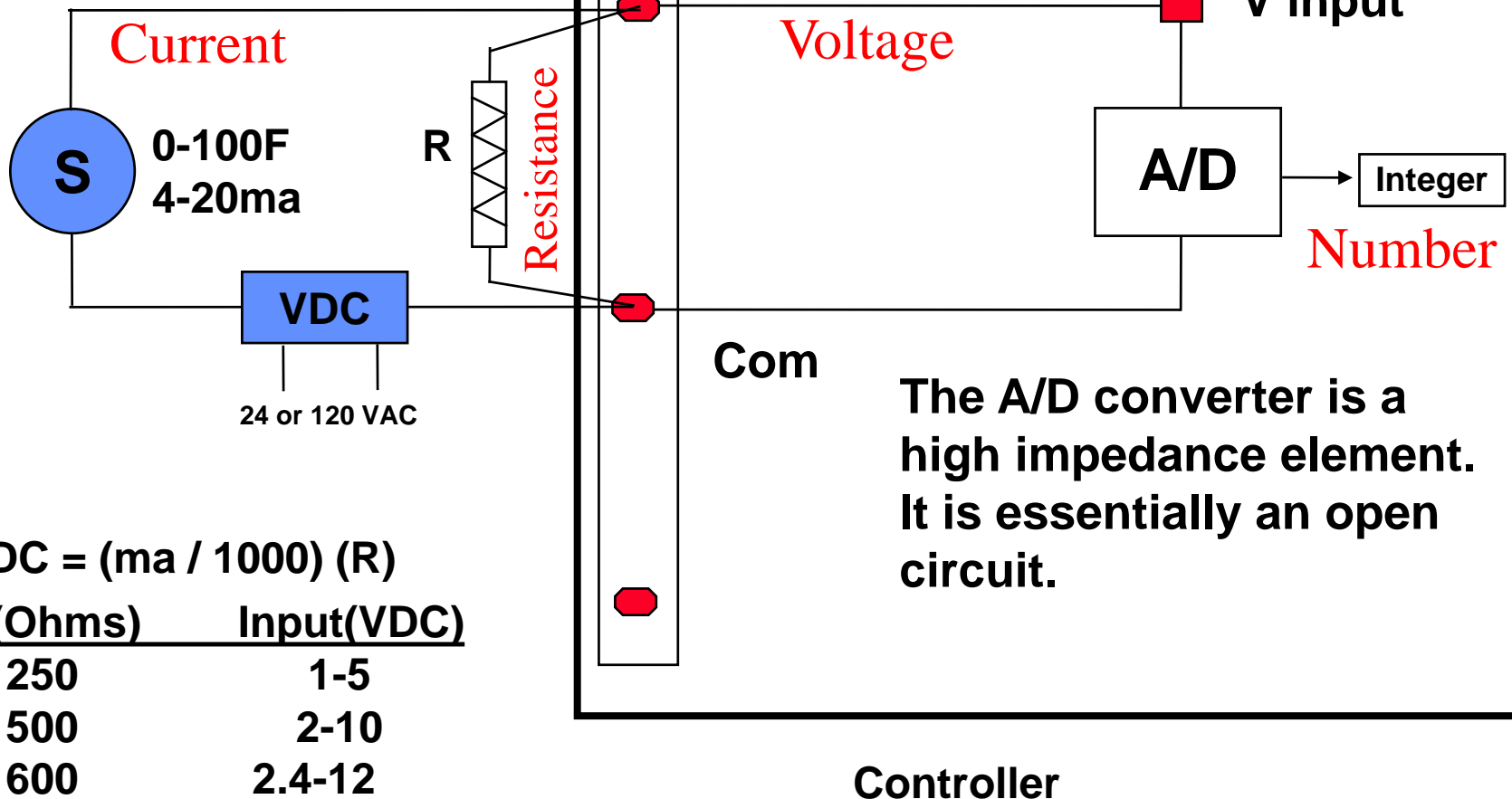
# AI Configuration



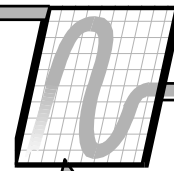
- The required physical modification will involve the installation of resistors on an input by input basis.
- The resistor size and installation details will depend on the type of sensor and “Universal Input” characteristics of the DDC controller.
- For most modern DDC Hardware, actual configuration 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

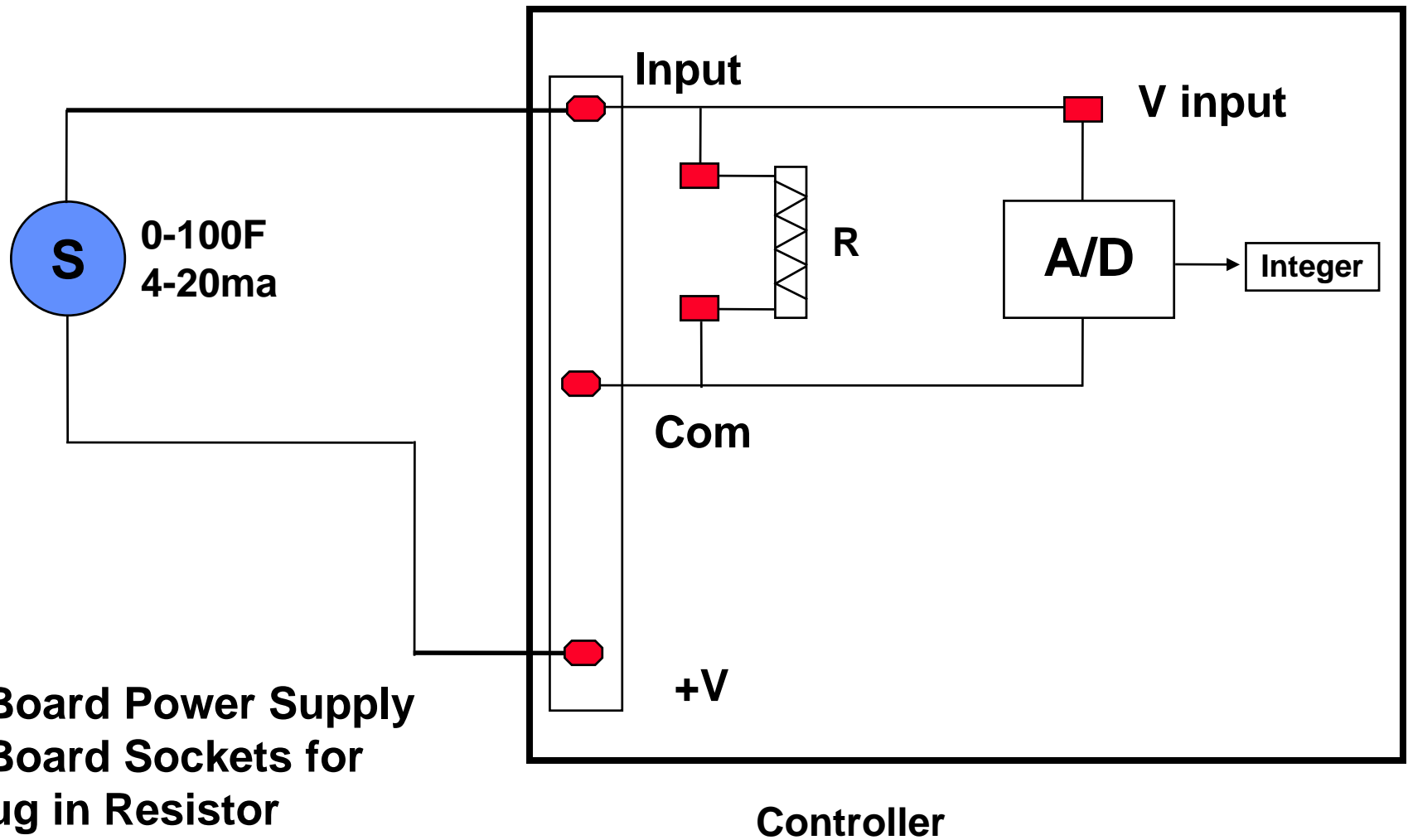
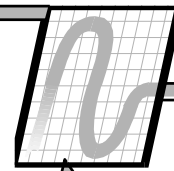


