PCI 101

Basics of Process Measurement

- **May 12-23, 2001**
- Dammam office building

PCI –101

Basics of Process Measurement

- End Introduction

Professional Engineering Development Program

PCI 101 - Module 1

Determining Whether Process Measurement Instruments Meet Requirements of Saudi Aramco Applications

Module 1

- PCI-101 Material and Exercises
- Electrical Safety Presentations
- Video Tapes

Purpose of Process Measurement

- Reaching corporate economic goals
- Controlling a process
- Maintaining safety
- Providing product quality

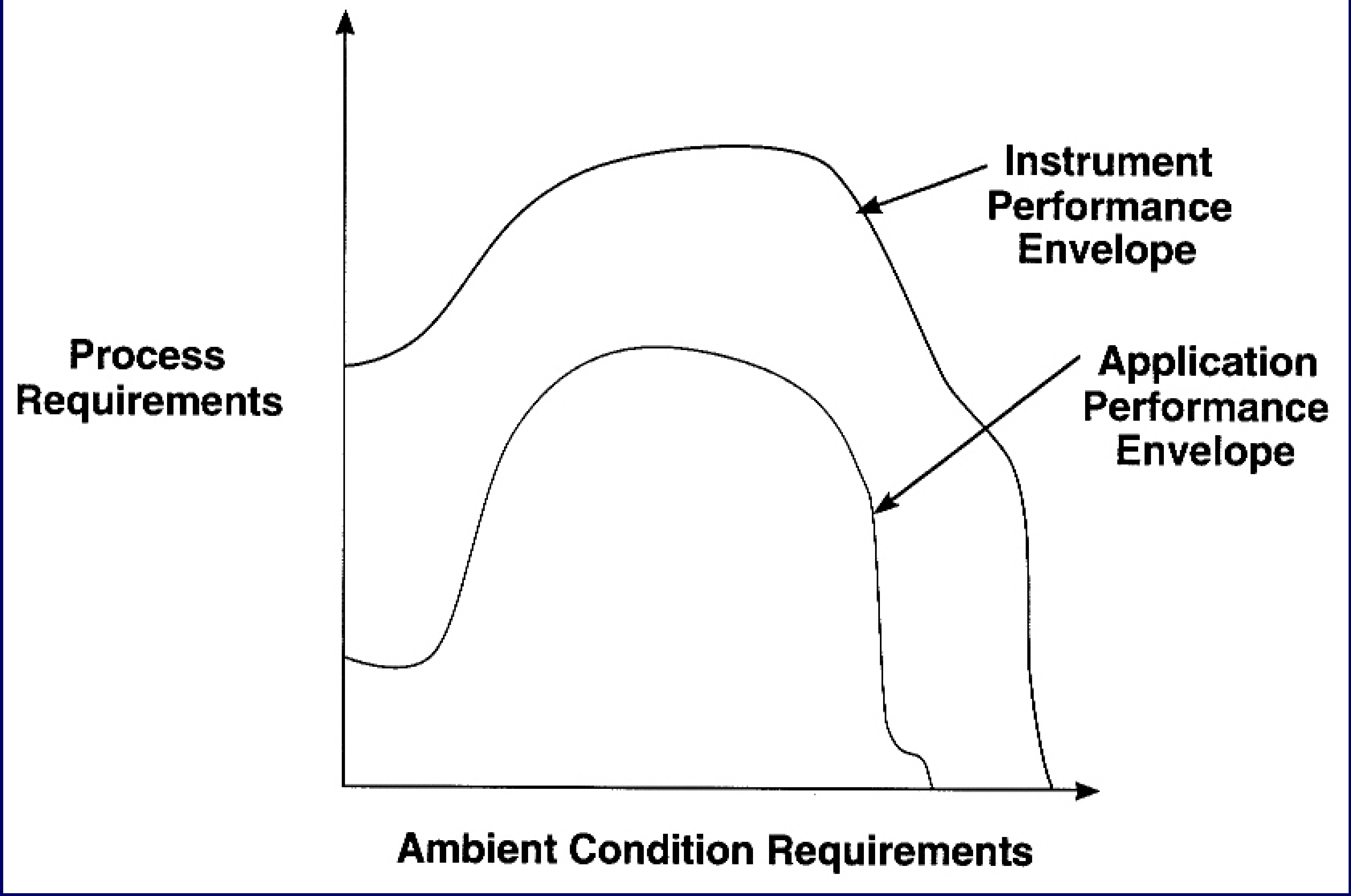
"Process measurement is the art and science of applying instruments to sense process conditions"

Purpose of Process Measurement

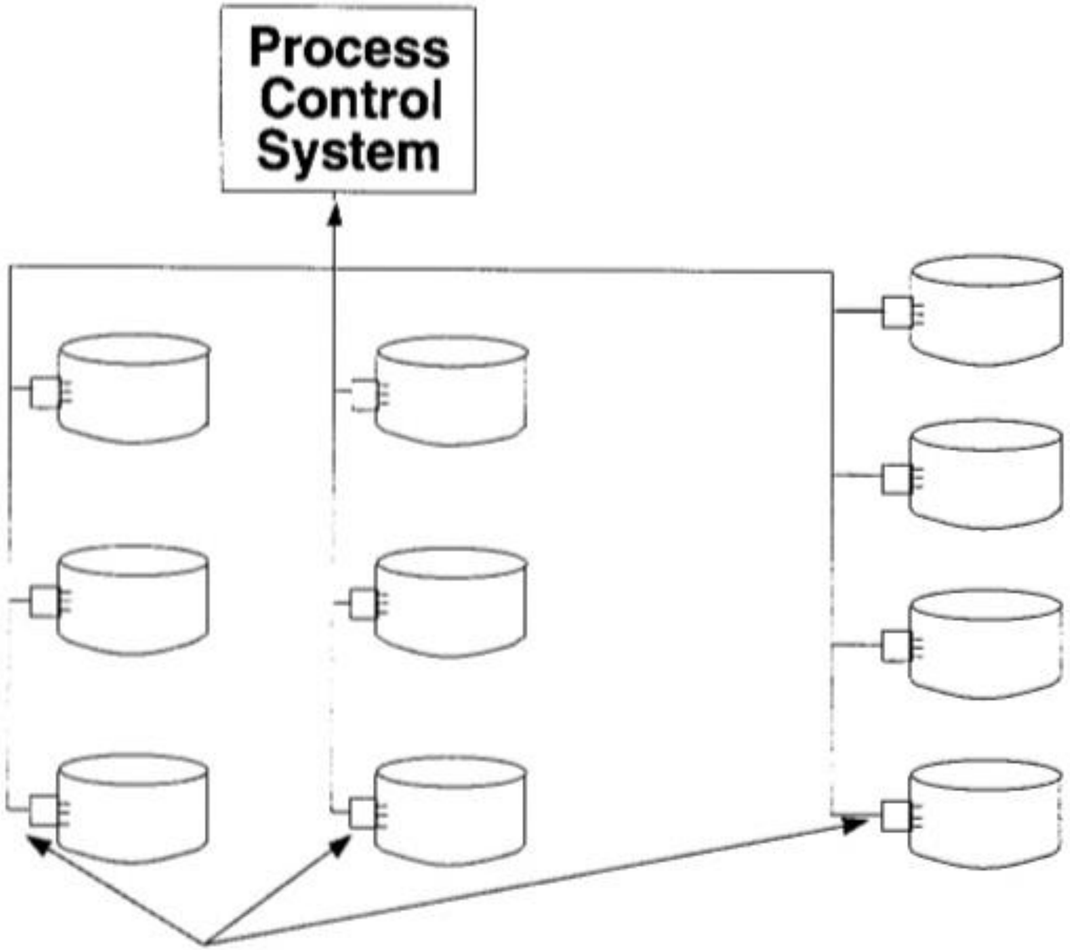
- Process sensors selected based on Range, Span, Accuracy, and Response time constant
- The controller makes decisions based on process sensors and modulates control valves to reach the user defined setpoint.
- Discuss control system diagrams on overhead projector.

“No matter how advanced or sophisticated the control system, it is only as effective as the process measurement instruments it is connected to”

Application and Instrument Envelopes

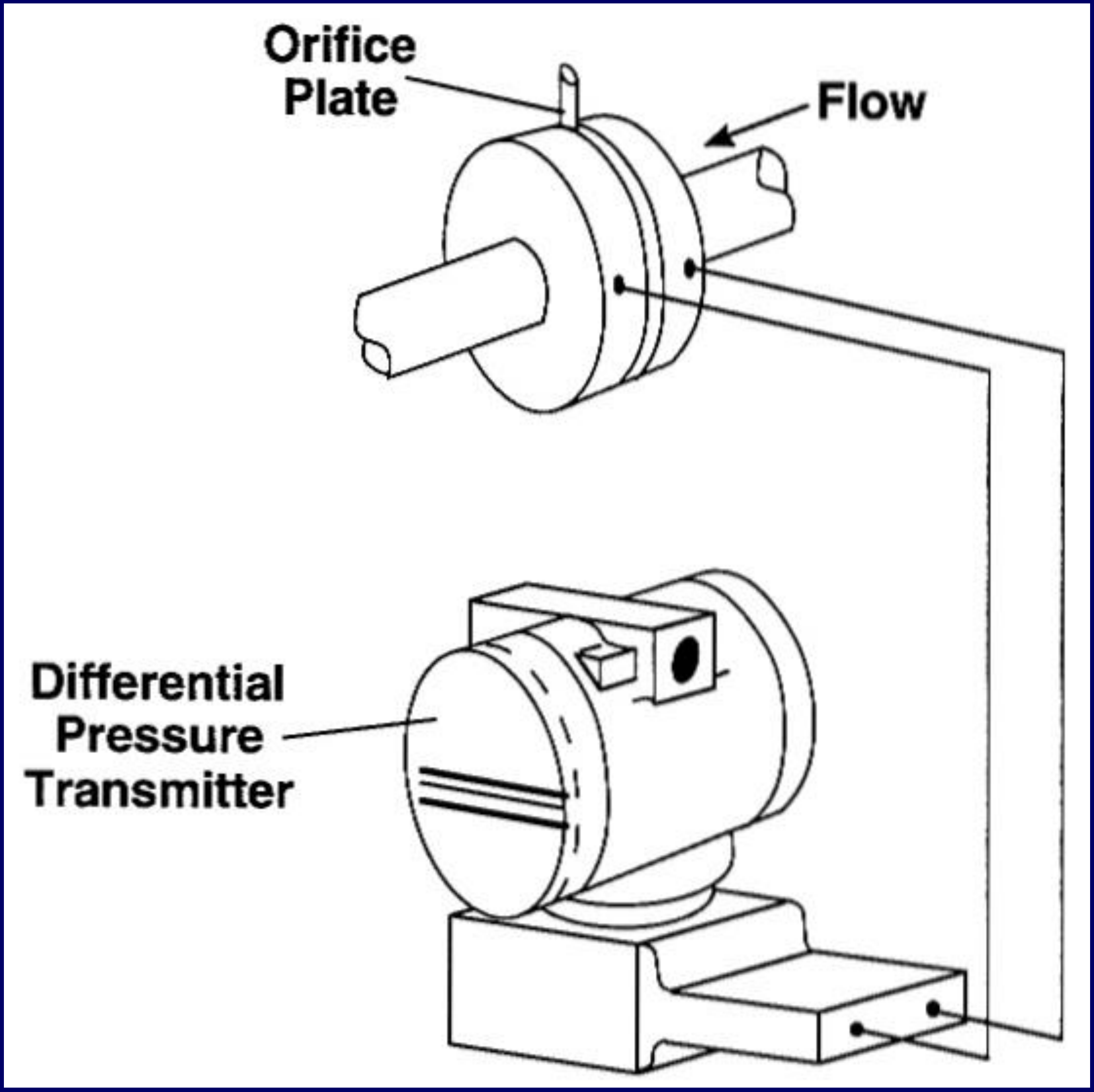


Process Measurement of Crude Oil Storage Tanks



Hydrostatic Tank Gauging
Measurement on Storage Tanks

Incorrect Gas Flow Example

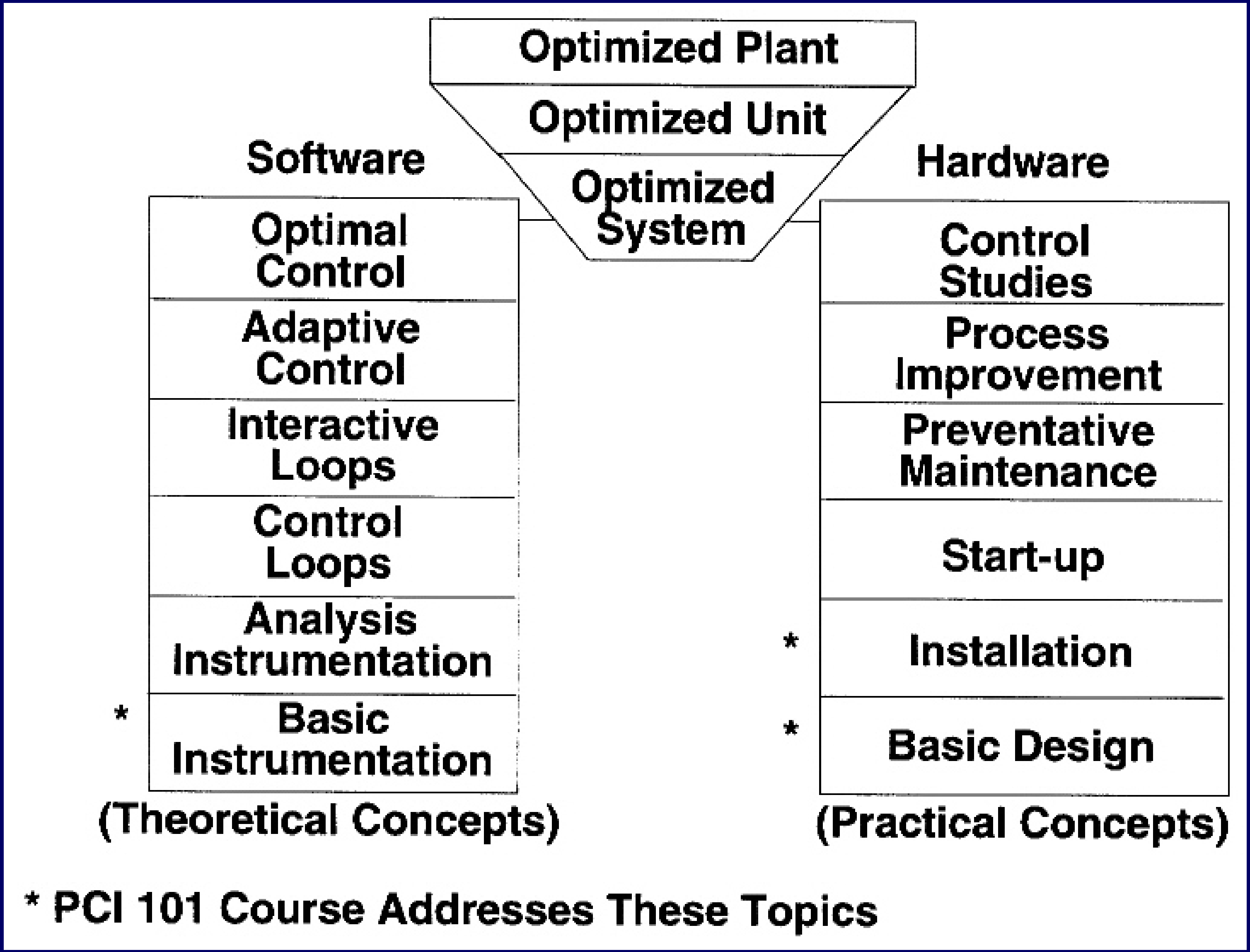


Metrology is the "Science of Measurement"

- Reference Terminology and Definitions in Liptak
- Join the local section of ISA to get involved and keep up with the latest in Instrumentation issues
- Standard bodies made up of vendors and users (must be a balance)

"Vendors may vary the use of a term…specmanship can be used to bewilder the uninformed instrument engineer"

Optimization Arch



Static and Dynamic Conditions Affect Process Measurement

- Temperature
- Static Pressure
- Interference
- Instrumentation Response
- Noise
- Damping and Digital Filtering

"No measurement, however precise or repeated, can ever completely eliminate uncertainty due to dynamic conditions"

Temperature Effects

- Induced phase transitions (process changes from liquid to solid or liquid to gas)
- Changes in dimensions of measuring element
- Resistance of a circuit
- Change in flux density of a magnetic element

"Temperature influences can exhibit some of the most severe effects on a process measurement"

Temperature Effects

- Corrections are required for static pressure, temperature, specific gravity etc.
- When making a gas measurement, increasing temperature increases volume
- Also, don't forget about maximum process and ambient temperature specifications of an instrument.

"A 10 degree F change in temperature causes a 2% change in density, which results in a 1% effect on total flow measurement"

Pressure Effects

- Pressure effects can also trigger phase transitions
- Pressure effects show up in dP measurements used in flow and level applications in addition to direct pressure measurements.
- Static pressure influences a transmitters output because of a physical distortion that occurs on the measuring element.

“The goal is to minimize the total error that pressure effects can cause…variations in line pressure are not accounted for during normal operations”

Electrical Interference

Electromagnetic Interference (EMI)

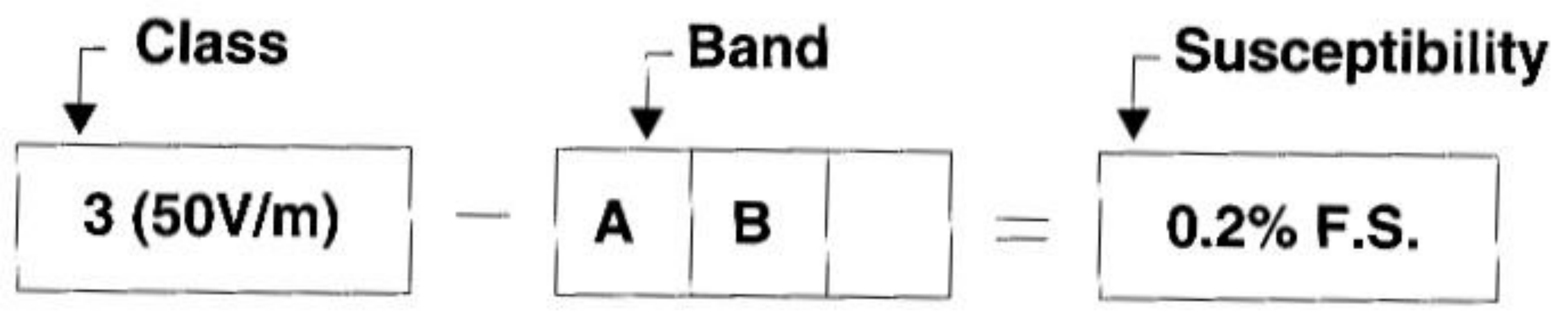
Radio Frequency Interference (RFI)

Common Mode

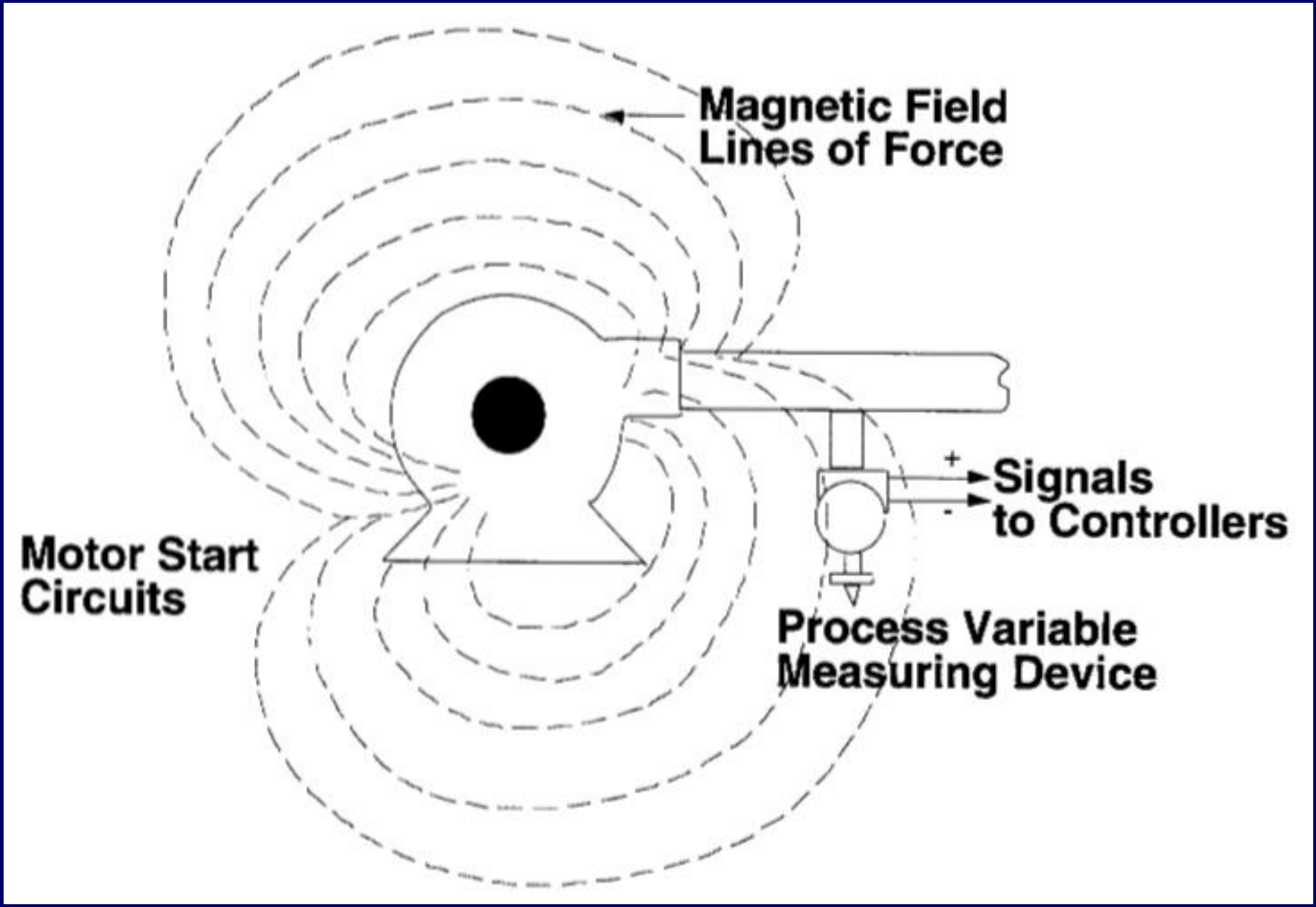
Normal Mode

“Instrument vendors often list specifications that indicate how resistant the device is to electrical interference”

