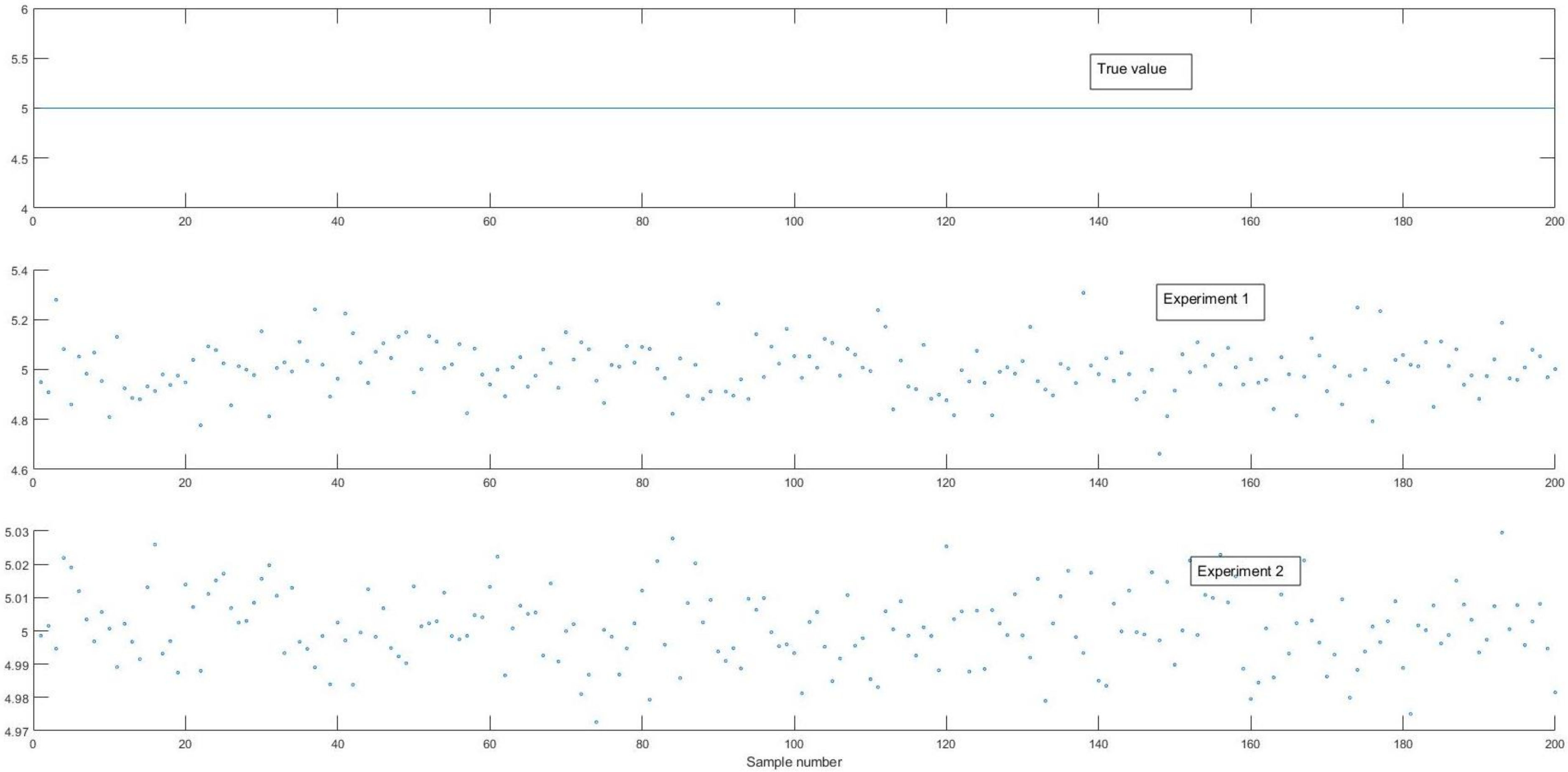
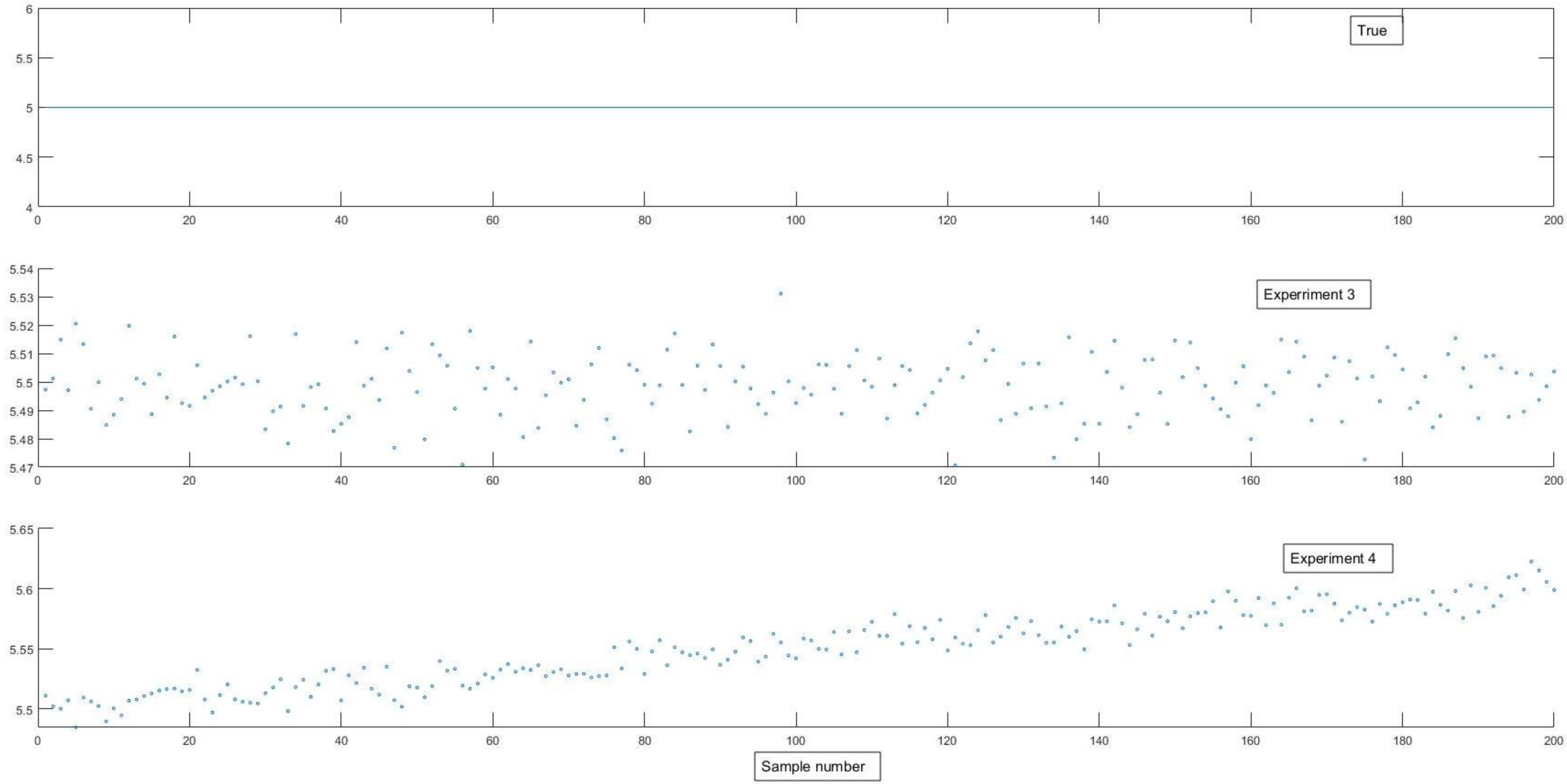
AE 242
Aerospace Measurements Laboratory



Two thermometers are used for measuring temperature. 200 samples are recorded when temperature input is 5 units. From the above two observations, what can be deduced about thermometers?



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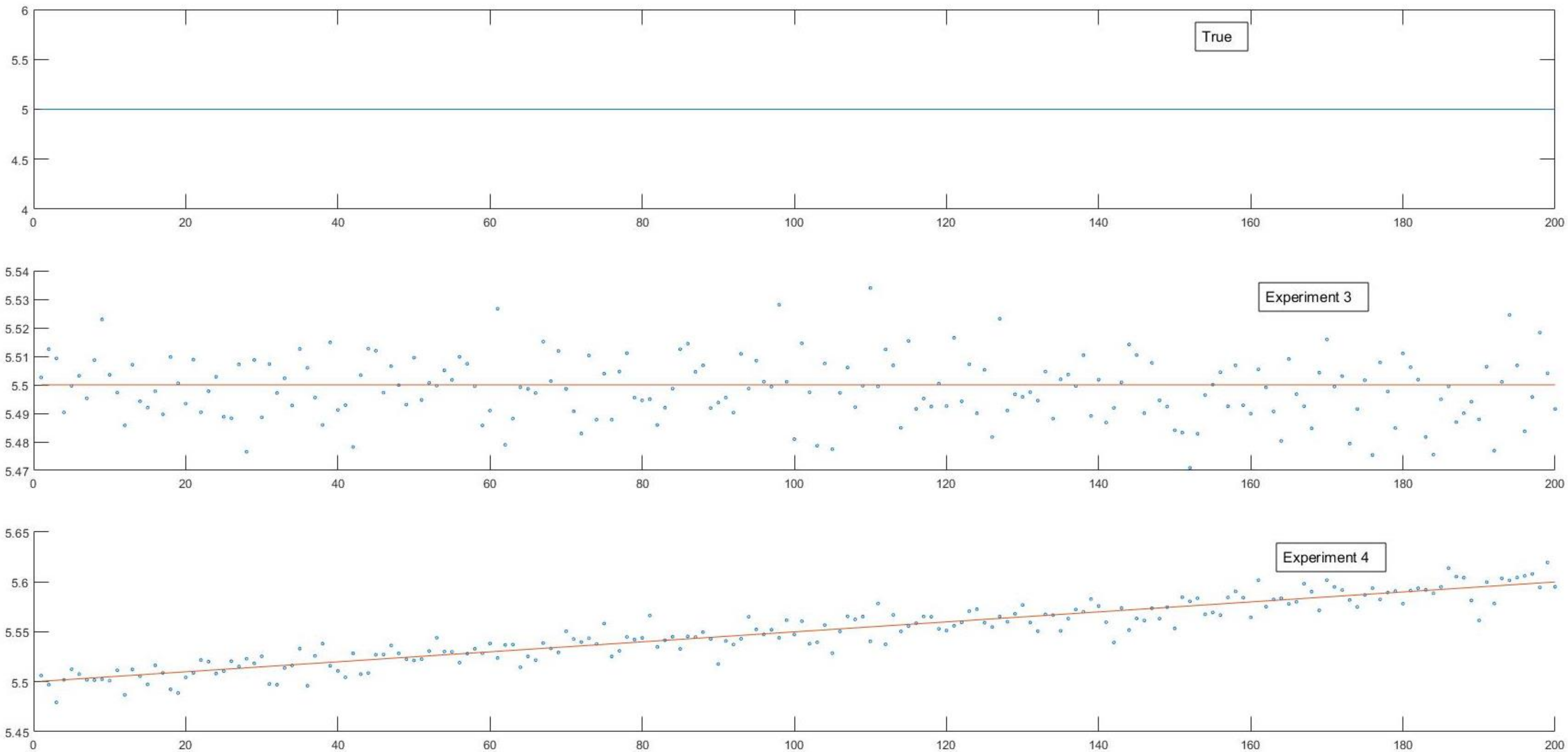
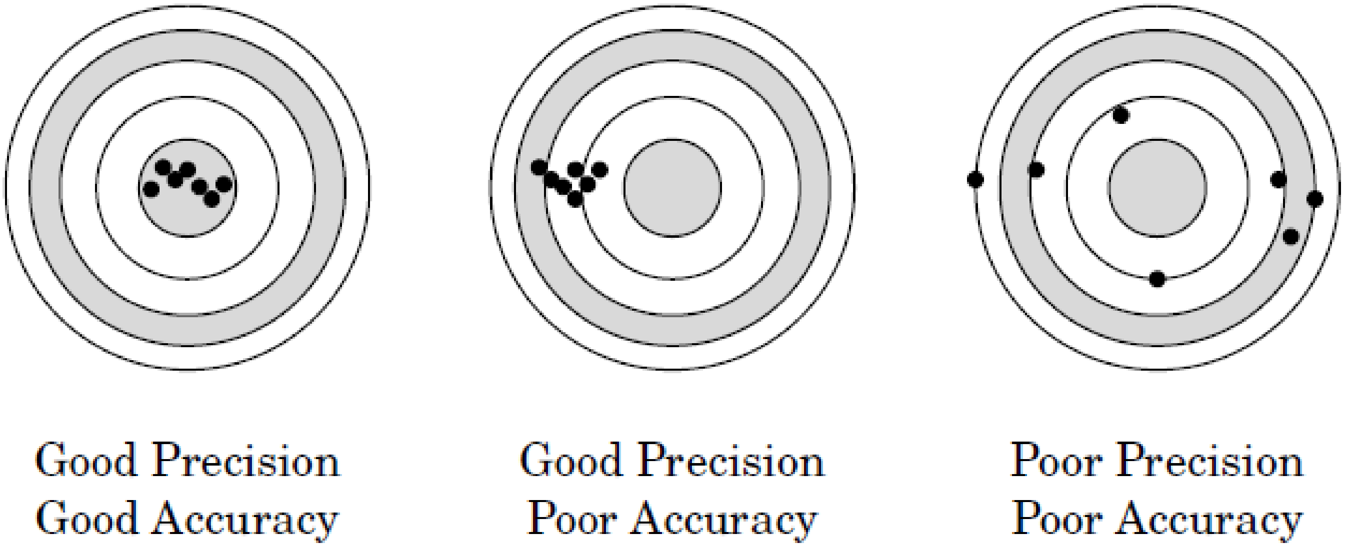


Bias and drift can be estimated by suitable curve fitting (static case).

Accuracy and Precision?



Accuracy: How close observations are with truth.

Precision: How close observations are with respect to each other under same conditions.

Absolute accuracy: When results are compared with truth.

Relative accuracy: When results are compared with observed data.

Accuracy and Precision?

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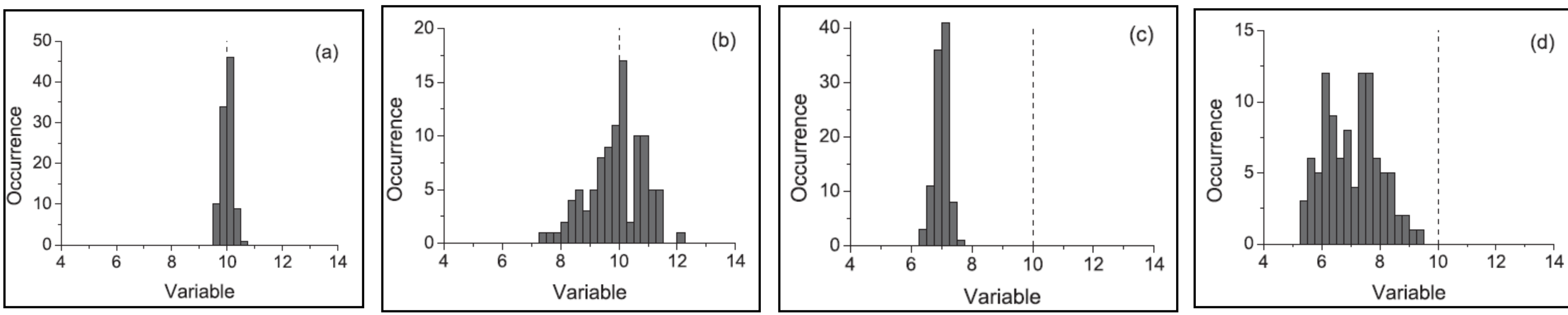


Simulation of 100 measurements, true value is 10.

a) Precise and accurate

b) Imprecise and accurate

c) Precise and inaccurate

d) Imprecise and inaccurate

Accuracy and Precision?

Absolute accuracy: When results are compared with truth.

When the results are presented as absolute value. i.e. deviation from the truth.

Relative accuracy: When results are compared with observed data.

When the results are presented as relative to measured value. i.e. percentage of deviation from the truth divided by truth .

$$Absolute\ accuracy\ error = Mesurement - true$$

$$Relative\ accuracy\ error = 100 * (Mesurement - true)/true$$

S. No.	True	Measurement	Error=measurement - true	Relative accuracy %
1	10	9.5	-0.5	-5.0
2	10	10.1	0.1	1.0
3	10	9.9	-0.1	-1.0
4	10	10.5	0.5	5.0
5	10	9.8	-0.2	-2.0
6	10	10.3	0.3	3.0
7	10	9.3	-0.7	-7.0
8	10	9.7	-0.3	-3.0

What is standard?

Standard forms the basis for consistency. Various measurements can be compared easily using standard. Standard unit of length, weight & time.

International standard: Units of measurement of physical quantities to the highest possible accuracy. Not used for day to day use. Not freely available. Not referenced to other standard.

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

1 sec is defined as 9,192,631,770 cycles of the atomic resonant frequency of cesium-133.