# The Circuit



- 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.

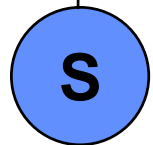
# Alternate Circuit





# Example Circuit

10 KOhm  
thermistor



+V

10Kohm  
Fixed

PS-DCV  
24 or 120 VAC



Input

V input

A/D

Integer

Com

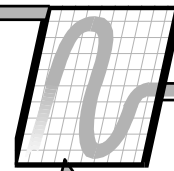
The A/D converter is a  
high impedance element.  
It is essentially an open  
circuit.

Controller

Thermistor:  
10 Kohm @ 77 F

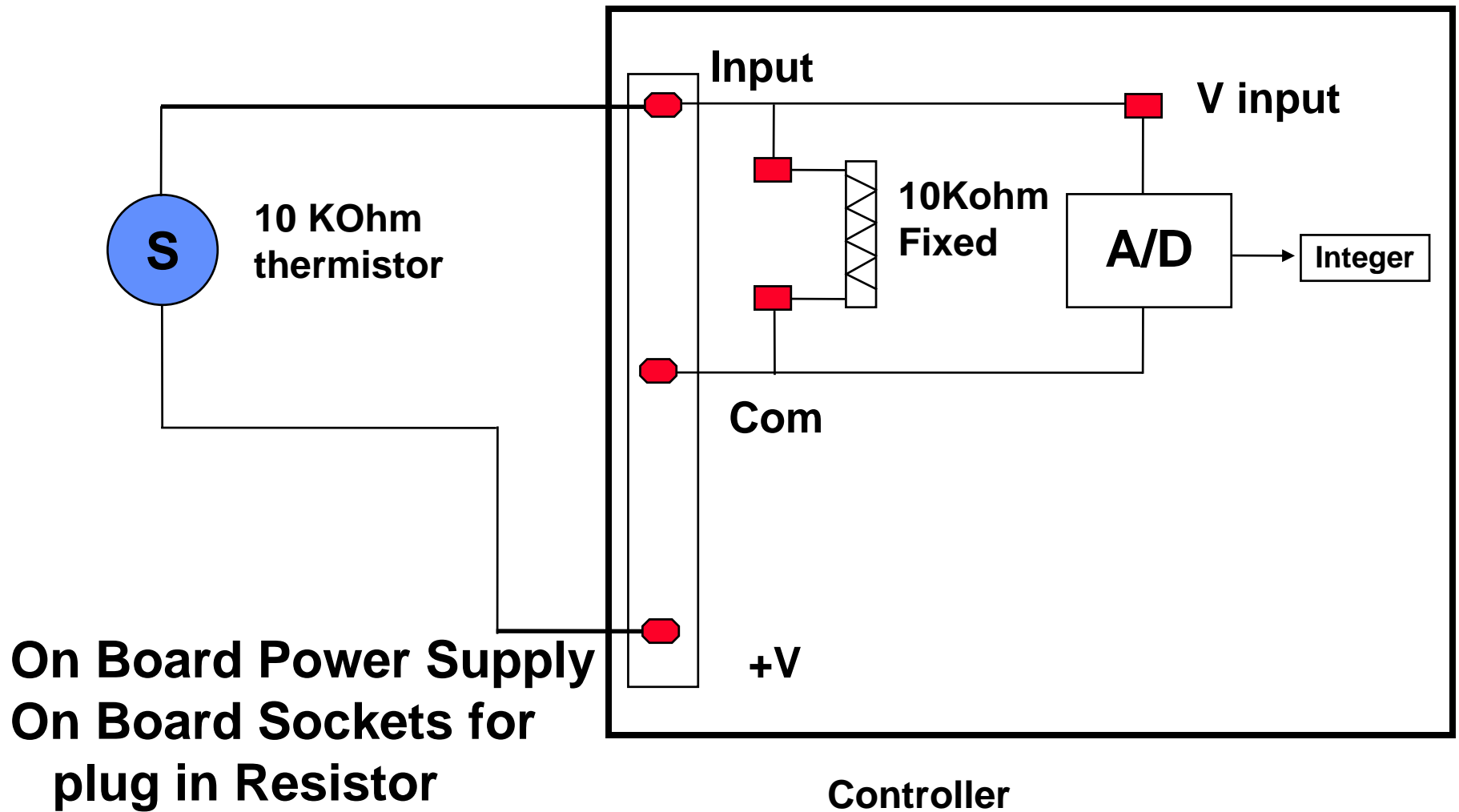
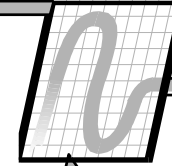
At 77 F,  $V_{\text{input}} = (0.5) (+V)$

# The Circuit

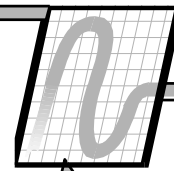


- Sensor is a 10K ohm temperature dependent resistor. As the temperature rises the resistance falls in a highly non-linear fashion.
- Sensor provides resistance, not voltage.
- 10 Kohm resistor creates a voltage divider: at the rated temperature (typically 77 F), the voltage input will be one half of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