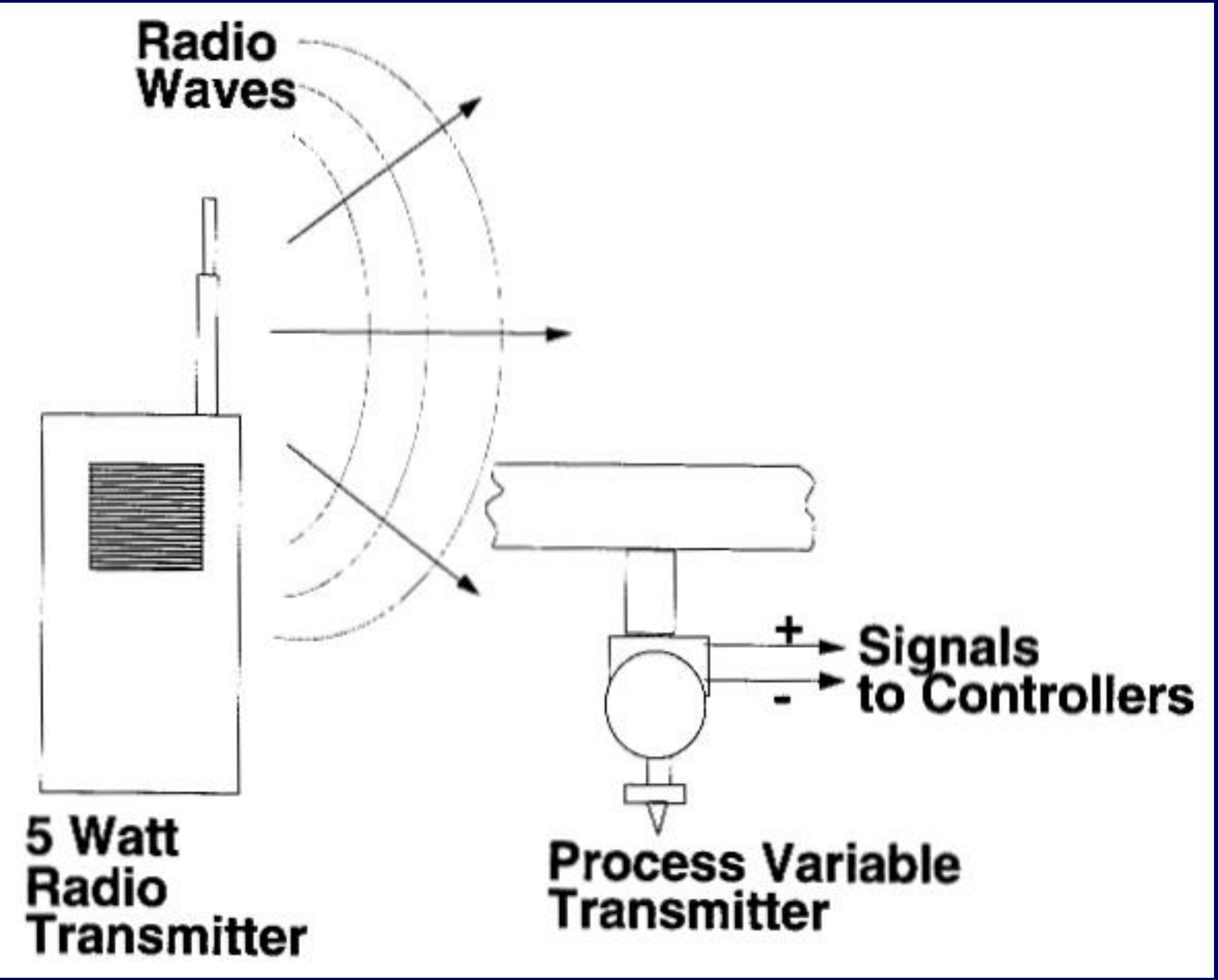
IEC RFI Specification



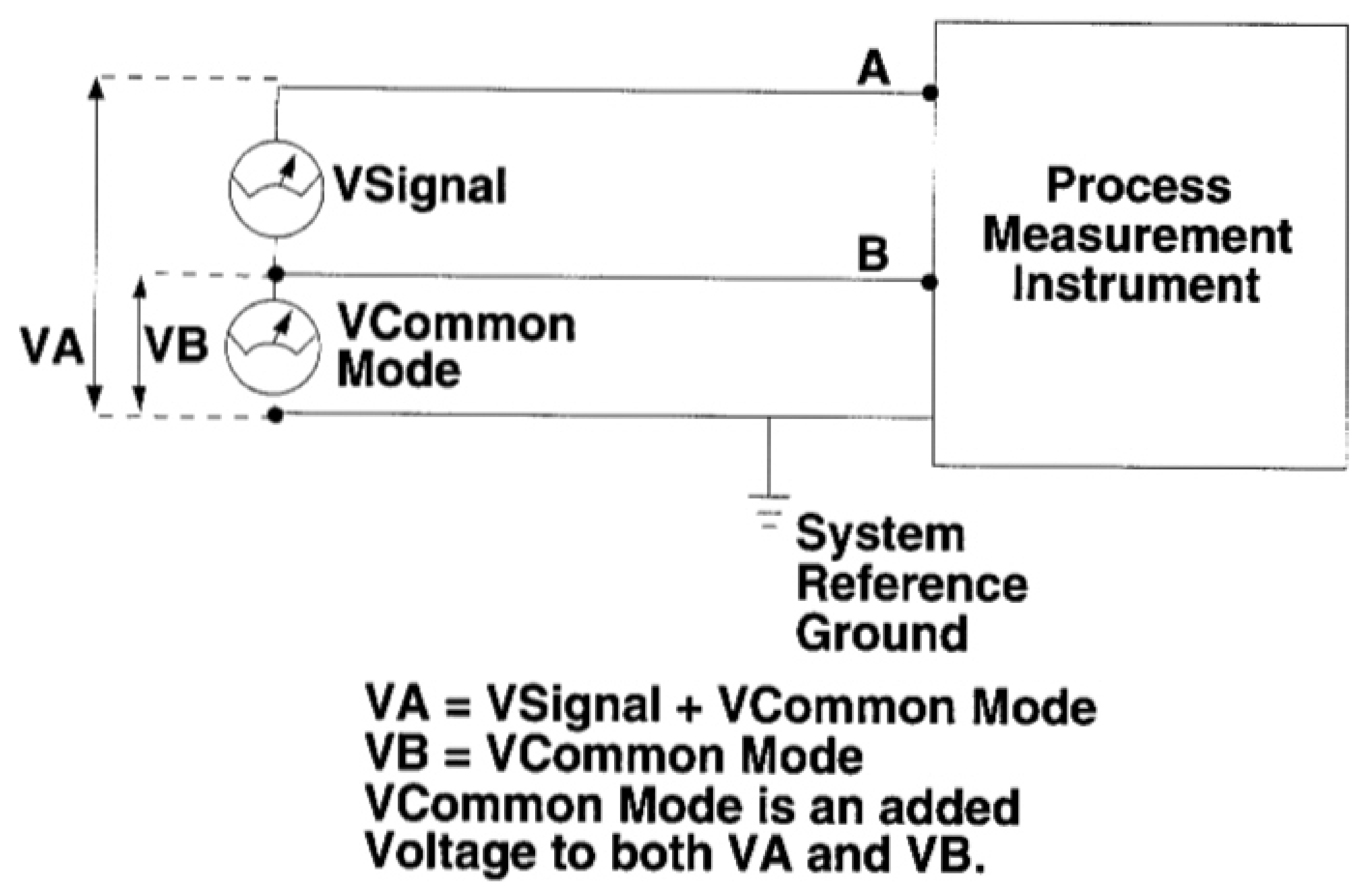
Electromagnetic Interference



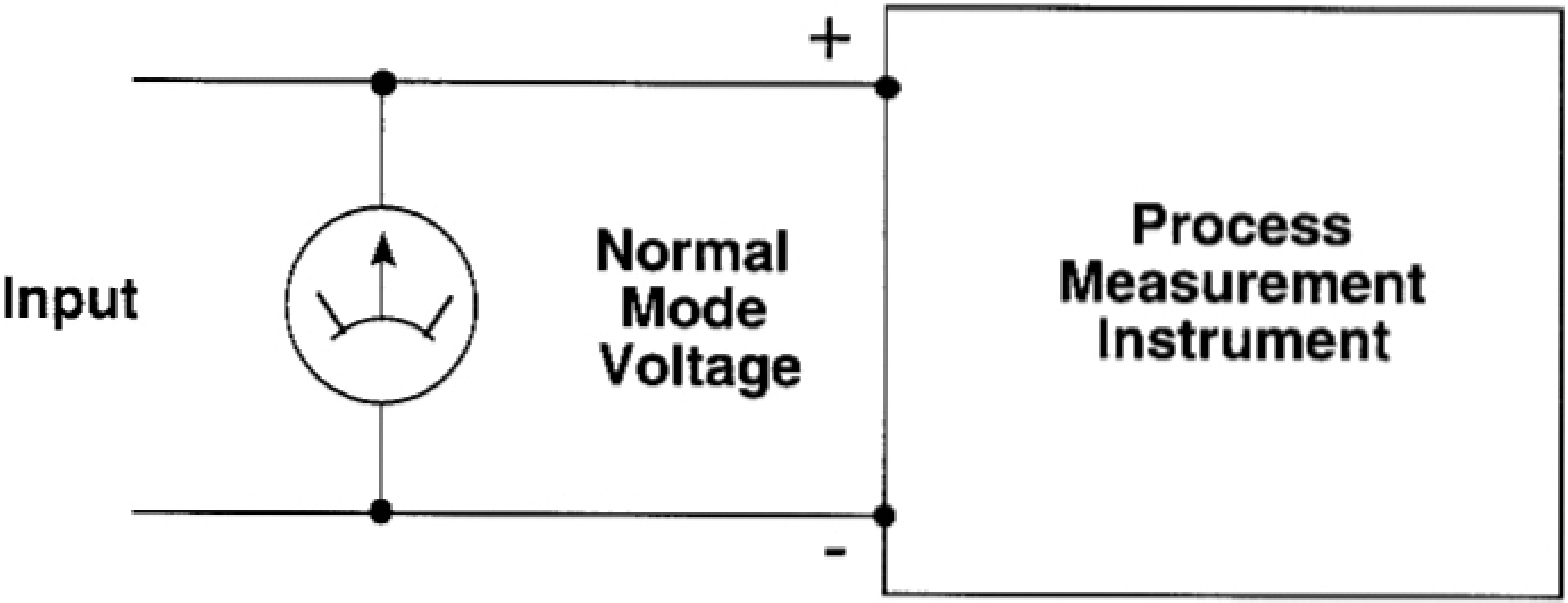
Radio Frequency Interference



Common Mode Interference



Normal Mode Interference



Electrical Interference

Handout

Reducing Electrical Noise in Instrument Circuits

IEEE Transactions

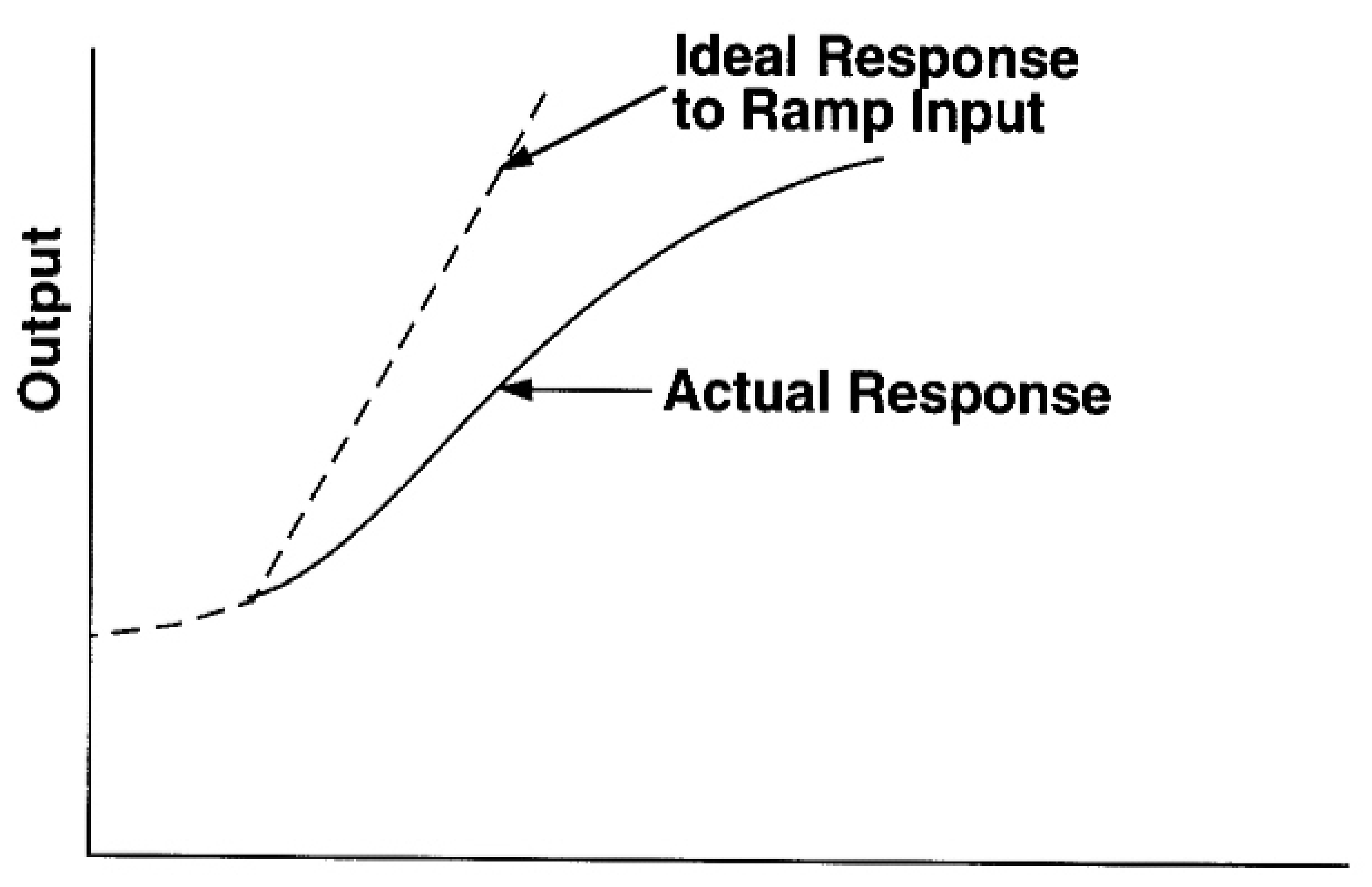
"With the trend toward more complete instrumentation in process plants using more sophisticated and more sensitive instruments than in the past, the reduction of electrical noise pickup by instrument circuits has become a real problem for the instrument engineer…Bruce Klipec, IEEE 1967"

Instrumentation Response

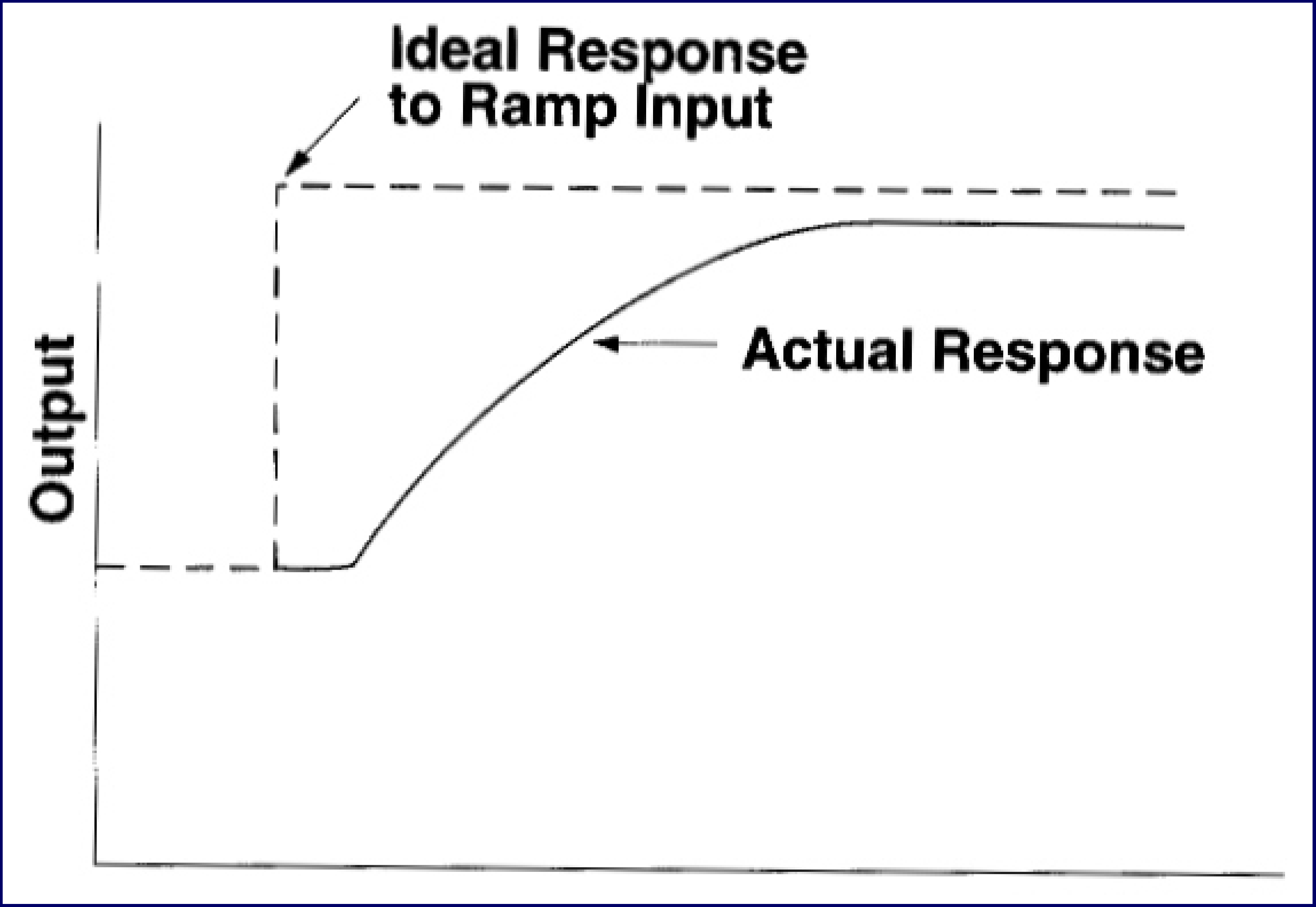
- Ramp Response
- Step Response
- Time Constant
- Settling Time
- Rise Time

"For the output of a first-order system forced by a step or an impulse, T is the time required to complete 63.2% of the total rise or decay at any instant during the process…"