Bureau International des Poits et Mesures standard http://www.bipm.org/en/about-us/
National Physical Laboratory http://nplindia.org/

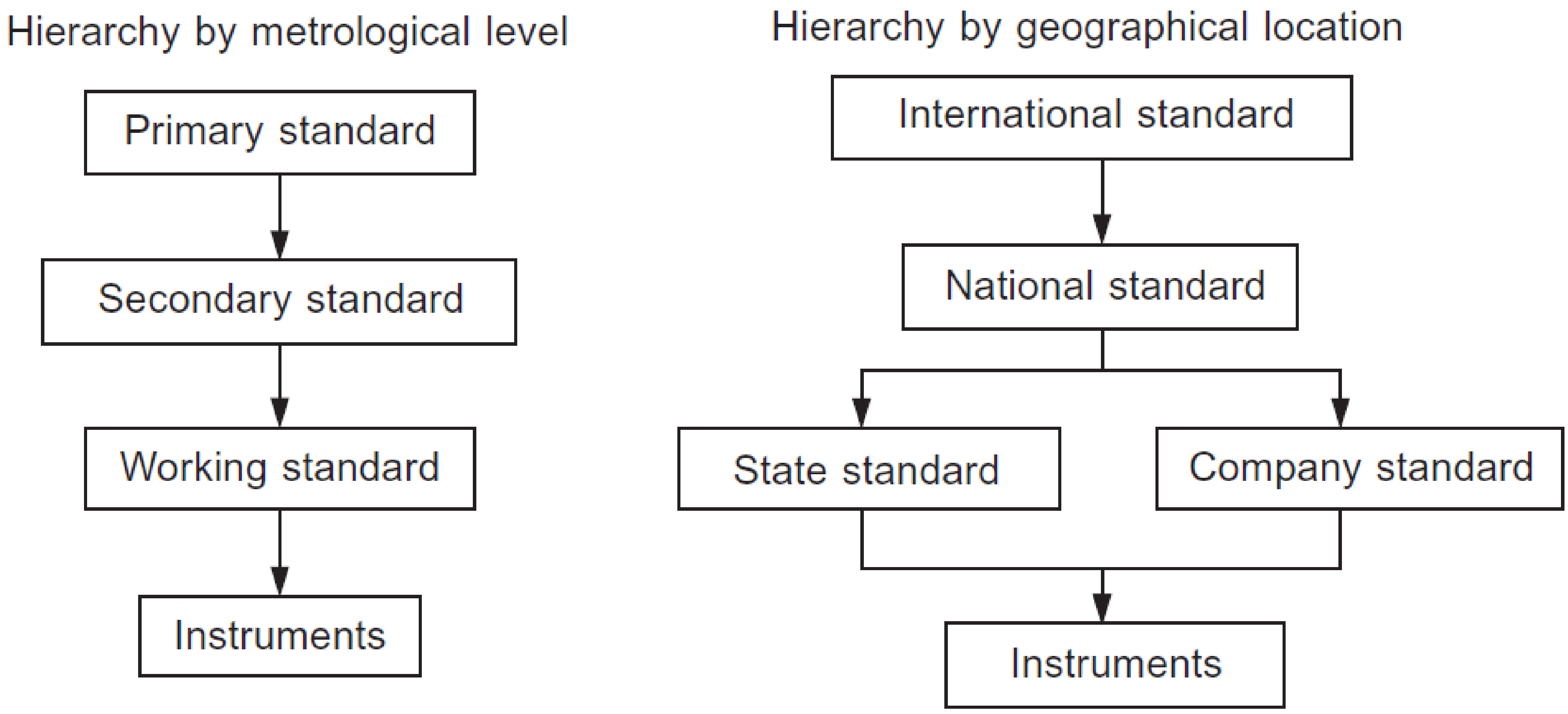
What is standard?

Primary standard: These standards are kept at national laboratories. These are calibrated against international standard. Not used frequently. Not freely available.

Secondary standard: These maintained by industrial measurement laboratory for their own calibration of working standard. These are freely available.

Working standard: These are high accuracy devices commercially available and calibrated against secondary or primary standard. These are used for calibrating laboratory equipment or for checking the quality of products etc.

Standard Hierarchy



G.M.S. de Silva, Basic Metrology for ISO 9000 Certification, Butterworth-Heinemann, 2002

What is calibration?

It is a act or result of quantitative comparison between known standard and the output of measuring instrument measuring the same quantity.

Comparing the standard and test instrument simultaneously.

Quantity is varied in ascending and descending order and results are compared.

Standard should be ten times more accurate compared to expected accuracy of the instruments.

Calibration can be done for various environmental conditions.

Types of calibration

Primary Calibration : Device / system calibrated against primary standards. Primary standards are available with national physical laboratories. After primary calibration device is employed as secondary calibration device.

Secondary Calibration : When secondary device is used for calibration then it is called as secondary calibration.

Types of calibration

Direct Calibration : Calibration using a known input source. It is as good as primary calibration. Direct calibrated devices can be used for secondary calibration. E.g. Flow meter is calibrated by accurately measuring the mass of fluid for a given time. In this another accurate flow meter is not required for calibration.

Routine Calibration : Periodically checking the accuracy and proper functioning of an instrument with standard. Very important for reliable functioning of a system.

Types of measurement

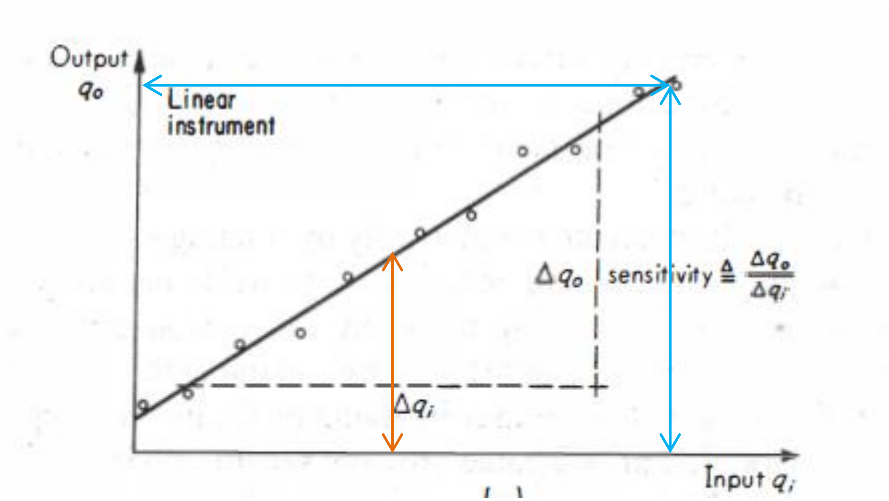
Static measurement : Quantities do not change with time or variation is very slow. Input and output can be related using algebraic expressions

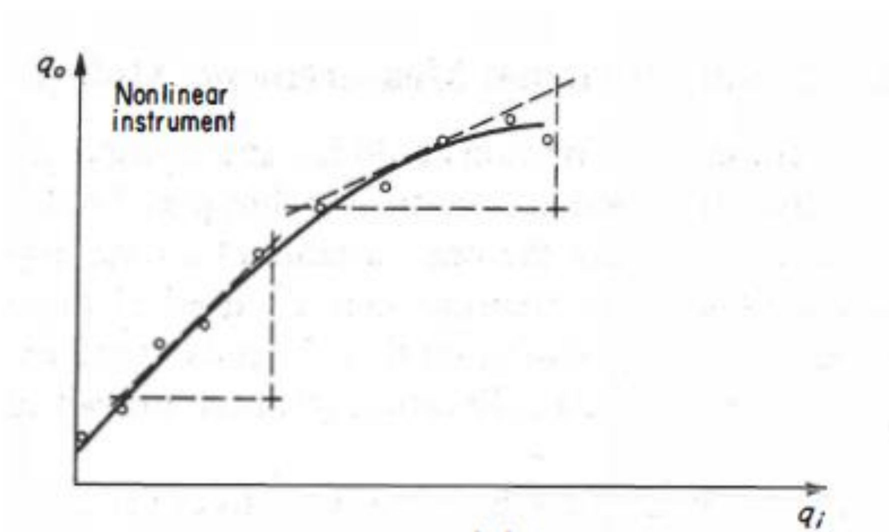
Dynamic measurement : When the signal is varying with time. Input and output related by differential equations. More complex relationship as compared to static measurement.

Measurement Errors

Errors in measurement are introduced due to construction of the sensor, due to specific transducer, due to threshold, due to dead space, due to random behavior etc. Error characteristics may remain constant over time or may change with time. Some errors are introduced only during switching.

Measurement Errors





Static sensitivity – slope of input-output calibration curve. It could be linear or nonlinear.

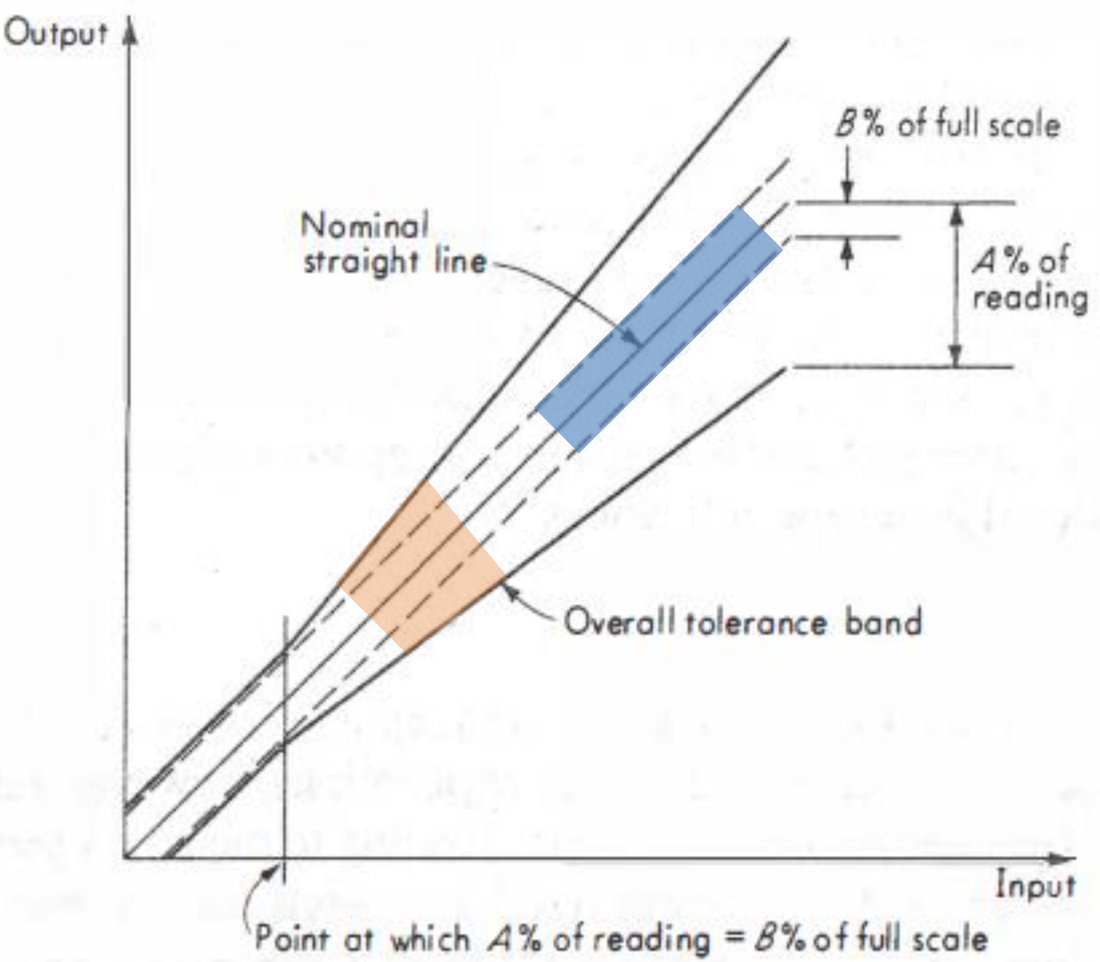
Calibration curve also effected by interfering or modifying inputs.

Accuracy is specified as

± A percent of reading

or ± B percent of full scale

Measurement Errors



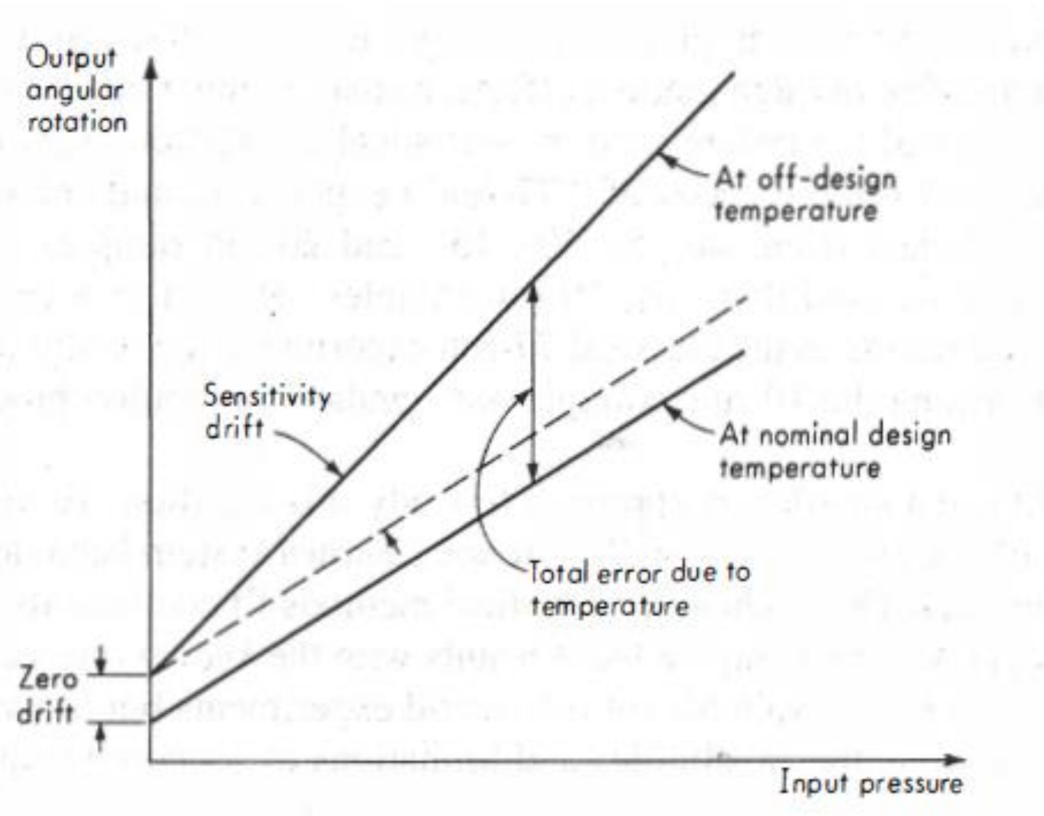
Accuracy is specified as

± A percent of reading

or ± B percent of full scale

For the first case error is zero when input is zero and it is also small for small input, this is not a practical case. There will be always finite error.

Measurement Errors



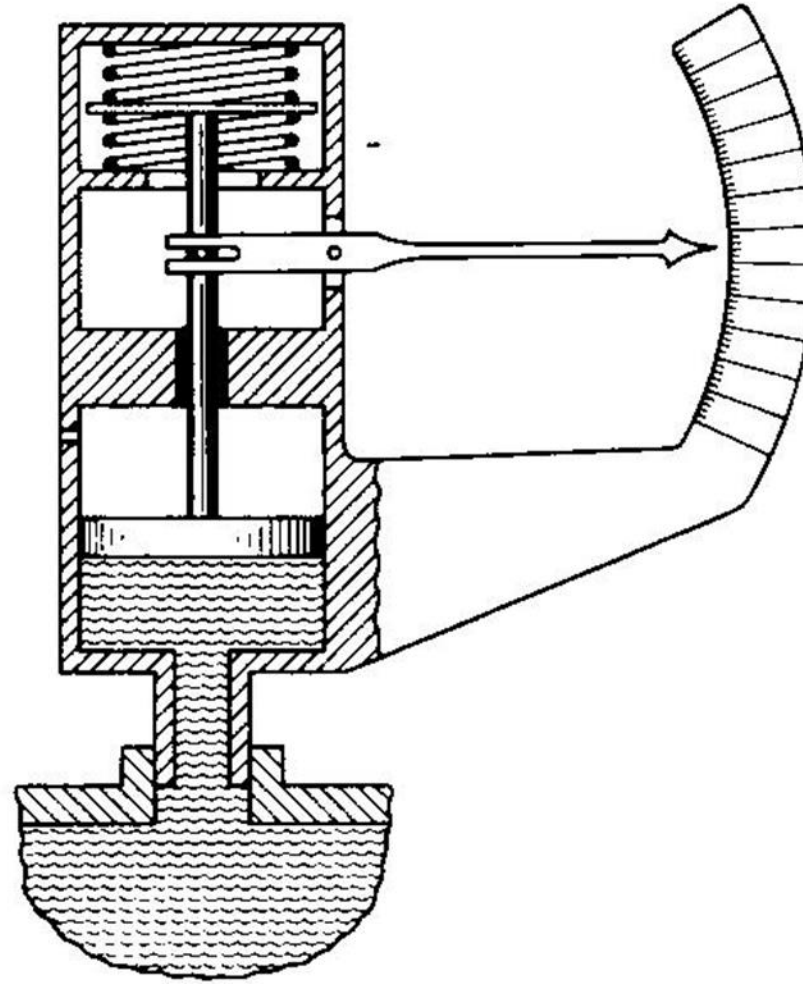
Calibration curve also effected by interfering or modifying inputs.

When the instrument is switched on, it may different bias. This bias may have dependency on interfering or modifying inputs.

Example

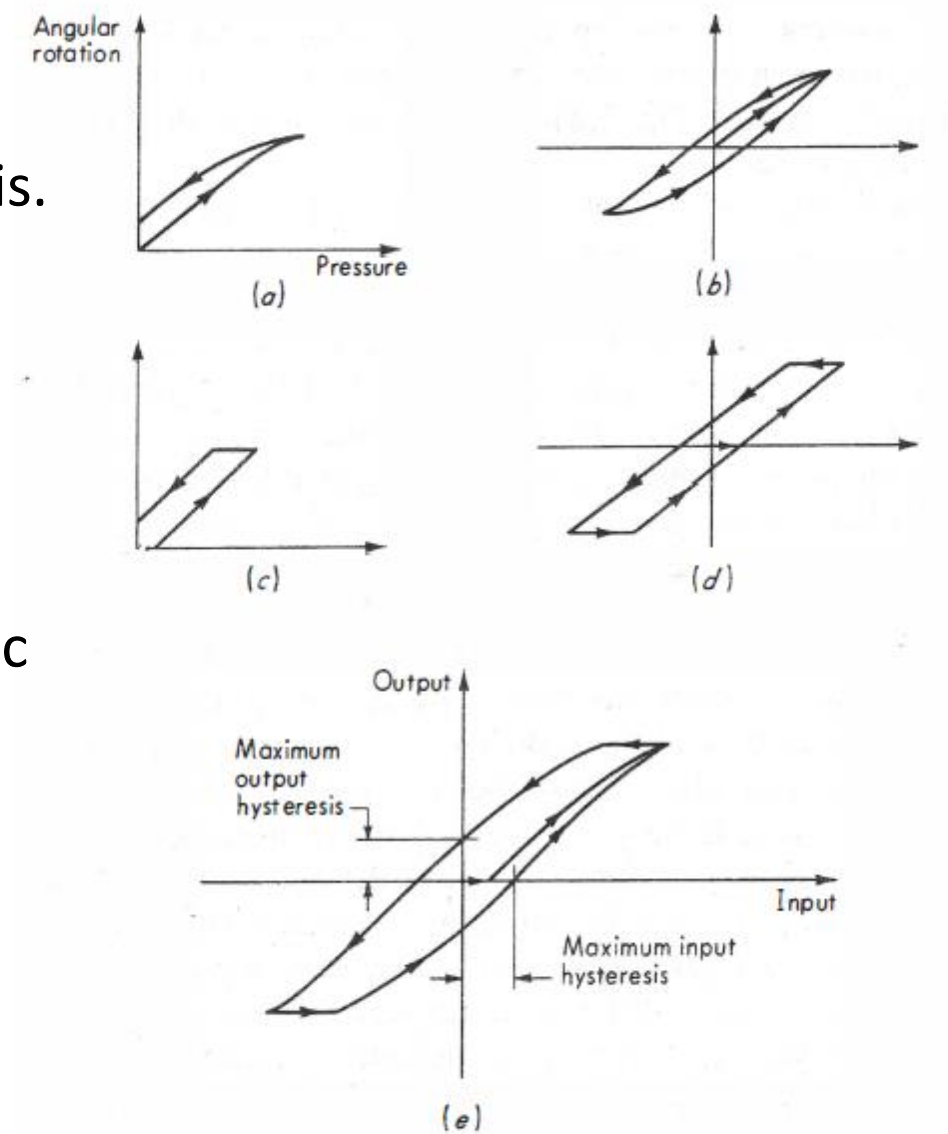
Fluid pressure exerted on piston results into force. Piston surface is sliding on cylinder surface (friction). Spring is deformed due to application of piston force (could be non-linear). Linear motion of piston is converted to rotary by needle mechanism (mechanical play).

