Calibrations of Measuring Instruments and Test Equipment

Lecture FIVE

Use measurement tools to perform calibrations of measuring instruments and test equipment	a) Determine operation requirements of measuring instruments and test equipment b) Use standard quantity to calibrate measuring and test equipment c) Evaluate calibration results	Adjustments and calibrations of measuring instruments and test equipment are properly performed to reduce errors

GENERIC CALIBRATION

- Tanzania Bureau of Standards (TBS) has been given the statutory responsibility for establishing custody and maintenance of the National Measurement Standards.
- The TBS Metrology laboratories undertake apex (top) level calibration of measurement standards and precision instruments in various fields of measurements such as length, mass, temperature, time and frequency, volume, pressure, electrical measurements in DC/AC voltage, current and resistance.

Calibration

- Calibration consists of comparing the output of the instrument or sensor under test against the output of an instrument of known accuracy when the same input is applied to both instruments.
- **Benefits of Calibration**
  1. It determines whether measurements made before the calibration were valid.
  2. It gives confidence that the measurements are accurate.
  3. It assures consistency and compatibility with those made elsewhere.
  4. It leads to repeatability and reproducibility assessments of the instruments and processes.
  5. It provides confidence that products meet their specifications, thus reducing legal liability, and others as mentioned in your booklet.

What is Calibration?

- Calibration process compares an instrument's output against an accurate standard.
- Once an error is known, any deviations can be corrected.
- For example, a thermometer could be calibrated and adjusted to show the true temperature in degree Celsius, Centigrade, degrees Fahrenheit or Kelvin.
- For medical devices, measurement from the patient (temperature, heart rate, blood pressure, etc.) needs to be calibrated periodically.
- Calibration is important for patient safety and accurate diagnosis and treatment.

Calibrators:

- A device that calibrates other equipment is sometimes referred to as a calibrator.

Example of a Calibrator, The Fluke 5730A Electrical Calibrator

Calibration Software

- Using calibration software with the calibrator allows a user to completely automate the calibration and calculate calibration uncertainty.
- Calibration software increases the efficiency of performing calibrations while reducing procedural errors and reducing sources of uncertainty.

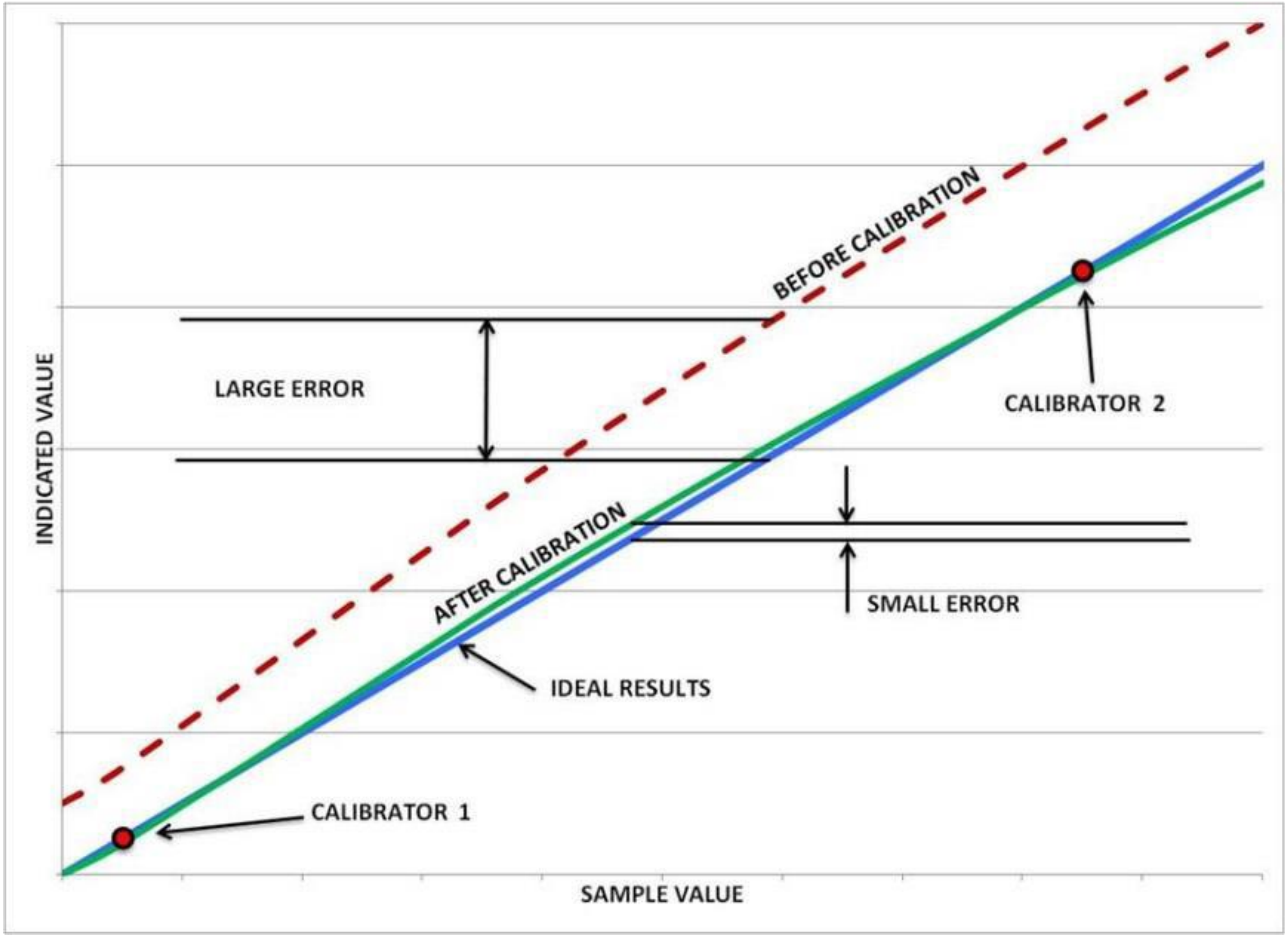
When to perform calibration?