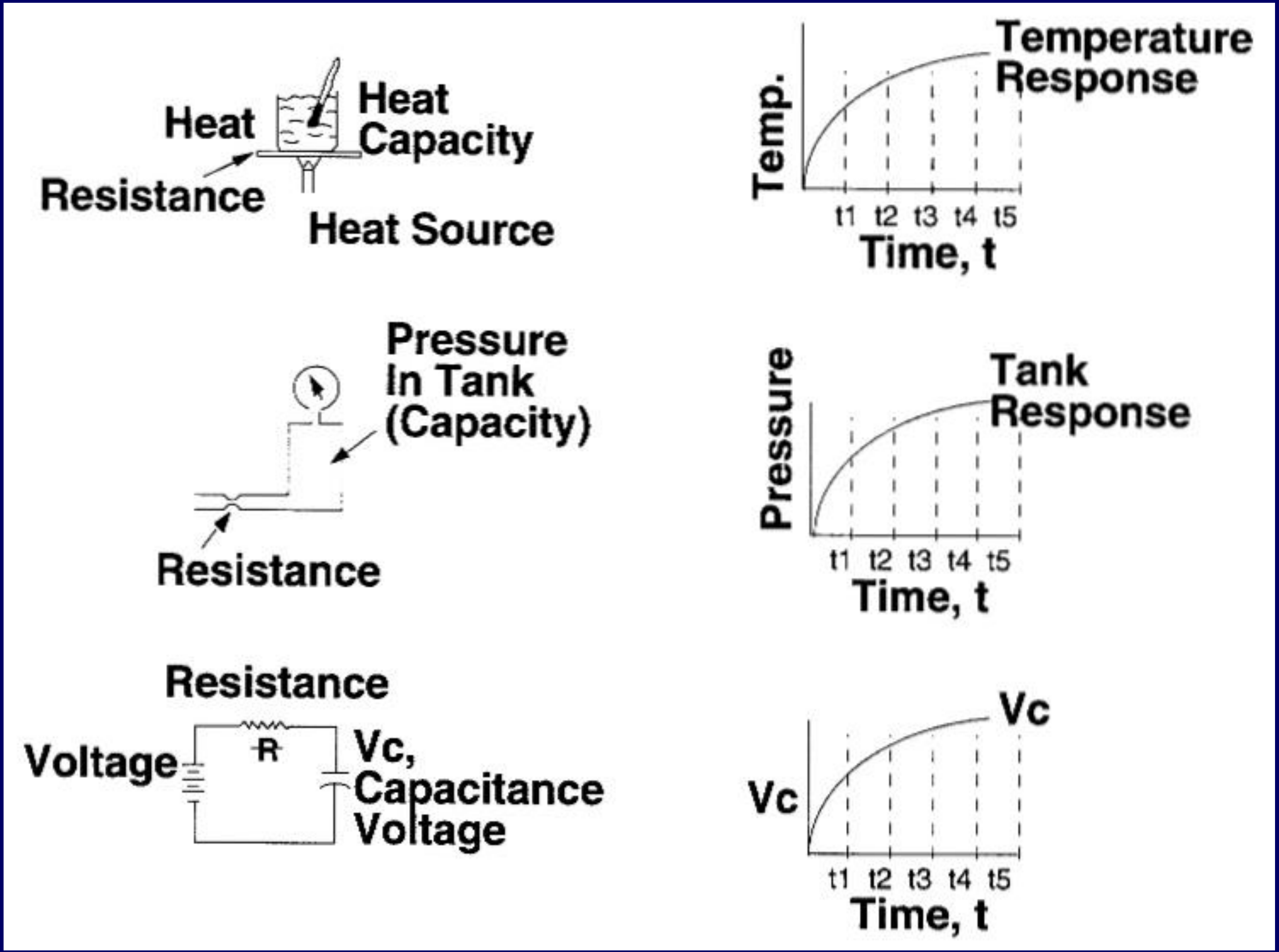
Ramp Response



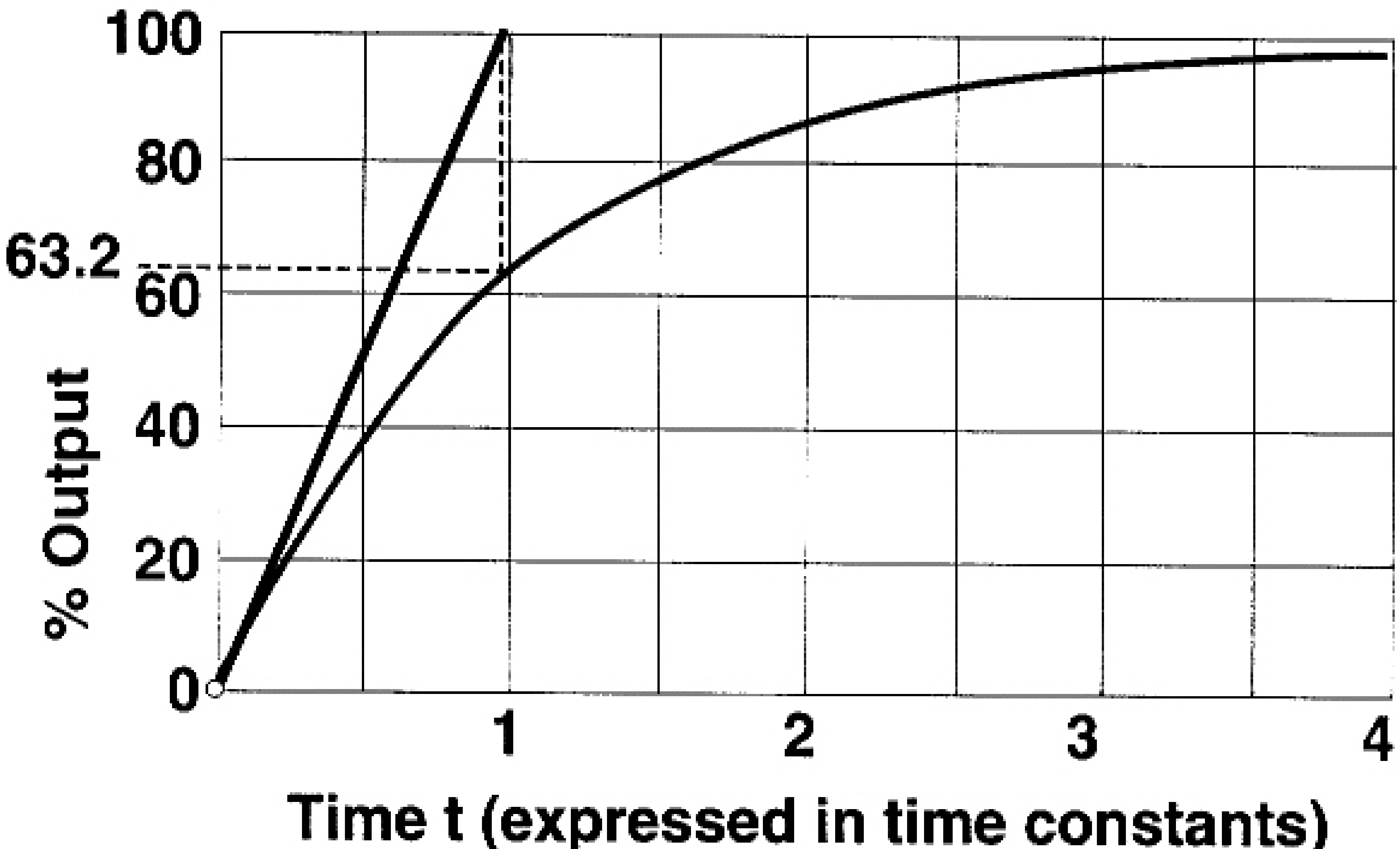
Step Response



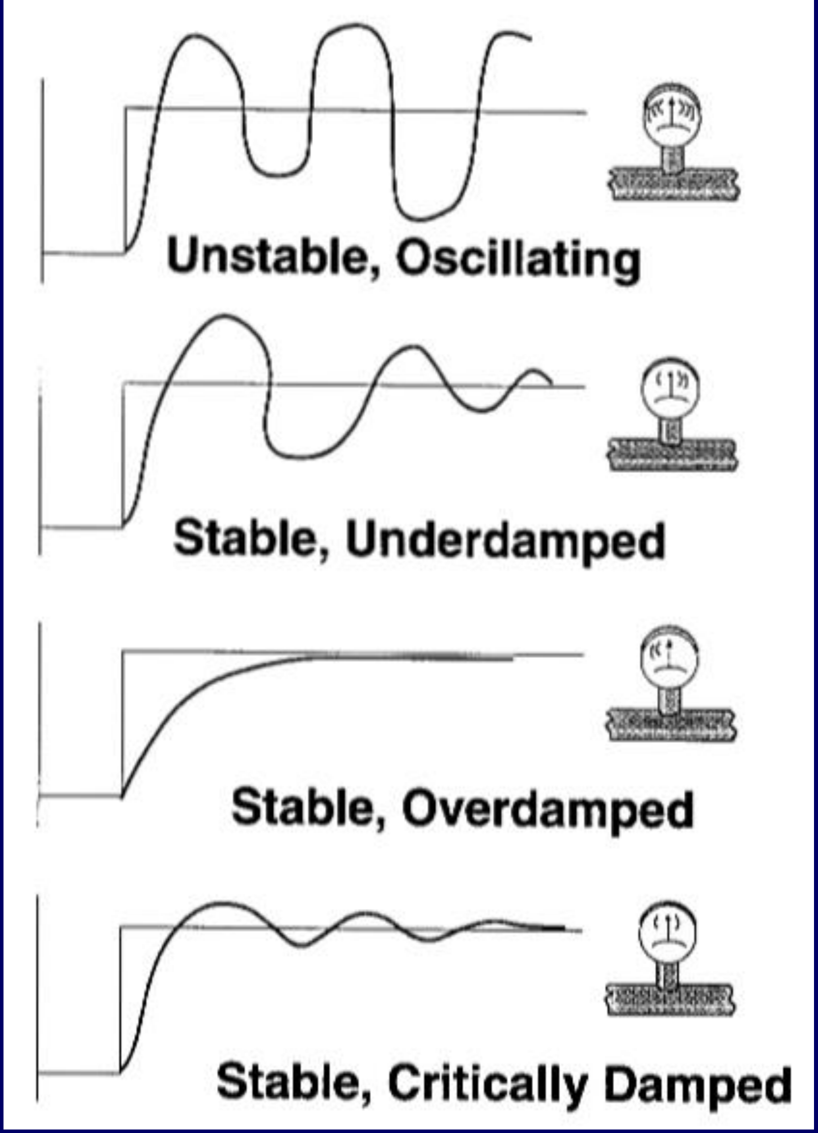
Time Constant Concepts



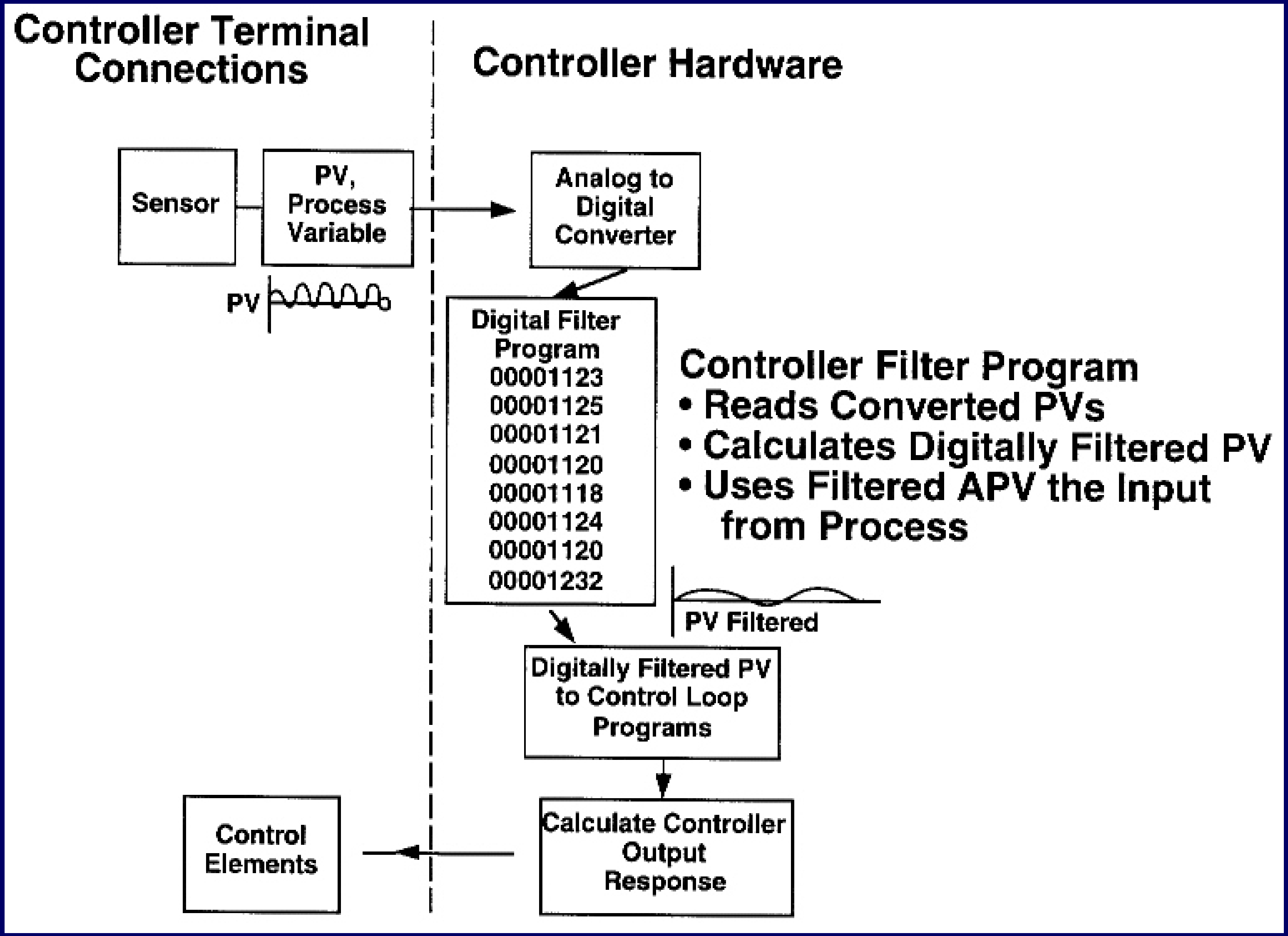
Time Constant Definition



Damping Definitions



Digital Filtering Example

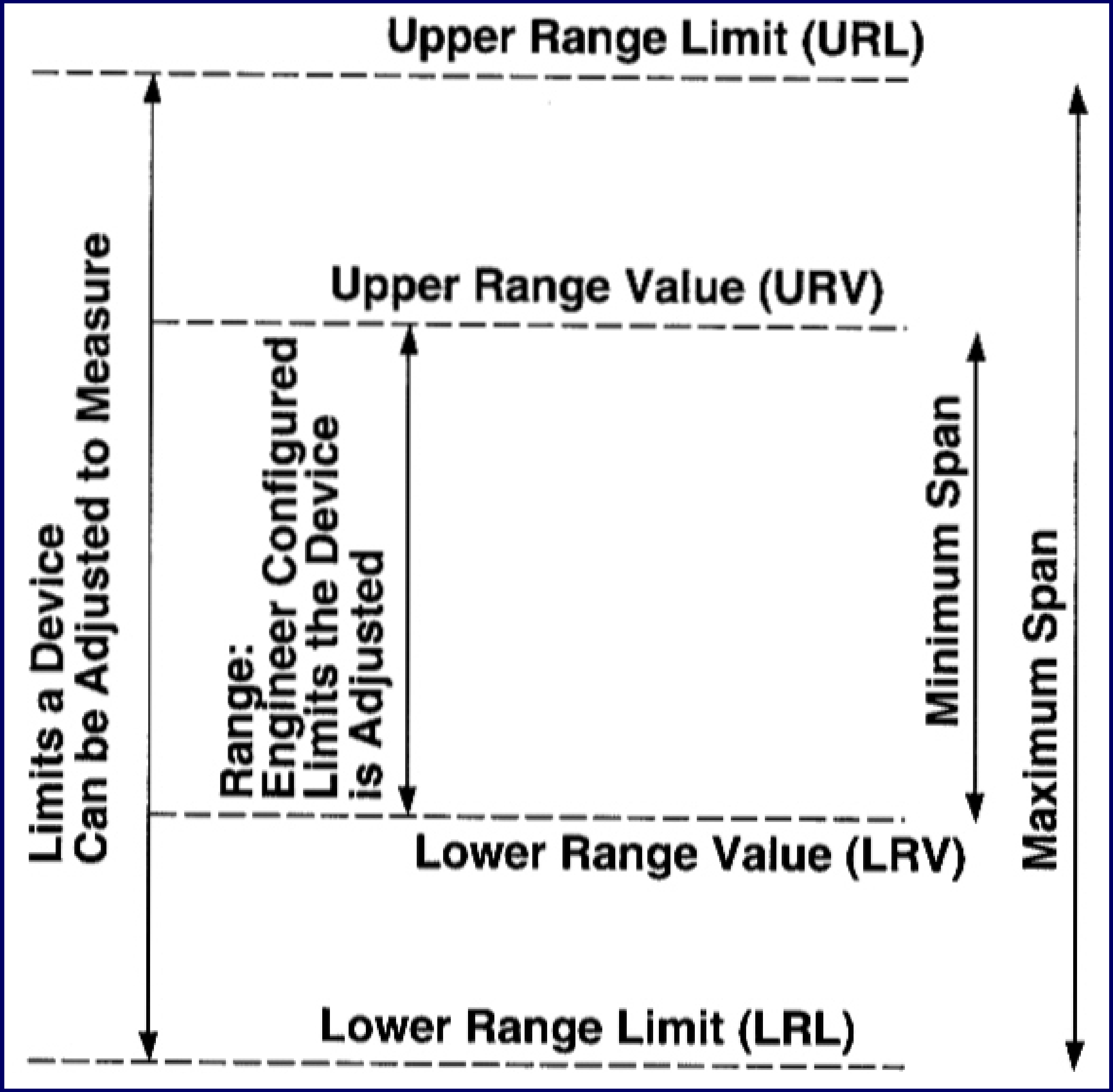


Range Examples

Range Examples	Range	Lower Range Limits	Lower Range Value	Upper Range Value	Upper Range Limits	Span
0 +100	0 to 100	-50	0	+100	+125	100
20 +100	20 to 100	-50	20	+100	+125	80
-25 0 +100	-25 to +100	-50	-25	+100	+125	125

Note: Assume Device LRL = -50 and URL = 125
Range Examples: LRL, LRV, URV, URL

Range Definitions



Rangeability and Turndown

- Rangeability vs. Turndown
- Zero Elevation Range
- Zero Suppression Range

"An instrument spec may claim 0.25% accuracy or even greater under reference conditions…however, the total error could be 2.5% once installed"

Temperature and Pressure Effects

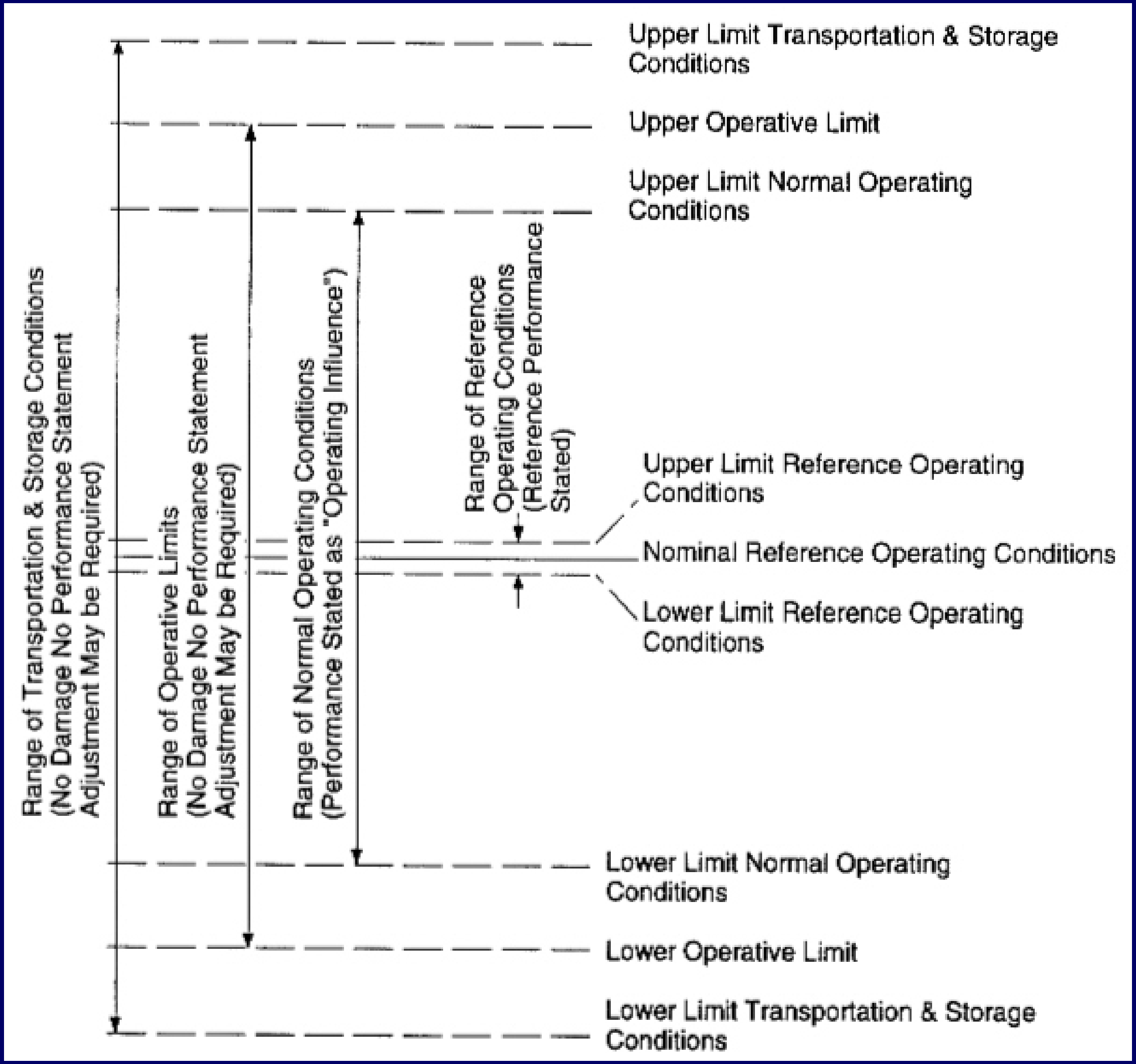
- Zero Shift /Span Shift with Temperature
- Zero and Span Error due to Static Pressure

“Work through example in text of Zero Shift with Temperature (pg. 28) and Static Pressure Effects (pg. 31) using Rosemount 1151 Handout”

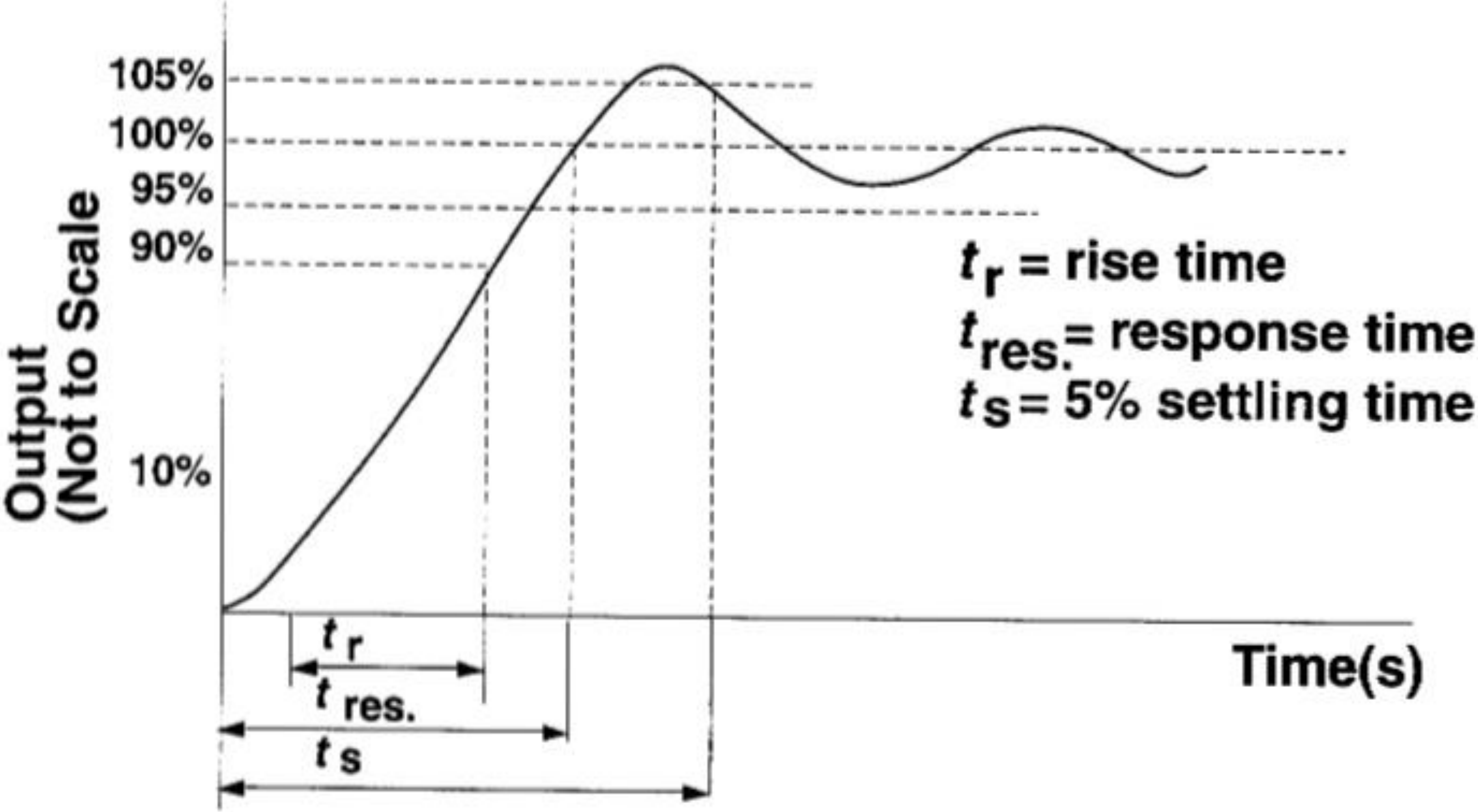
Operating Conditions Versus Performance

Operating Conditions	Performance
Reference	Reference – In this region the accuracy statements apply unless otherwise indicated.
Rated (Normal)	Conditional – In this region the influences of the operating environment are stated.
Operative Limits	Indefinite, not specified – In this region the influences of the operating environment are not stated. Operating beyond the limits may damage the instrument.

Relationship of Limits



Settling Time, Rise Time, and Response Time

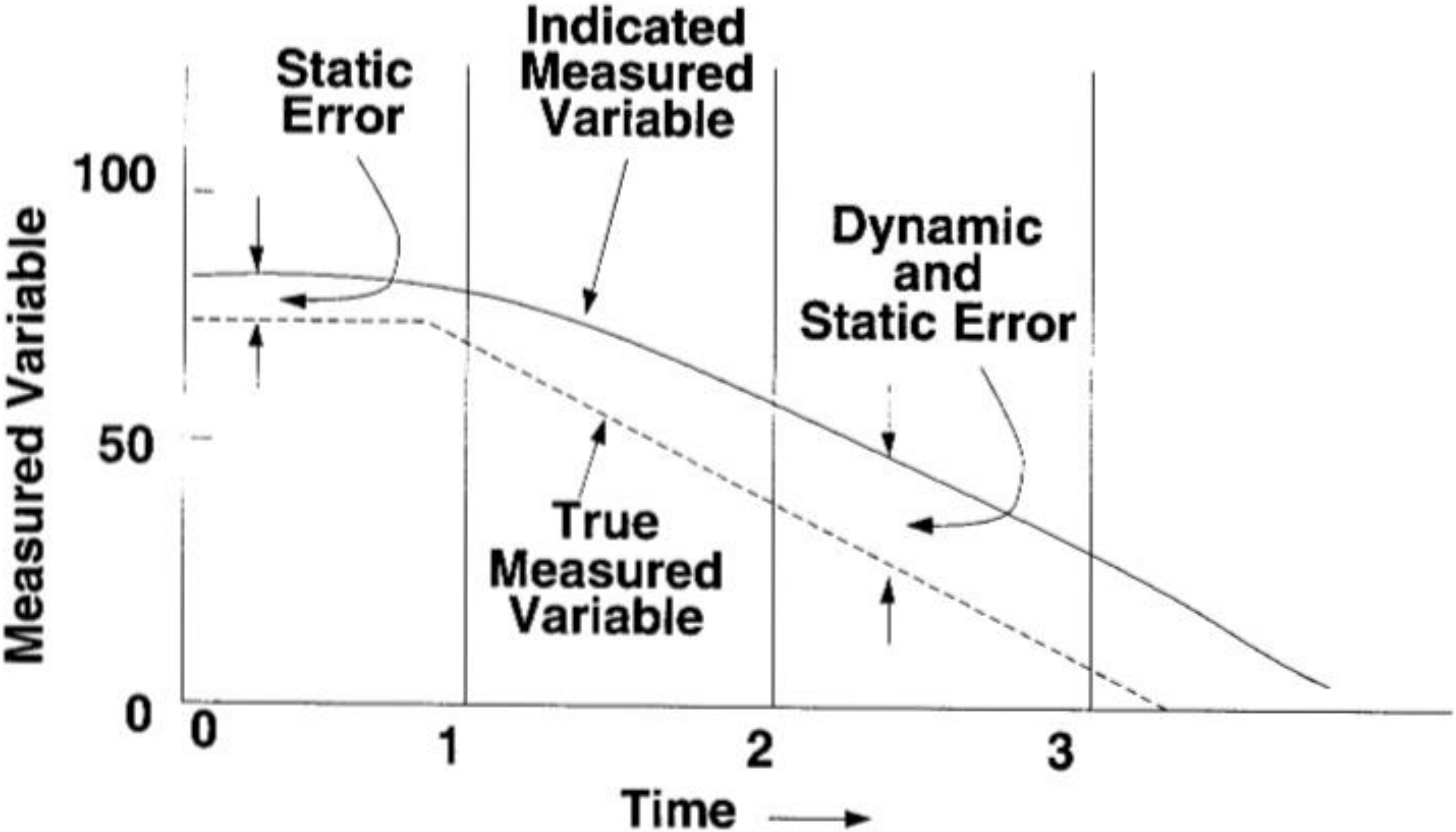


Accuracy and Static Steady State Conditions

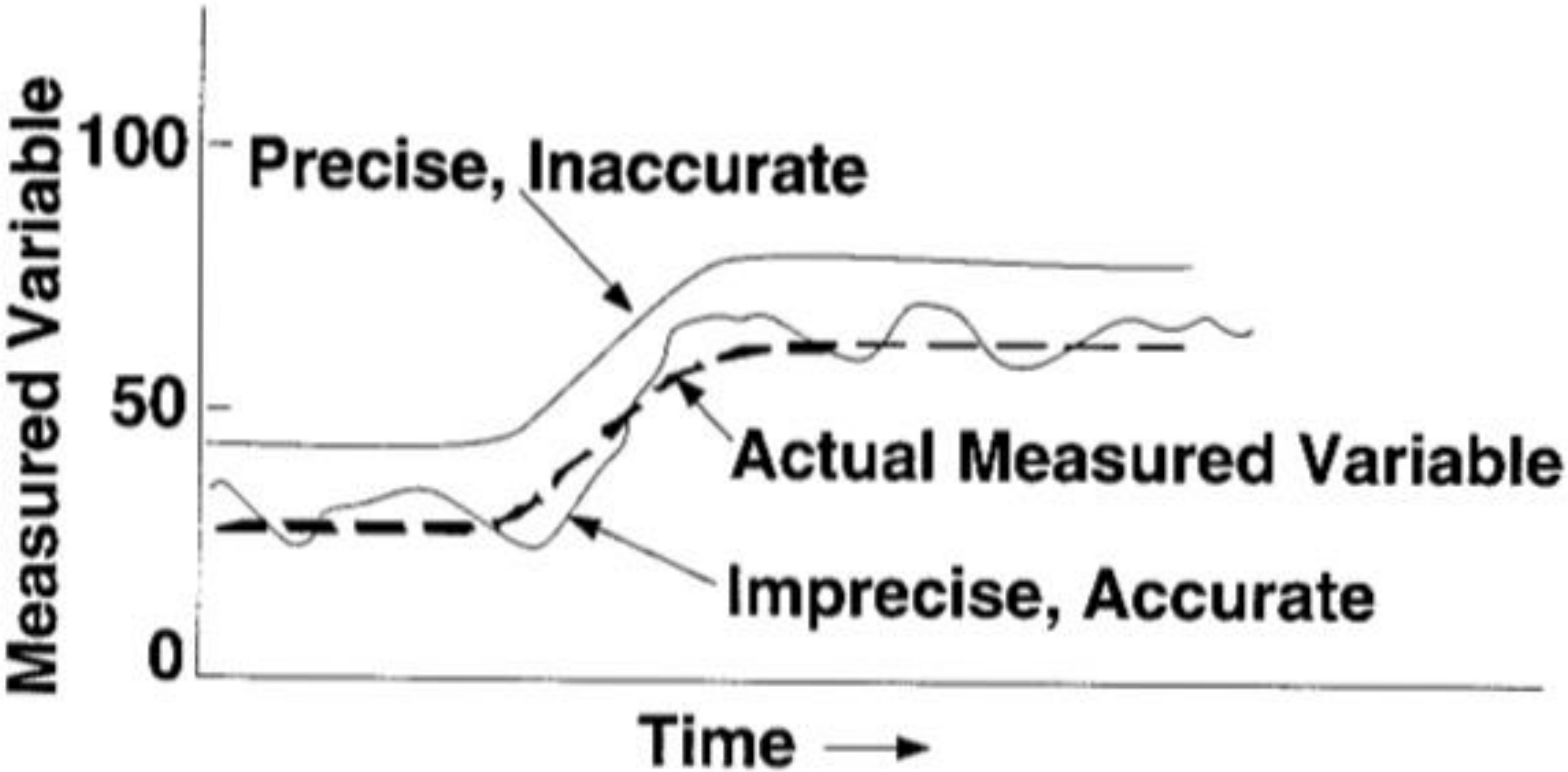
- Discuss Examples of Accuracy Statements of various instruments (Vendor Spec. Sheet handouts)
- Comparison of Flow Meter Accuracy Statements (F&P handout 10E-3b)

"These examples show that accuracy can be expressed in several ways"