Many of the above factors introduces error.

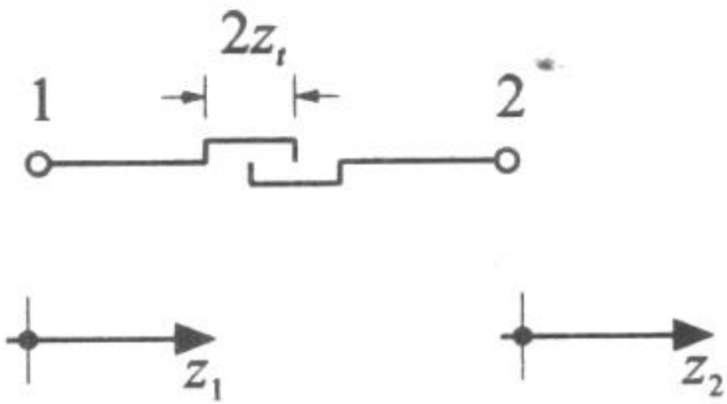


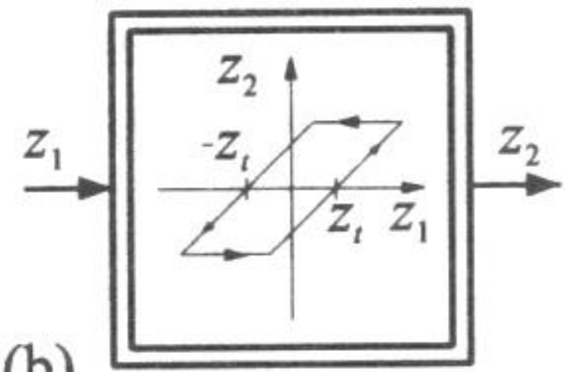
Measurement Error - Hysteresis

Noncoincidence of loading and unloading curve results in hysteresis. This could be due to material behavior i.e. energy stored during loading is not recovered during unloading or friction force like stiction. It is also observed in ferromagnetic material during cyclic application of magnetic field, resulting into heating.



Backlash

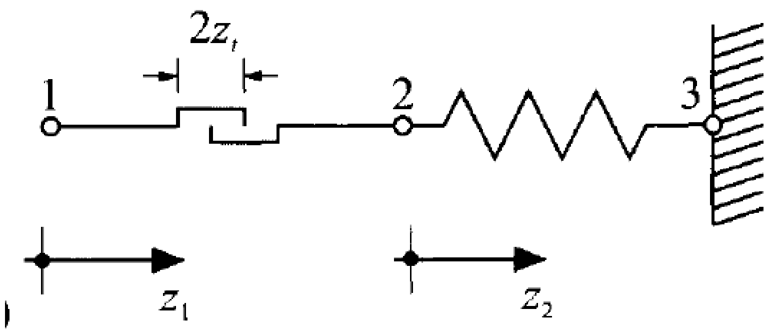


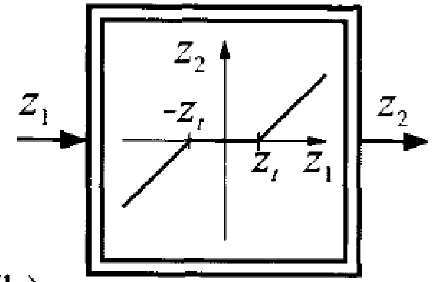


(b)

Whenever direction of motion changes, output will be change after some input (amount of backlash). Found in mechanical system. Important to estimate for precise control. It can result to oscillations in the system.

Deadzone





(b)

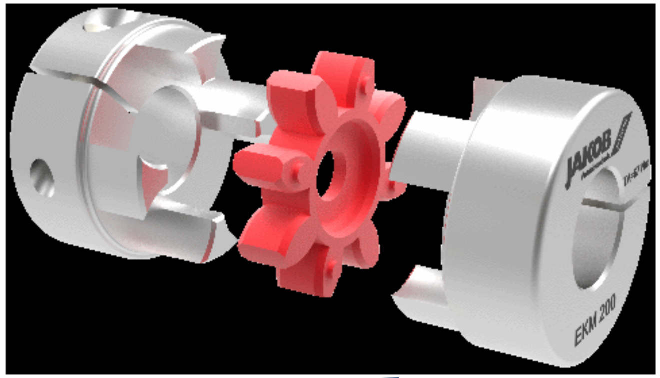
z_t is deadzone

$$z_2 = z_1 - z_t \text{ for } z_1 \geq z_t$$

$$z_2 = z_1 + z_t \text{ for } z_1 \leq z_t$$

$$z_2 = 0 \text{ for } -z_t < z_1 < z_t$$

Some specific zone in which output will not change even when input is given. It may be intentionally introduced e.g. joystick.

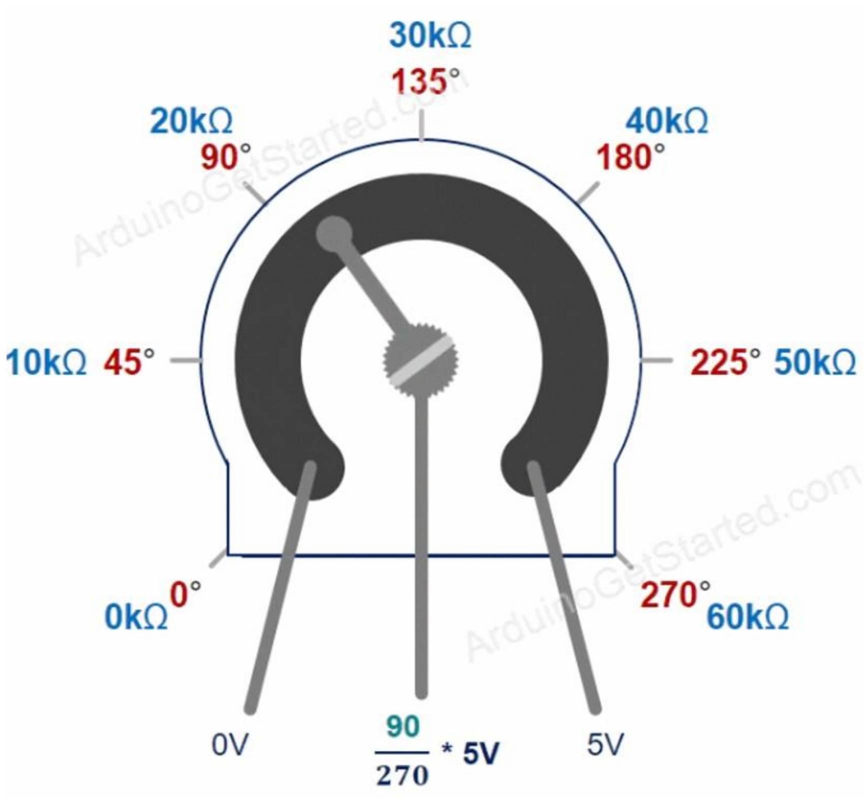


Assembled view

Input – clockwise or anticlockwise rotation

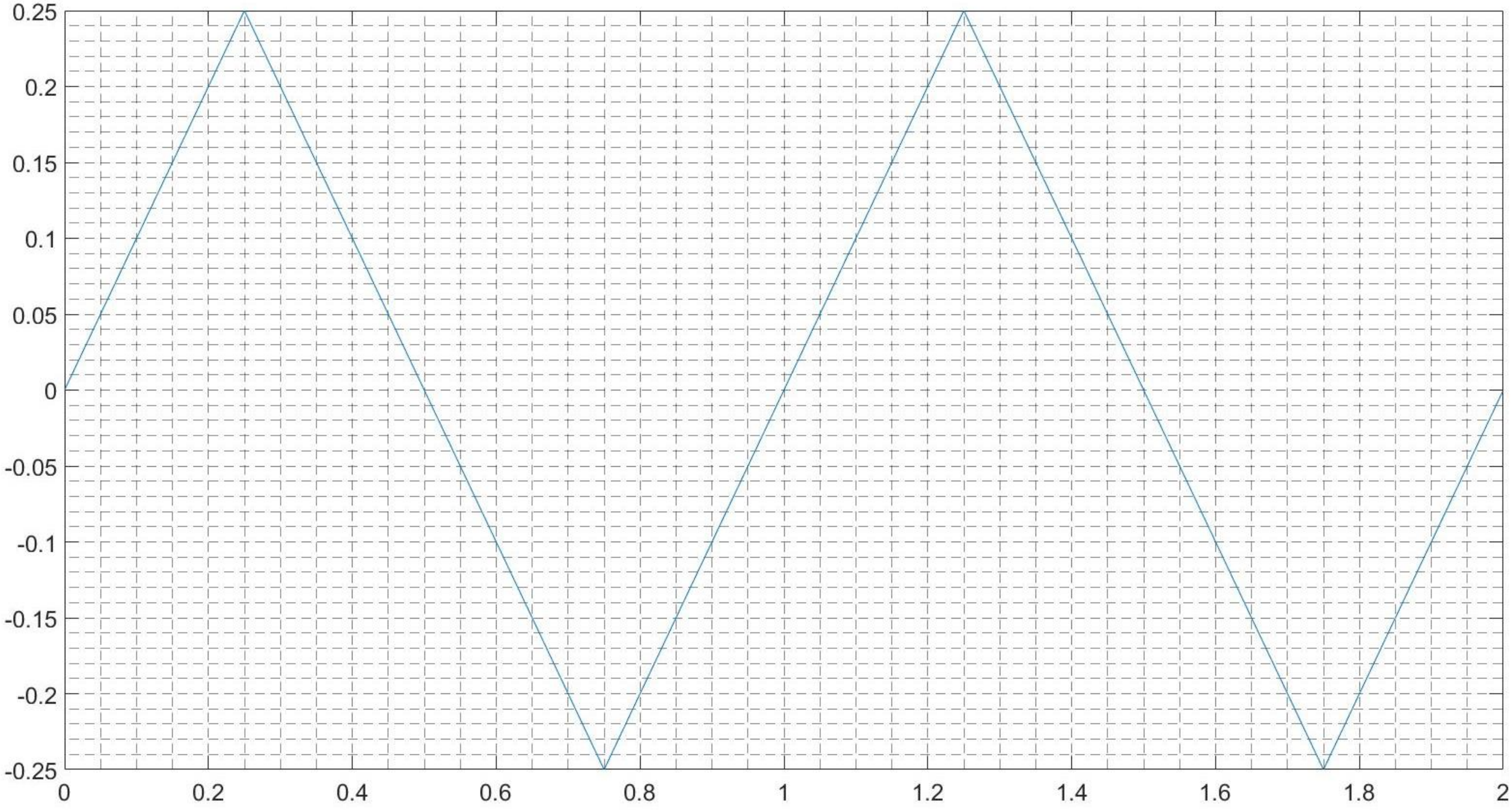
output – connected to angle measurement sensor

What happens when direction of rotation changes?



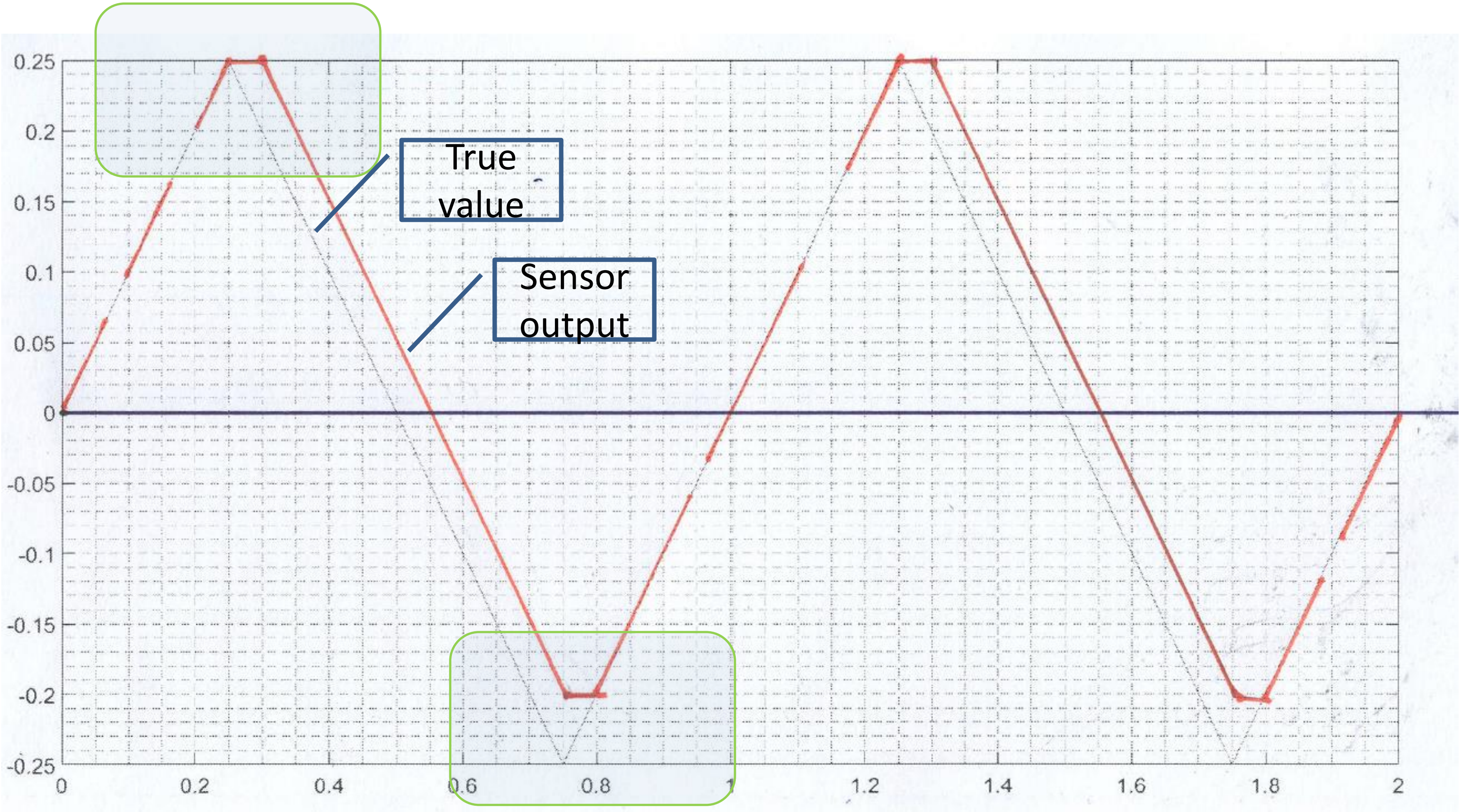
Angle can be measured using rotary potentiometer.

What will be output between 270 and 0 degree?

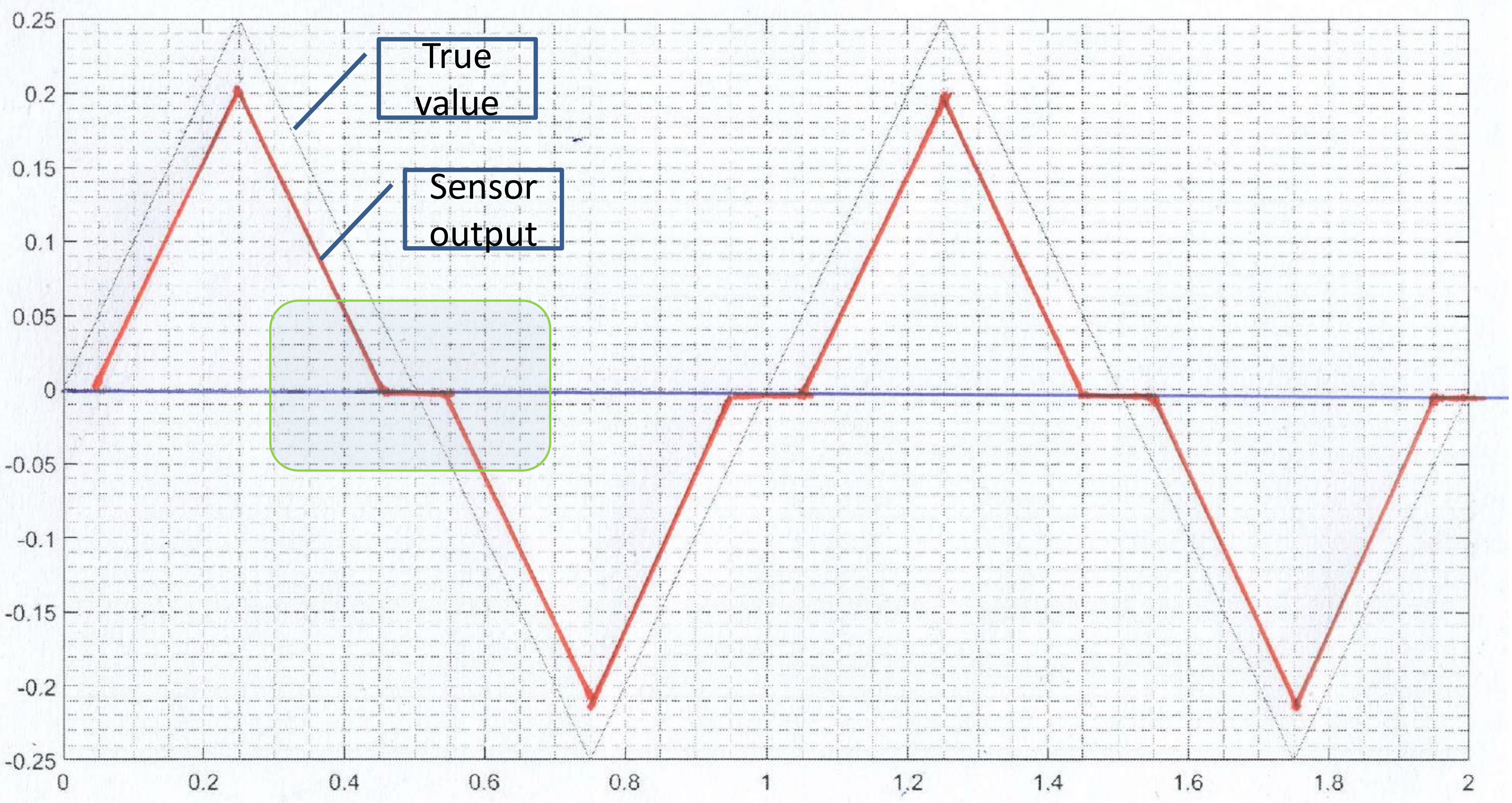


A shaft is rotating (clockwise and anticlockwise) and its true angular position is given in above figure.