- with a new instrument
- for preventative maintenance
- if an instrument has had a shock or vibration which may have put it out of calibration
- when there is a change in weather
- whenever observations appear questionable, etc

Definitions

- Calibration range – the region between the within which a quantity is measured, received or transmitted which is expressed by stating the lower and upper range values.
- Zero value – the lower end of the calibration range
- Span – the difference between the upper and lower range
- Instrument range – the capability of the instrument; may be different than the calibration range

- For example, an electronic pressure transmitter may have an instrument range of 0–750 psig and output of 4-to-20 milliamps (mA).
  - —However, the engineer has determined the instrument will be calibrated for 0-to-300 psig = 4-to-20 mA.
  - —Therefore, the calibration range would be specified as 0-to-300 psig = 4-to-20 mA.
  - —In this example, the zero input value is 0 psig and zero output value is 4 mA.
  - —The input span is 300 psig and the output span is 16 mA.


BEFORE CALIBRATION
LARGE ERROR
CALIBRATOR 2
INDICATED VALUE
AFTER CALIBRATION
SMALL ERROR
IDEAL RESULTS
CALIBRATOR 1
SAMPLE VALUE

- Every calibration should be performed to a specified tolerance.
- In ISA's (The Automation, Systems, and Instrumentation) dictionary, the definitions for each are as follows:
  - Tolerance - permissible deviation from a specified value; may be expressed in measurement units, percent of span, or percent of reading.
  - Accuracy - the ratio of the error to the full scale output or the ratio of the error to the output, expressed in percent span or percent reading, respectively.

Tolerance

- It is recommended that the tolerance, specified in measurement units, is used for the calibration requirements performed at your facility.
- Calibration tolerances should be determined from a combination of factors. These factors include:
    - Requirements of the process
    - Capability of available test equipment
    - Consistency with similar instruments at your facility
    - Manufacturer's specified tolerance

Example:

- You are assigned to perform the calibration of the previously mentioned 0-to-300 psig pressure transmitter with a specified calibration tolerance of ±2 psig.

  The output tolerance would be:

$$2 \text{ psig}/300 \text{ psig} * 16 \text{ mA} = 0.1067 \text{ mA}$$

- The calculated tolerance is rounded down to 0.10 mA, because rounding to 0.11 mA would exceed the calculated tolerance.

Accuracy

- The term Accuracy Ratio was used in the past to describe the relationship between the accuracy of the test standard and the accuracy of the instrument under test.
- A good rule of thumb is to ensure an accuracy ratio of 4:1 when performing calibrations.
- This means the instrument or standard used should be four times more accurate than the instrument being checked.
- In other words, the test equipment (such as a field standard) used to calibrate the process instrument should be four times more accurate than the process instrument.

Traceability

- Last but not least, all calibrations should be performed traceable to a nationally or internationally recognized standard.