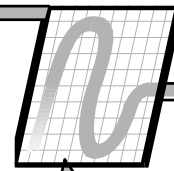


# Sensor Resolution



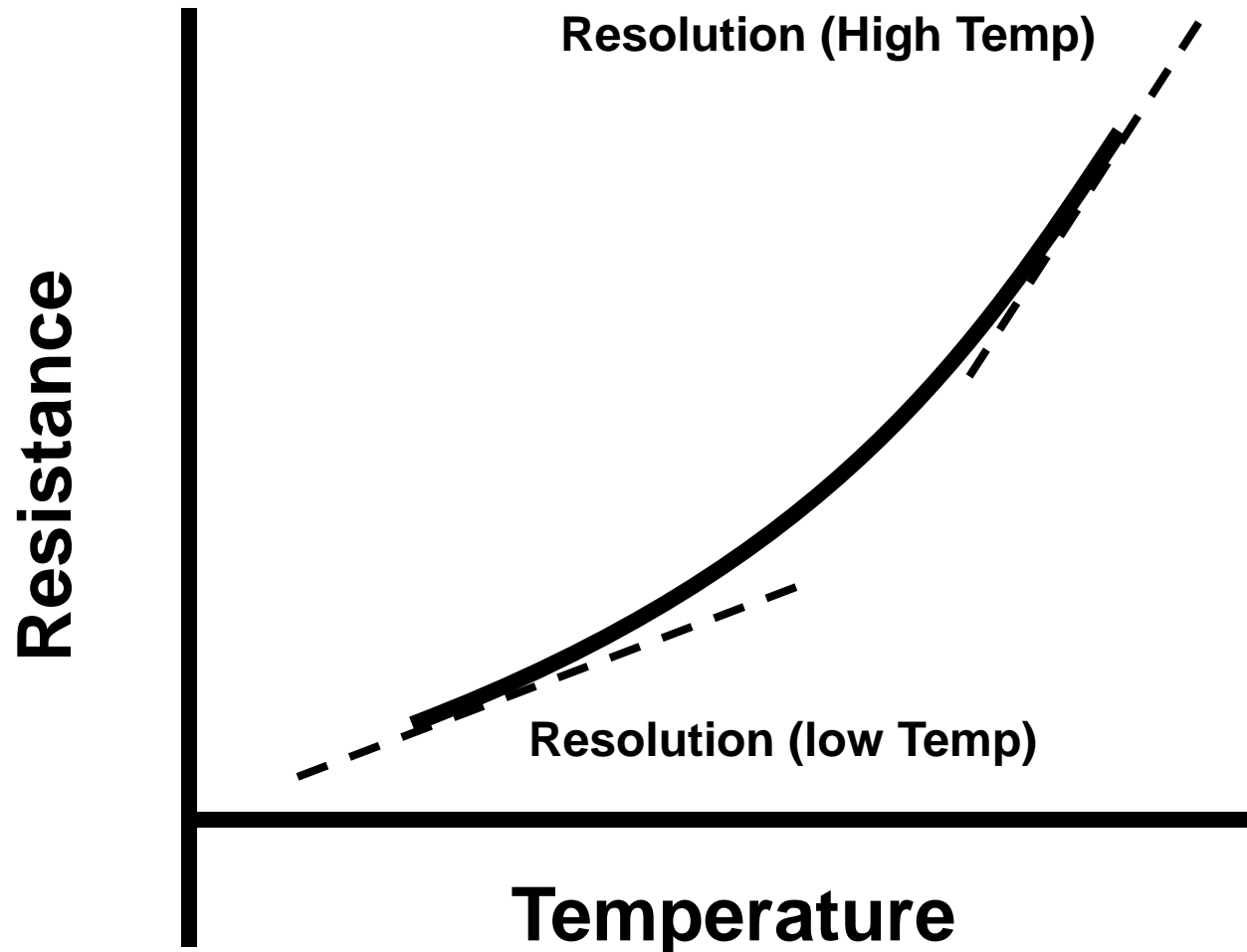
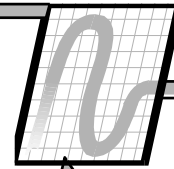
- The sensor resolution is defined as the engineering units per volt.
- Example: A temperature sensor rated 0 to 150 F, 0 to 10 VDC has a resolution of 15 F per volt.
- A temperature sensor rated 50 – 90 F, 0 - 10 VDC has a resolution of 4 F per volt.
  - Careful when writing specs: Is “higher” resolution 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

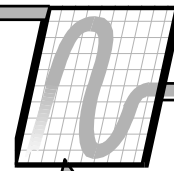


- With the non-linear thermistor input circuit, the sensor resolution will not be fixed.
- It will vary over the range of the sensor.
- In this case it will be necessary to describe the anticipated operating range and define the worst resolution within that range.

# Nonlinear Resolution

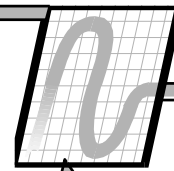


# Thermistors



- 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 °F.
- Between 32 and 160 °F a conformity of plus or minus 0.5 °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.

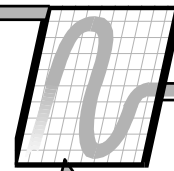


# Software Processing



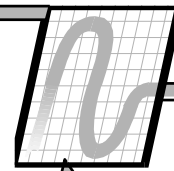
- Calibration via Gain and Offset parameters
  - Point Value = Gain x Integer + Offset
- Converts the calibrated value into the appropriate engineering units.
  - Curve fit equation
  - Look up table
  - Square root function

# Calibrating AI Inputs



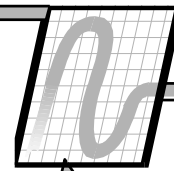
- Controls contractor often say they install calibrated sensors and calibration is not required.
- Do not accept this statement!!
- Adjustment in the processing of the input signal such that the reported value matches the measured value from a test instrument.
- Many field factors introduce error and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