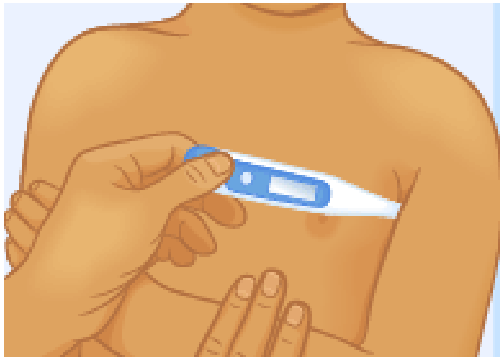
What will be the output of sensor connected to shaft which is a) Having backlash b) Having dead zone



Sensor with back lash. Whenever the direction of rotation changes, it will take finite movement before the output changes.



Sensor with dead zone. Whenever the shaft position is in dead zone output will remain constant.



Body temperature measurement

Pressure measurement

What are the common functions in above measurement systems?

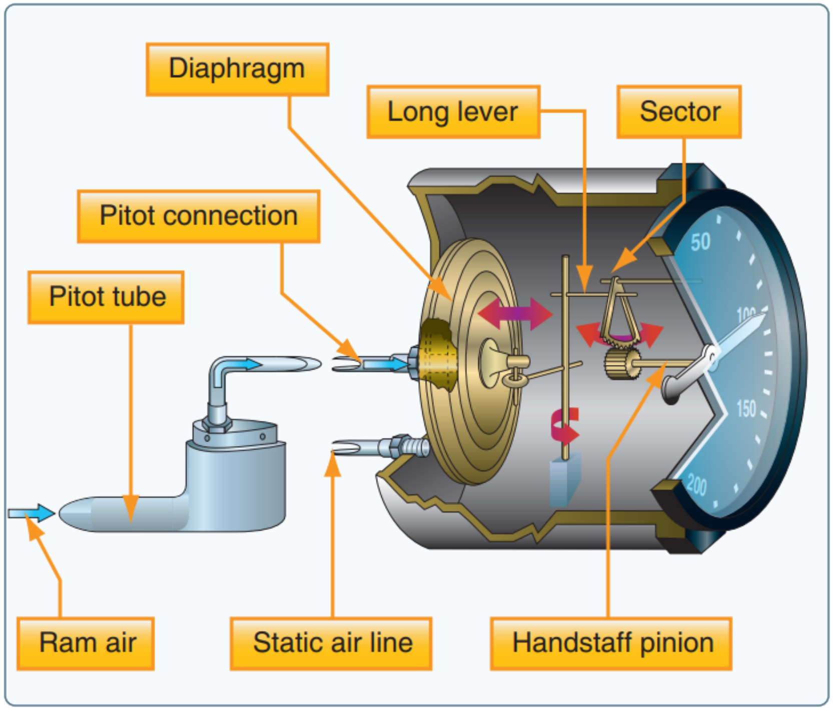
Functional elements of a measurement system

$$V = \sqrt{2\Delta p / \rho}$$

Differential pressure → Air Speed

Human needs information which can be comprehended

Functional elements of a measurement system



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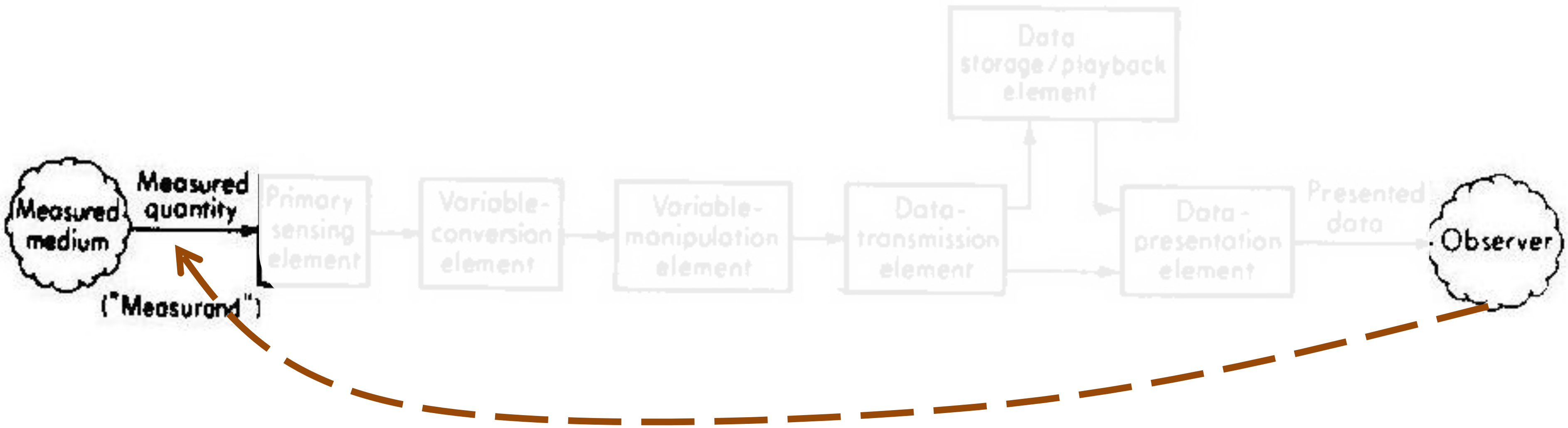
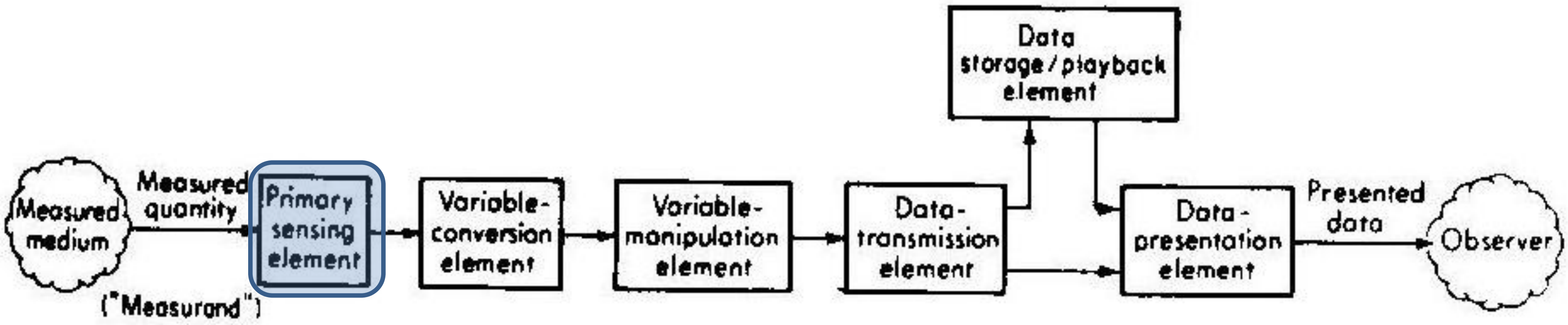


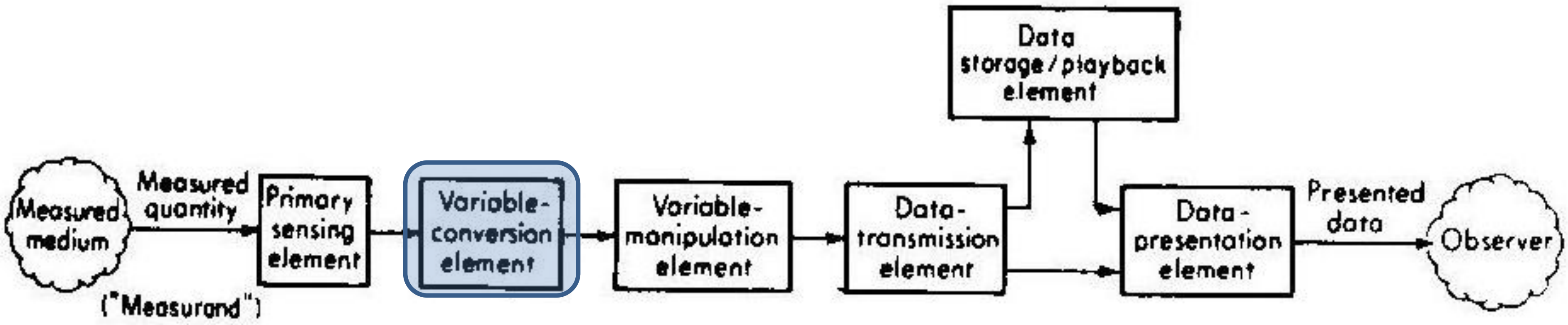
Observer has interest in measured quantity. It may not be directly available, may have intermediate steps.

Functional elements of a measurement system



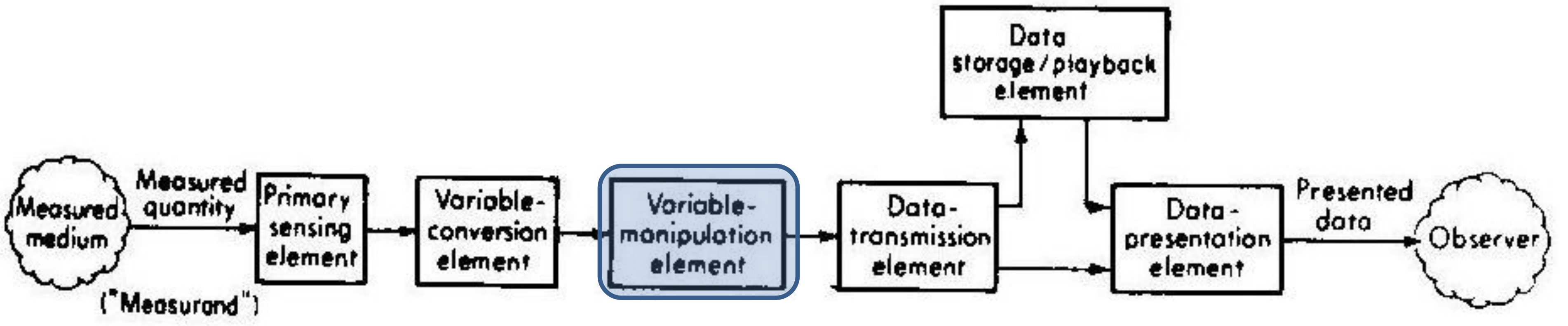
Primary sensing element: It converts measured quantity (measurand) into some other form. Output of primary sensing element converts into some other convenient variable while preserving the information content of the original signal. Electrical quantity (resistance, capacitance, inductance, voltage and current) is preferred. Easier to process. E.g. Resistance is proportional to temperature.

Functional elements of a measurement system



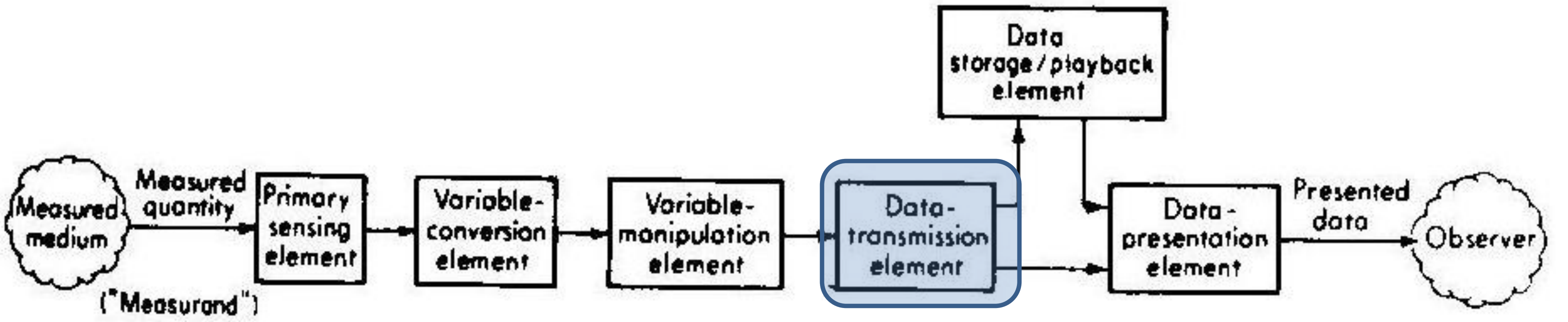
Variable conversion element: This element will convert output of the primary sensing element to another variable suitable for instrumentation. e.g. strain measurement: strain to resistance (strain gage) and resistance to voltage (Wheatstone bridge).

Functional elements of a measurement system



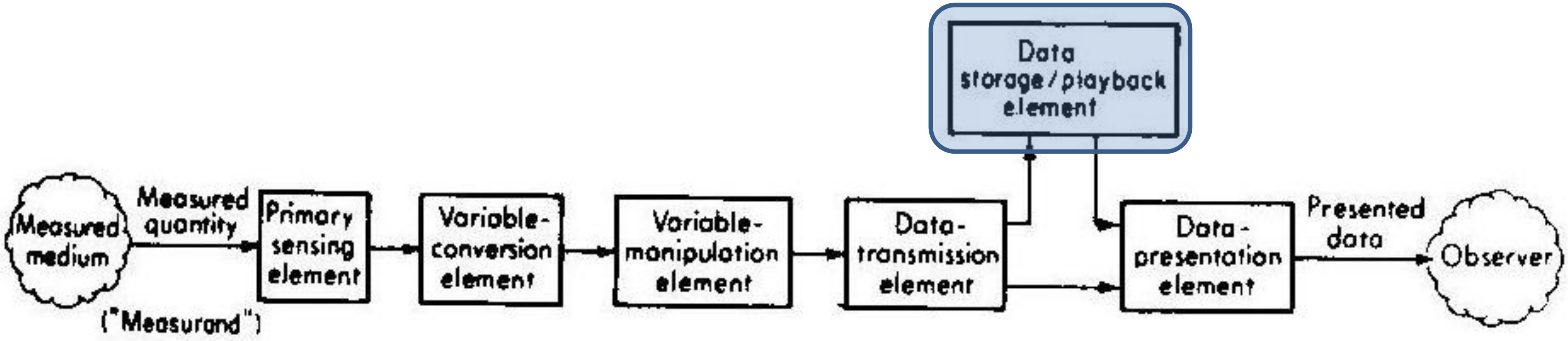
Variable manipulation element: This element will use a predefined mathematical operation. e.g. opamp

Functional elements of a measurement system



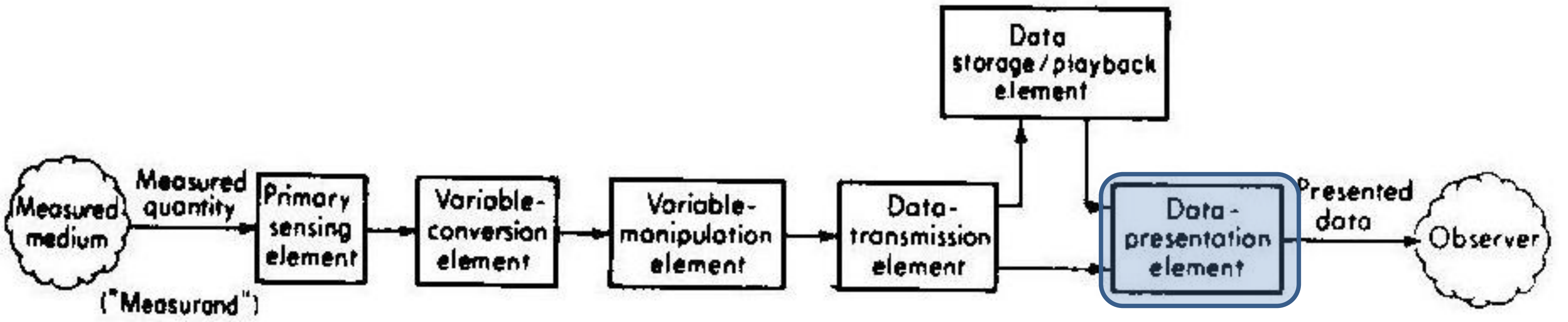
Data Transmission element: Primary sensing element and data storage or display may not be co-located. It could be simple wired or wireless.

Functional elements of a measurement system



<u>Data Storage element</u>: Data storage may be analog or digital. Used for analysis and archiving information

Functional elements of a measurement system



<u>Data presentation element</u>: User will typically need information in units relevant to measured medium (temperature, pressure, displacement etc.). Information is reconverted to present in the original units.