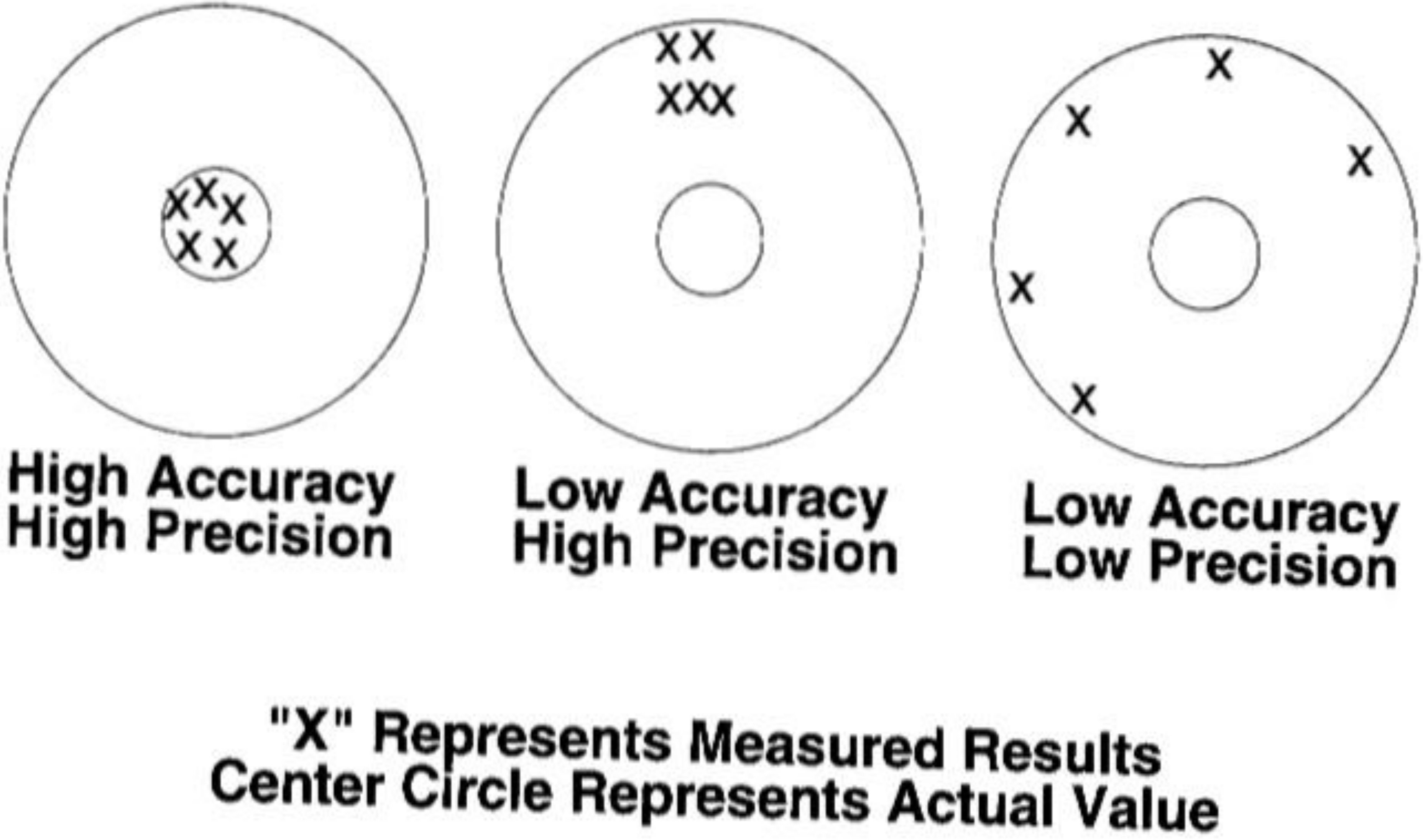
Static and Dynamic Accuracy



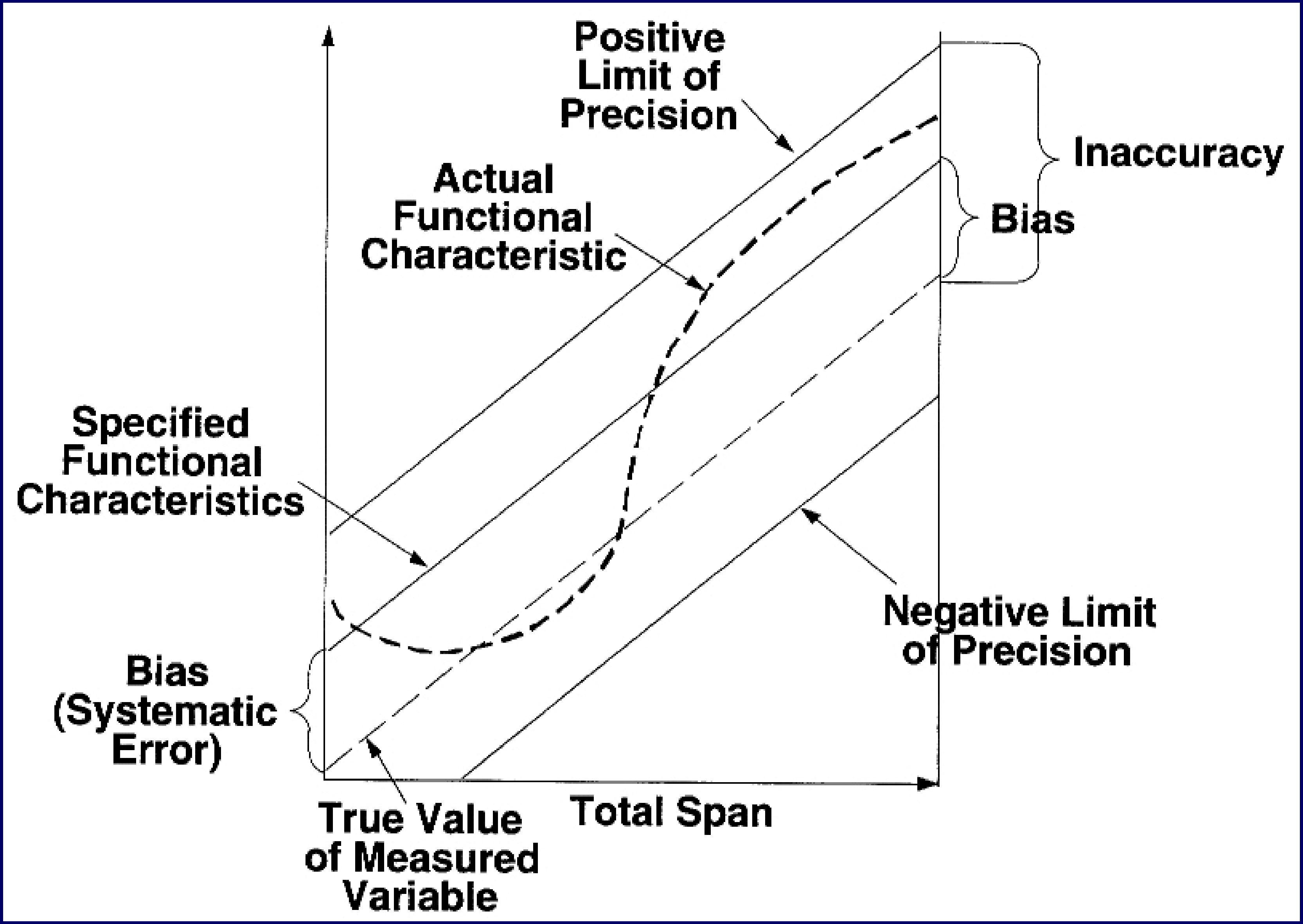
Precision and Accuracy Difference



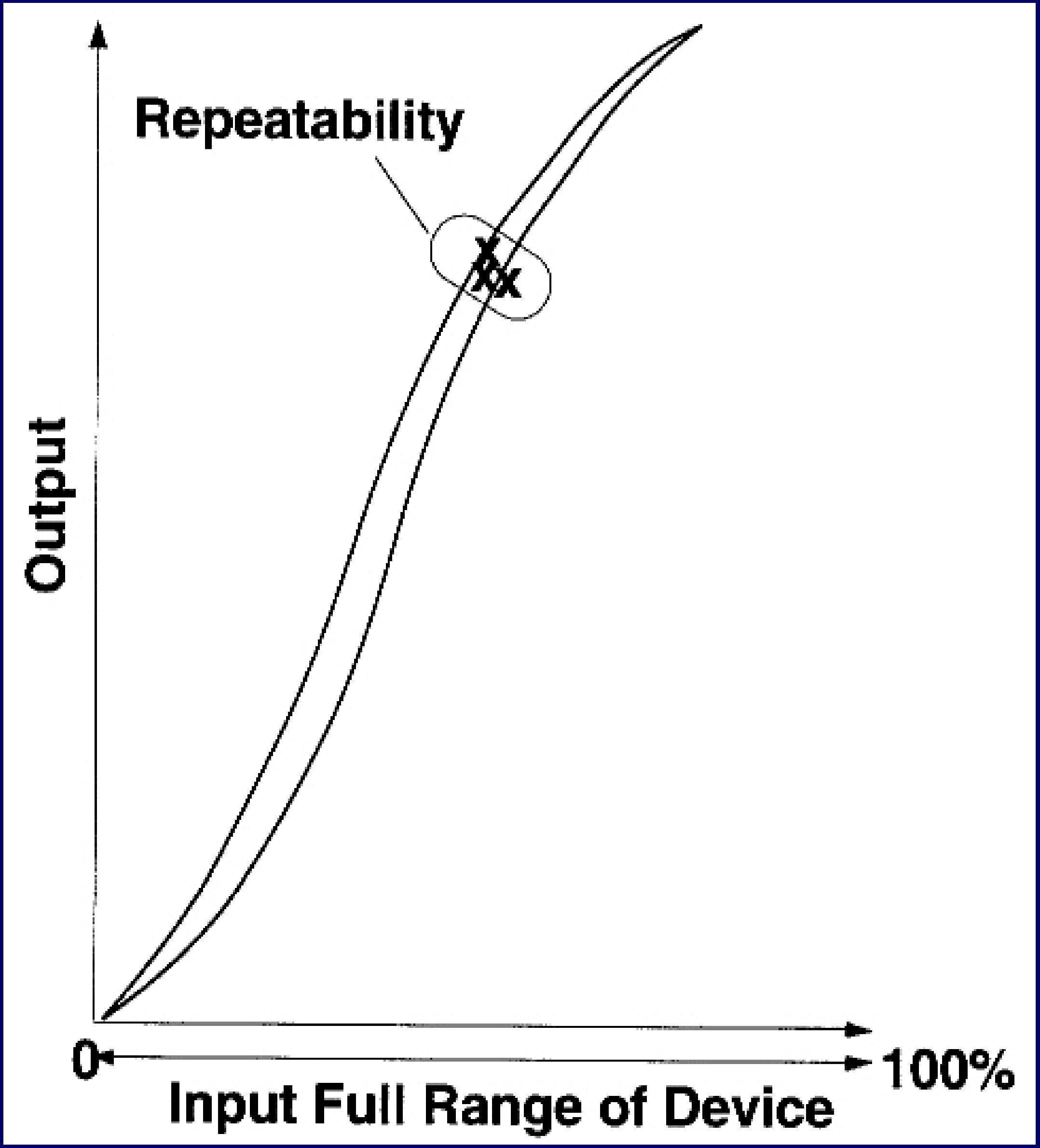
Precision Versus Accuracy



Accuracy Versus Bias



Repeatability

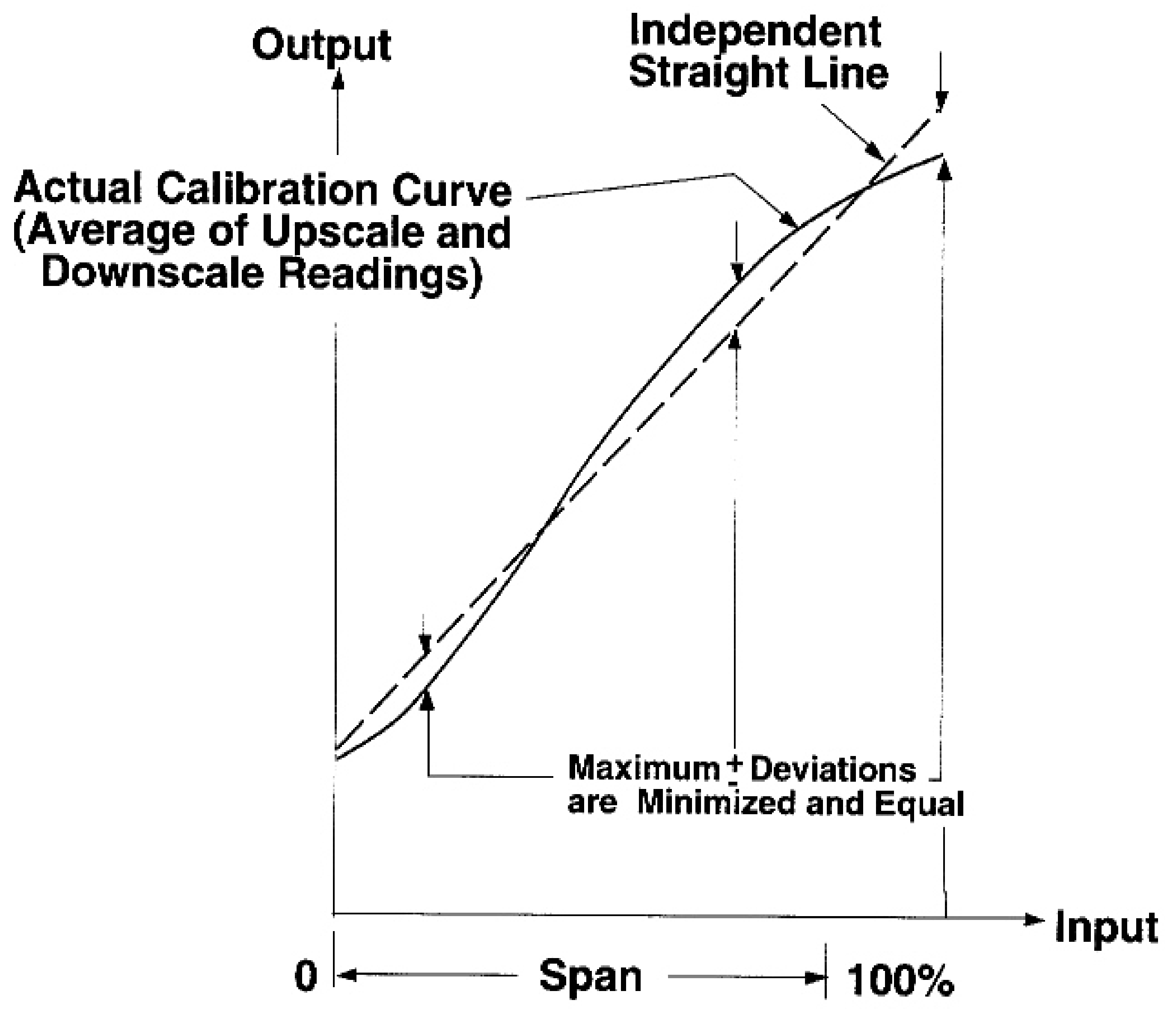


Linearity

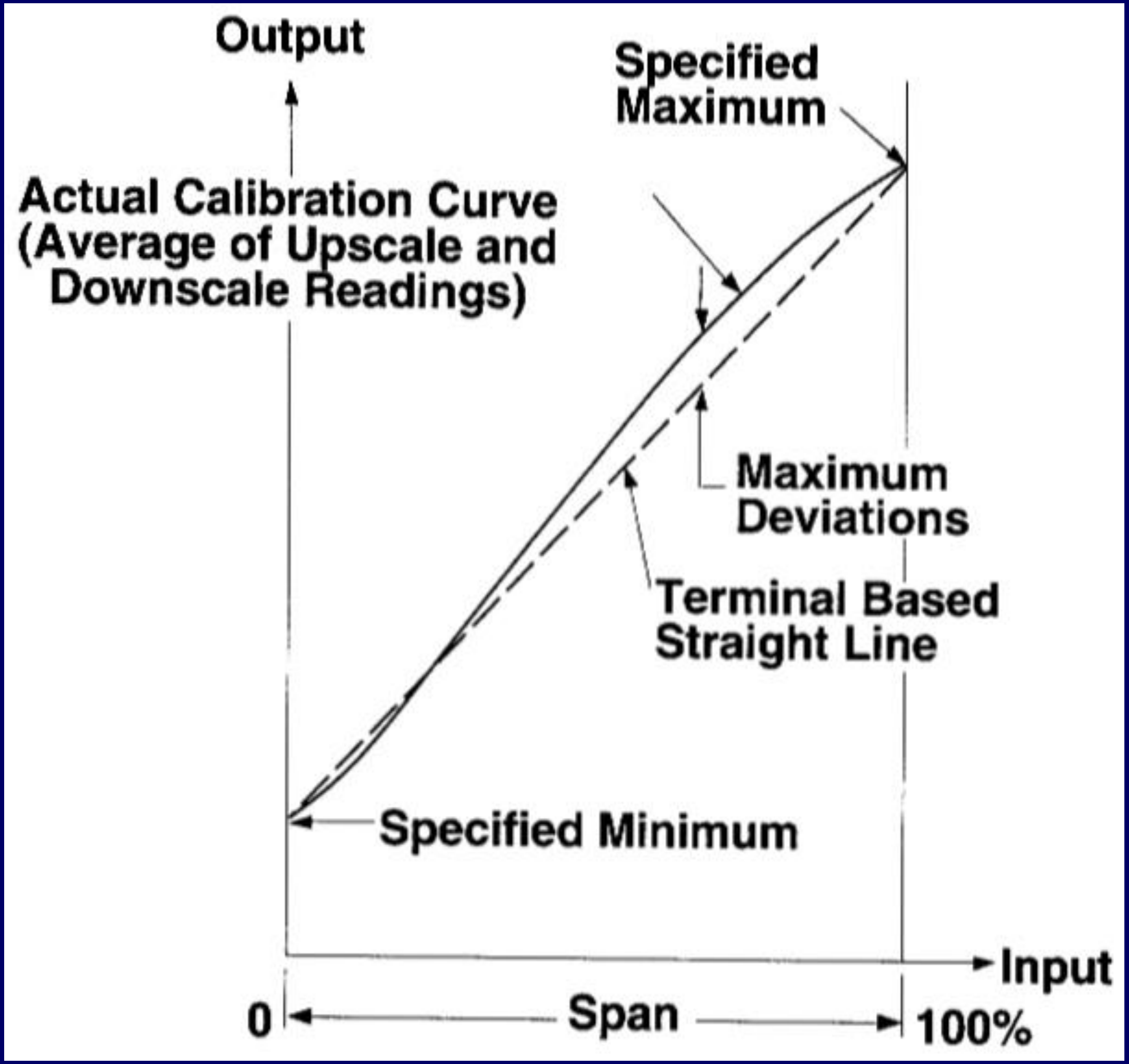
- Independent
- Terminal
- Zero

"How closely an input/output relationship approaches a straight line"

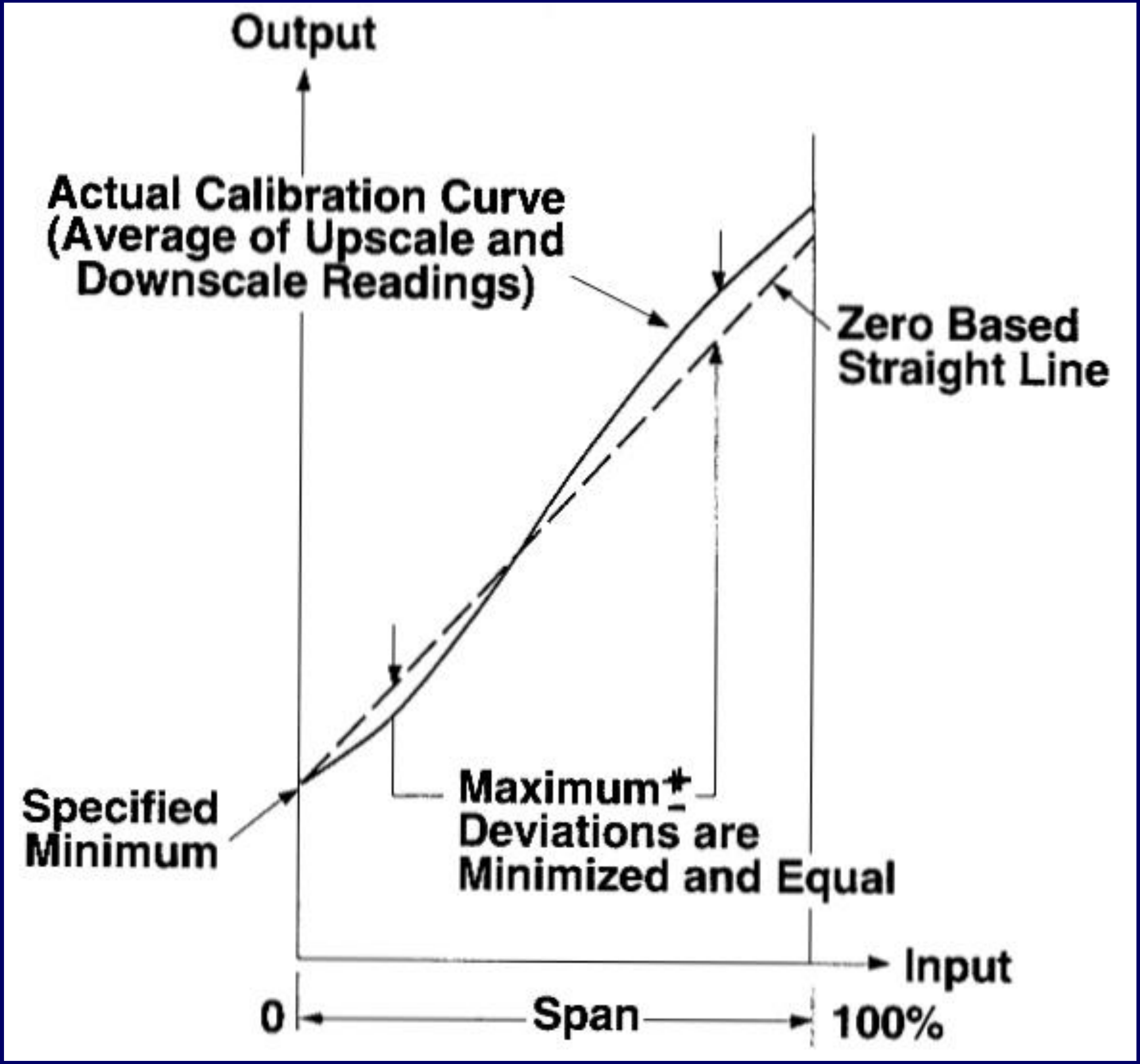
Independent Linearity



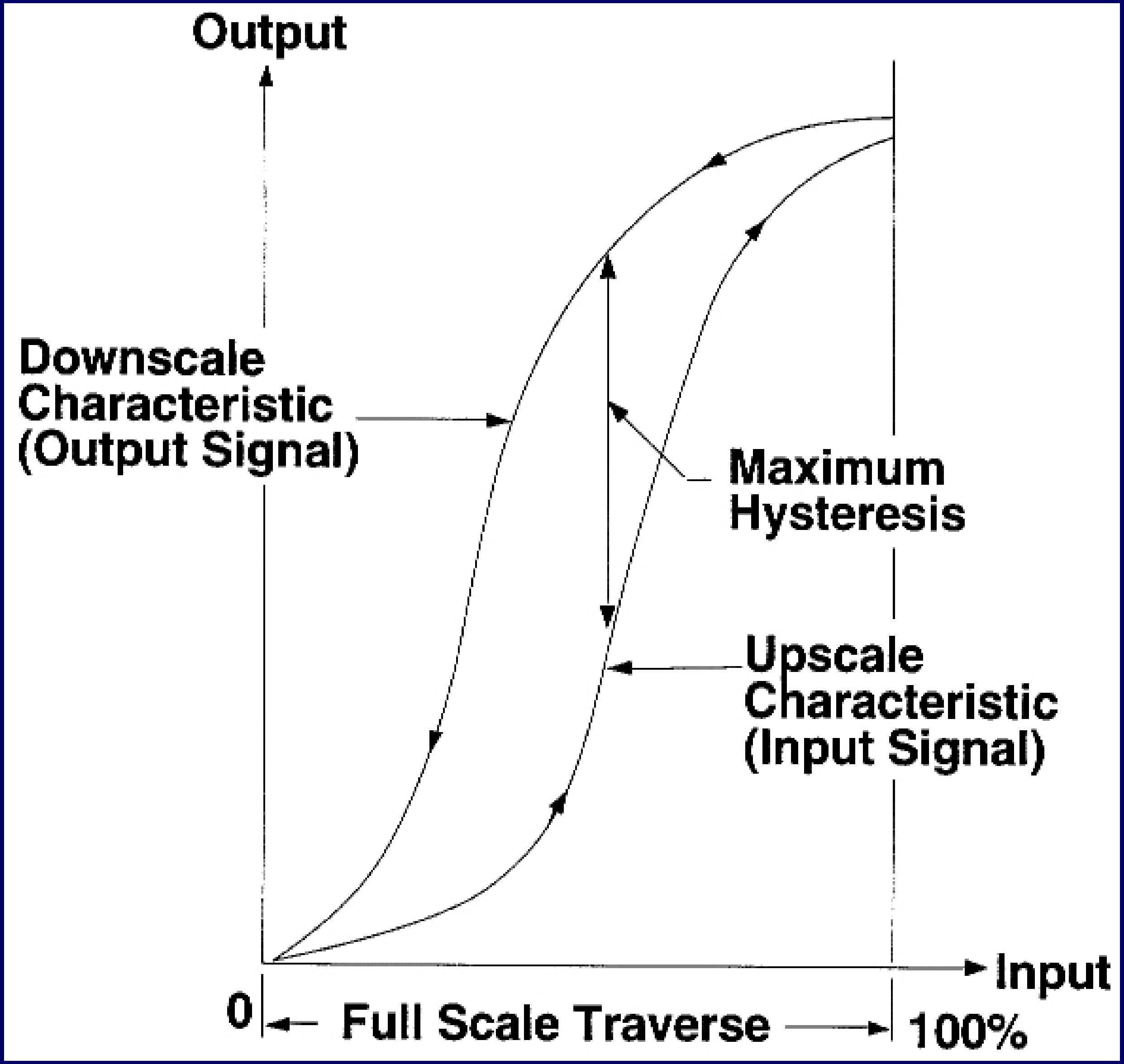
Terminal Linearity



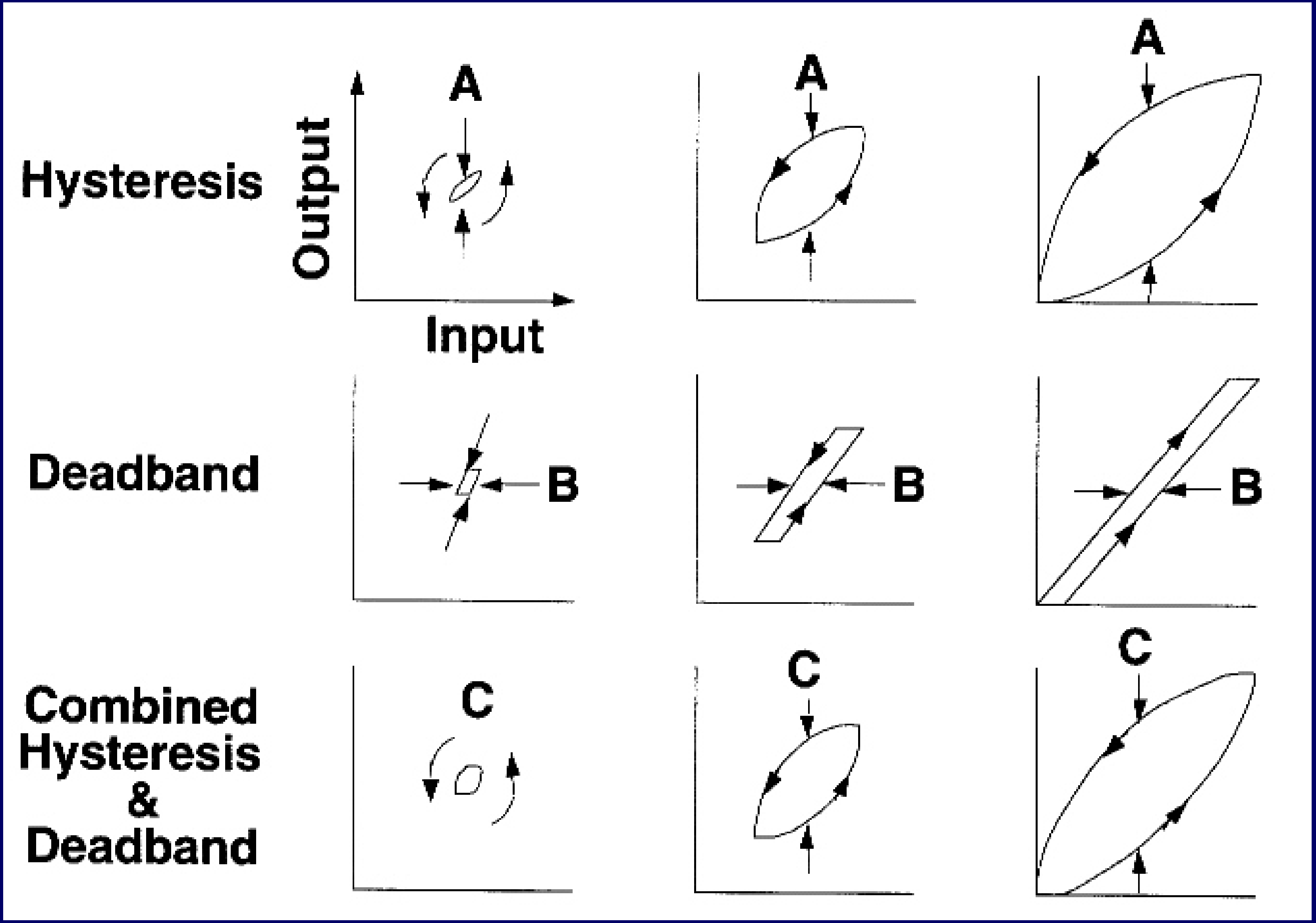
Zero-Based Linearity



Hysteresis


Output
Downscale
Characteristic
(Output Signal)
Maximum
Hysteresis
Upscale
Characteristic
(Input Signal)
Input
0
Full Scale Traverse
100%

Hysteresis and Deadband



Drift

- Zero Drift
- Span Drift
- Partial Drift

"Undesired slow change or amount of variation in the output signal over a period of time"

Reliability

- MTTF
- MTTR
- MTBF = MTTF + MTTR

“Used to quantify a devices ability to perform a function without failure over a specified period of time or amount of use”

Exercise 1
Vendor Data for 1151DP4E22

EXERCISE 1: INTERPRET VENDOR DATA SHEETS AND SAUDI ARAMCO INSTRUMENT SPECIFICATION SHEETS

Directions: Use the exercise directions along with Work Aids 1A through 1G to complete Exercises 1A through 1C.