# Calibrating AI Inputs



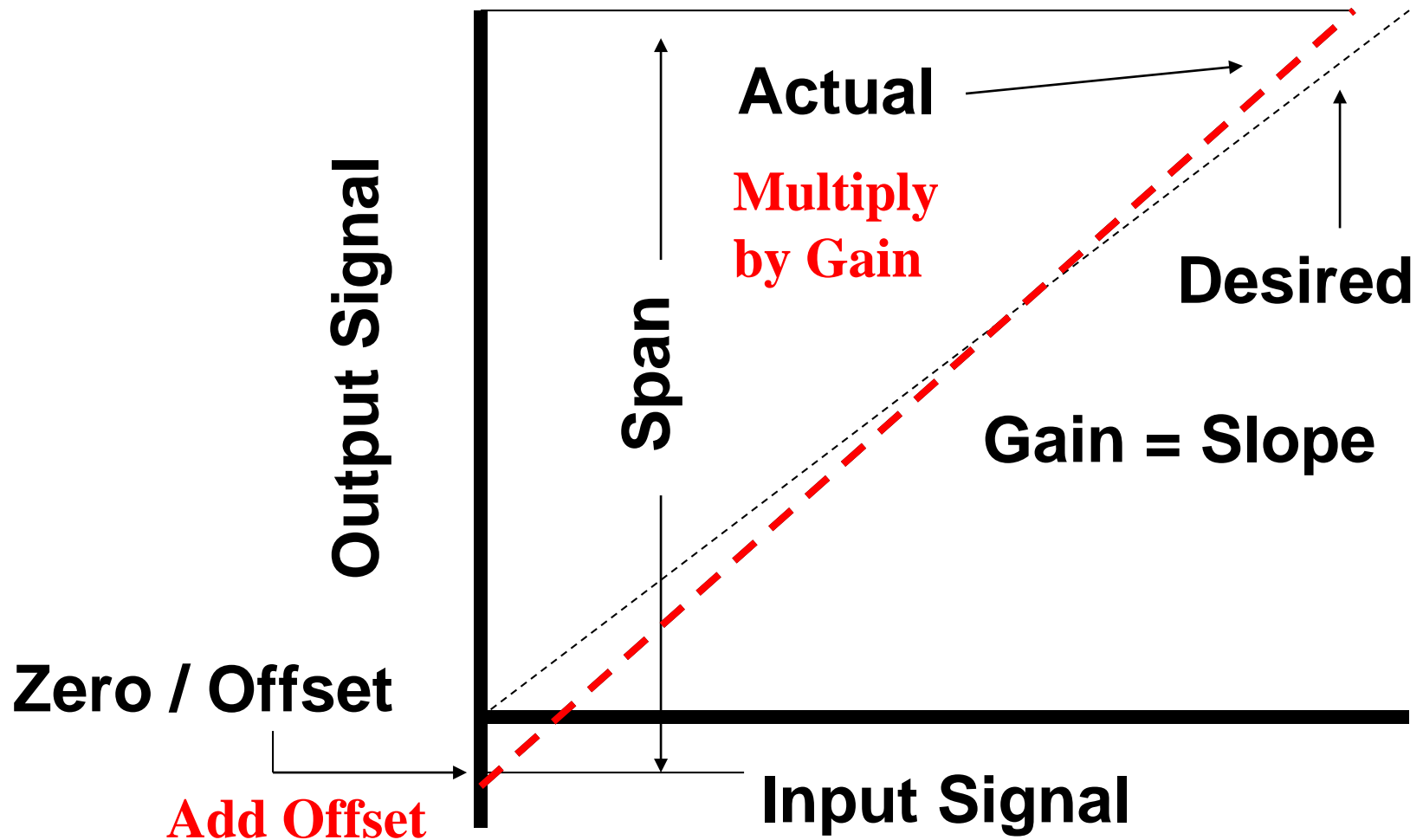
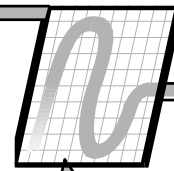
- Calibration software varies from vendor to vendor.
- Require each vendor to clearly state how you can adjust the software processing.
- Some Concepts:
  - Built in offsets within the point template
  - Adjustable ranges
  - Programmed within the logic

# Calibration Example

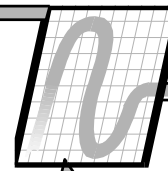


- Temperature sensor: 40 – 90 F gives 0 – 10 Volts
- When measured, 40 F = -.2 V, 90 F = 10.4 V
- Zero offset = -.2 V
- Span (desired) = 10 V, (actual) = 10.6 V
- Gain (desired) = .2 V/F, (actual) = .212 V/F
- Input parameters (zero, span, gain) to correct actual readings to desired.

# Calibration Example

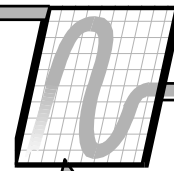


# RTDs



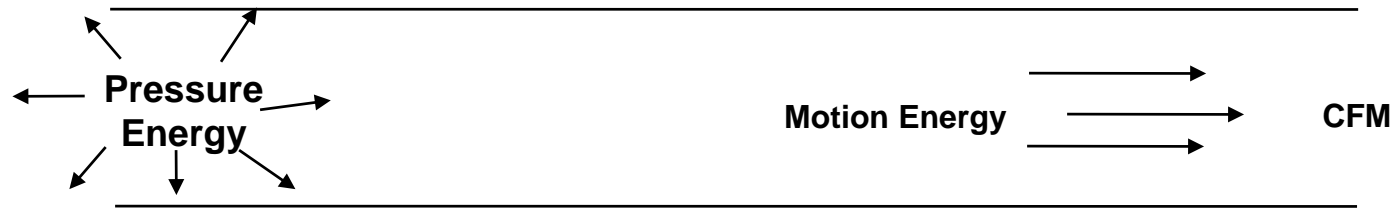
- Resistance Temperature Detectors
  - 100 ohm platinum
  - 1000 ohm platinum
  - 1000 ohm nickel
  - 1000 ohm balco
- RTDs require special circuits to give accurate and consistent results.
- Not all DDC vendors support the use of RTDs.

# 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”

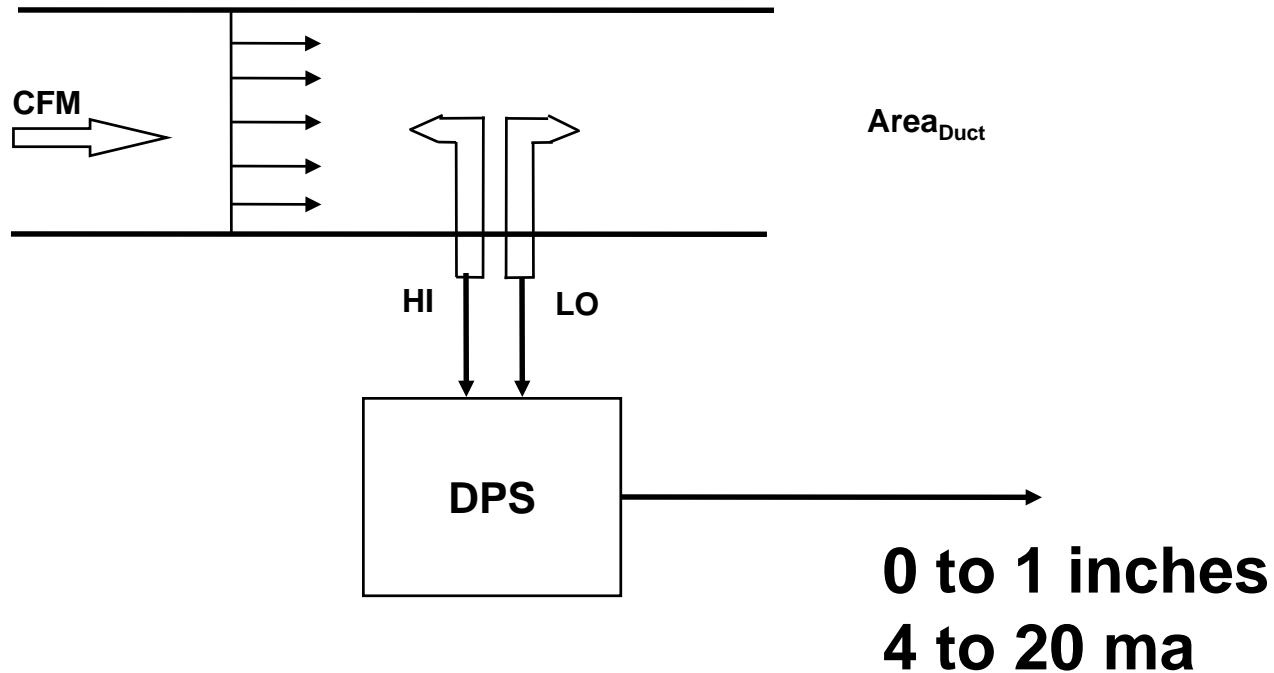
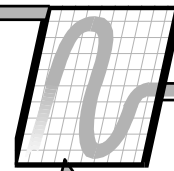