In a measurement system it is not necessary that all the elements are present and may not be in same sequence

Example - 1

Piston – primary sensing element, variable conversion element (pressure to force)

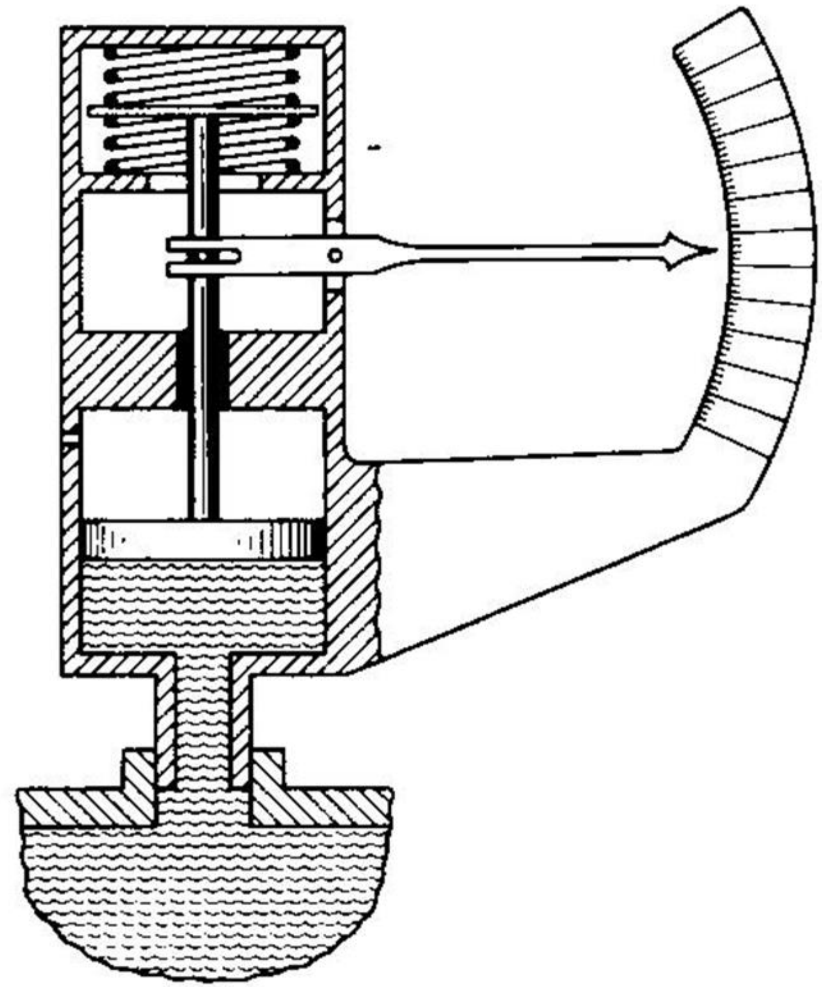
Piston rod – Data transmission

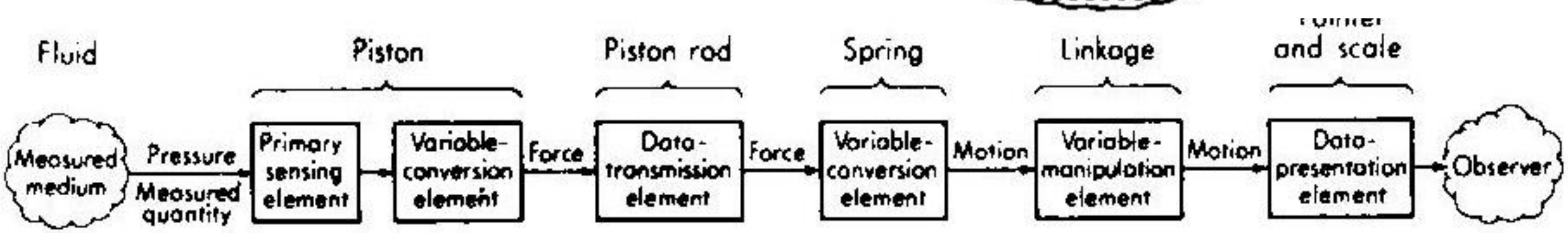
Spring – Variable conversion element : spring force is converted to linear motion

Linkage: Variable manipulation element: Amplification of the piston movement

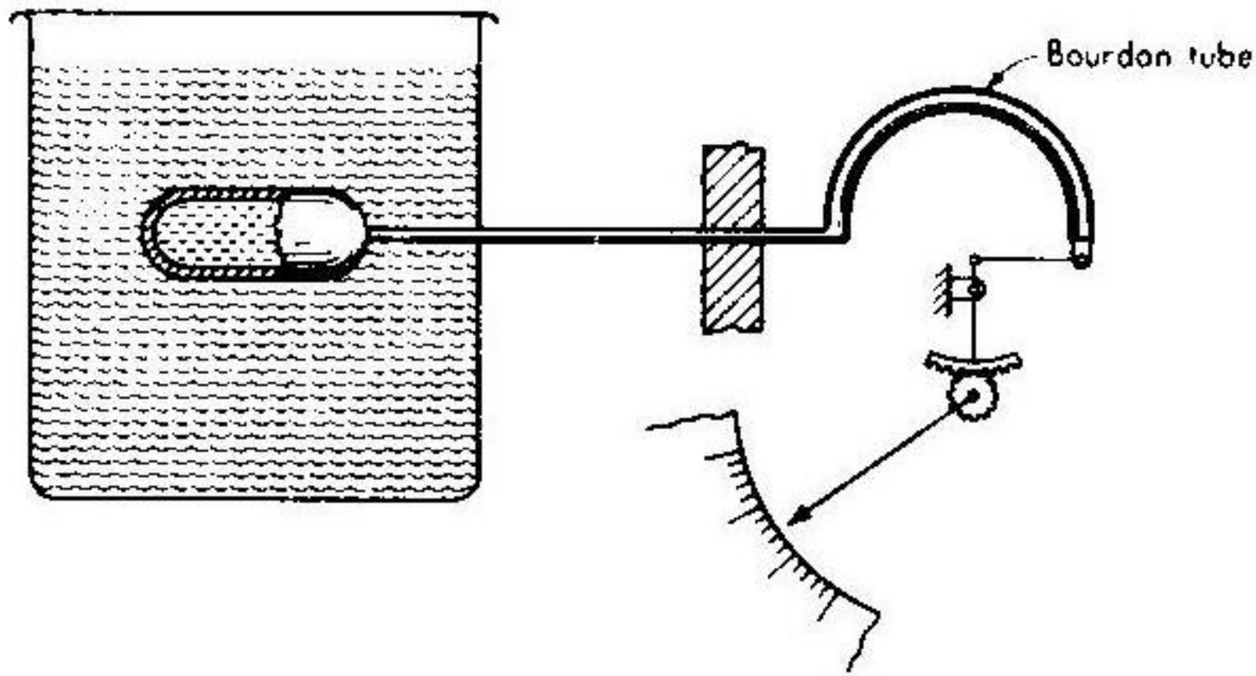
Pointer & scale : Data presentation element

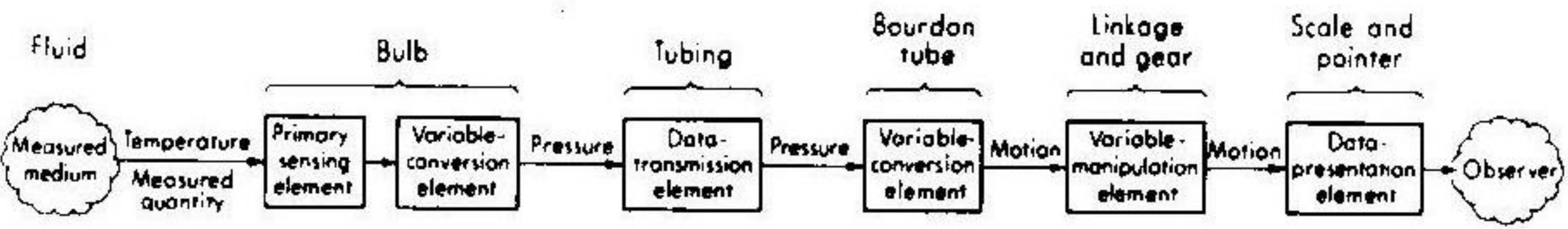
All the elements may not be present or may not be in sequence for all the instruments





Example - 2


Bourdon tube


Fluid
Bulb
Tubing
Bourdon tube
Linkage and gear
Scale and pointer
Measured medium
Temperature
Measured quantity
Primary sensing element
Variable-conversion element
Pressure
Data-transmission element
Pressure
Variable-conversion element
Motion
Variable-manipulation element
Motion
Data-presentation element
Observer

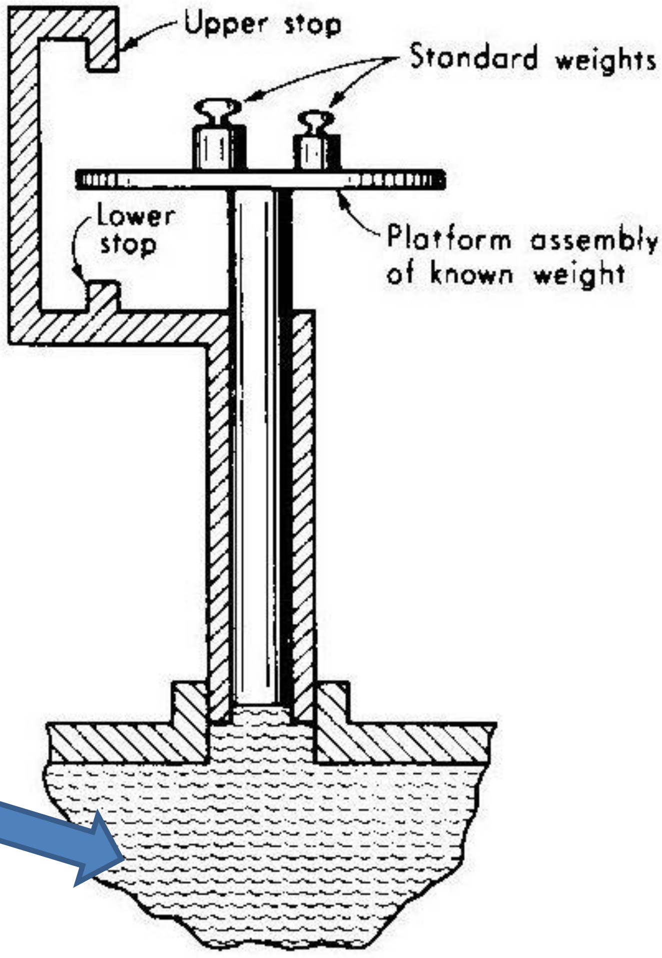
Null and Deflection methods

Wish to measure weight of unknown object?

Null and Deflection methods

Pressure gage: Weights are kept in such a way that plunger do not move

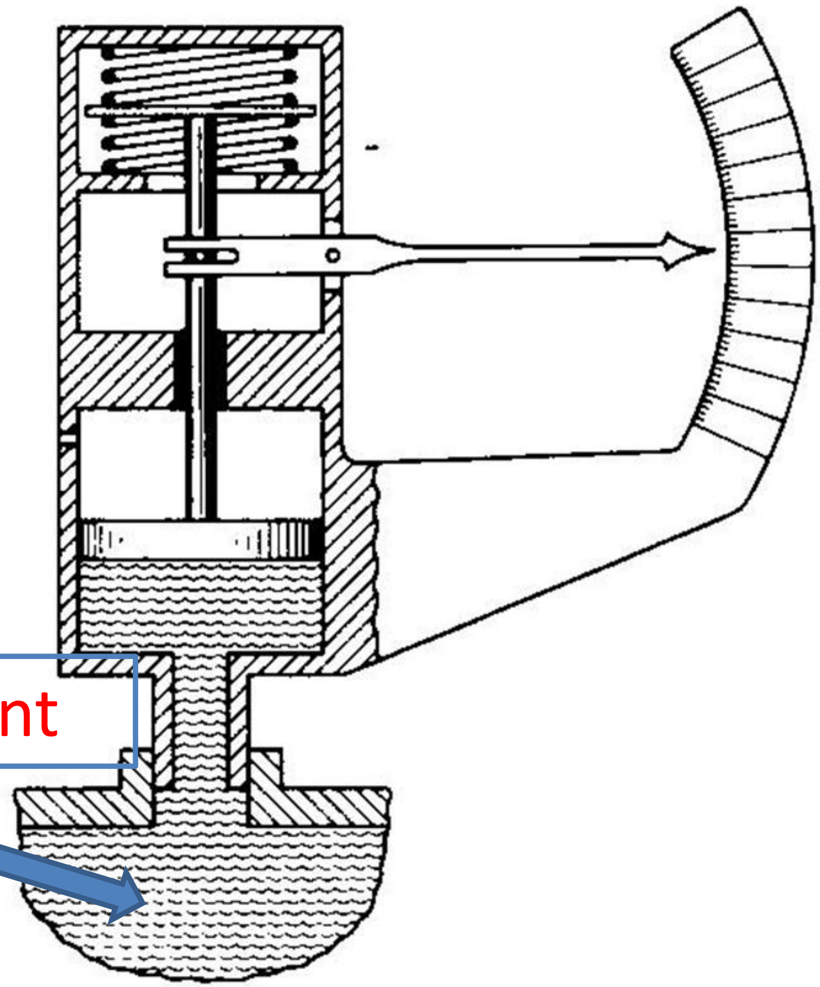
Volume will remain constant



Null and Deflection methods

Pressure gage: Force is balanced by spring deflection. Plunger movement rotates the indicator

Volume will not remain constant

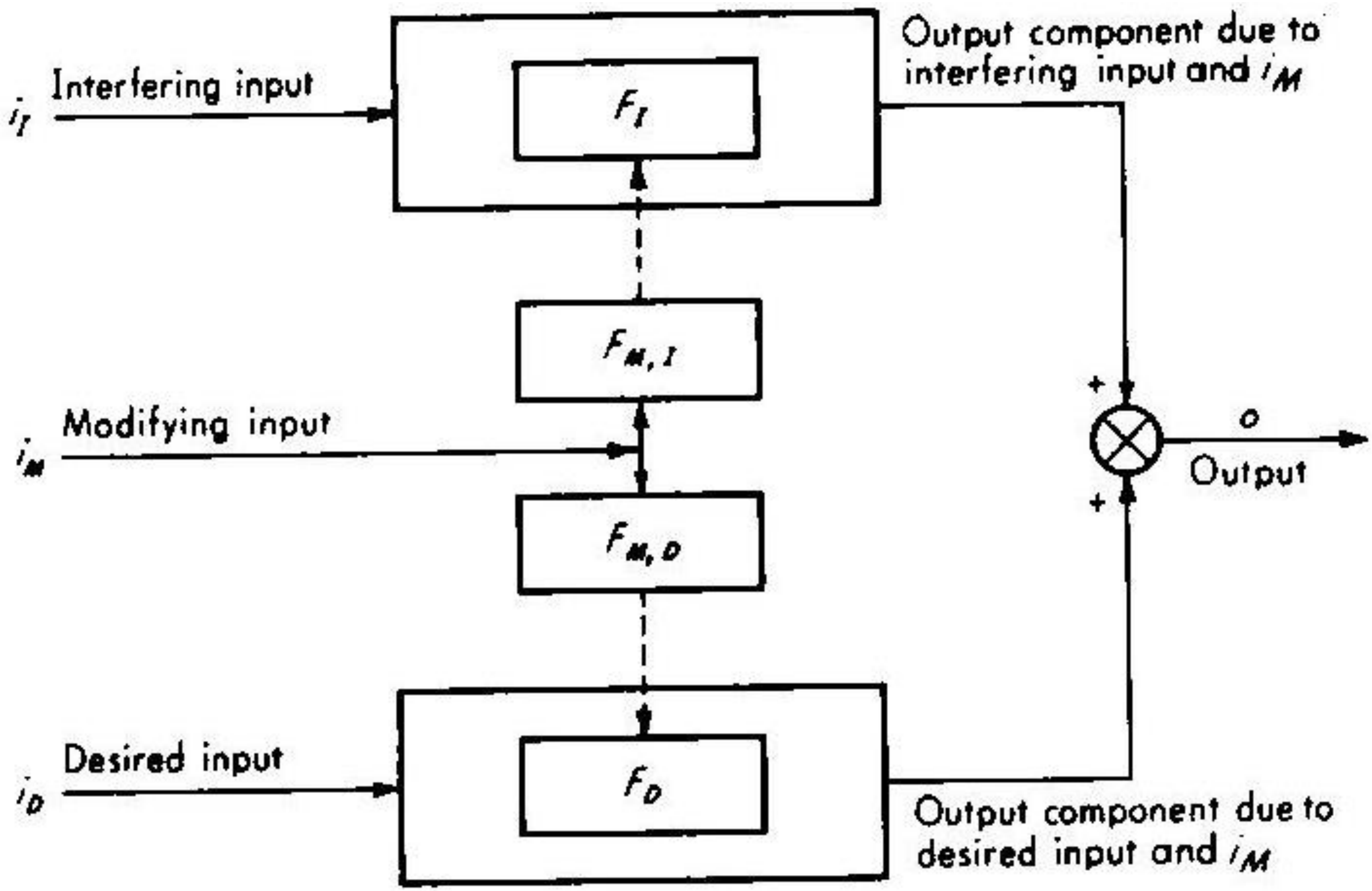


Null and Deflection methods

Deflection type: Measured quantity produces some physical effect that causes some opposing effect in the system and which is balanced. The balance is achieved by deflection. Easier to use.

Null type: Device attempts to maintain deflection at zero by suitable application of an effect opposing that generated by the measured quantity. Measure quantity is inferred from the opposing effect. Requires feedback mechanism to balance. Generally used for precise and accurate measurements.

Input and Output Configuration



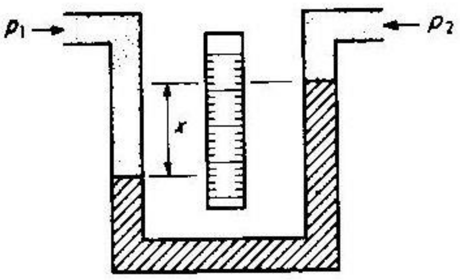
Input and Output Configuration

<u>Desired inputs</u>: Quantities that the instrument is specifically intended to measure.

<u>Interfering inputs</u>: Quantities to which instrument is unintentionally sensitive

<u>Modifying input</u>: That causes a change in input-output relationship for the desired and interfering inputs

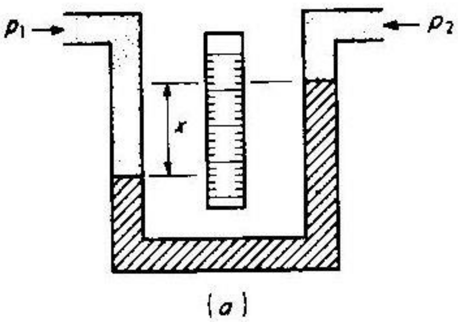
Mercury Manometer



$$p_1 - p_2 = \boxed{\rho g x}$$

What could be modifying input?

Mercury Manometer



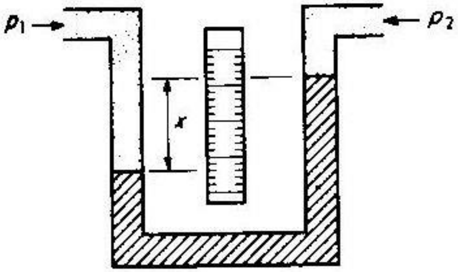
$$p_1 - p_2 = \boxed{\rho g x}$$

What could be modifying input?

Uncertainty in any or all of these will lead to error.

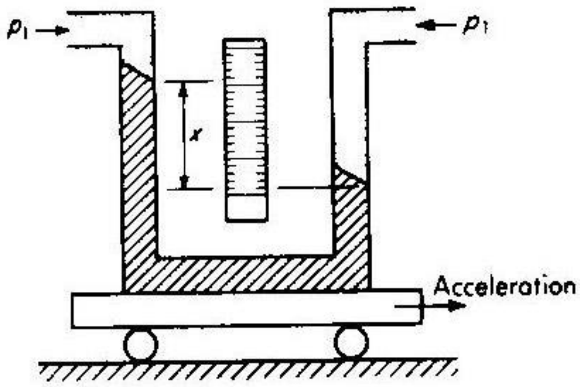
Temperature, location etc.