Exercise 1A: Interpret Vendor Data Sheets

Given a vendor data sheet for Smith Turbine Meter Model #K2BBAF01D01 (Work Aid 1B) and a checklist for cross-referencing process measurement terms (Work Aid 1A), enter the data for the identified model in the list of measurement terms table. State any qualifications to the vendor's terms (such as a different metrology term that a vendor used, whether the term is not listed, whether the term requires factory consultation, or whether the term required extrapolating data). Use Work Aid 1G for conversions to metric units where necessary.

List of measurement terms for Smith Turbine Meter #K2BBAF01D01		
Measurement term	Specified data	Enter any qualifications to vendor data
Range		
Upper Range Limit		
Lower Range Limit		
Maximum Span		
Minimum Span		
Turndown		
Overrange		
Reference Conditions		
Rated Ambient Temperature Limits		
Response Time		
Accuracy		
Reproducibility		
Repeatability		
Linearity		
Drift		
Reliability		

Total Probable Error

- Total Error
- TPE
- F&P Handout 10E-3b

“Because of the random distribution of errors, the square root of the sum of the squares of error contribution is used in practice”

Exercise 2 - Calculate the Total Probable Error for a 1151DP4E22

The application data for the Total Probable Error calculation is as follows :

- Transmitter output : 16 mA
- Ambient temperature :120°F
- Atmospheric pressure : 760 mm Hg (1 Atm., 14.7 psia)
- Transmitter calibrated for 0-150 in H2O
- Calibrated at 70 degrees F and atmospheric pressure

Exercise 2 Solution

Transmitter is performing at 120°F and is measuring 112.5“ H_2O.

Reference accuracy = ± 0.2% of calibrated span

= (.002)x(150”)

= 0.3” H_2O

Temperature effect = total error

=(± 0.5% URL+ 0.5% calibrated span)/100°F x deltaT

=(.005)(150)+(.005)(150)/100°F x 50°F

= 0.75” H_2O

Static pressure = Zero + Span error

Zero error = ± 0.25% URL/2000 psi (does this apply?)

Span error = ± 0.25% Input reading/1000 psi (does this apply?)

Exercise 2 Solution

TPE = $(Accuracy^2 + Tzero^2 + Tspan^2 + Pzero^2 + Pspan^2)^{1/2}$

Total Probable Error= $((0.3)^2 + (0.75)^2 + (0)^2 + (0)^2)^{1/2}$

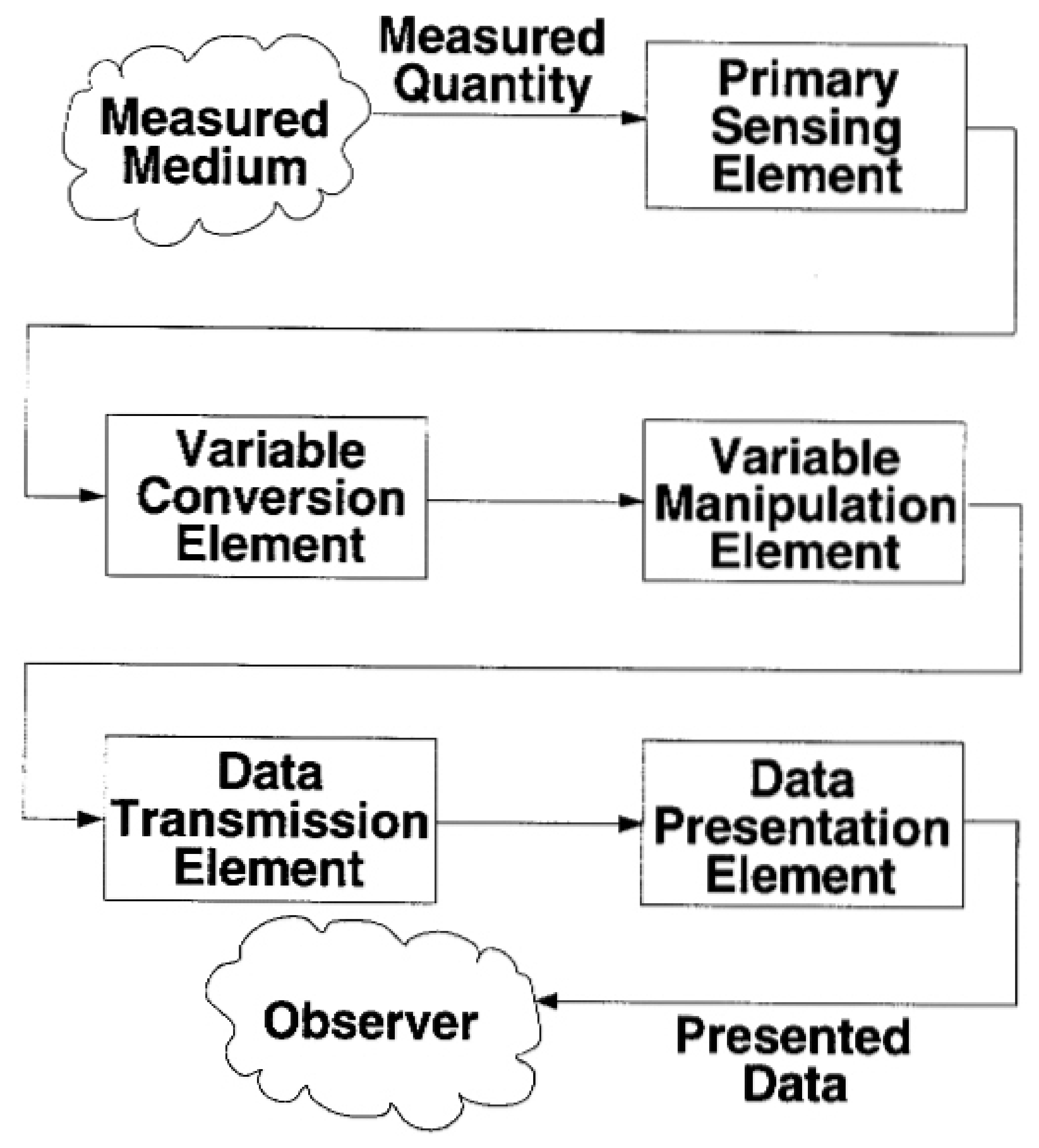
Total Probable Error= + 0.81 “ H_2O

Typical Design Criteria

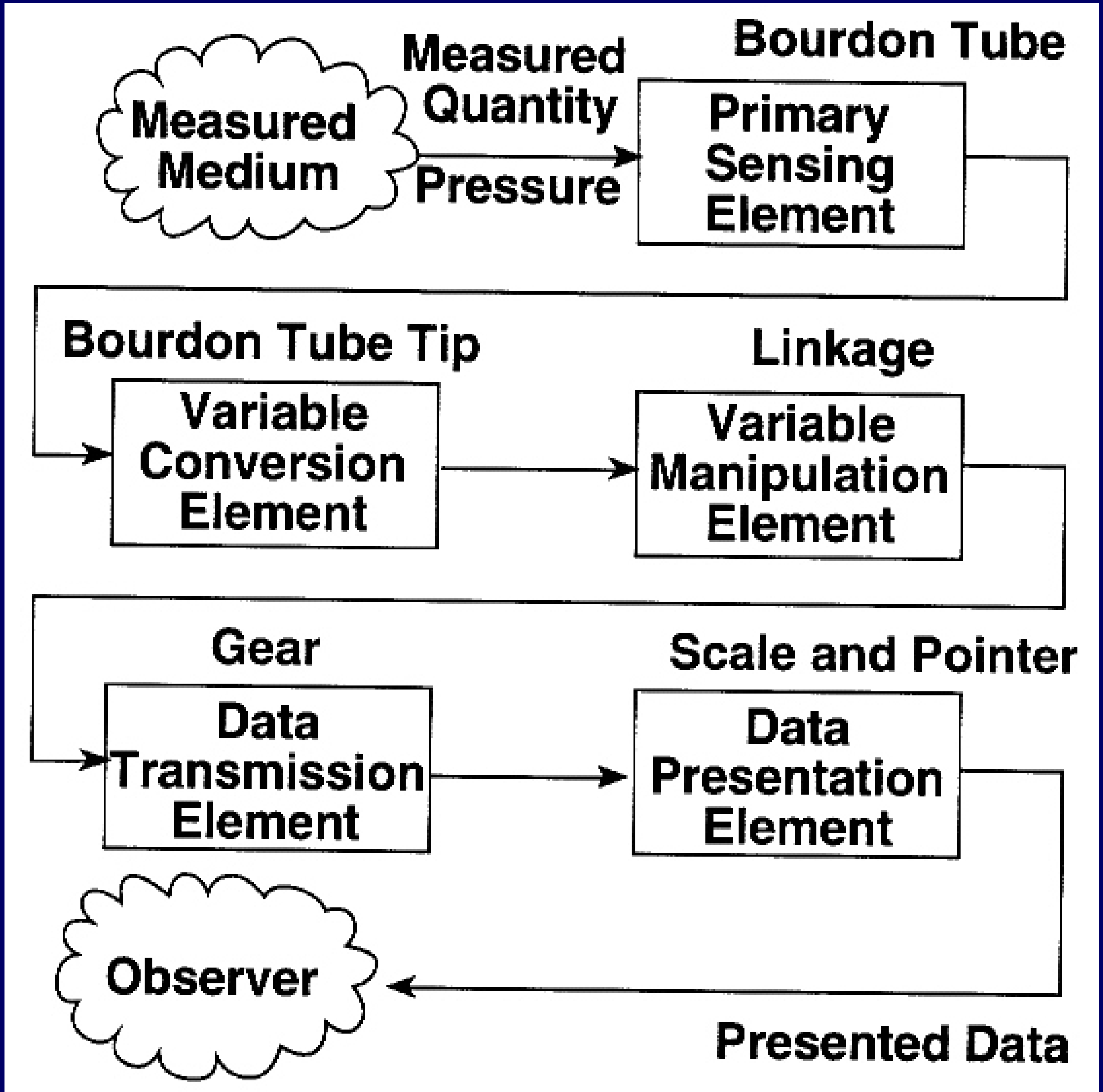
- Keep the Design Simple
- Avoid using glass
- Keep electronics Cool
- Provide easy Serviceability
- Safety

"Considering these issues will help ensure an installation that will not result in problems down the road."

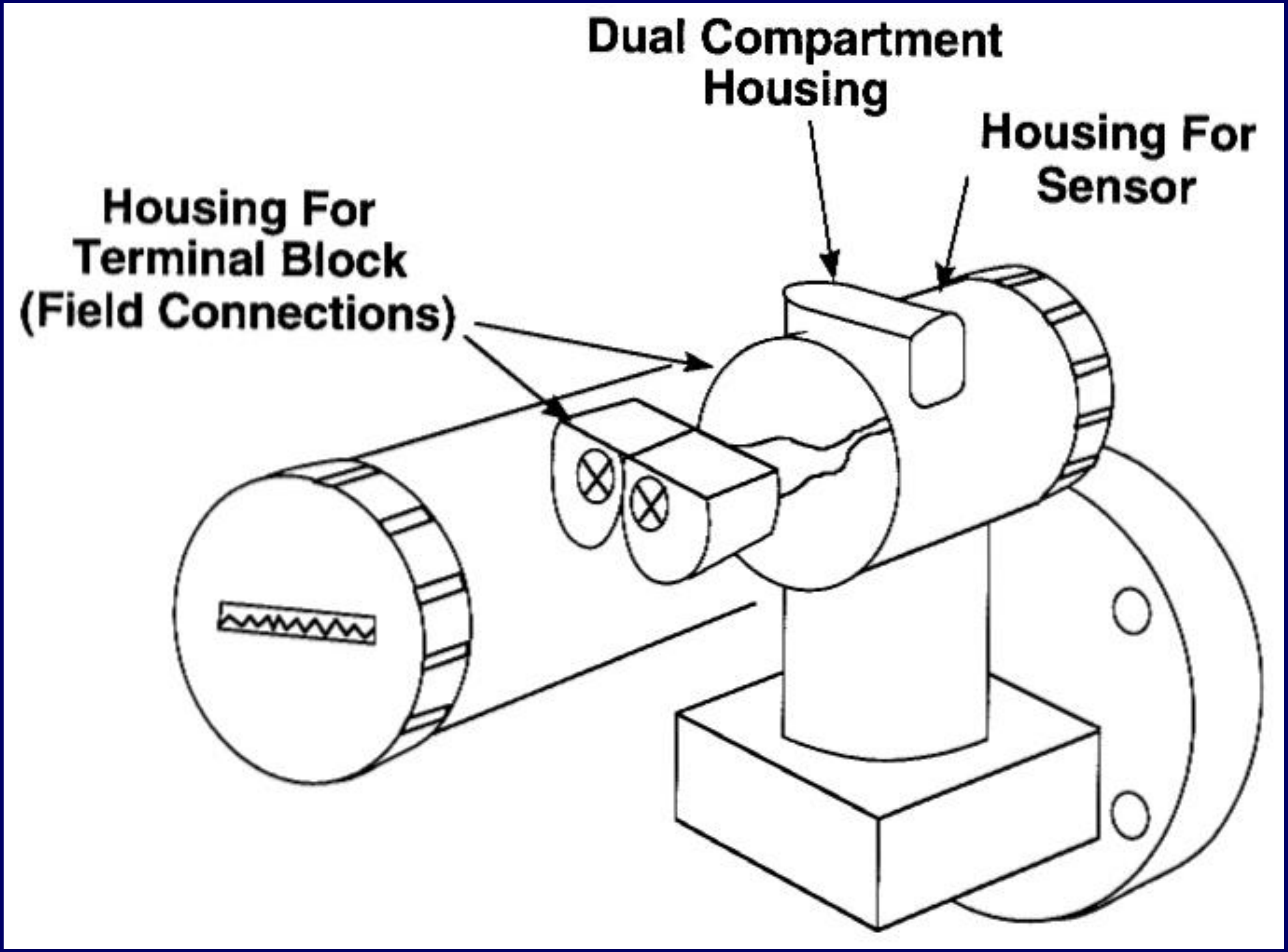
Functional Elements of Process measurement



Functional Elements of Pressure Gauge



Housing Example



Corrosion References

Saudi Aramco Reference	Title	Comments
SAEP-119 Section 1.2	Saudi Aramco Material System Specifications	On and off shore ambient corrosion conditions that equipment must meet.
SAES-J-101, Section 6.2	Custody Metering of Hydrocarbon Gases	Corrosion-resistant material such as stainless steel 316 or better required for sour gas applications.
SAES-J-902, Section 7.5.2	Electrical Systems for Installation	Tinning of field wiring acceptable for corrosion protection.
SAES-P-111, Section 5.4	Grounding	Conductors in areas of severe corrosion are green PCV covered.
SADP-J-100	Process Flow Meters	General corrosion references.
SADP-J-200	Pressure	Installation to avoid corrosion.
SADP-J-300	Level	Housing requirement.
SADP-J-400	Temperature	Thermowell protects sensor.

Process Fluid Considerations

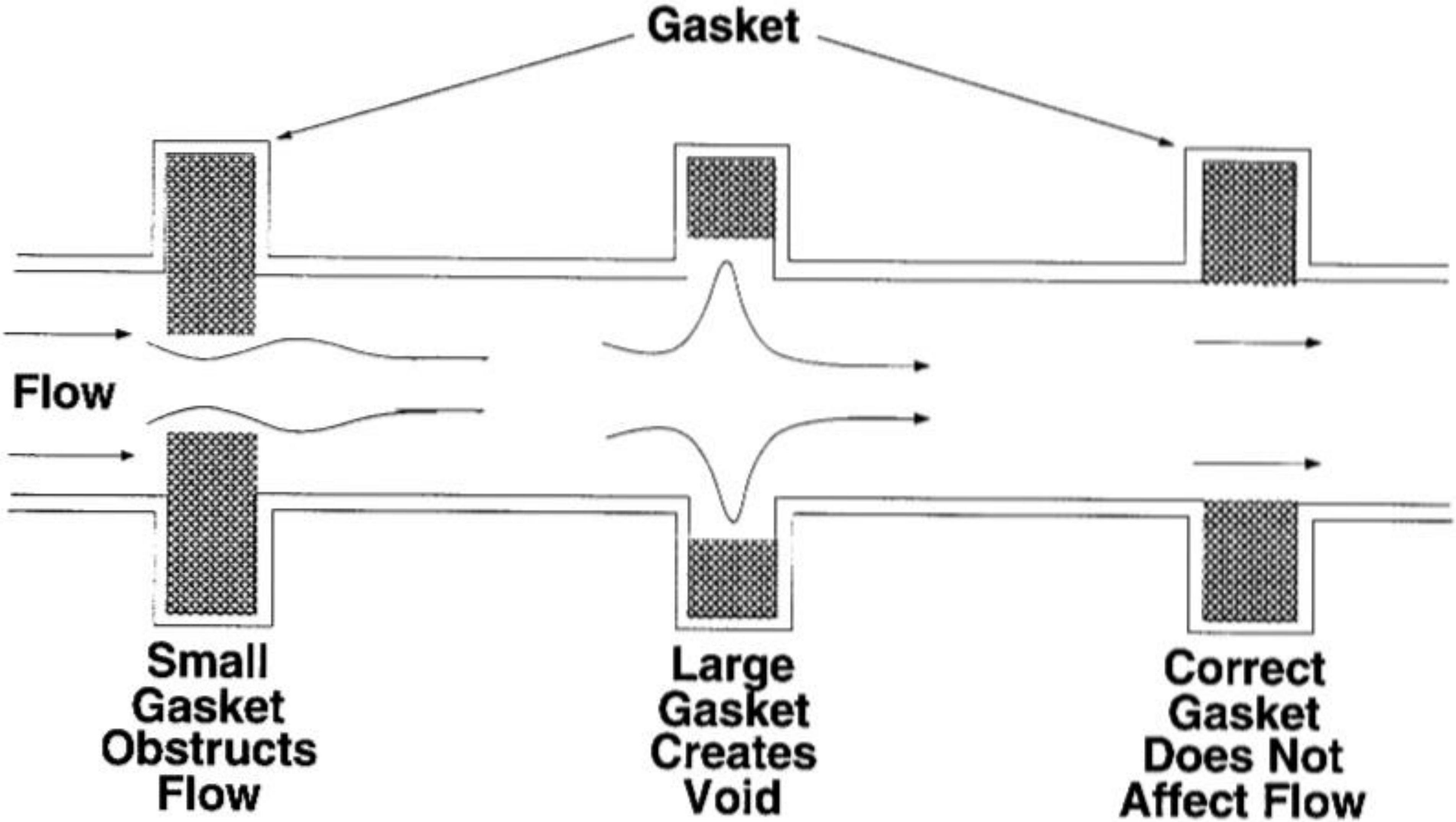
- Clean or dirty?
- Slurries (high or low viscosity)?
- Corrosive?
- Pressure (high or low)?
- Steam?
- Reverse flow (pulsating flow)?

"Ensure the measurement device is actually capable of performing the required measurement."

Checklist for Process Media Compatibility

Process Media Characteristic	Process Data
Process Name	
Process State (Standard temperature and pressure, STP, conditions)	
Composition	
Molecular Weight	
Density	

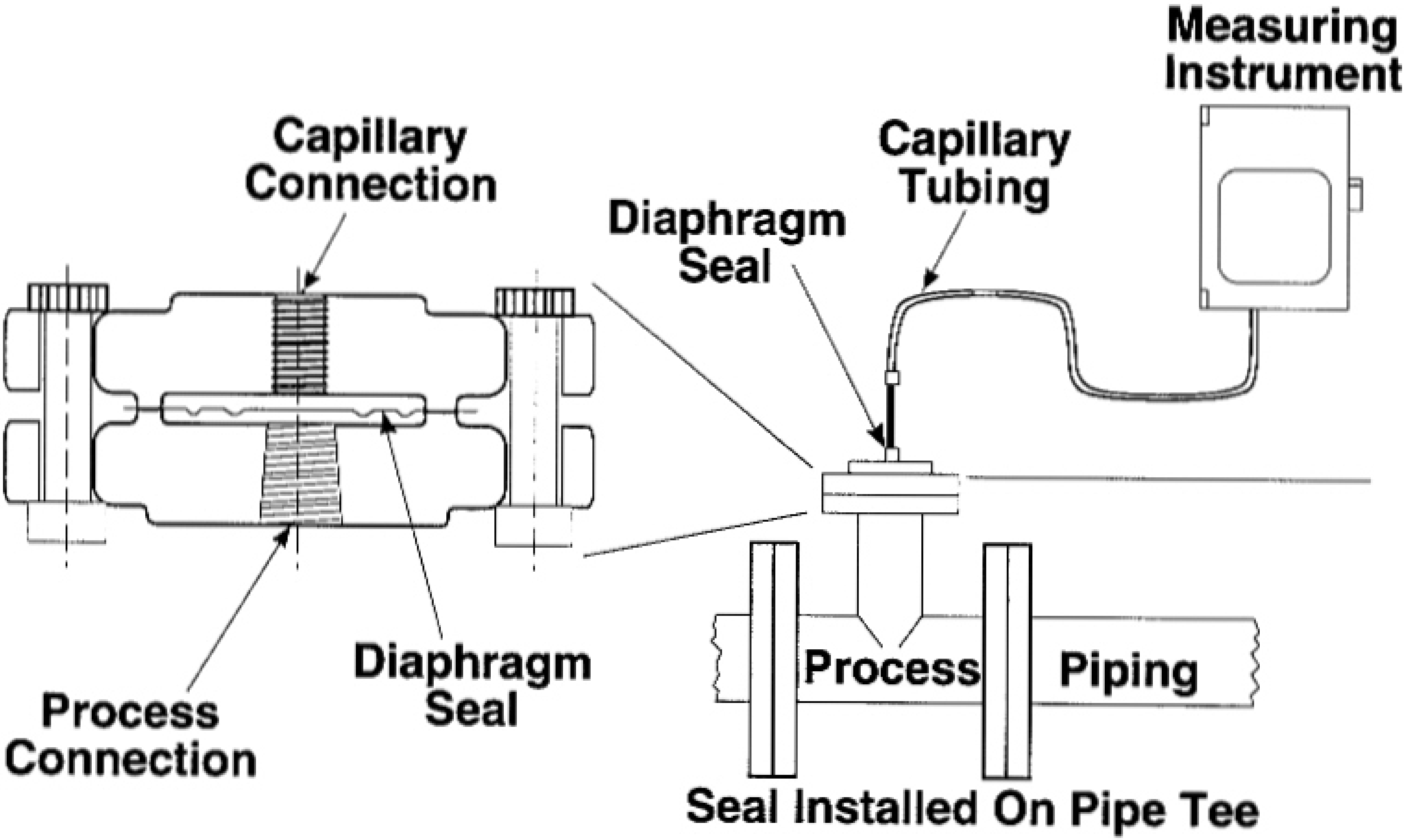
Gasket Installation in Flow Application



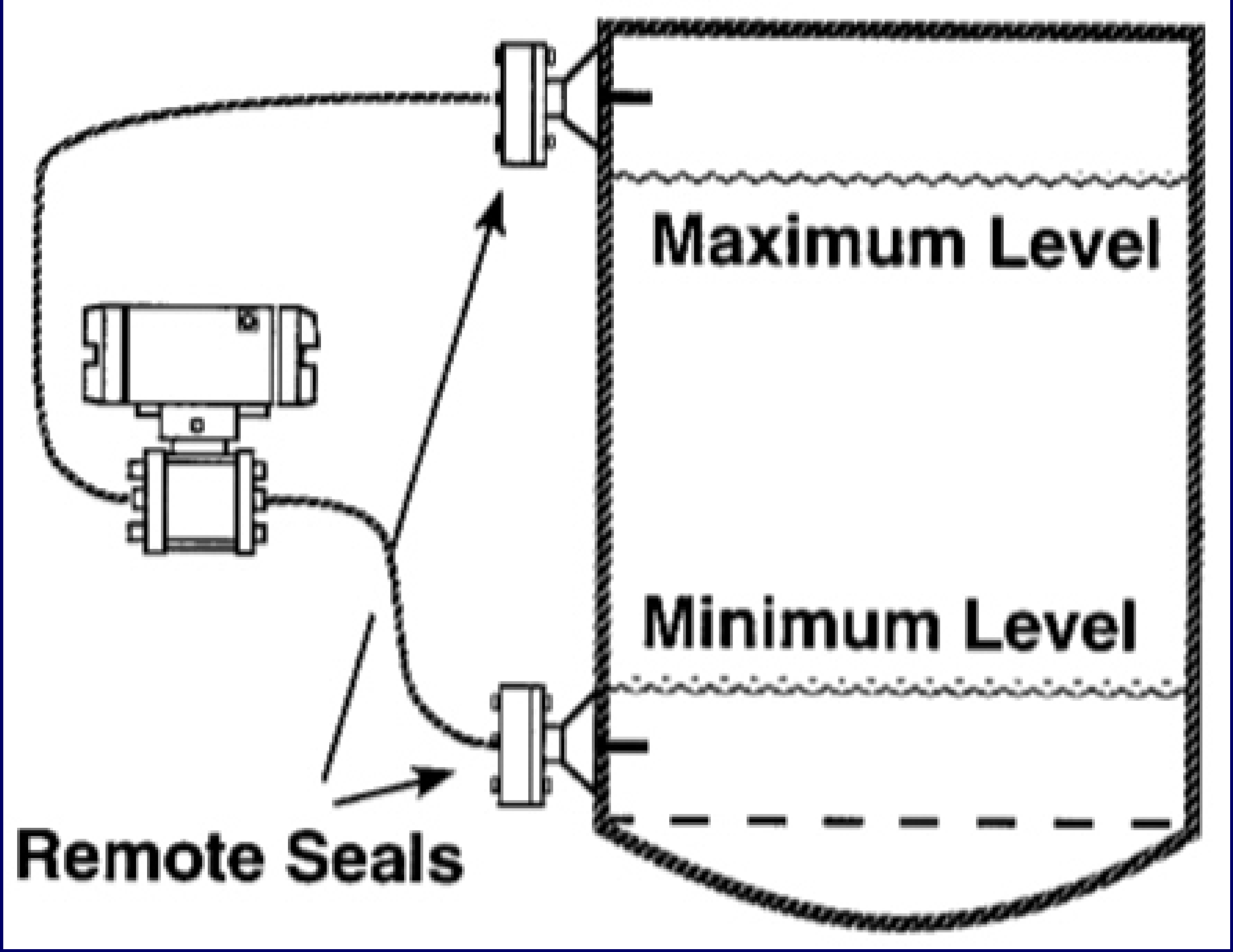
Gasket Considerations

Saudi Aramco reference	Title	Comments
SAES-J-101, Section 6.6	Custody Metering of Hydrocarbon Gases	Gasket alignment
SAES-J-102, Section 4.4, 6.6	Royalty and Custody Metering of Hydrocarbon Liquids	Gasket alignment
SAES-J-300	Level	Gauge gasket material characteristics (asbestos free, graphoil impregnated,pressure requirements)
SAES-L-009	Metallic Flanges, Gaskets and Bolts	Requirements for pressure services
SAES-L-005	Limitations on Piping Components	Gasket material characteristic is dependent on type of service