# Measuring Air Flow



- 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



# Air Flow Measurement



$$\text{VEL} = (\text{Flow Coeff}) (\text{SQRT}(\text{VP}))$$

$$\text{CFM} = (\text{AREA}) (\text{Flow Coeff}) (\text{SQRT}(\text{VP}))$$

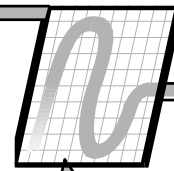
- The software processing of the electrical input will include a square root function to linearize the input.
- Flow coefficient will be a number between 2000 and 4000 (4005 is “theoretical limit”).
- With modern DDC hardware, the controller will know the flow coefficient for VAV boxes from many vendors.

# Analog Output Points



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

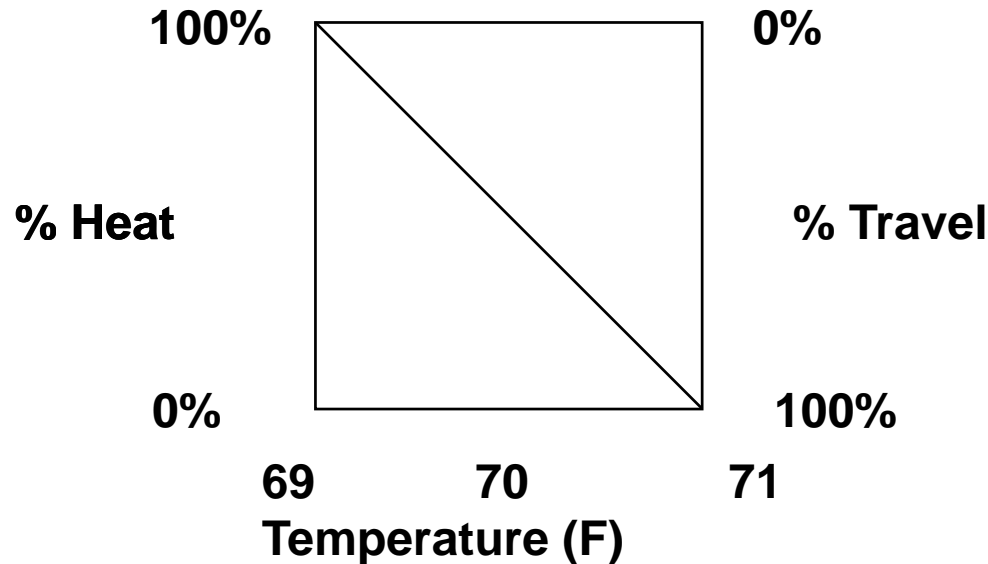
# Percent Travel



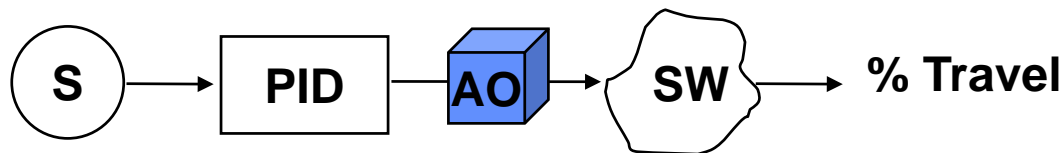
- Do not confuse *percent travel* with *percent open*, *percent closed*, *percent heat* or *percent cool*.
- **Percent travel** refers to the stroke of the actuator on a controlled device.
- If a valve is normally open, it will be 100% open at 0% travel and 0% open at 100% travel.
- Just the opposite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

# The Term “Percent”

**Proportional  
Heating control**



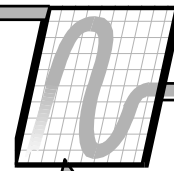
**Assume  
heating is NO  
valve**



**RA**

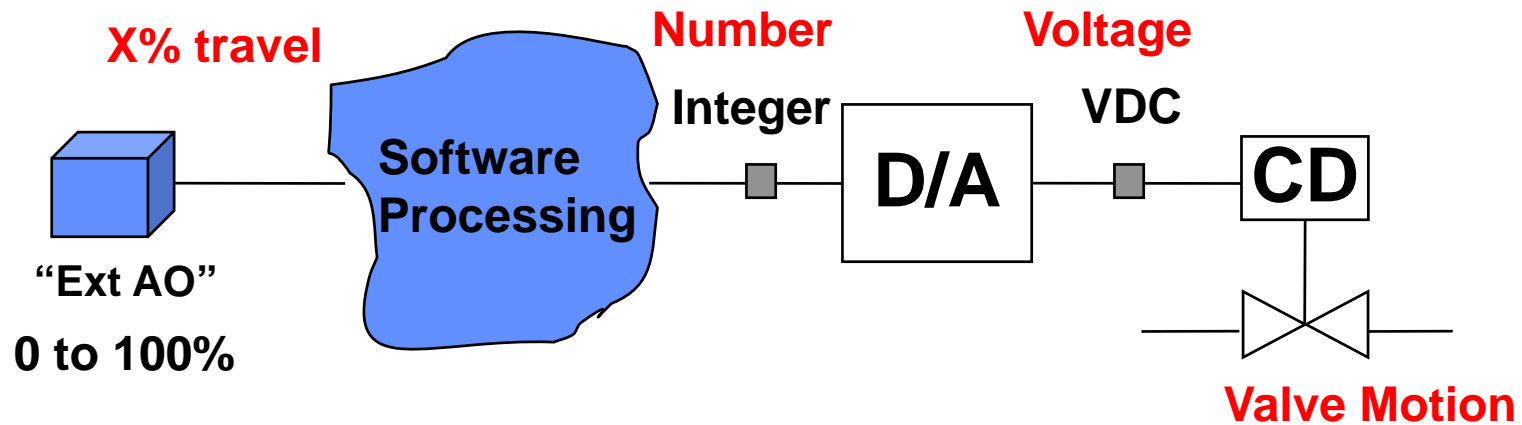
**SW configuration of AO inverts  
0%-100% to 100%-0%**

# Analog Outputs



- AO, Direct Connect
  - 4 - 20 ma, no transducer
  - 0 - 10 VDC, no transducer
- AO, with transducer to pneumatic
  - 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.