Mercury Manometer – spurious inputs



(a)

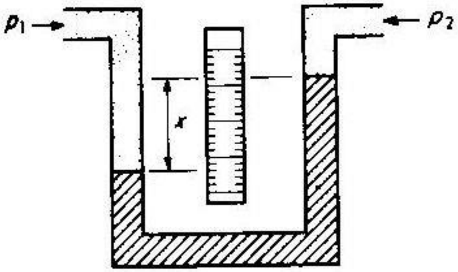
$$p_1 - p_2 = \rho g x$$



(b)

Desired inputs: Pressure difference
Interfering inputs: Acceleration (force balance, mass is involved in measurement)

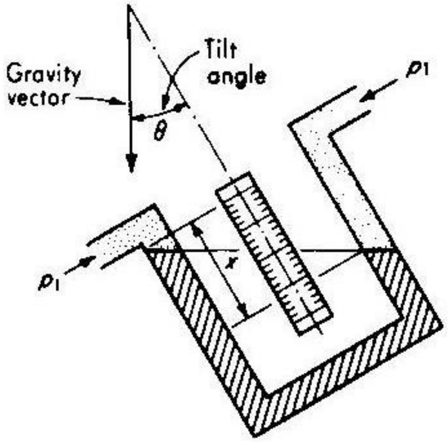
Mercury Manometer – spurious inputs



(a)

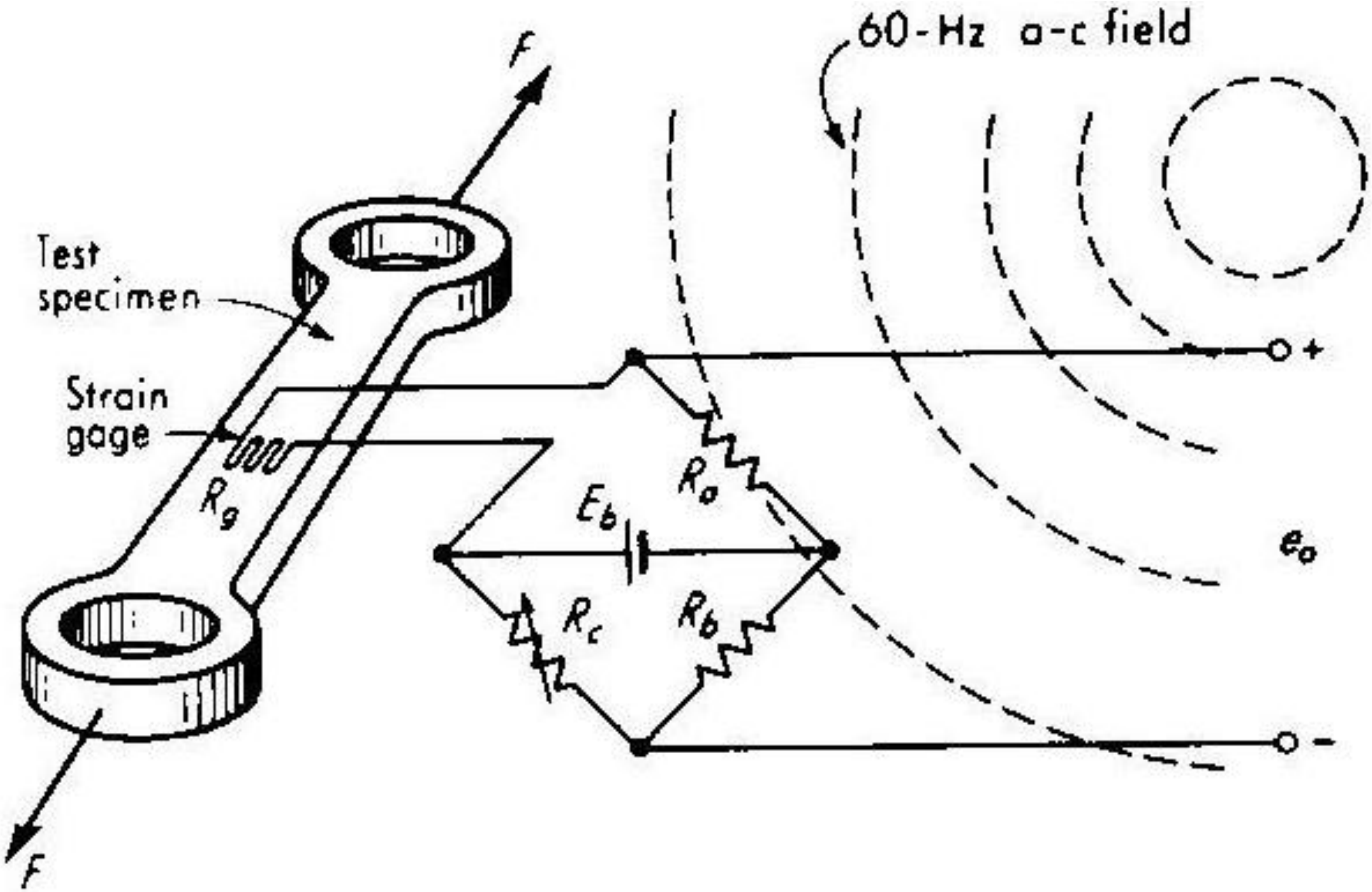
$$p_1 - p_2 = \rho g x$$

Desired inputs: Pressure difference
Interfering inputs: Gravity (force balance, weight is involved in measurement)

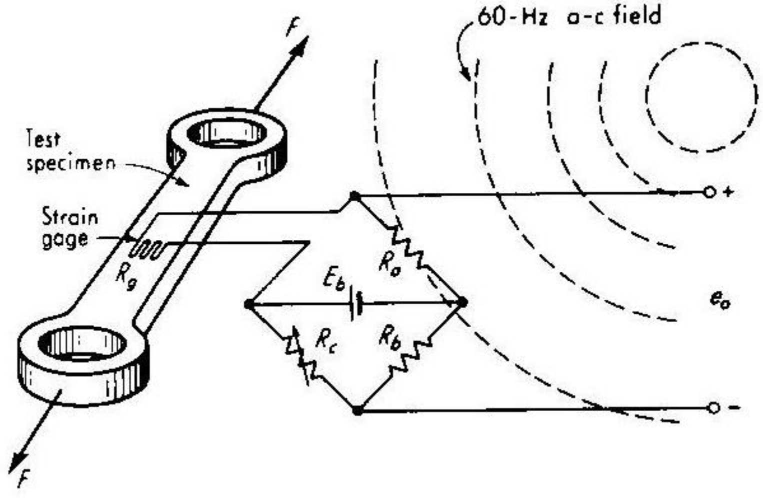


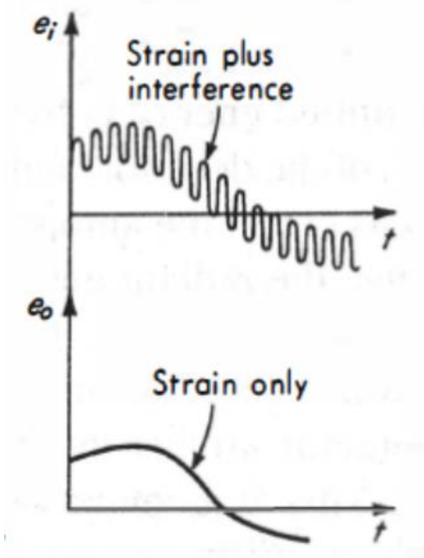
(c)

Strain Measurement



Strain Measurement





<u>Desired inputs: </u>Strain

<u>Interfering inputs: </u>magnetic field due to electric lines carrying current

<u>Modifying input</u>: Temperature, have effect on material property and electrical properties

Interfering and modifying inputs

Can we minimise effects of interfering inputs and modifying inputs?

Interfering and modifying inputs

Can we minimise effects of interfering inputs and modifying inputs?

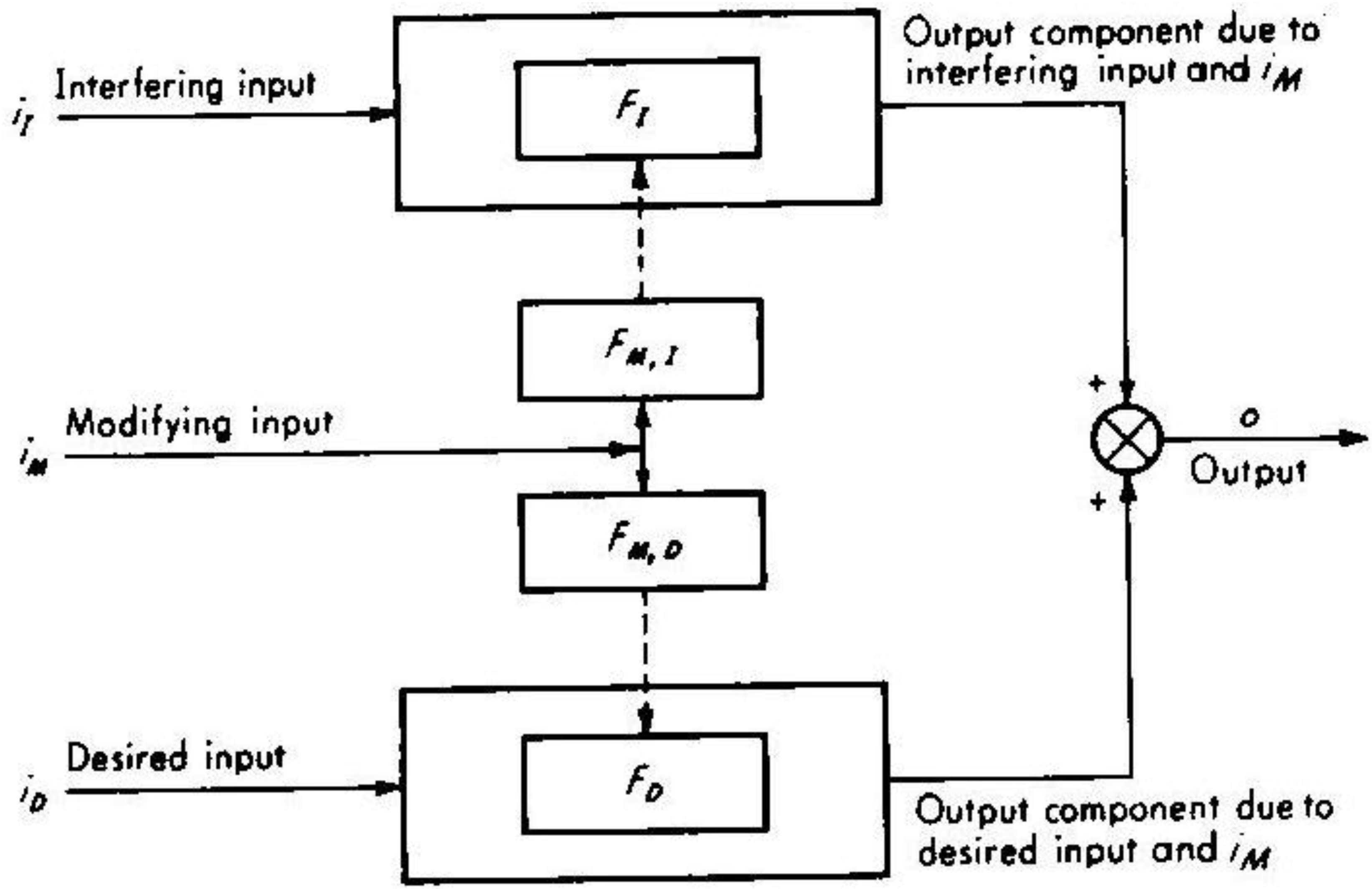
Isolating input from interfering or/and modifying inputs.

Identifying sensors which are insensitive to interfering or/and modifying inputs.

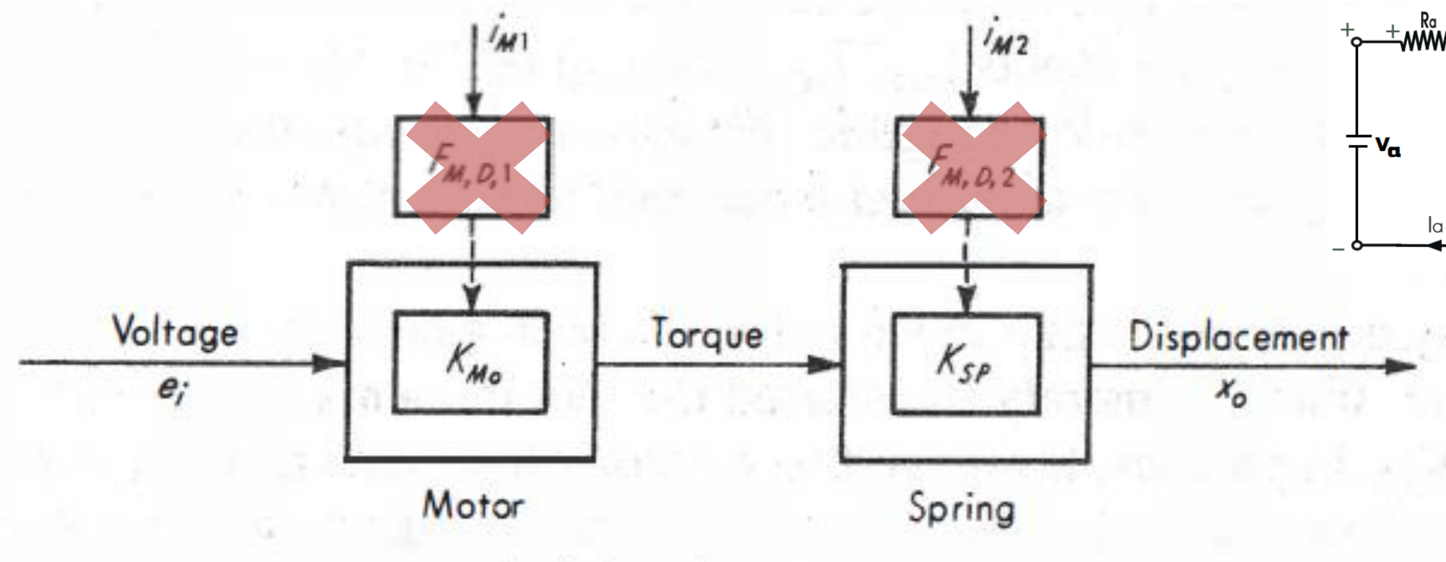
If we know the relationship of output with respect to interfering and modifying inputs. Independent measurement of interfering and modifying inputs can be used to remover errors due to these effects.

Using feedback methods to minimise contributions of interfering or/and modifying inputs.

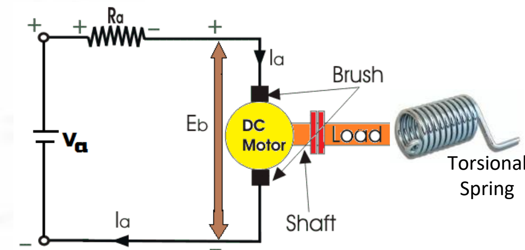
Input and Output Configuration



Methods of Correction for Interfering and Modifying Inputs



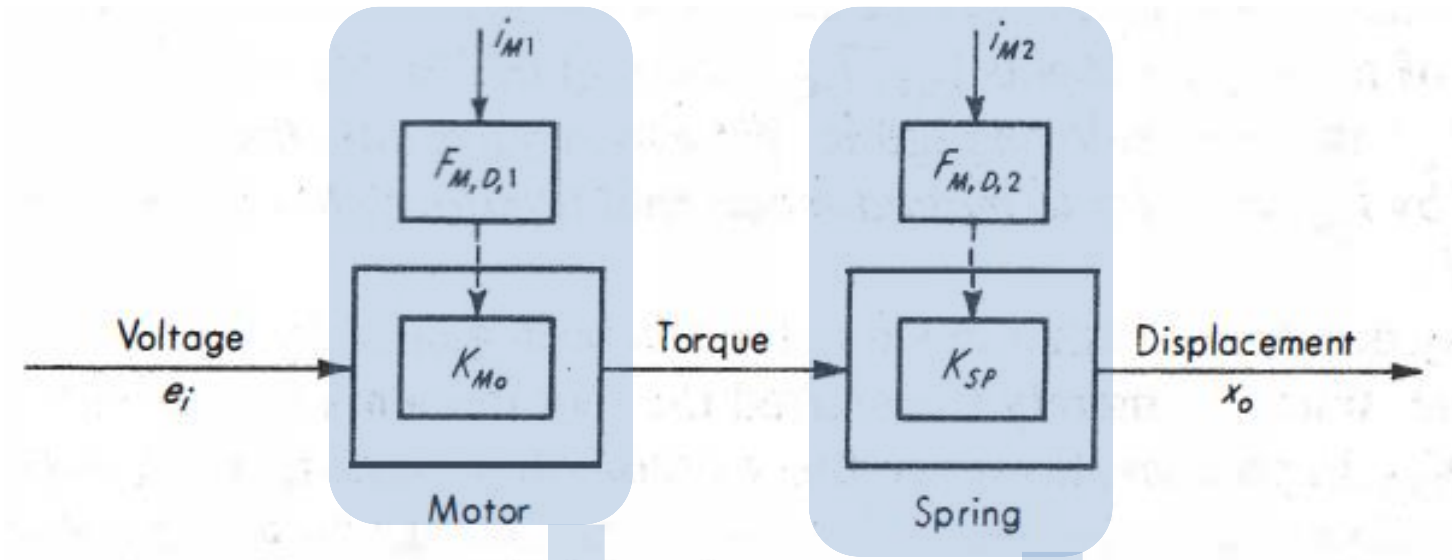
(a) Open-loop system



Wish to measure voltage applied to DC motor by displacement of a spring connected to it. By design, displacement can be made proportional to applied voltage.