    - Traceability is defined as “the property of a result of a measurement whereby it can be related to appropriate standards, generally national or international standards, through an unbroken chain of comparisons.”

- Traceability is accomplished by ensuring the test standards we use are routinely calibrated by “higher level” reference standards.
- Typically the standards we use from the shop are sent out periodically to a standards lab which has more accurate test equipment.
- The standards from the calibration lab are periodically checked for calibration by “higher level” standards, and so on until eventually the standards are tested against Primary Standards maintained by national or internationally recognized standard.

Calibration Chain and Traceability

- The calibration facilities provided within the instrumentation department of a company provide the first link in the calibration chain.
- Instruments used for calibration at this level are known as working standards.

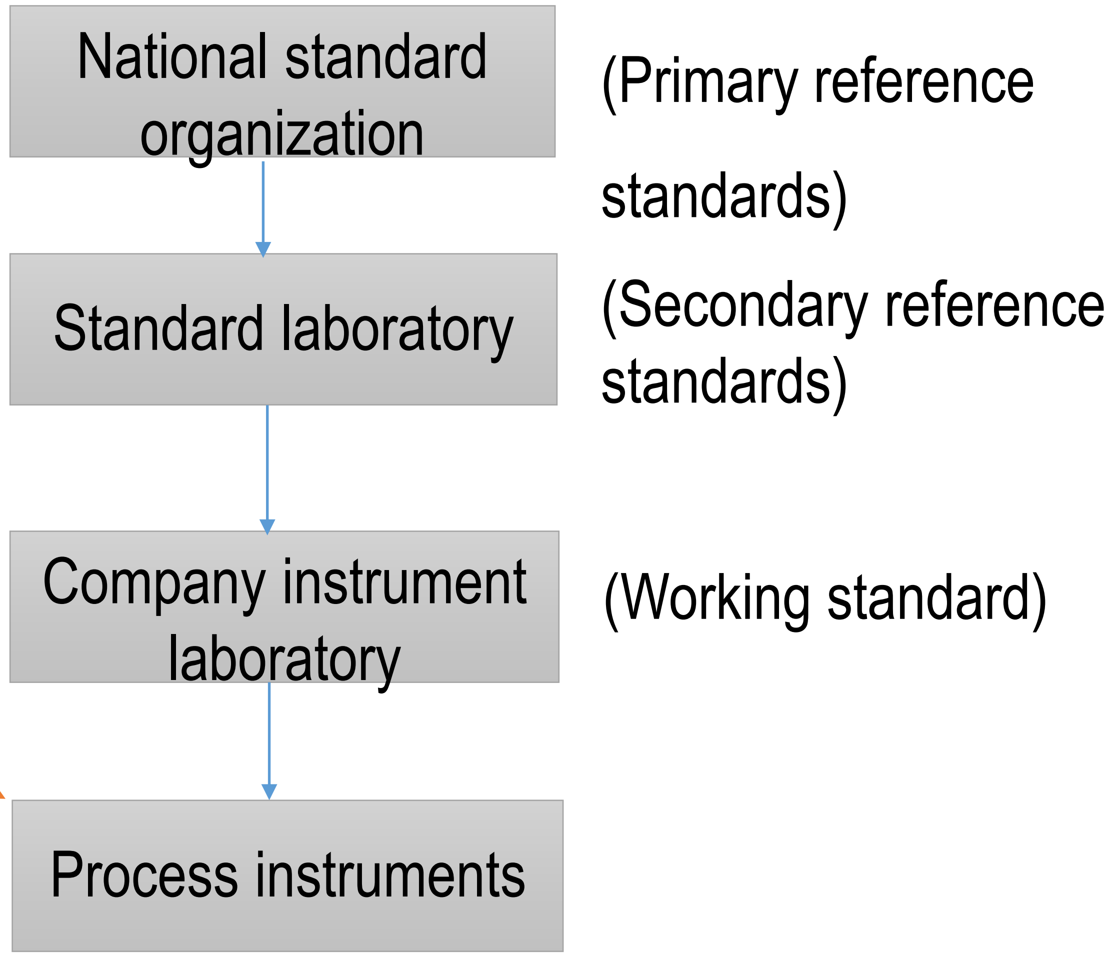
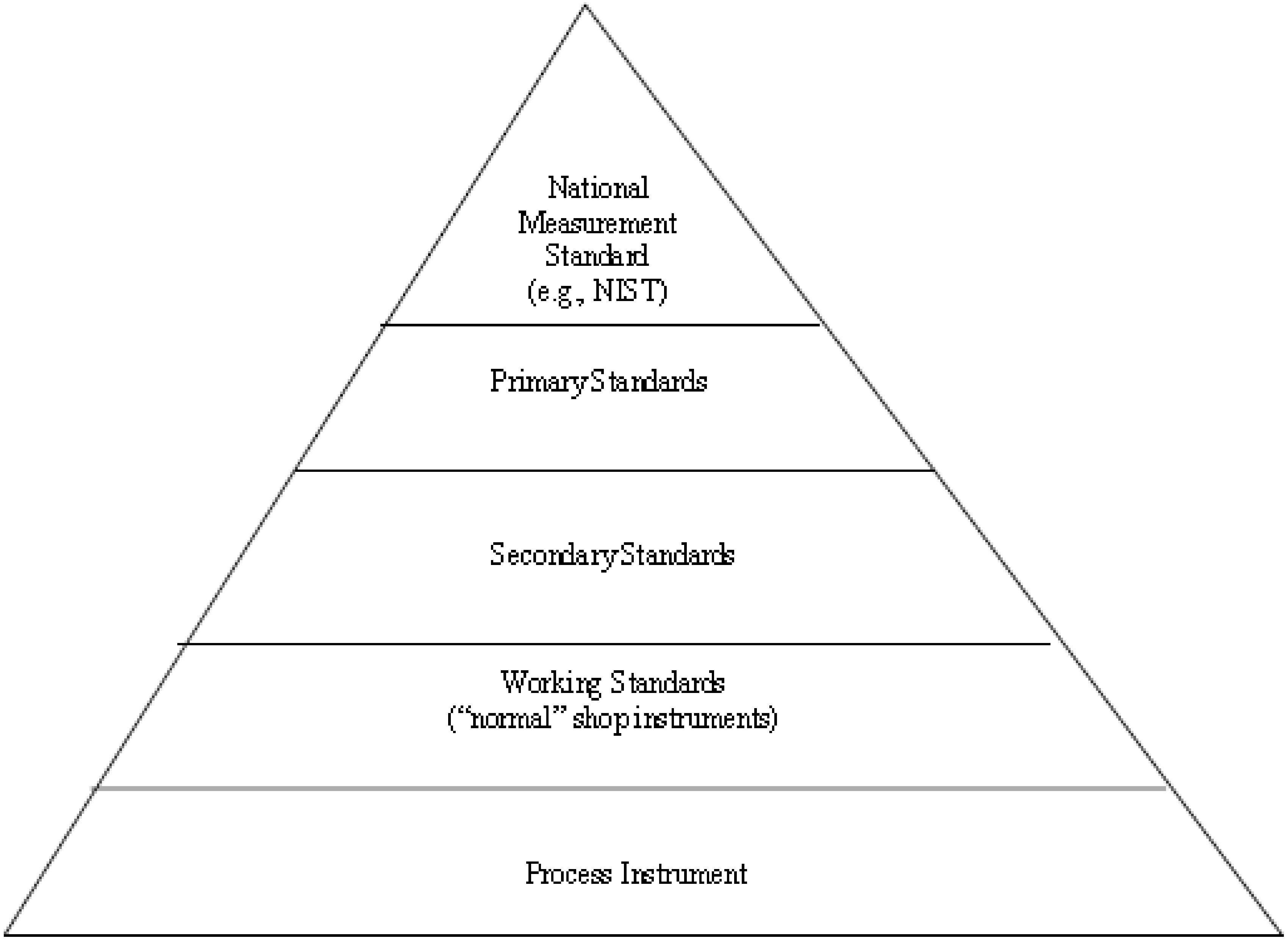