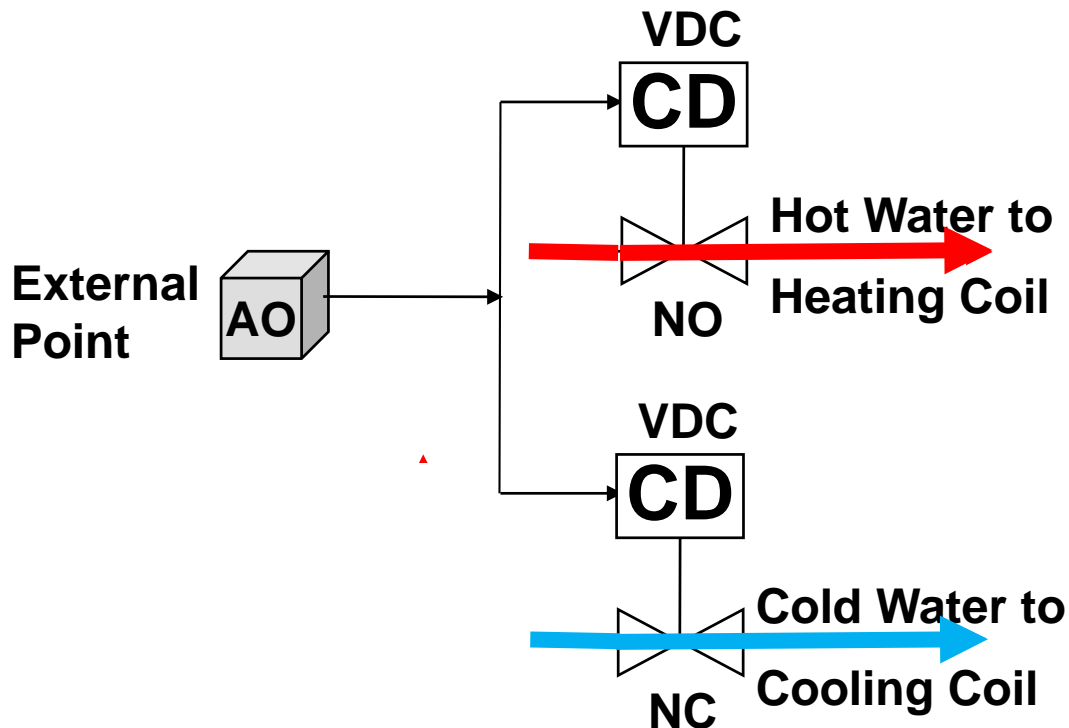


# Output Device Range



- 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

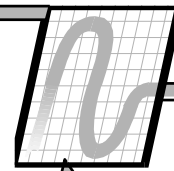
# Sequenced Valves



As output goes from 0% to 100%:

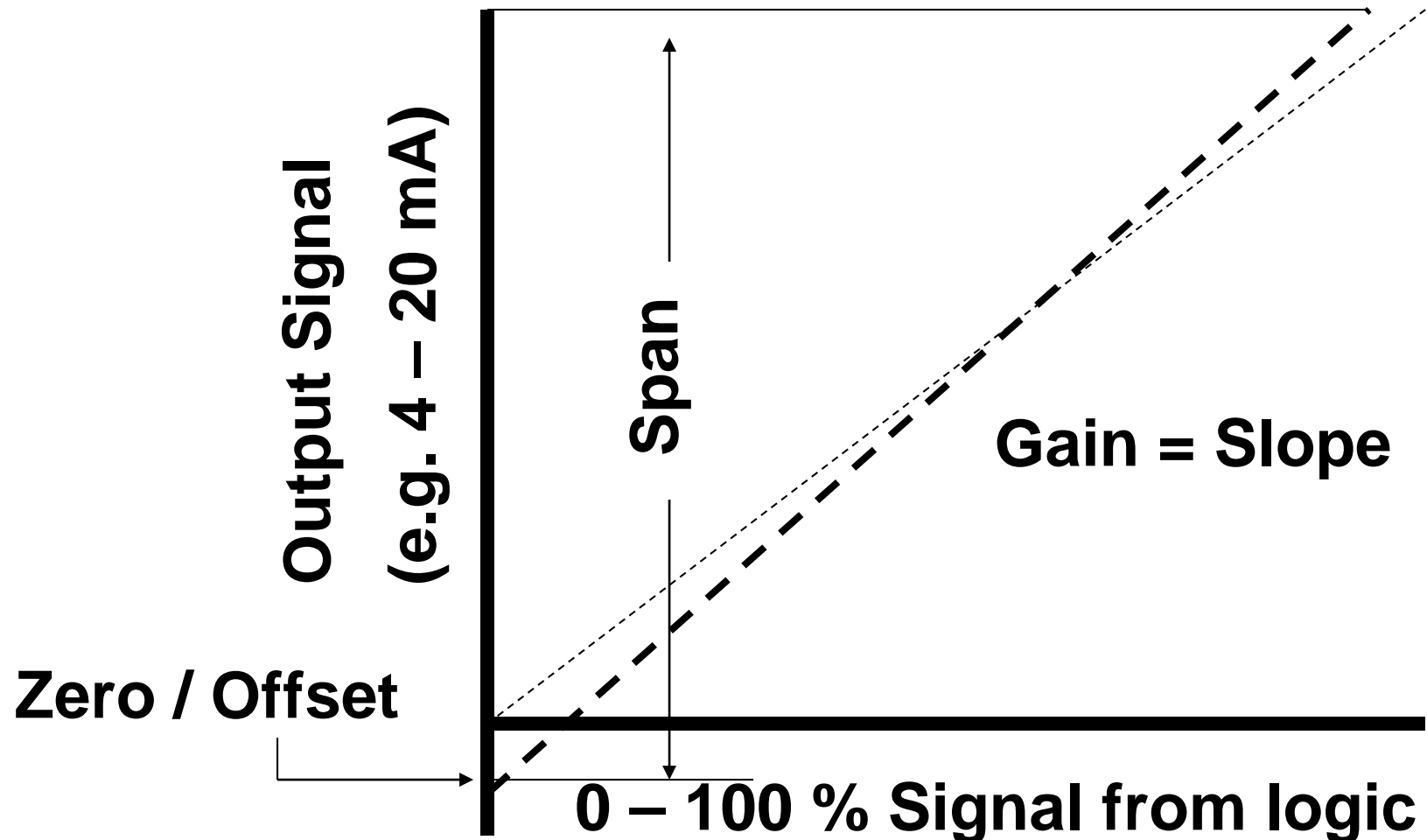
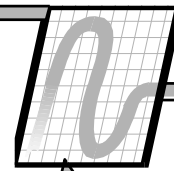
- 1) Heating valve full open, Cooling valve full closed.
- 2) Heating valve partially open
- 3) Heating valve full closed
- 4) Cooling valve partially open
- 5) Cooling valve full open.