$$x_0 = (K_{M0} K_{SP}) e_i$$

Methods of Correction for Interfering and Modifying Inputs



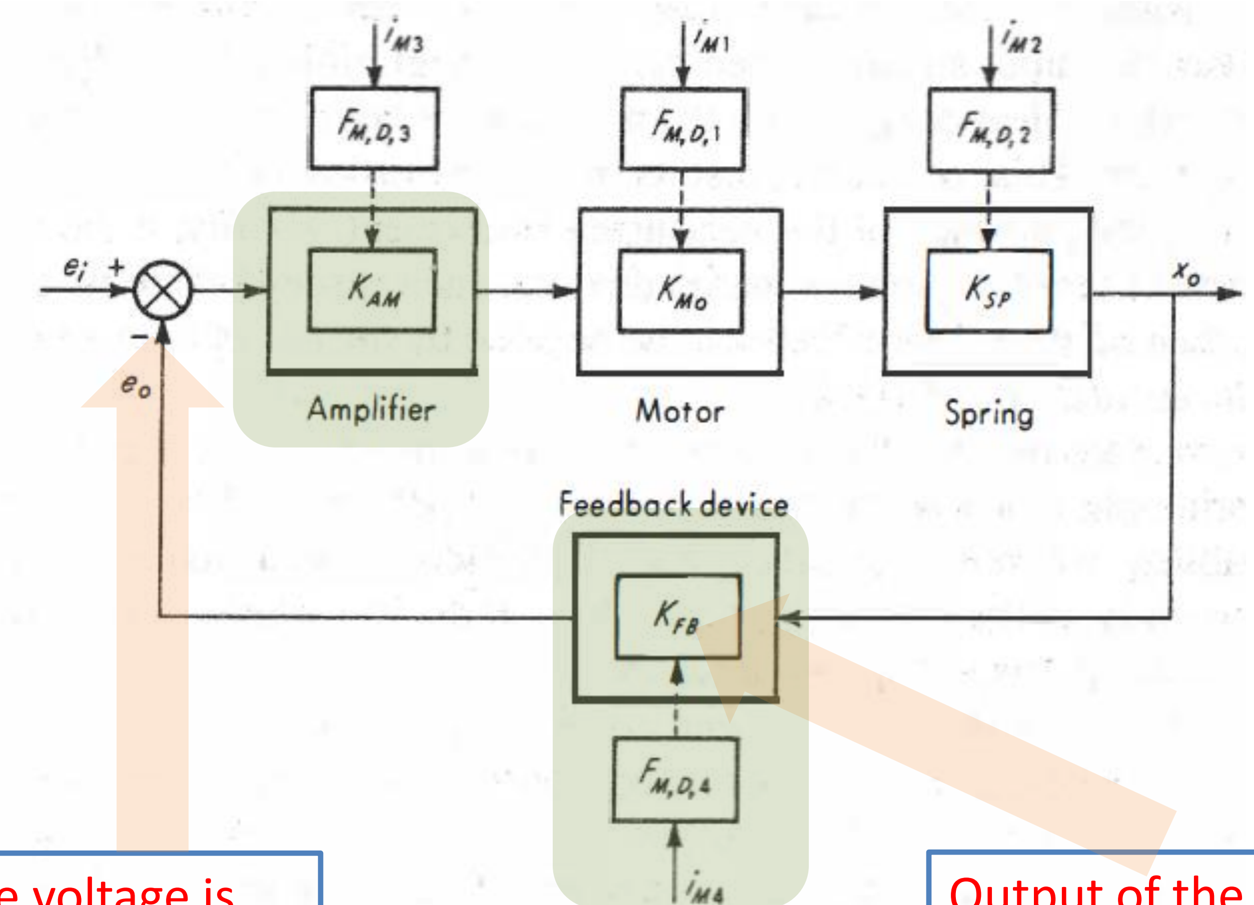
(a) Open-loop system

$$x_0 = (K_{M0} + i_{M1}F_{M,D,1})(K_{SP} + i_{M2}F_{M,D,2})e_1$$

Motor constant and spring constant are vulnerable to interfering input

$$x_0 = K'_{M0}K'_{SP}e_i$$

Methods of Correction for Interfering and Modifying Inputs

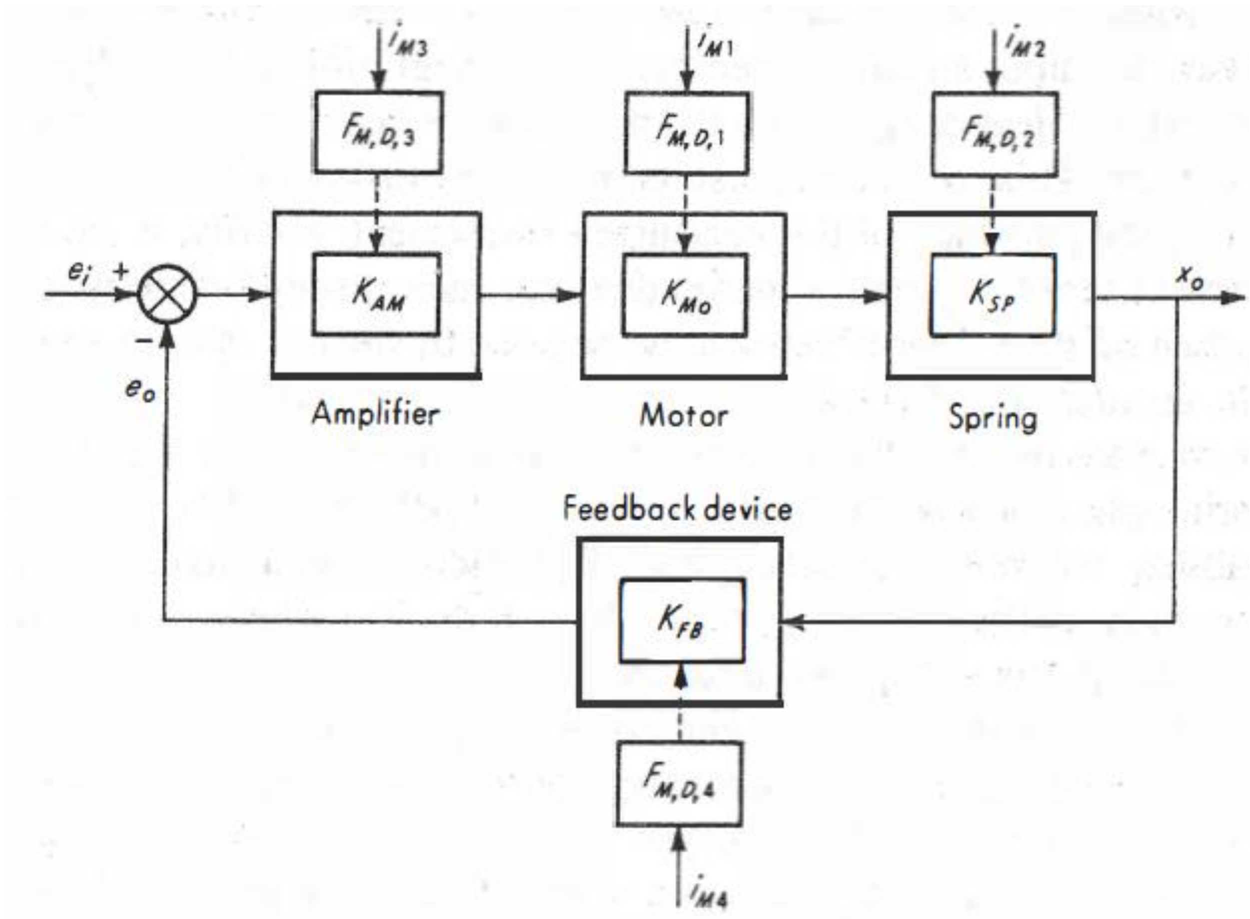


(b) Closed-loop or feedback system

Difference voltage is amplified and it drives the motor

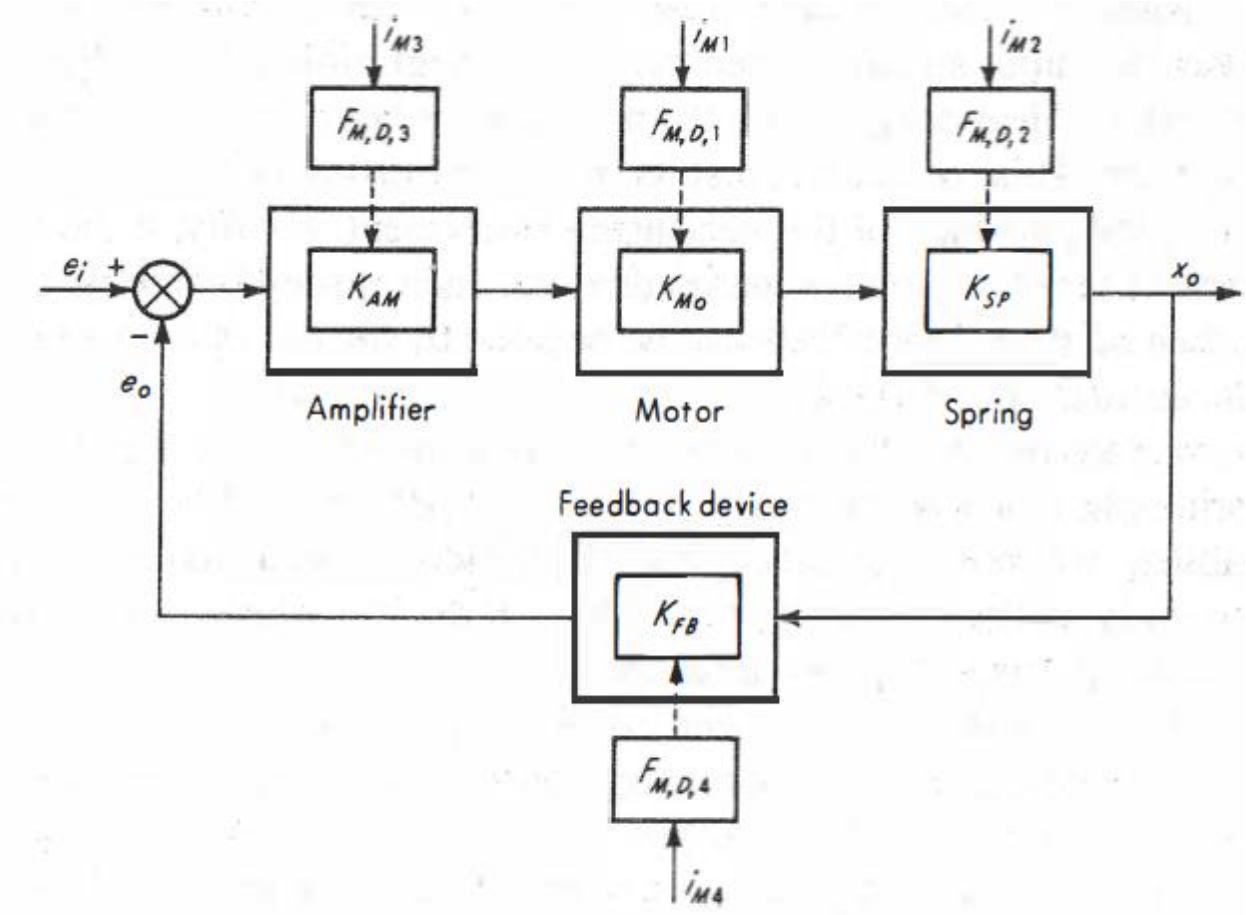
Output of the spring is measured by feedback device which produces voltage proportional to spring displacement.

Methods of Correction for Interfering and Modifying Inputs



$$(e_i - e_0)K_{AM}K_{M0}K_{SP} = x_0$$

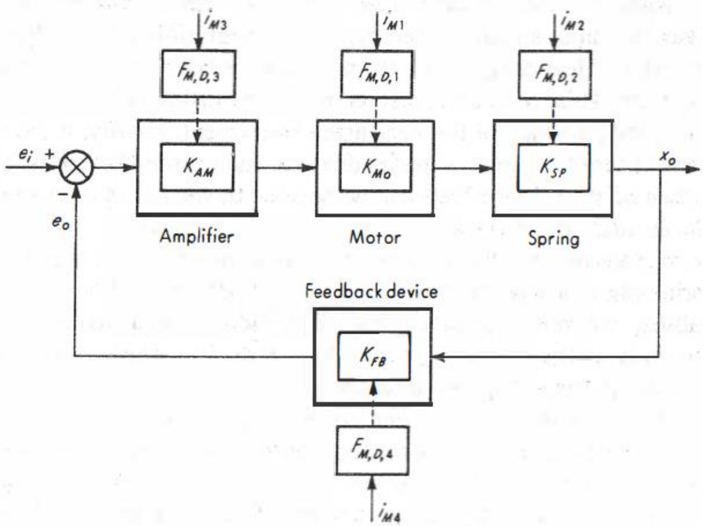
Methods of Correction for Interfering and Modifying Inputs



$$(e_i - e_0)K_{AM}K_{M0}K_{SP} = x_0$$

$$(e_i - K_{FB}x_0)K_{AM}K_{M0}K_{SP} = x_0$$

Methods of Correction for Interfering and Modifying Inputs



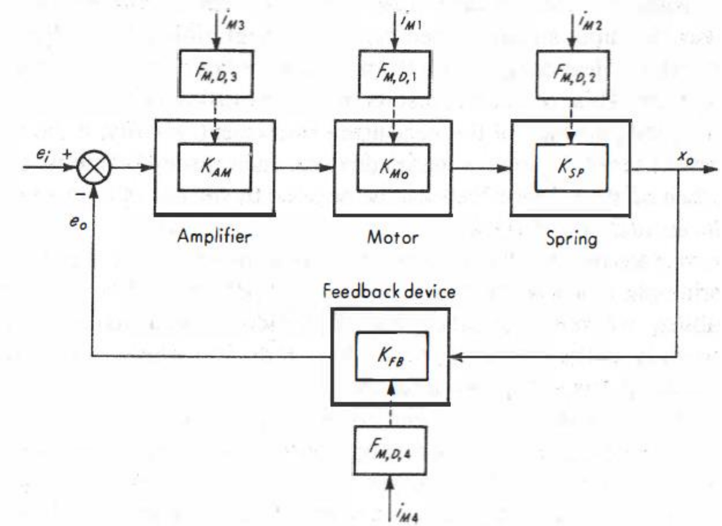
$$(e_i - e_0)K_{AM}K_{M0}K_{SP} = x_0$$

$$(e_i - K_{FB}x_0)K_{AM}K_{M0}K_{SP} = x_0$$

$$\boxed{e_i K_{AM}K_{M0}K_{SP} = (1 + K_{FB}K_{AM}K_{M0}K_{SP})x_0}$$

$$\boxed{x_0 = e_i \frac{K_{AM}K_{M0}K_{SP}}{1 + K_{FB}K_{AM}K_{M0}K_{SP}}}$$

Methods of Correction for Interfering and Modifying Inputs



$$(e_i - e_0)K_{AM}K_{M0}K_{SP} = x_0$$

$$(e_i - K_{FB}x_0)K_{AM}K_{M0}K_{SP} = x_0$$

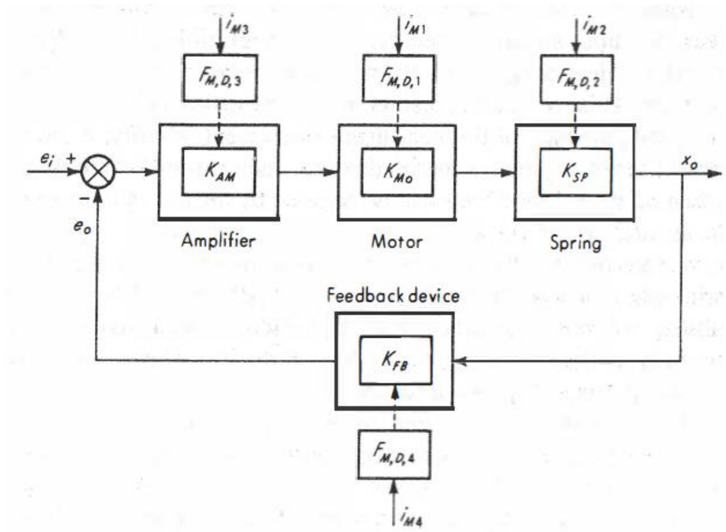
$$\boxed{e_i K_{AM}K_{M0}K_{SP} = (1 + K_{FB}K_{AM}K_{M0}K_{SP})x_0}$$

$$\boxed{x_0 = e_i \frac{K_{AM}K_{M0}K_{SP}}{1 + K_{FB}K_{AM}K_{M0}K_{SP}}}$$

Amplifier Gain is very large

$$\boxed{x_0 \approx e_i \frac{1}{K_{FB}}}$$

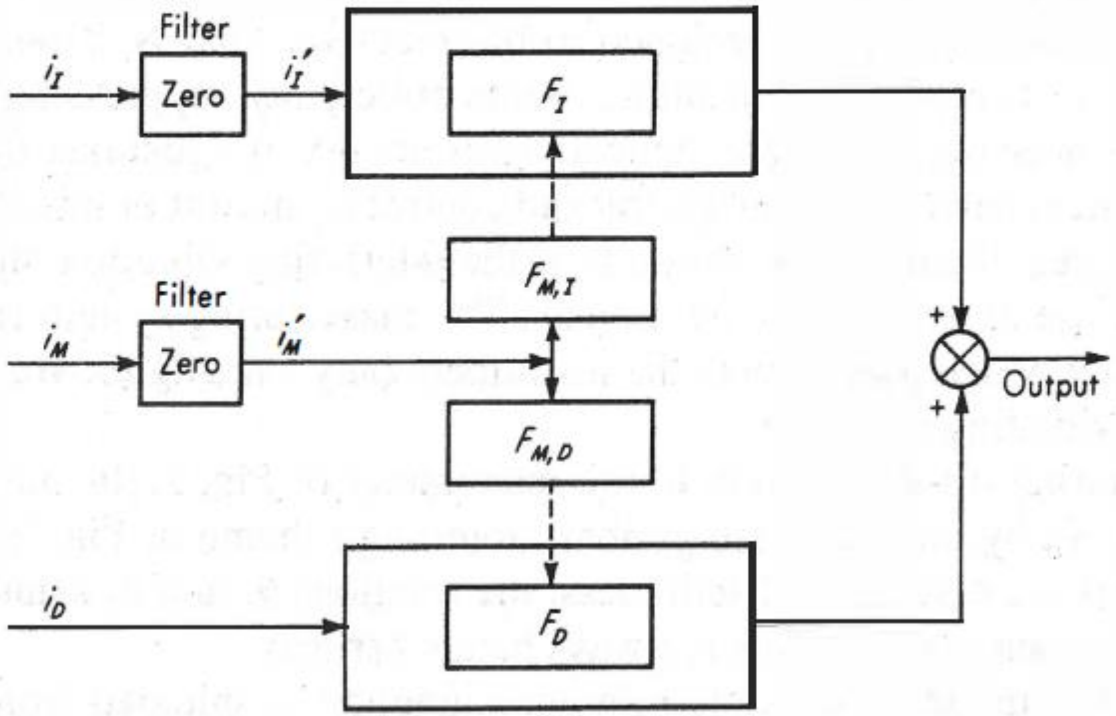
Methods of Correction for Interfering and Modifying Inputs



$$x_0 \approx e_i \frac{1}{K_{FB}}$$

By using a high gain amplifier in series effect of interfering inputs is reduced by factor of amplifier gain. High gain amplification is also susceptible to instability. It also draws less power from the source. Power required to drive motor is supplied by amplifier.