Seal Example



Remote Seal Example



Seal References

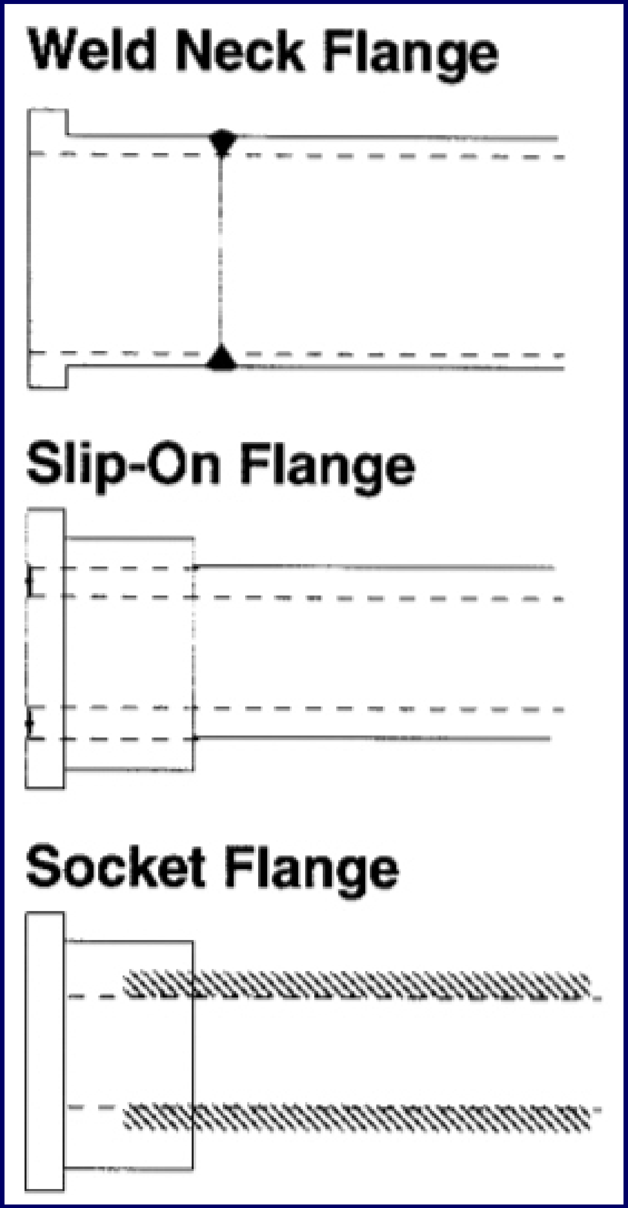
Saudi Aramco Reference	Title	Comments
SAES-J-200, Section 4.6	Pressure	Seals must be shown on P&IDs.
SAES-J-300, Section 10.1	Level	Application of seals in level measurement.
SADP-J-100, Section 6.11, Section 6.13	Process Flow Meters	Use of diaphragm and liquid seals, Table 1 lists acceptable seal fluids.
SADP-J-200, Section 4	Pressure	Reasons for seal installation

Associated Hardware Options

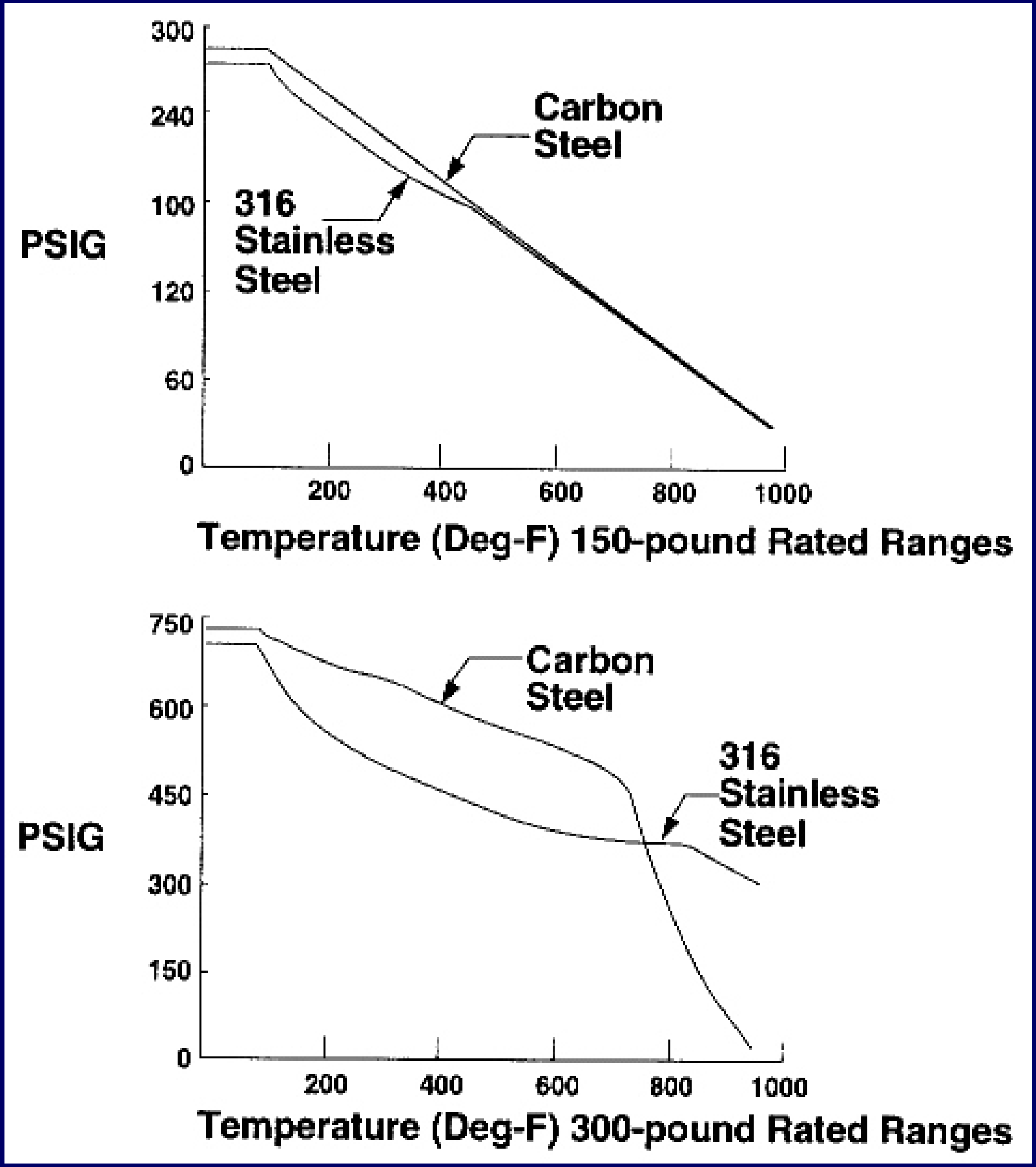
- Mounting brackets, bolts, etc.?
- Piping support, grounding, etc.?
- Flanges?
- Location?

"Don't forget your Maintenance buddies… install the instrument where it can be easily accessed."

Flange Styles



Flange Temperature Ratings



Flange References

Saudi Aramco Reference	Title	Comments
SAES-J-100, Section 4.3	Flow	Orifice flange orientation; minimum ANSI class ratings for pipe sizes.
SAES-J-101, Section 6.6	Custody Metering of Hydrocarbon Gases	Installation requirements.
SAES-J-102, various sections	Custody Metering of Hydrocarbon Liquids	Meter flange requirements.
SAES-J-200	Pressure	ANSI B16.4 followed
SAES-J-300, various sections	Level	Mounting and material requirements
SAES-J-400	Temperature	ANSI B16.5 followed
SAES-L-005, various sections	Limitations on Piping Components	Description of flange ratings and how to interpret them.
SADP-J-100, Section 6	Flow	Orifice flange installation, types.
SADP-J-300, Section 3	Level	Standpipe and transmitter flange use.

Mechanical Design Considerations

- Manifolds (SST)
- Impulse Lines (1/2” SST tubing typical)
- Orientation critical (more in modules to come)
- Thermowell insertion length/vibration

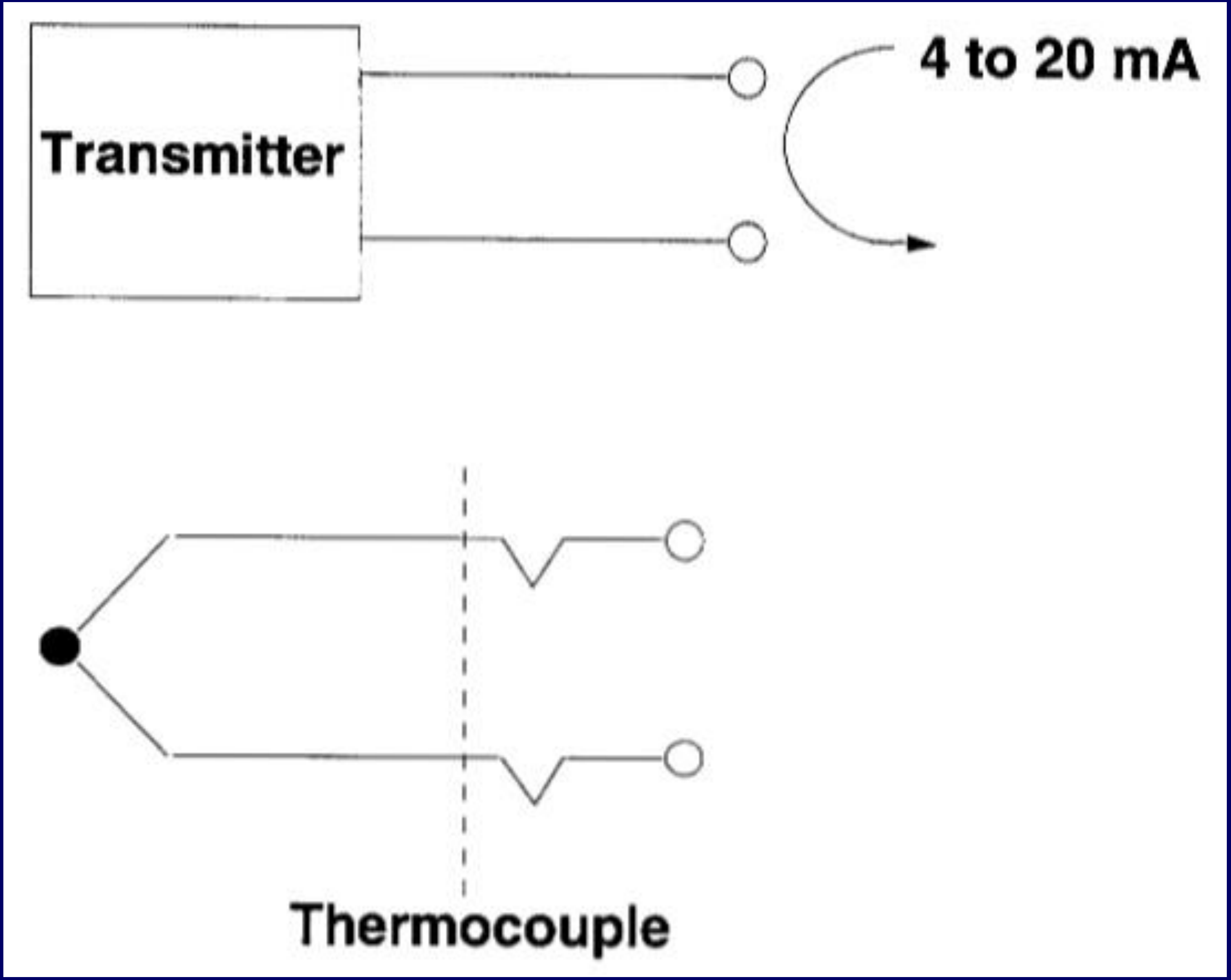
“Consider how the instrument will be used…the installation should be suited to the application.”

Electrical Design Considerations

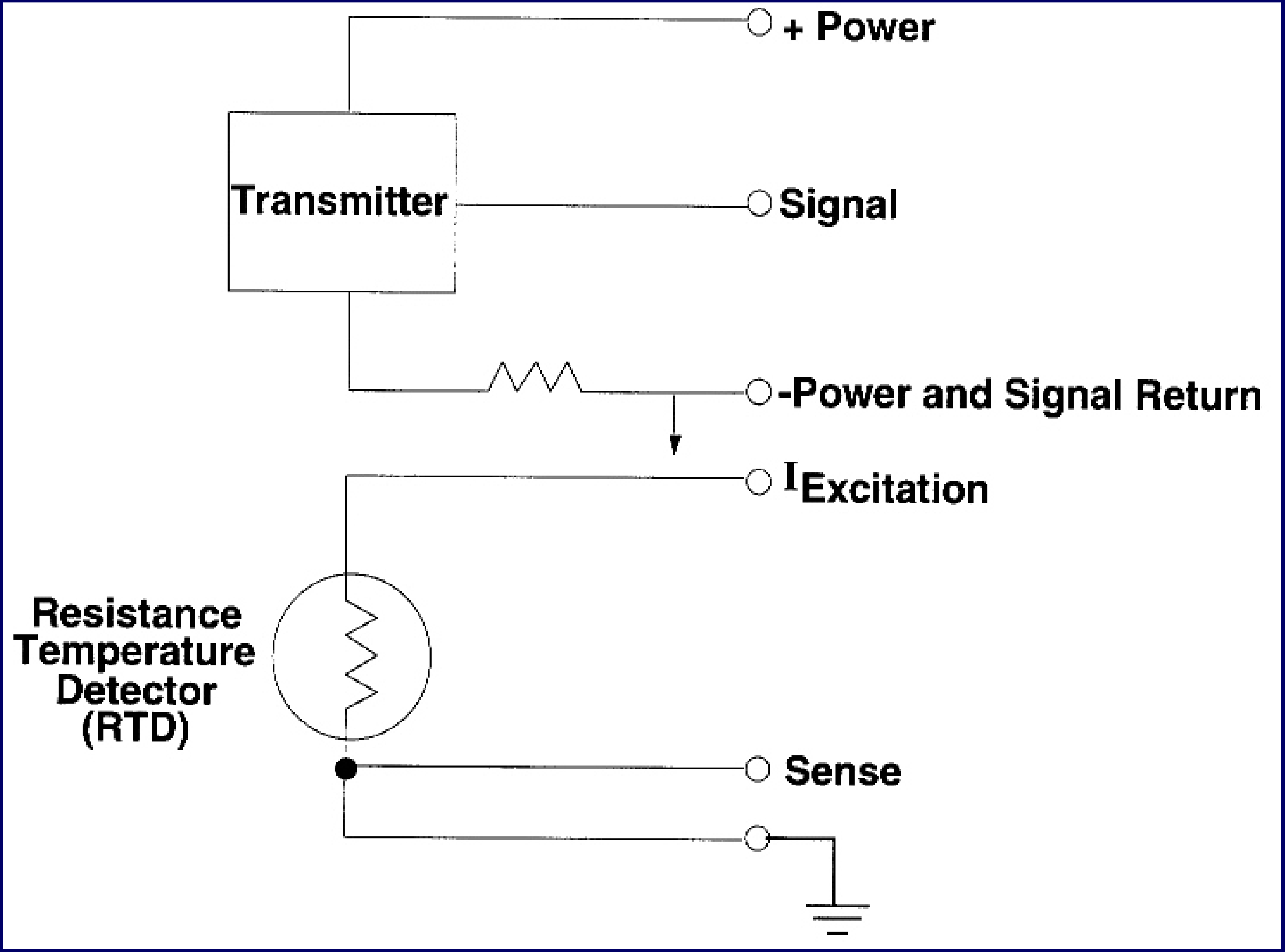
- Data Transmission
- Power (Requirements and Consumption)
- Wiring methods
- Safety (protection methods in hazardous areas)

“Consider all the aspects of electrical design… the loop may work, but may not be safe to operate in the intended location.”

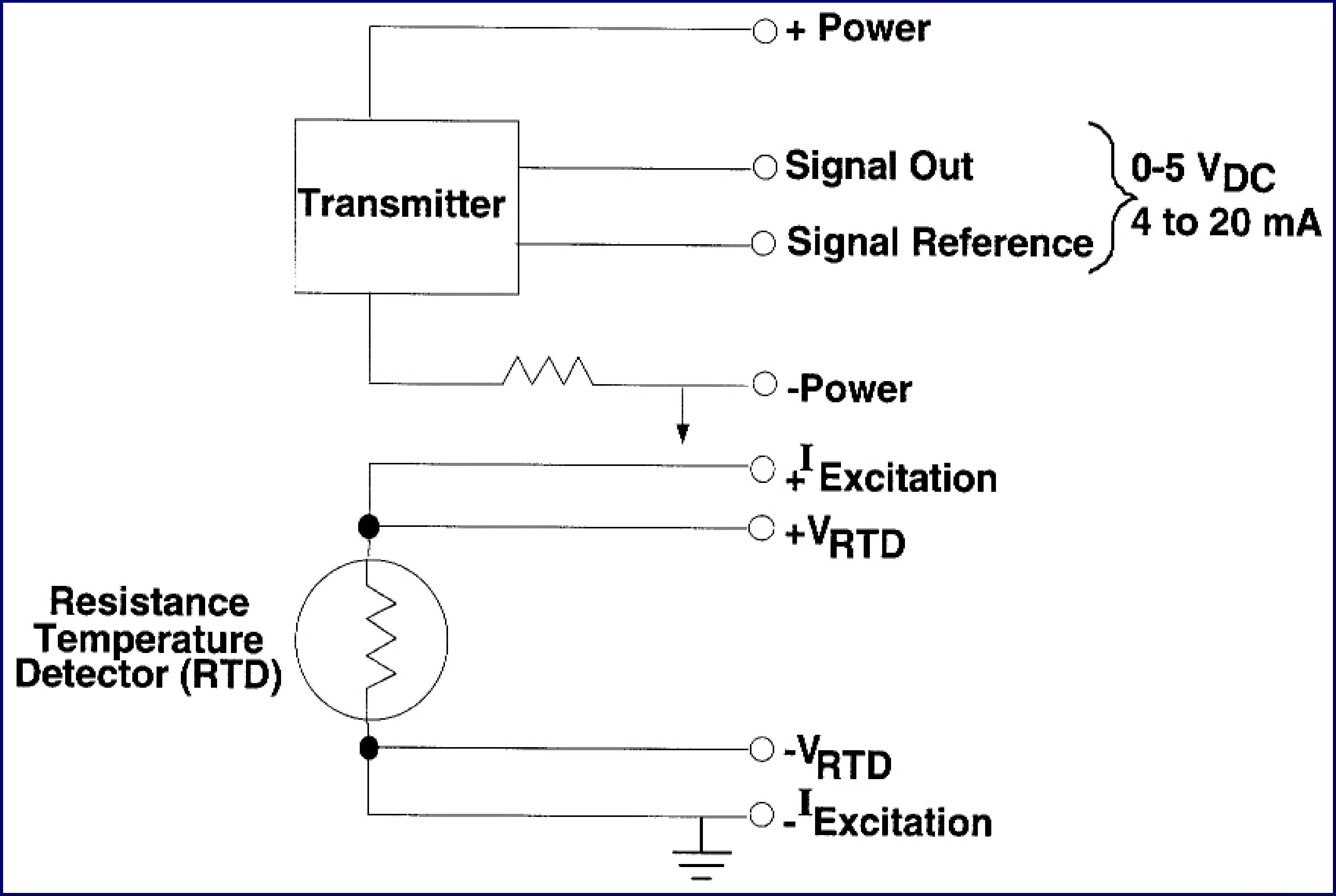
Two Wire Loop Examples



Three Wire Loop Examples



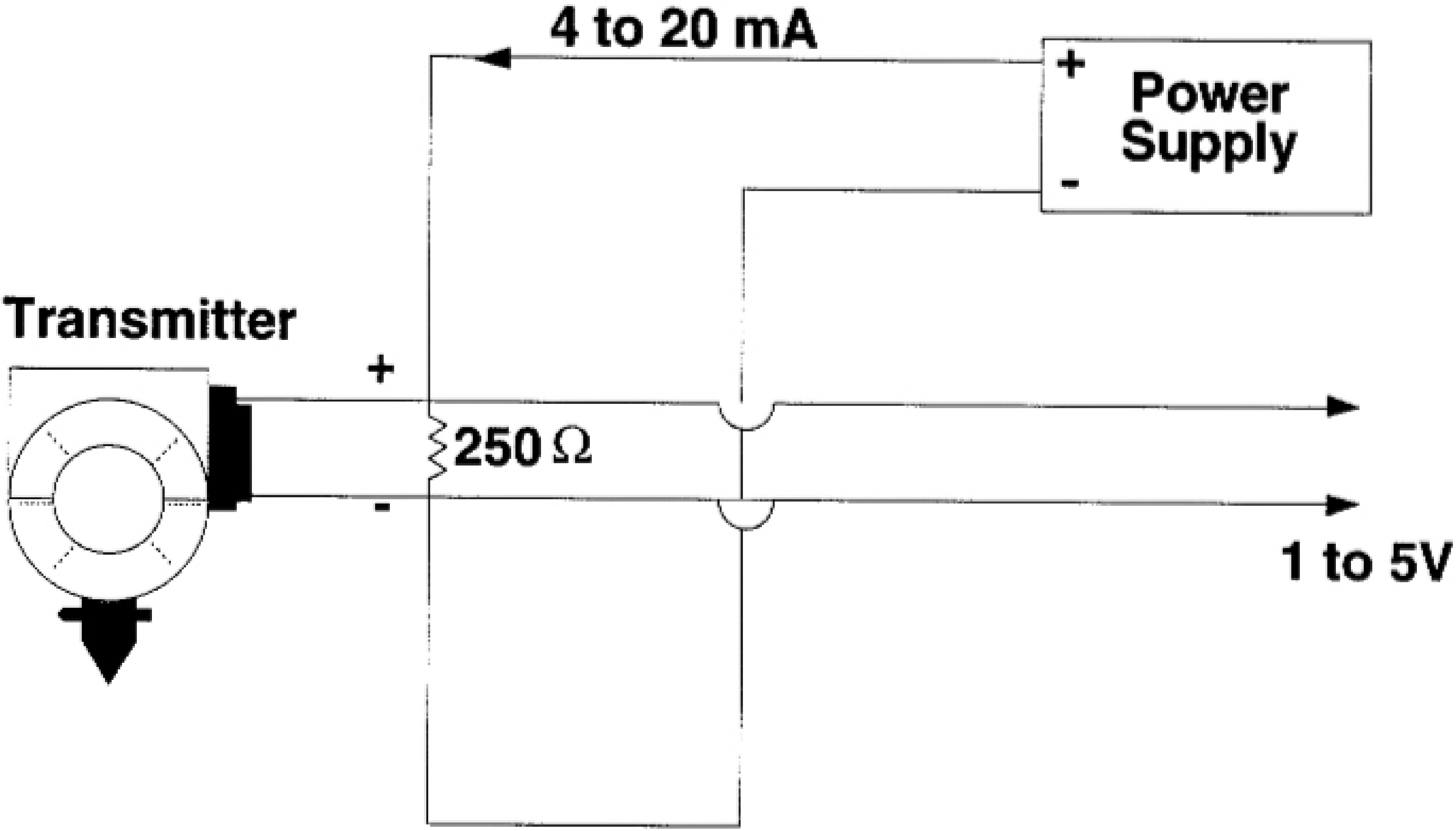
Four Wire Loop Examples



Design and Wiring Considerations

	Conventional (Electronic analog)	Microprocessor-based (smart devices)	Microprocessor-based (Fieldbus devices)
Power Supply	24 VDC nominal	24 VDC nominal	24 VDC nominal
Wiring	twisted pair	twisted pair	twisted pair, or coaxial cable, multidropped
Output signal	4 to 20 mA	4 to 20 mA and/or proprietary (Hart, Foxboro AI, Honeywell DE).	Industry standard finalized
Noise (RFI, shielding, grounding)	2 wire loops offer more noise immunity than 3-wire or 4-wire loops	Same noise immunity as conventional instruments if used in analog mode. In digital mode, better noise immunity than conventional instruments.	If cabling is common twisted pair and instrument is in analog mode, same noise immunity as conventional. If coaxial cable used, better noise immunity than microprocessor-based.