# Calibrating AOs

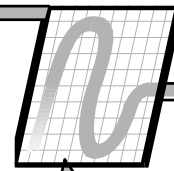


- Calibration software varies from vendor to vendor.
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# Calibrating AOs

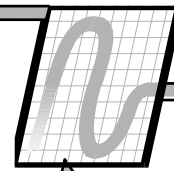


# Hardware Transducers



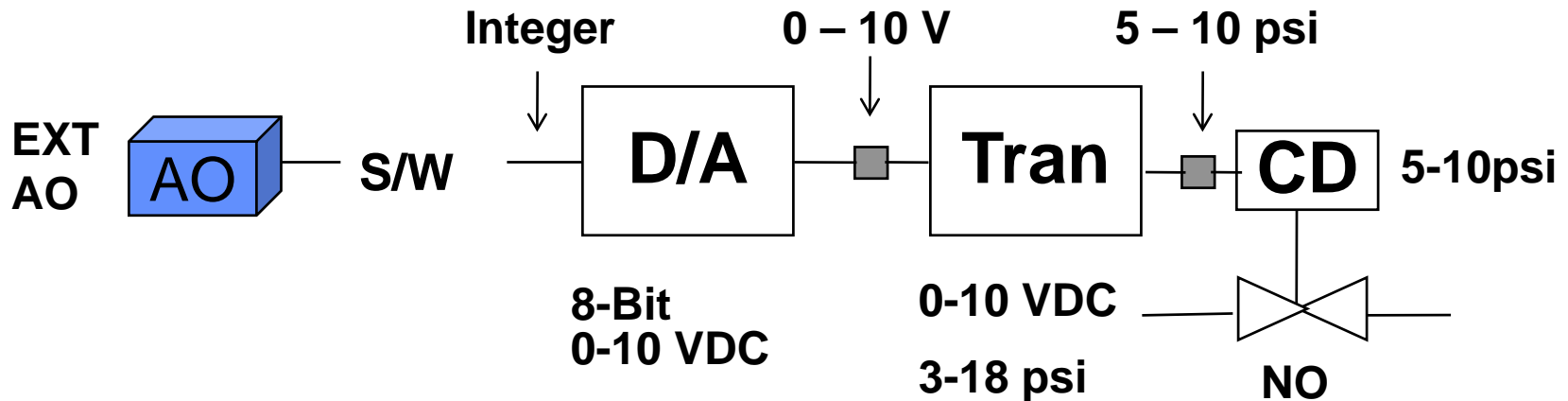
- Transducers are inserted into the data flow between the D/A converter output and the controlled device.
- A typical example is an V-P transducer that will change a 0 to 10 VDC output from an A/D converter to 3 to 18 PSI for a pneumatic valve or damper operator.
- Note that while full range of the output 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



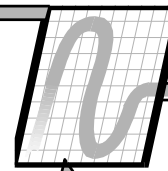
Calibrate AO so

0% = Closed and 100% = Open



The Transducer converts  
VDC to PSI.

# Configuring an AO

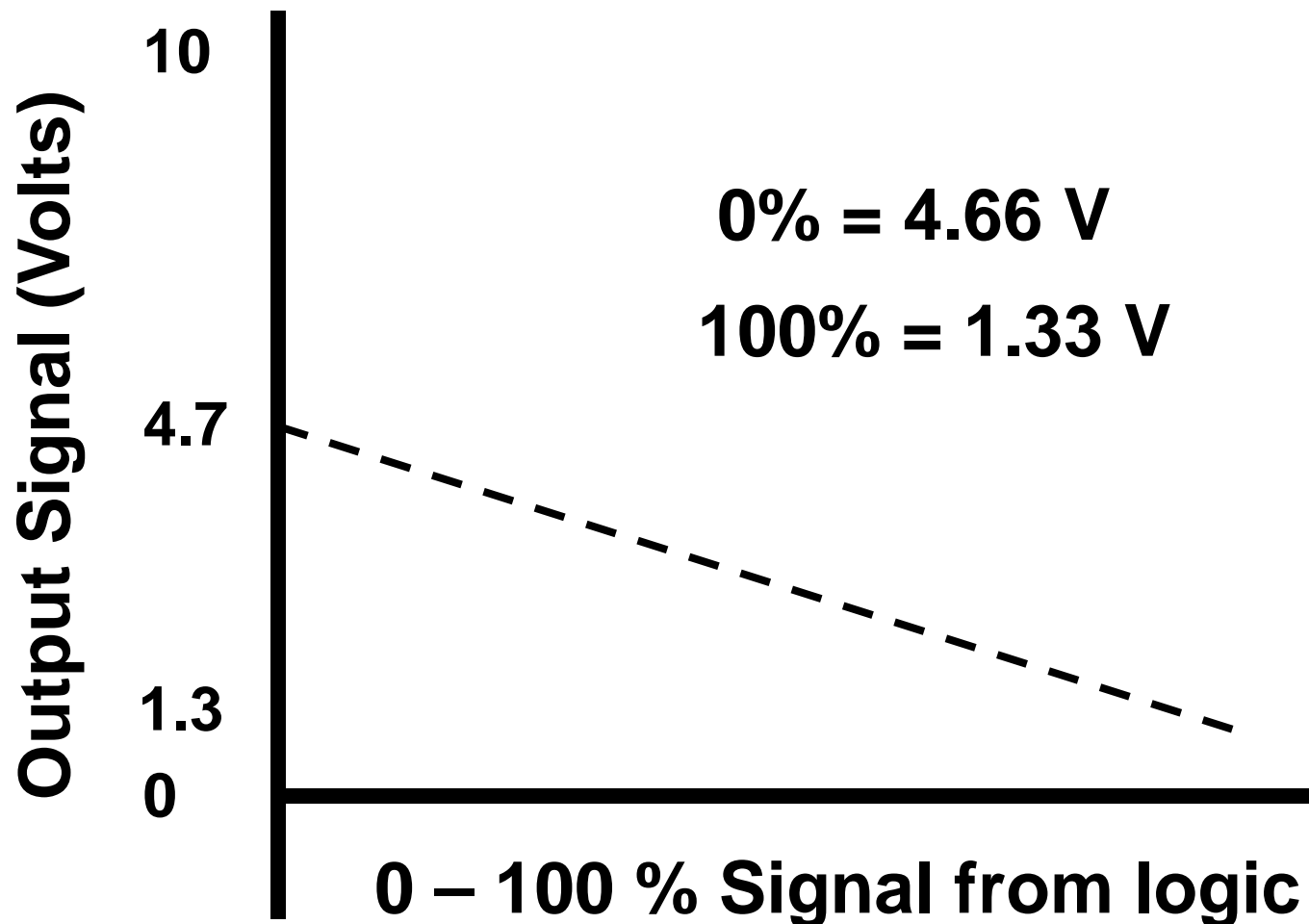
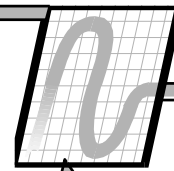