Input and Output Configuration

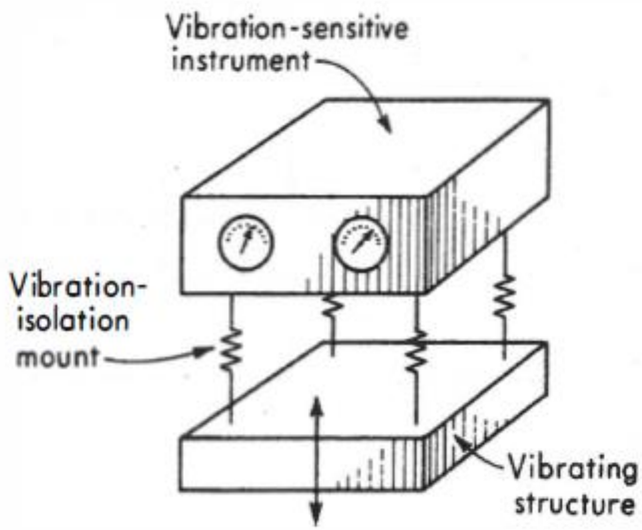


(a) Input filtering

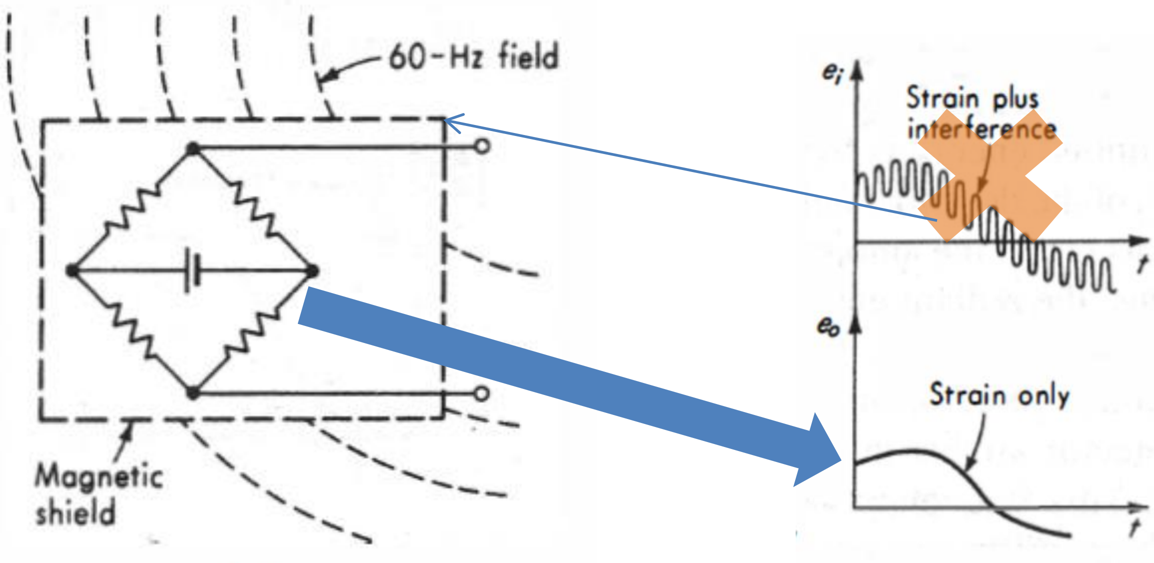
Output will be only due to input. Filters will remove / attenuate the effect of interfering and modifying inputs.

Isolating interfering and modifying input by using filters which will only pass the signal of interest.

Input and Output Configuration

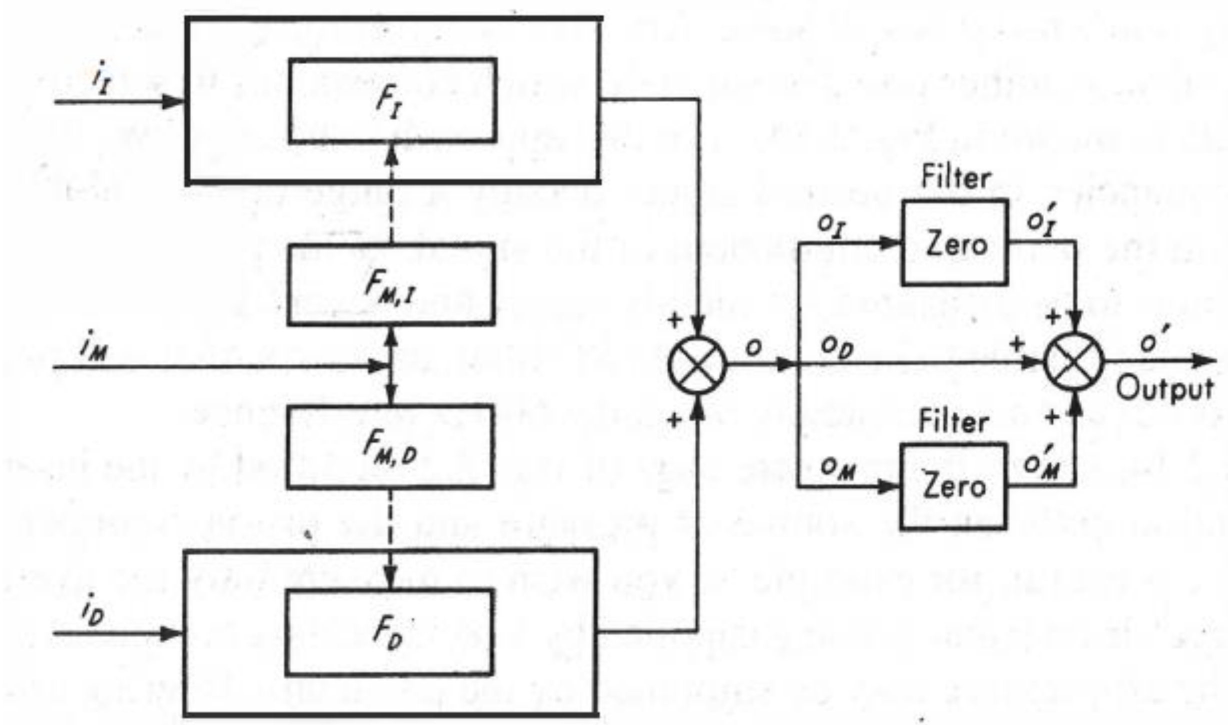


Mechanical damper isolates onboard sensors from platform vibration



Some enclosure can shield the strain gage from external electrical interference

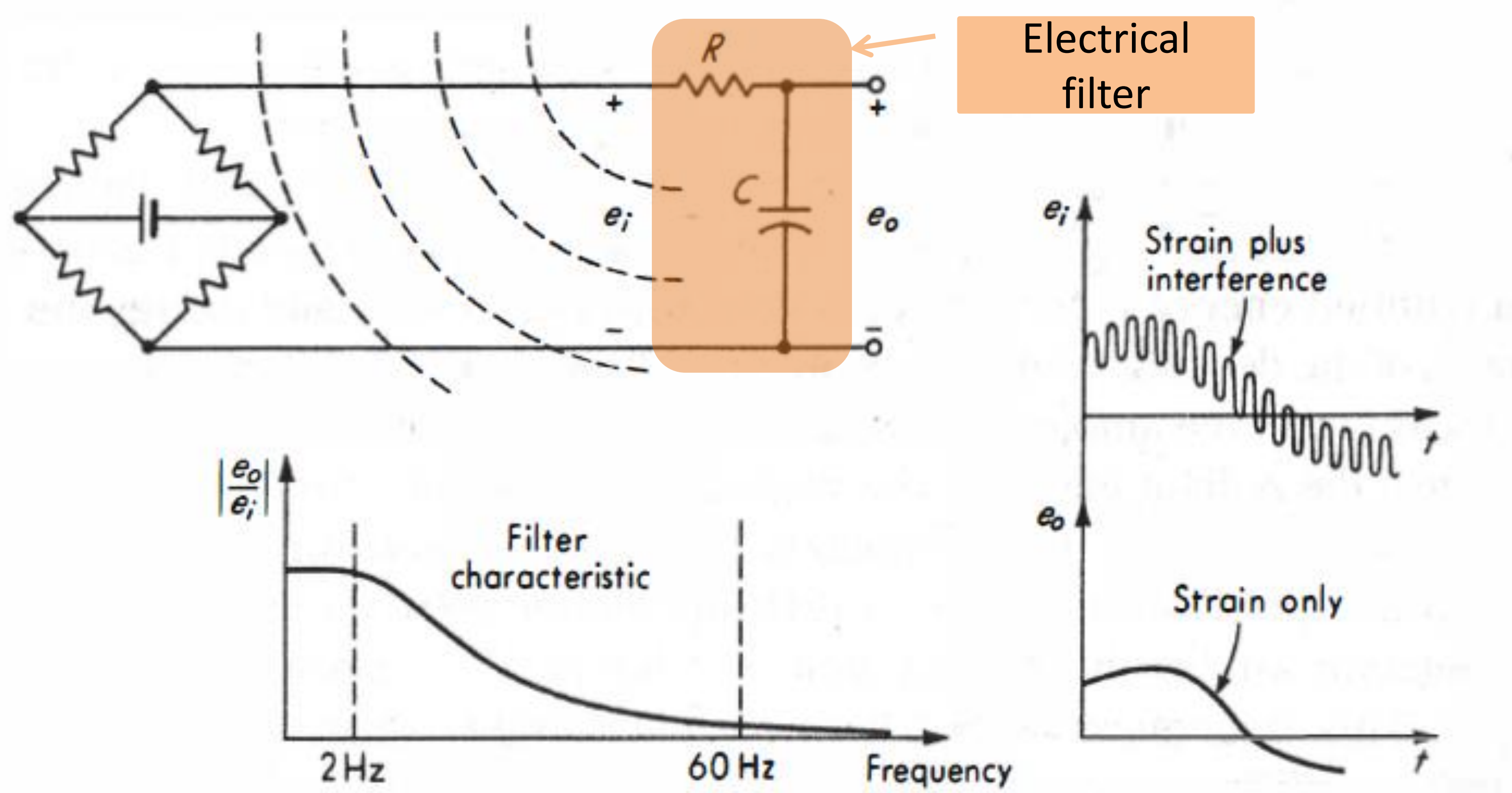
Input and Output Configuration



(b) Output filtering

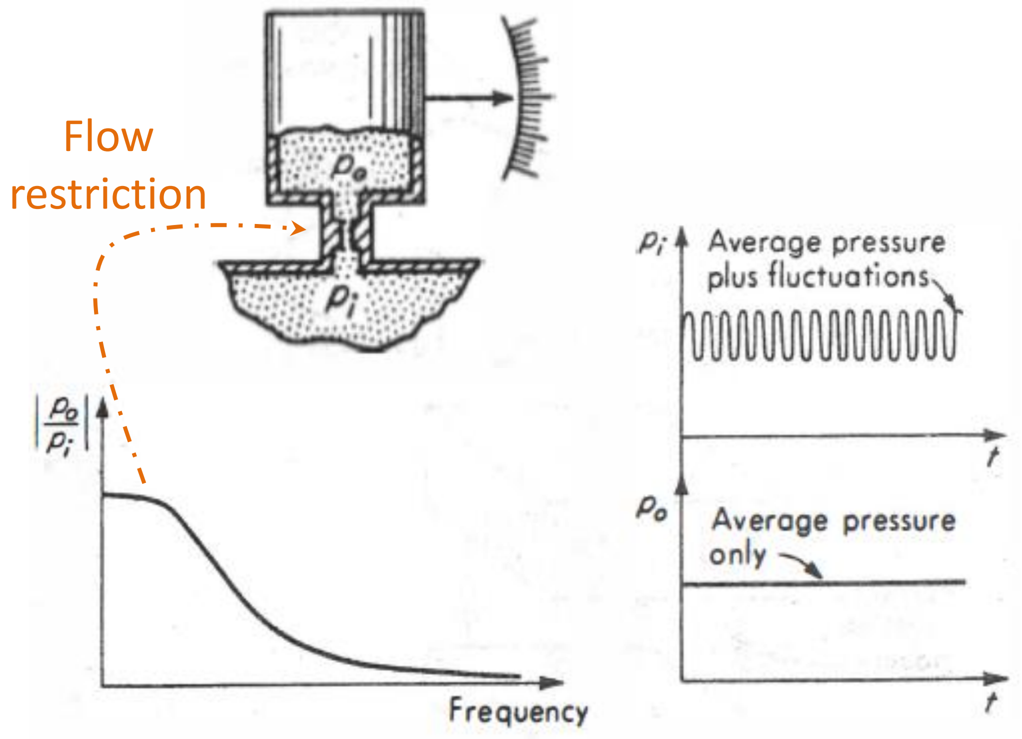
Output signal is passed through filter to remove the undesired signal.

Input and Output Configuration



Using electrical filter at output. Effective when interfering signal frequency and input signal frequency are well separated.

Input and Output Configuration



Pulsating pressure input is there like from a compressor. Interested in steady state value

Electrical filters can be replaced by alternative e.g. flow restriction using valve.

Input and Output Configuration

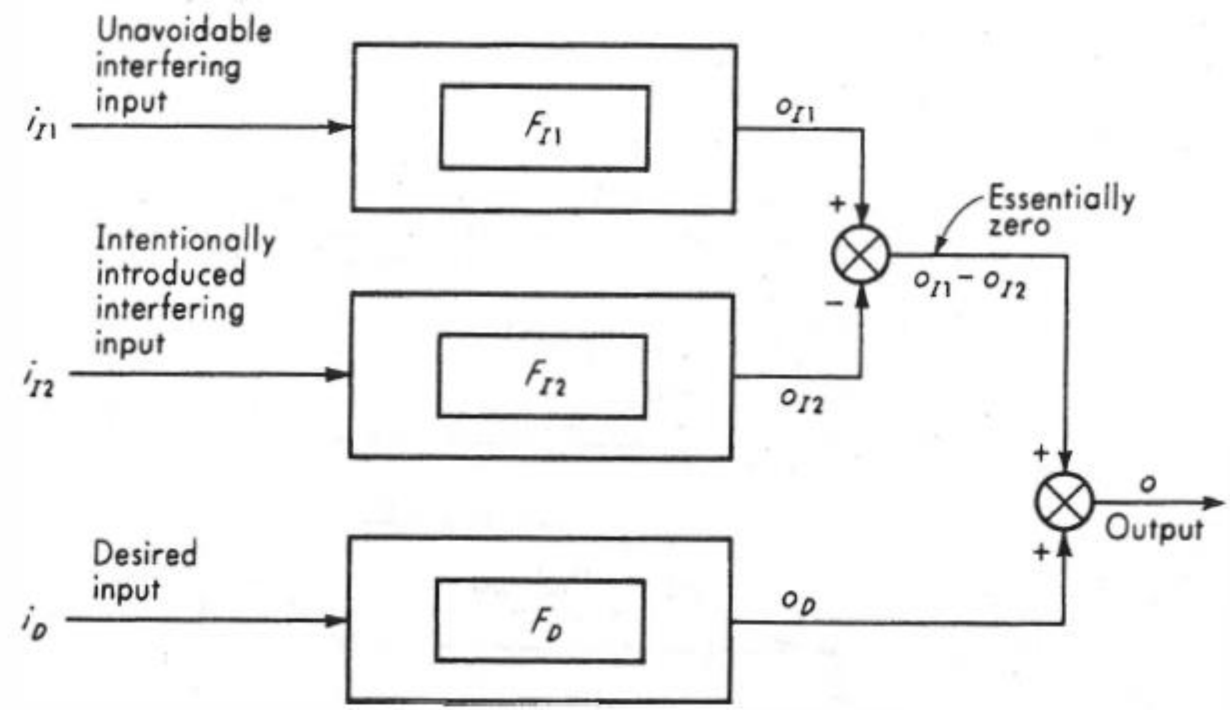
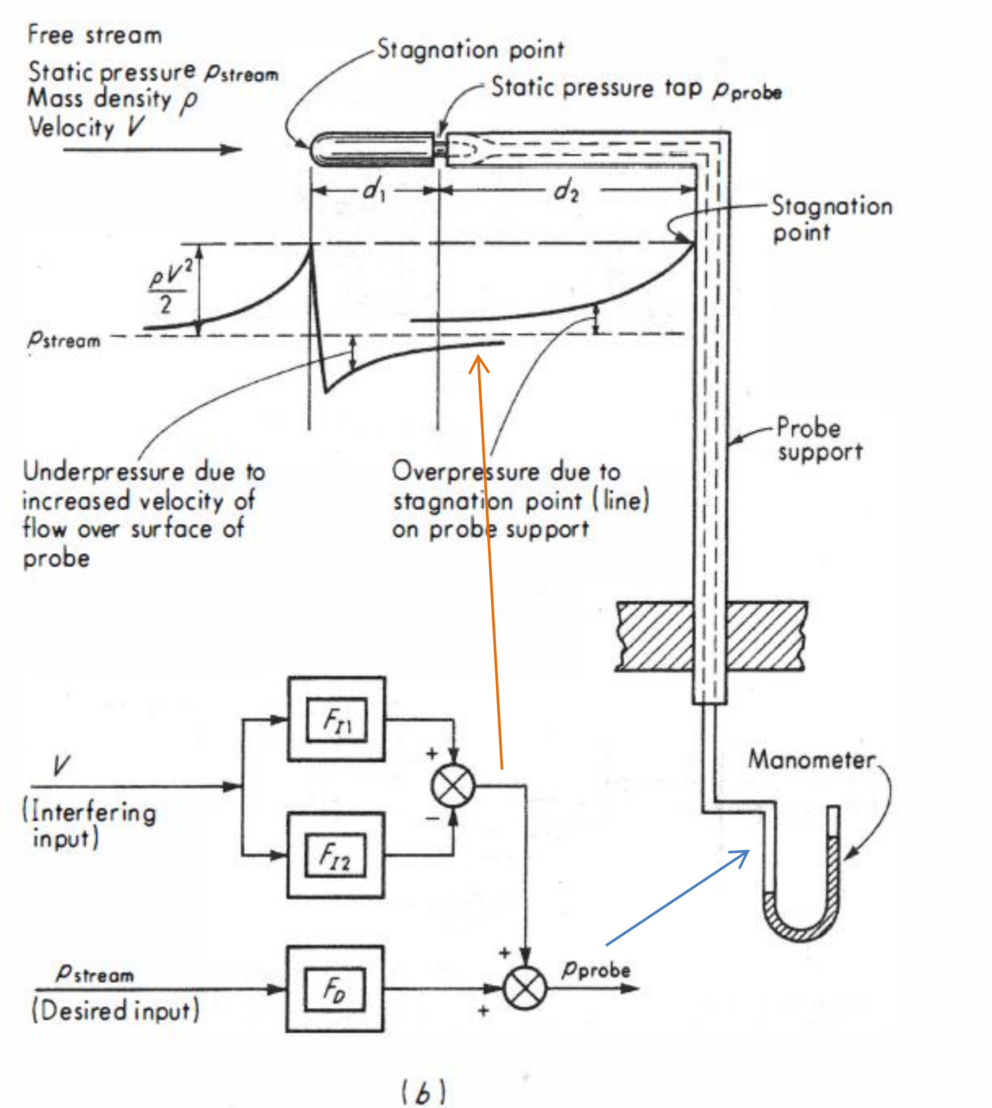


Figure 2.16

Method of opposing inputs.

Devising a method to nullify the modifying and interfering method. Output will be due to input and some part which was not nullified.

Input and Output Configuration



Static pressure is less due to flow over the static port (negative effect). Pressure increases due to stagnation point (positive effect). By adjusting the distance between static port and stagnation point the effect can be nullified.