Transmitter Configuration Example

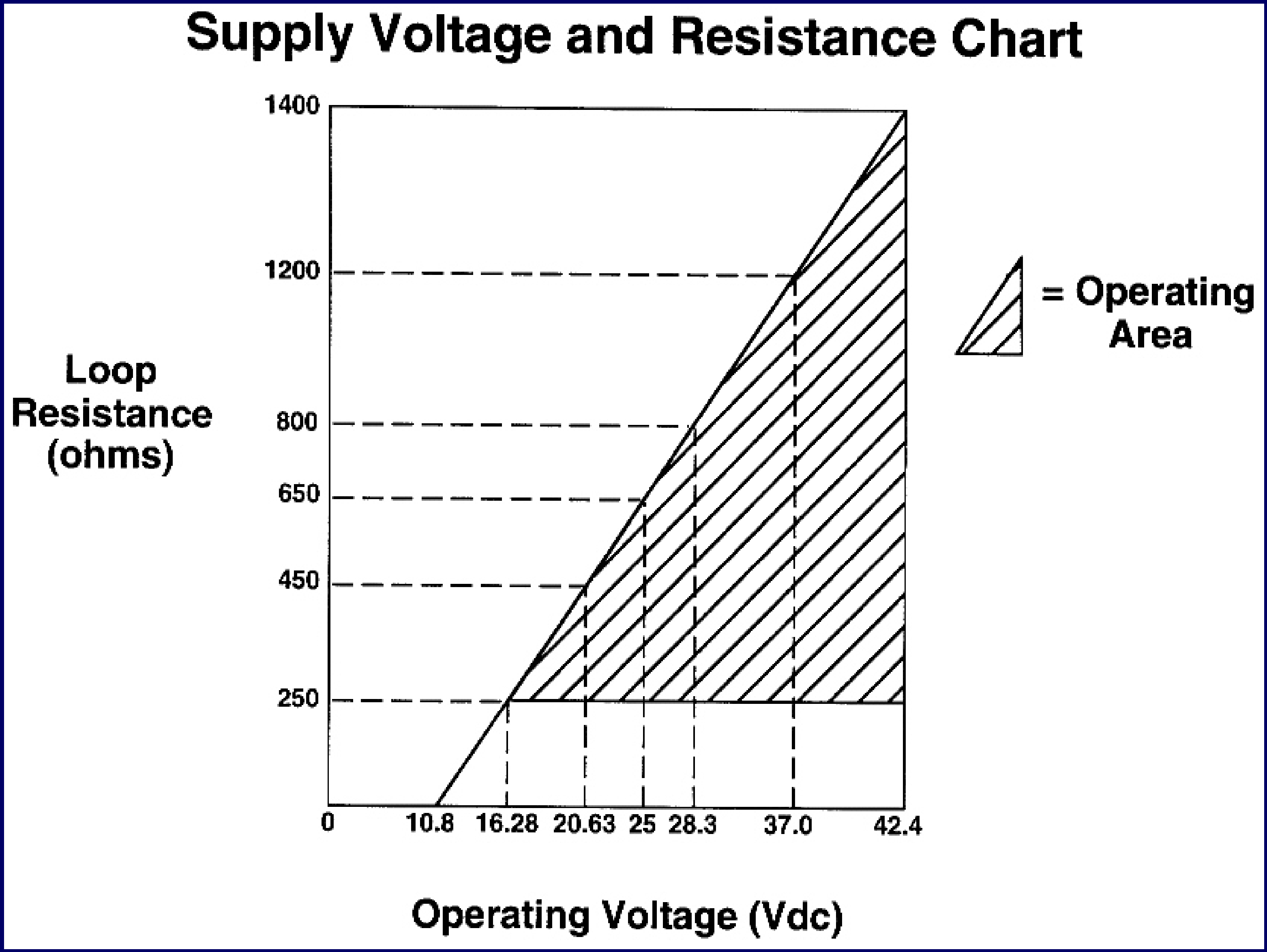


Instrument Loop Wiring Considerations

- Instrument power from separate distribution panels
- Capability to disconnect instrument power (knife edge terminations)
- Fused Terminations
- Supply voltage levels (24 VDC, 120 VAC, etc.)
- UPS requirements for control systems and analyzers

“These requirements help ensure reliability of measurement long term”

Supply Voltage and Resistance Chart



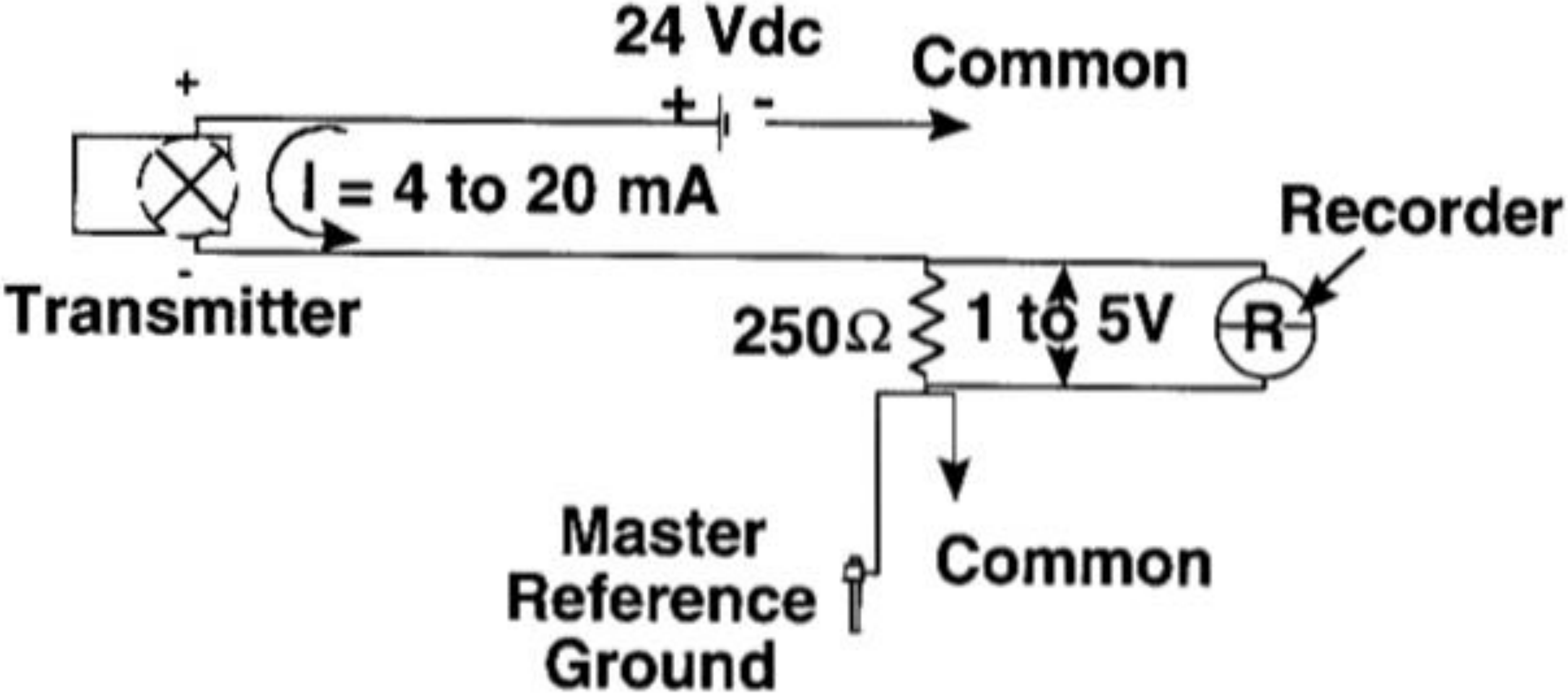
Wiring References

SAES-J-902 Reference	Reason for Use	Summary
Section 7.1	General wiring	NEC compliance required. Splice and twist-on wiring nuts not permitted.
Section 7.2	Routing	Segregation of cabling. Above ground, underground, under computer floor routing.
Section 7.3	Signal separation	Minimum spacing requirements.
Section 7.4	Cable types	Field wiring to junction box and termination panels.
Section 7.5	Terminations	Termination methods, block styles, strip assemblies, wire ducts and gutters.

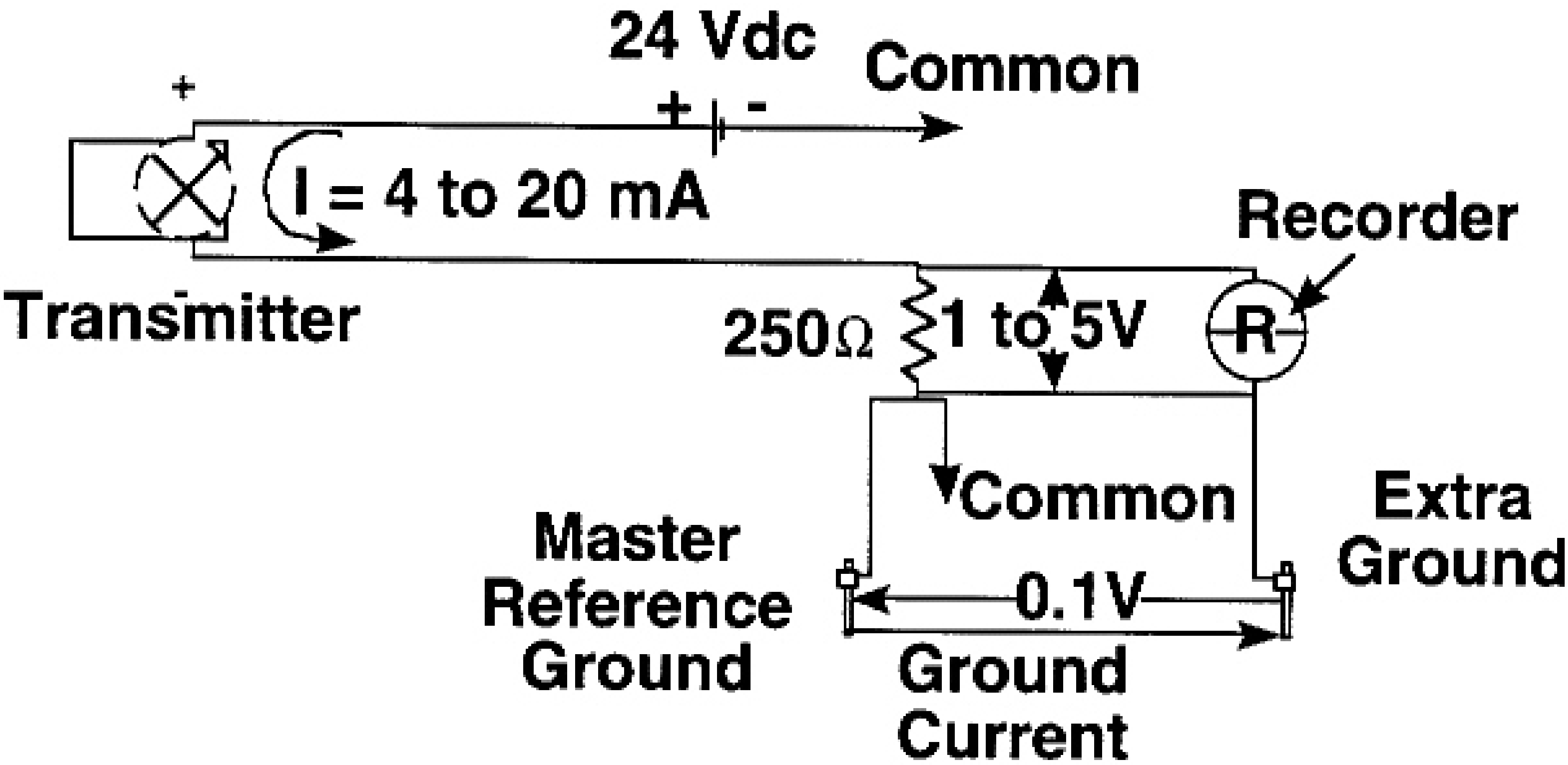
Noise Considerations

SAES-J-902 Reference	Reason for Use	Summary
Section 8.1	Definition	How noise is caused.
Section 8.2	Shielding	Shielding requirements for instrumentation.
Section 8.3	Twisting	Rationale for twisted pair.

Instrument Loop with Single Ground



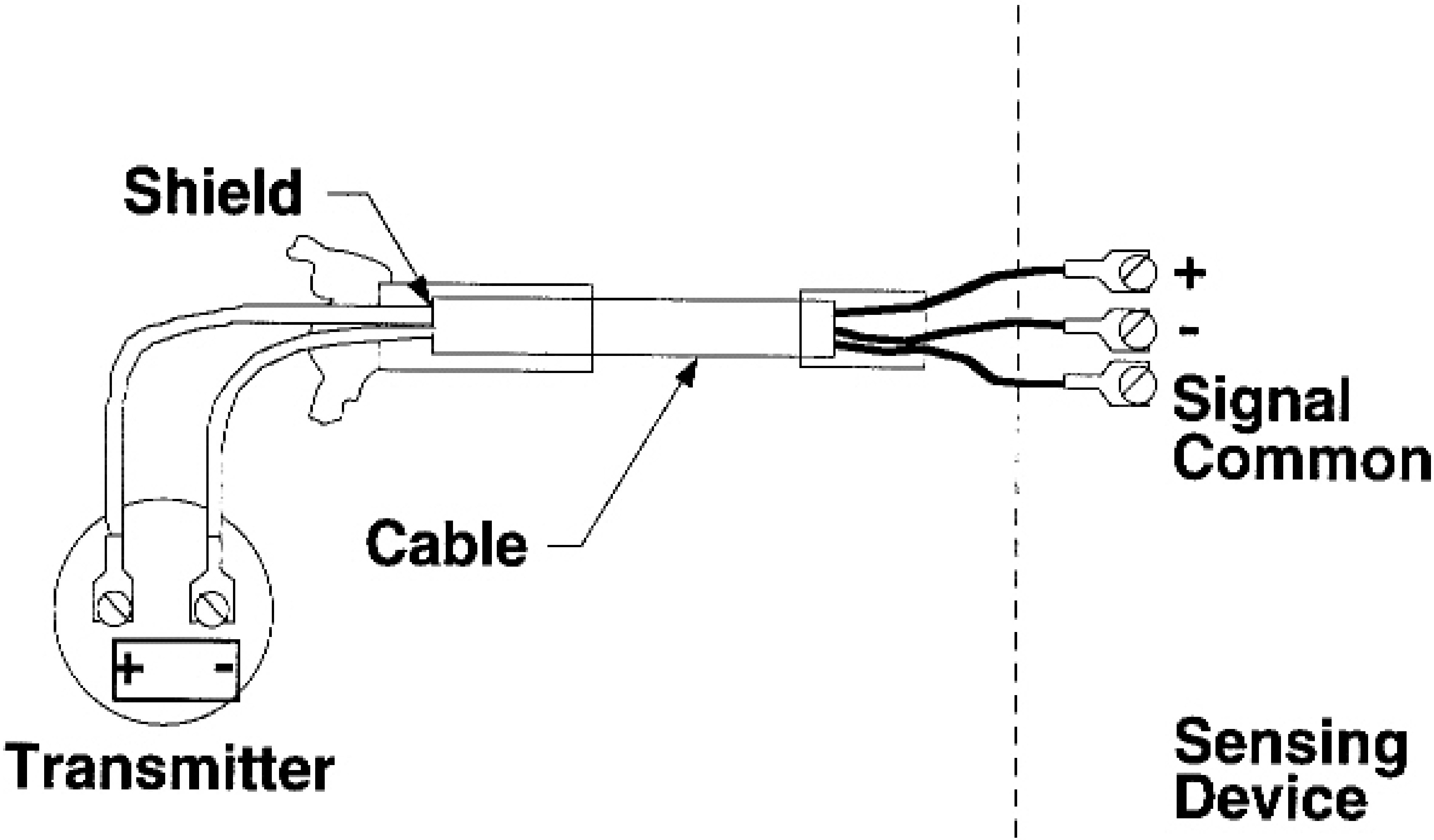
Instrument Loop with 2 Grounds



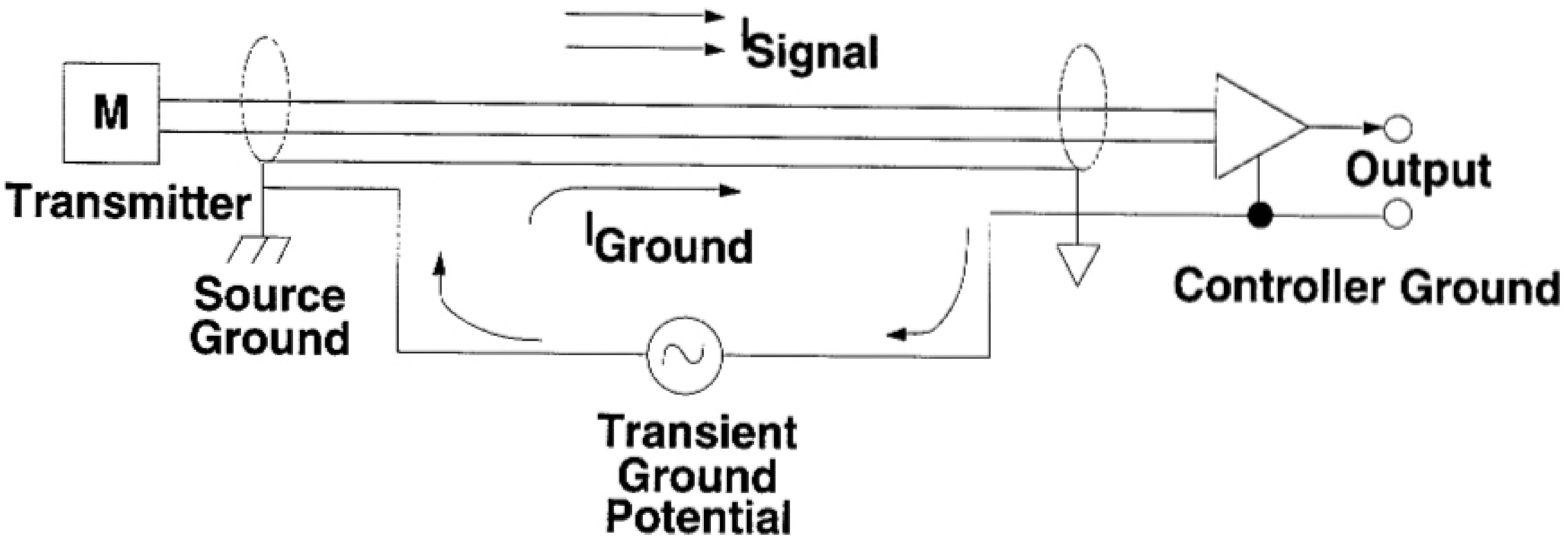
Grounding Considerations

SAES-J-902 Reference	Reason for Use	Summary
Section 9.1	General requirements	NEC conformance per article 250
Section 9.2	Safety ground	Enclosures grounded to protect personnel.
Section 9.3	Circuit ground	Signal common connections reduce interference.
Section 9.4	Special considerations	Manufacturer's recommendations followed.
Section 9.5	Ground fault detection	Required on emergency shutdown systems.

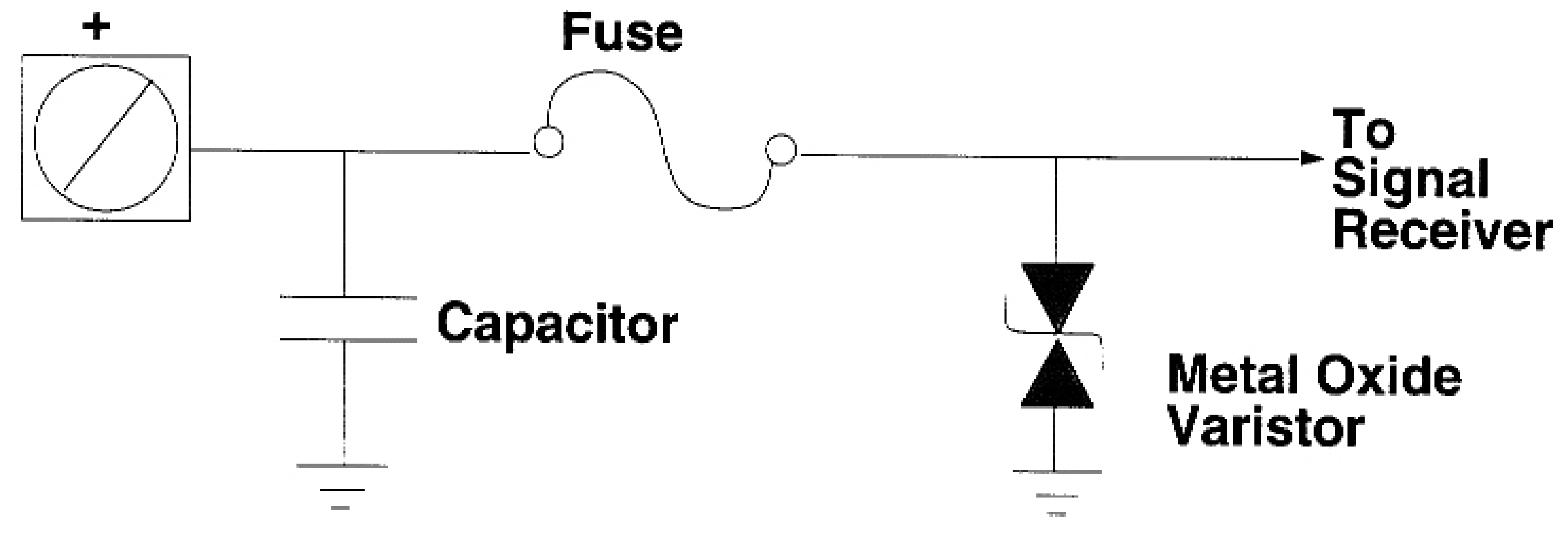
Electrostatic Shield Example



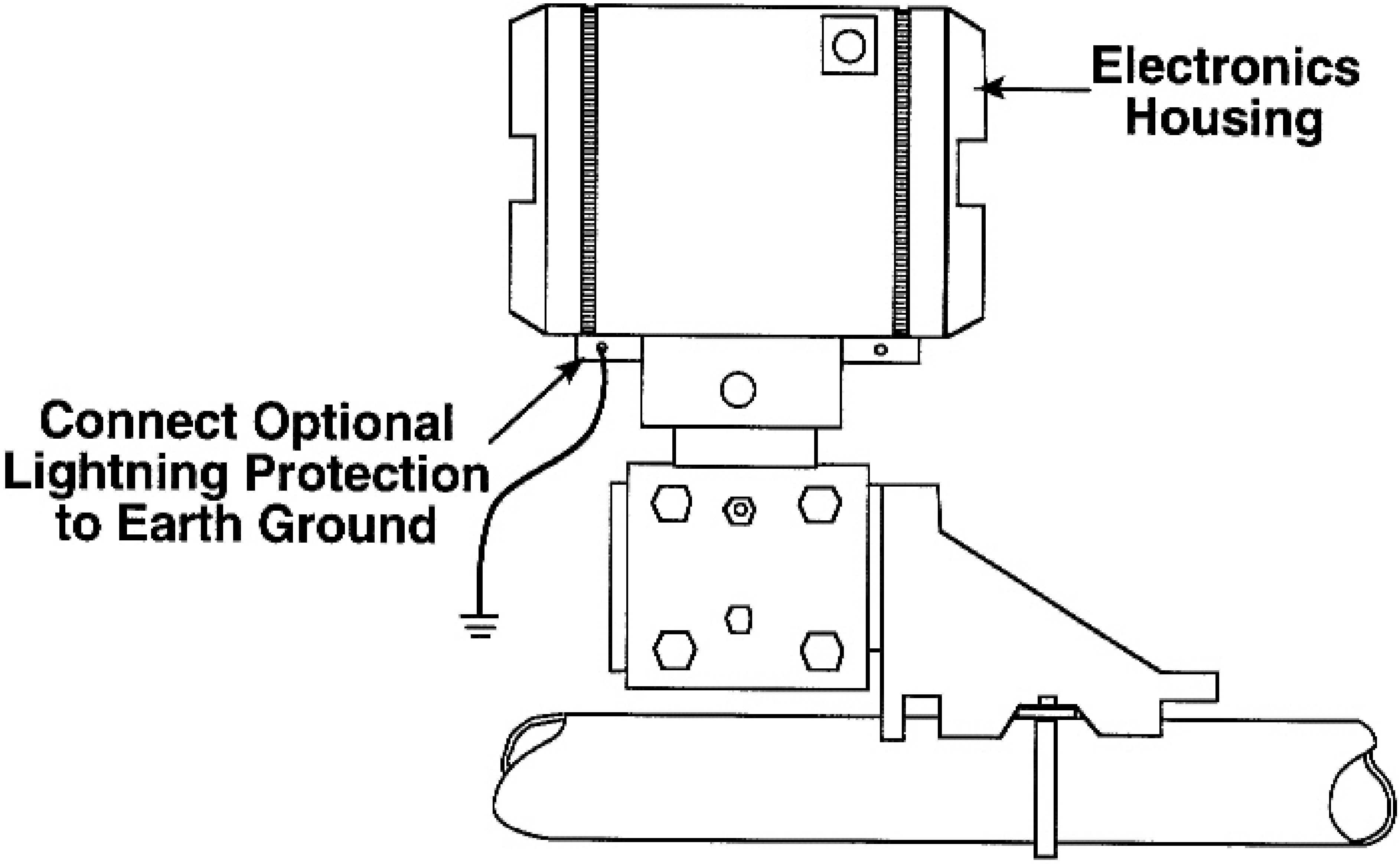
Shielding Error Example



Typical Surge Protector



Optional Lightning Protection



Conversion of NEMA Type Numbers to IEC Classification Designations

NEMA Enclosure Type Number	IEC Enclosure Classification Designation
1	IP10
2	IP11
3	IP54
3R	IP14
3S	IP54
4 and 4X	IP56
5	IP52
6 and 6P	IP67
12 and 12K	IP52
13	IP54

Instrument Safety Considerations

- Hazardous Area Classification
- Protection Methods Available
- Intrinsically Safe Systems

“The key to electrical safety is to ensure that the electronic instrumentation will not become the source of an ignition source”

Instrument Safety Considerations

- Zone Migration Presentation
- Intrinsically Safe Presentation

“The key to electrical safety is to ensure that the electronic instrumentation will not become the source of an ignition source”

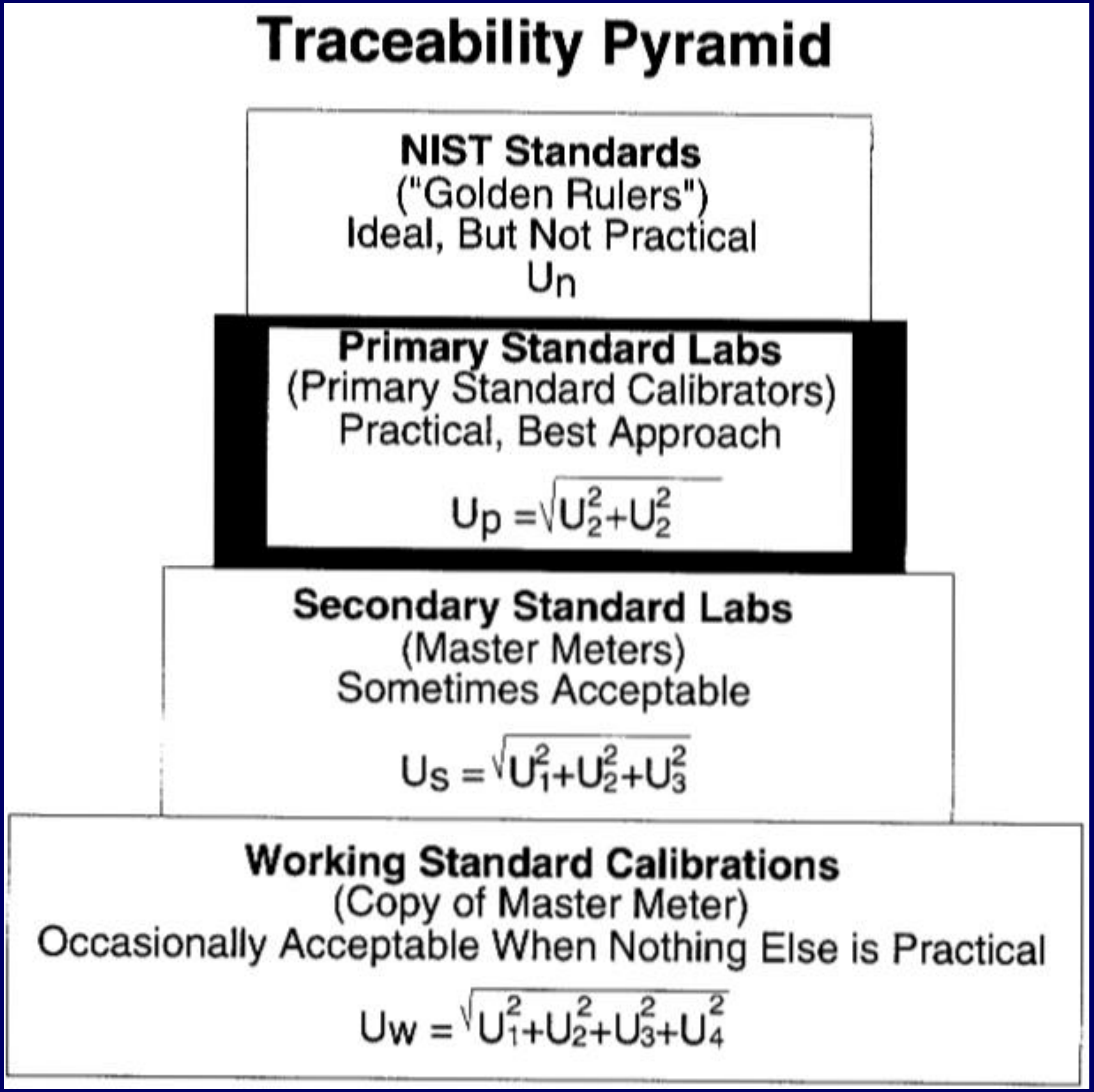
Instrument Calibration Activity

Process measurement instrument type	Saudi Aramco calibration activity
Temperature instruments	Test thermometer placed in test thermowell adjacent to temperature sensing element. Calibration performed on whole loop.
Static pressure instruments	Full range calibration.
Differential pressure instruments	Full range calibration. Additionally, zero differential check performed.
Orifice plates	Checked during instrument calibration for flatness and damage.
Flow computers	Sealed to prevent unauthorized modification of flow instrument calibration data.
Flow meter (turbine)	Calibration requires a portable small volume meter prover to establish meter factor.
Level systems (bubblers)	Verification of bubble system against tank dipping.
Level instrument (automatic tank gauging)	Checked monthly against manual tape gauging. If error more than half-inch, recalibrate tank gauging equipment.
Custody transfer flow meters (turbine and positive displacement)	Meters calibrated using the product for which it is intended or using product with similar properties.