- Start with: 5 PSI is Open, 10 PSI is close
- Then for the 0-10 V  $\rightarrow$  3-18 PSI transducer:

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

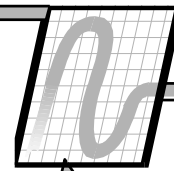


- Hardware pulse counters are connected to external binary pulse sensors.
- Each sample rate of the program the number of pulses accumulated during the sample rate time period are multiplied by the “meter factor” and then added or “accumulated” in a point.
- The count will increase until the data set 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

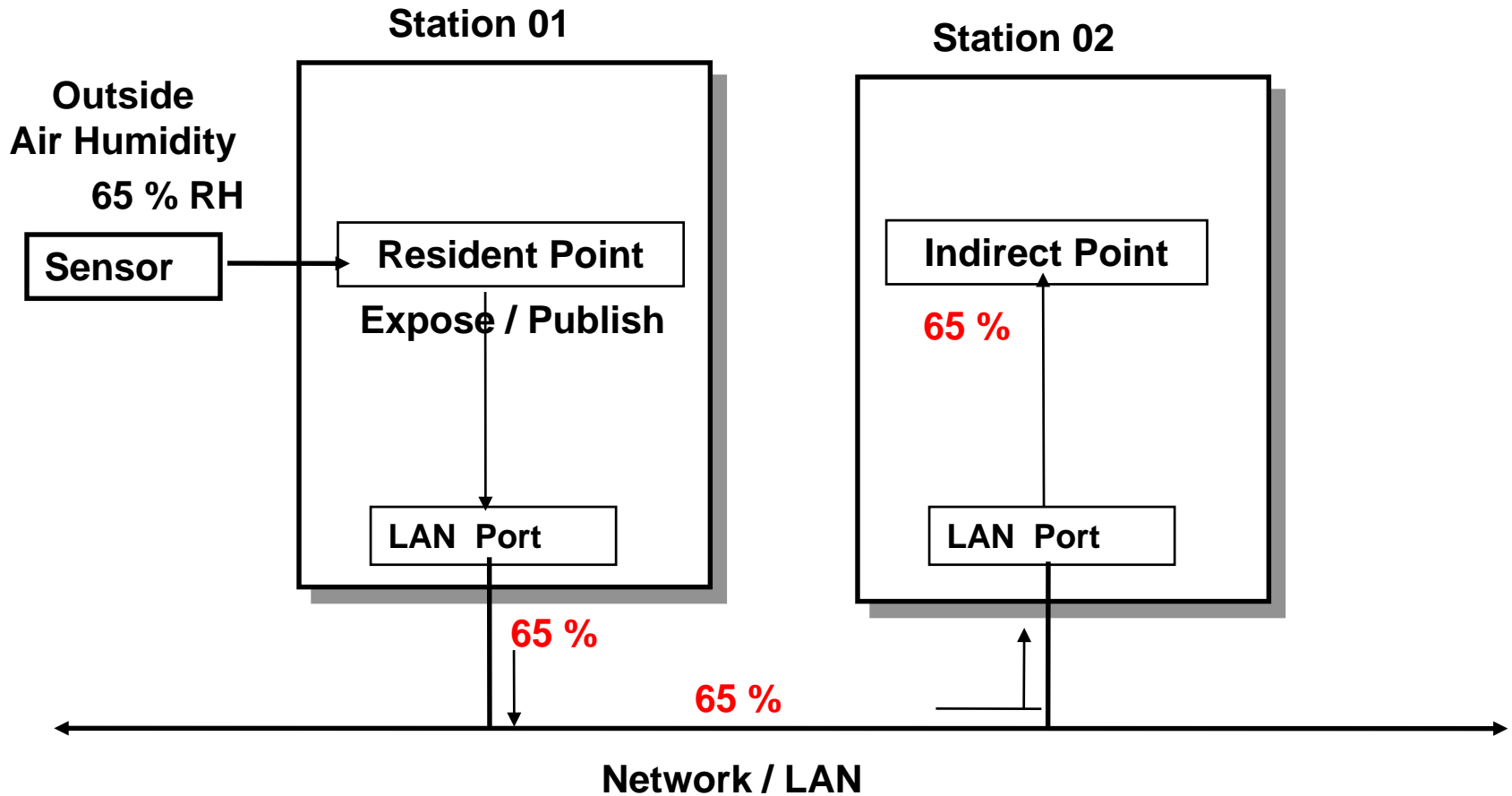
- Internal Accumulator points accumulate the value resulting from a calculation.
- When the calculation is executed, the result is added (or subtracted) to the previous analog value stored on the point.
- The analog value will continue to increase (or decrease) until it reaches a limit or it is reset 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

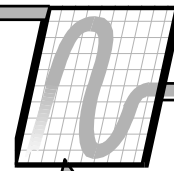


# Exposed / Indirect Data



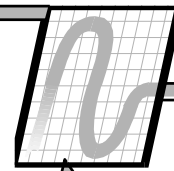
- A hardware point in a controller receives data from an external sensor.
- The data from the external sensor can be sent to another controller.
- An input variable in a second controller is programmed to receive the data.
- Be very careful not to overload the network.
- Broadcast updates only as often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

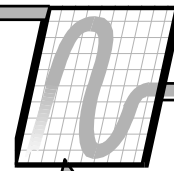
# “Value” Points



- 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.