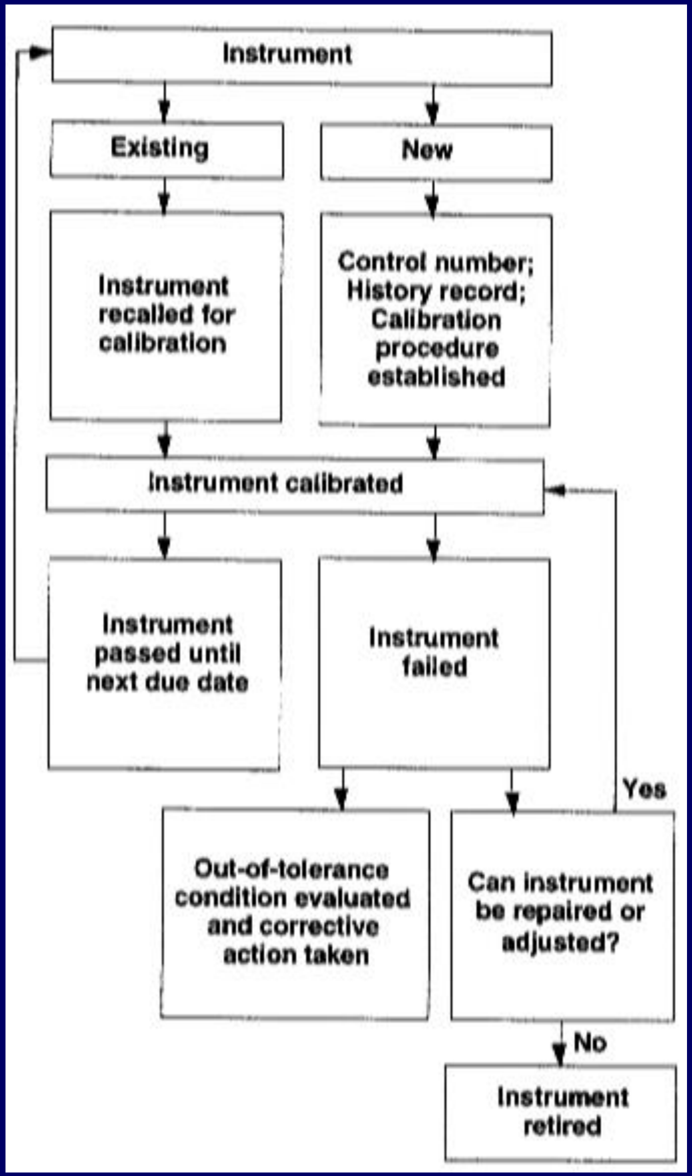
Calibration References

Reference	Title	Comments
GI405.001, Section 6.4	Transfer of Liquid Hydrocarbon Products and Sulfur	Meter, temperature, and pressure instrument calibration
GI405.002, Section 5	Custody Transfer of Natural Gas and Ethane	Temperature, static, and differential pressure, and analyzer instrument calibration
GI405.003, Section 6	Custody Transfer of Mixed LPG from PSRC to Saudi Aramco	Turbine (pay) meter and analyzer calibration
GI405.005, Sections 2 and 3	Royalty Metering Facility Responsibilities	Departmental calibration responsibilities
GI405.006, Section 5.3 to 5.4	Custody Transfer of Liquid Sulfur from PSRC to Saudi Aramco	Bubbler system and differential pressure transmitter calibration
SAES-J-100, Section 4.3	Process Flow	Orifice plate calibration requirements
SAES-J-101, Section 8	Custody Metering of Hydrocarbon Gases	Orifice plate calibration requirements
SAES-J-102, Appendix 2-3	Royalty and Custody Metering of Hydrocarbon Liquids	Calibration points for multipoint meter factor versus flow curve
SAES-J-300, Section 10	Level	• Differential pressure type instrument calibration • Transmitter calibration capabilities
SAES-J-400	Temperature	Temperature calibration references
SADP-J-100	Process Flow Meters	flow meter installation practices that affect calibration
SADP-J-200	Pressure	Pressure installation practices that affect calibration
SADP-J-300	Level	Installation and selection practices that affect calibration

Traceability Pyramid



Calibration Procedure to Meet ISO 9001

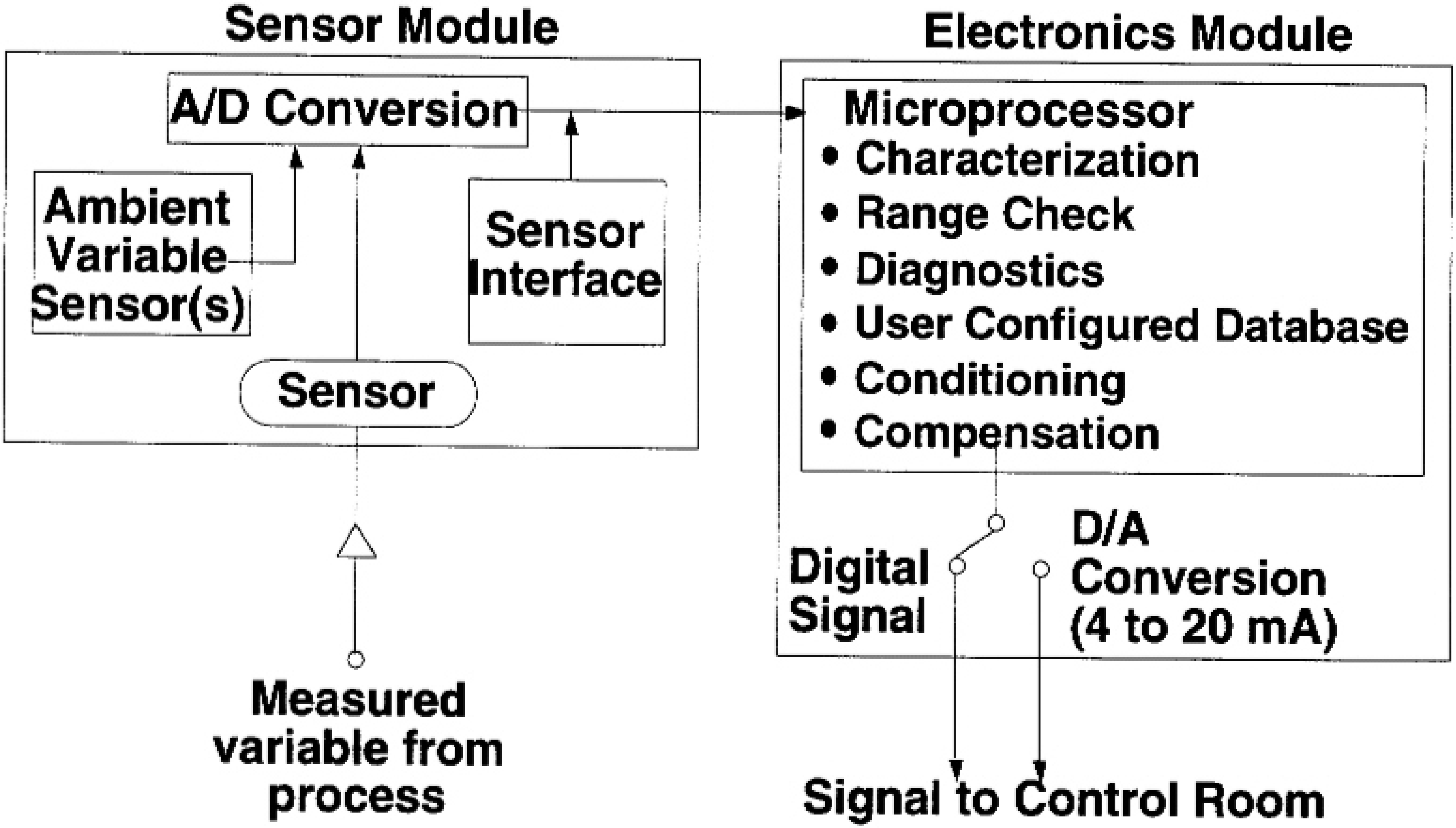


Instrument Calibration Video

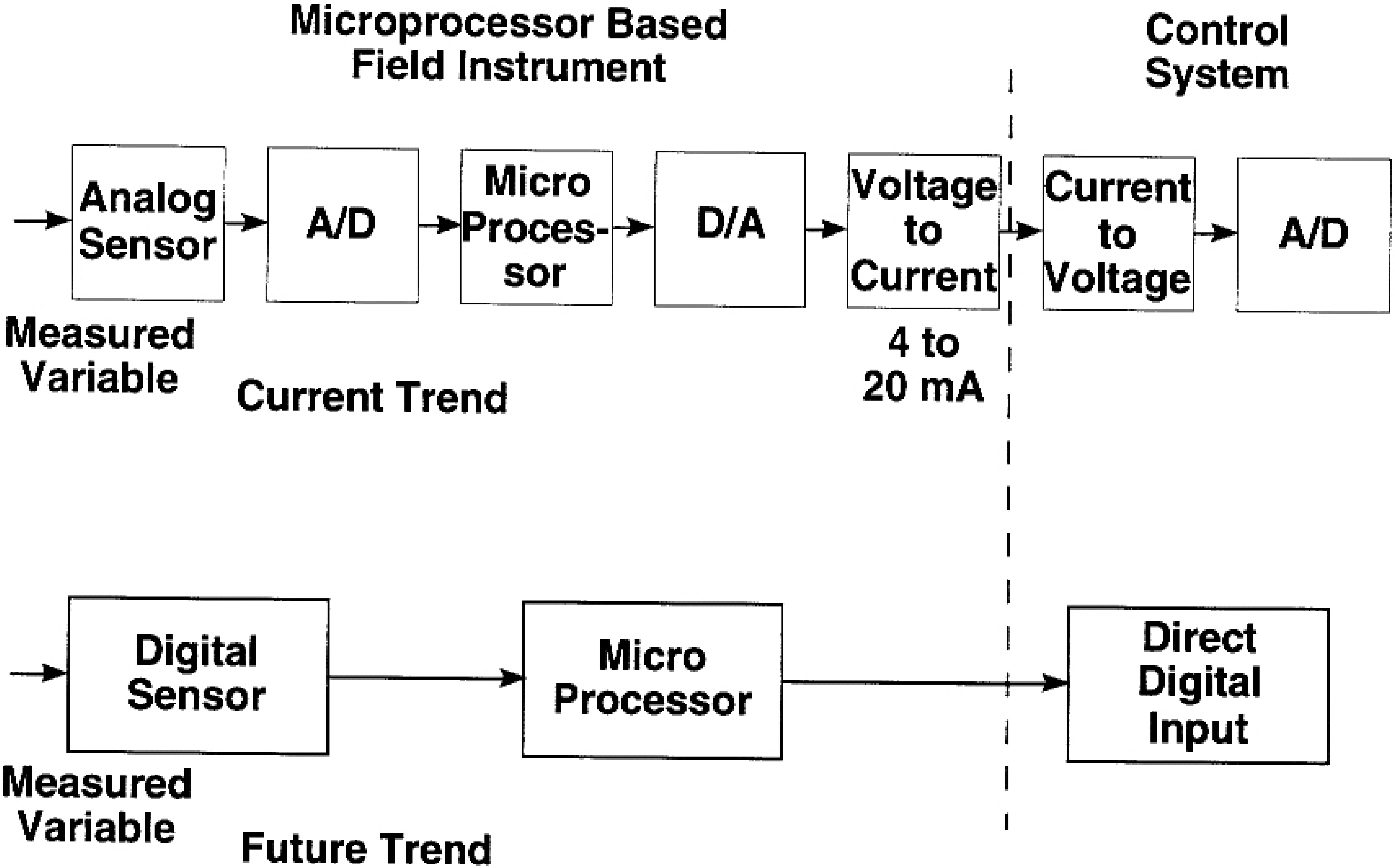
- Out of the box…Model 3051 Calibration and Test (30 minutes)

“Comparing a measurement to a known standard is called calibration”

Microprocessor Instrument Architecture



Possible Microprocessor Instrument Trends



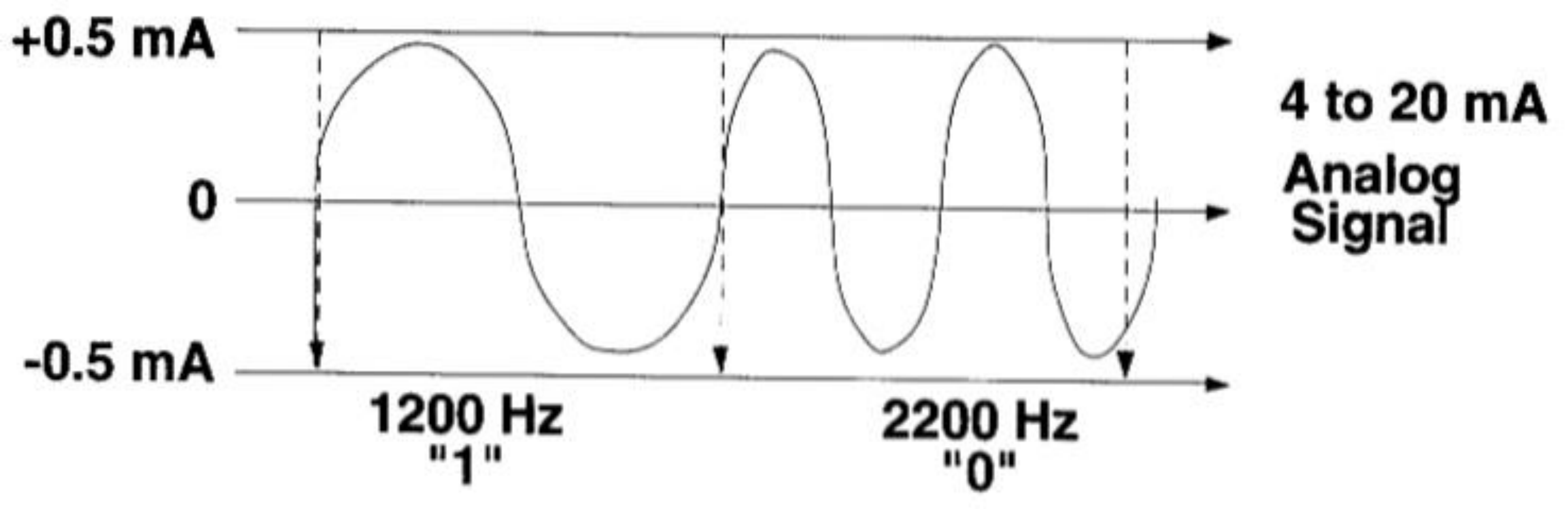
Metrology Comparison: Conventional versus Microprocessor

	Conventional Instrument	Microprocessor-based instrument	Comments
Accuracy	.25%	.1%	Accuracy over range is greater in microprocessor-based
Turndown and rangeability	6:1	up to 400:1	Higher turndown permits reranging
Drift	susceptible	less susceptible	Compensation available in microprocessor-based
Temperature effects	1% to 3.5%	.5%	Effects for conventional instrument greater at higher turndowns
Static pressure effects	1% to 3.5%	.2%	Effects for conventional instrument greater at higher turndowns

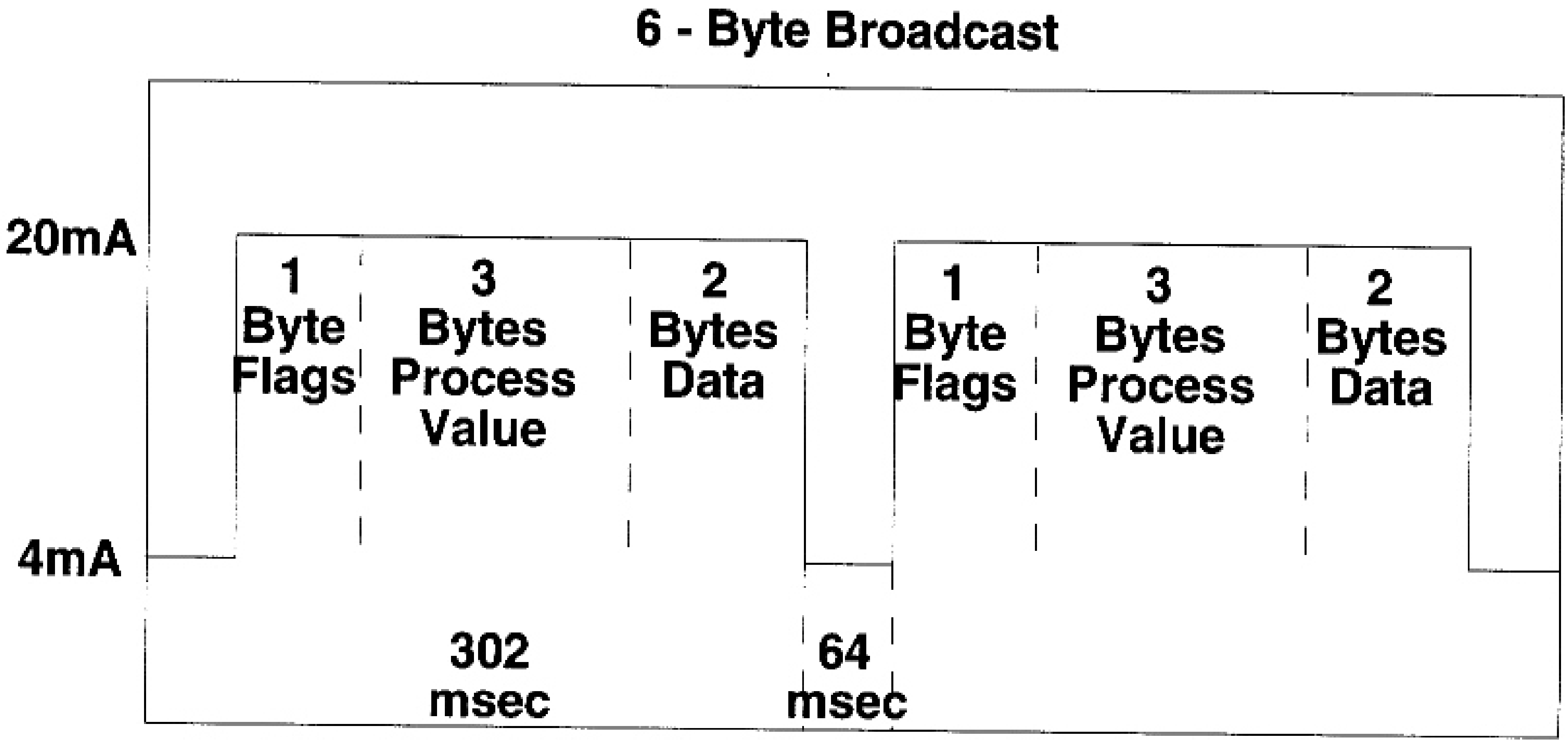
Tradeoffs of Conventional versus Microprocessor Instrumentation

Conventional Instrument (4 to 20 mA)	Microprocessor-based Instrument
Proven performance record	Improved performance because of sensor enhancements and compensation
4 to 20 mA accepted standard allows inter-operability among vendors.	Standard definition in progress. Protocols vary at this time, inhibiting interoperability among vendors.
Communicates one way	Bidirectional communication
Process data limited to measured variables	Protocols permit variety of process data, device data, in real time.
Requires several A/D and D/A conversions from device to control system.	Communications digitally, IEEE floating point accurate to seven digits.
Must operate within power budget that includes 4 mA to 20 mA standard.	Power limited by 4 mA to 20 mA standard
Device must be configured locally.	Configuration and calibration can be remote or local
Conventional Instrument (4 to 20 mA)	Microprocessor-based Instrument
Individual wire pairs required for each filed device.	Currently true until development of Fieldbus standard, which would eliminate individual wiring.
Hand held communicators can be expensive.	Hand held communicator expedite troubleshooting.
No memory.	Control system memory can store maintenance activity.
Analog signal could be in error by significant amount. Bad signal could go undetected for too long a period of time.	Digital transmission provides better security, ability to detect bad signal, ensures reception of data.

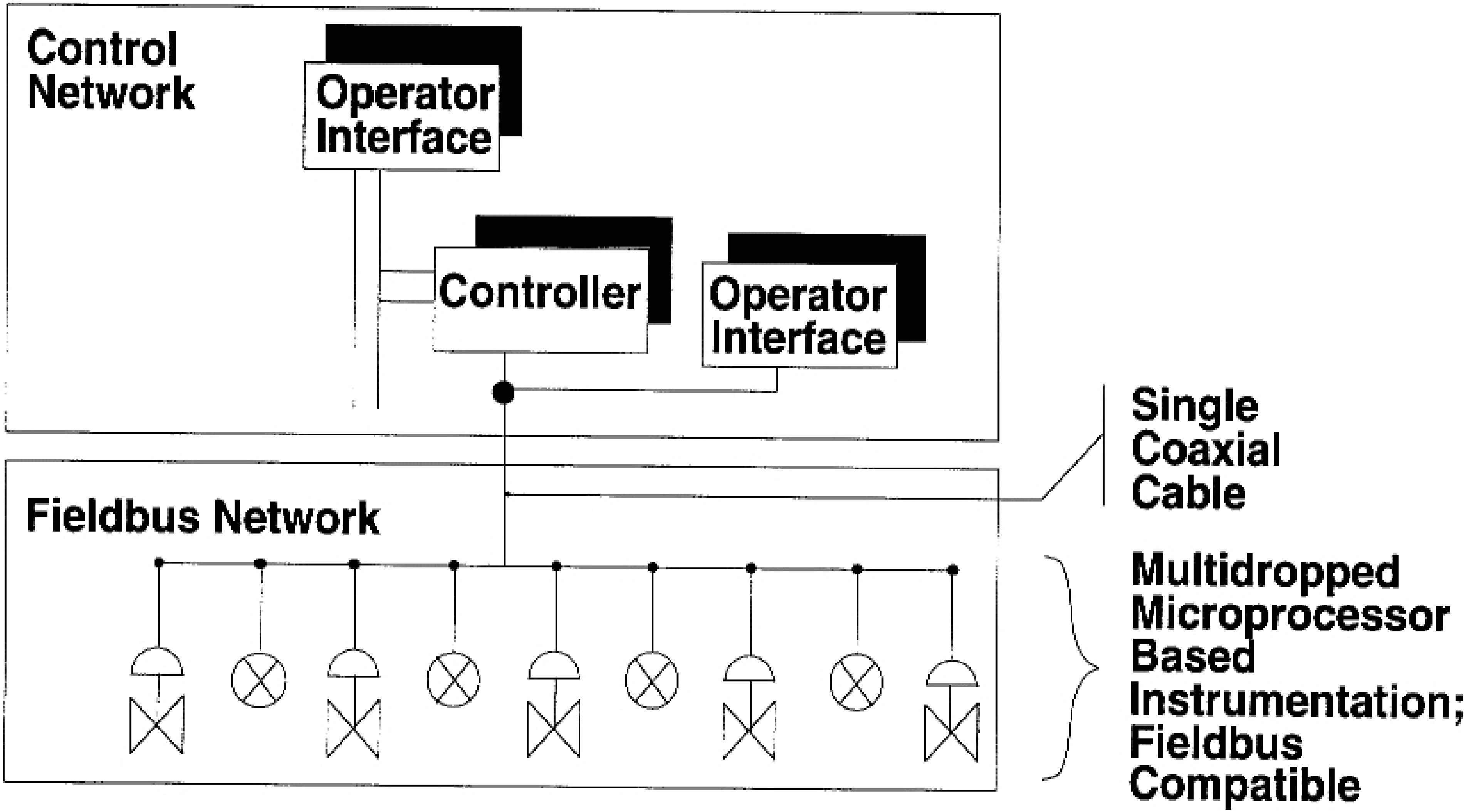
Hart Protocol



Honeywell DE Protocol



Fieldbus Architecture



PCI –101

Basics of Process Measurement

- End Module 1