Figure 1.1: *Instrument calibration chain*

Traceability Pyramid



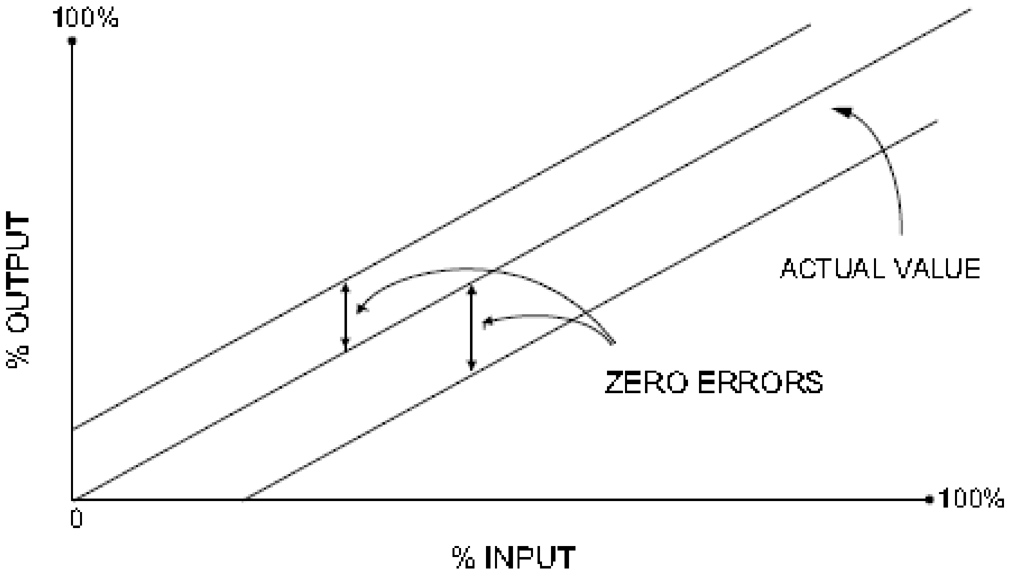
WHY IS CALIBRATION REQUIRED?

- It makes sense that calibration is required for a new instrument.
- We want to make sure the instrument is providing accurate indication or output signal when it is installed.
- Instrument error can occur due to a variety of factors:

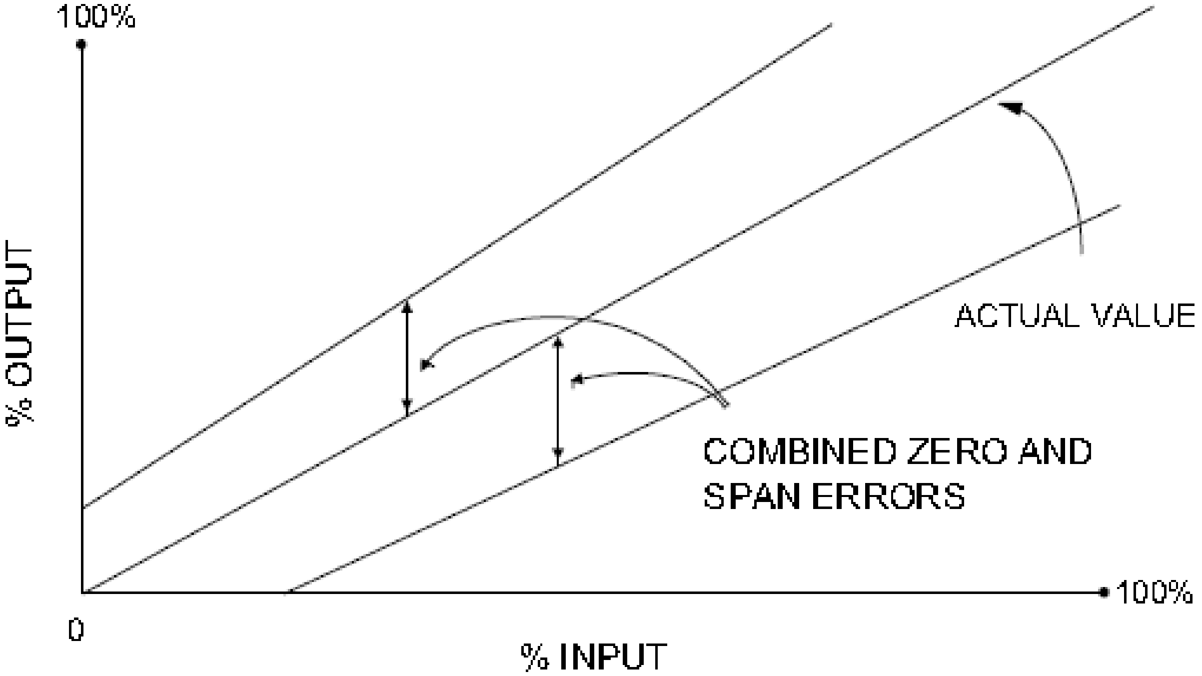
  drift, environment, electrical supply, addition of components to the output loop, process changes, etc.
- Since a calibration is performed by comparing or applying a known signal to the instrument under test, errors are detected by performing a calibration.
- An error is the algebraic difference between the indication and the actual value of the measured variable.

Typical errors that occur include:

1. Zero error,
2. Span error, and
3. Linearization error

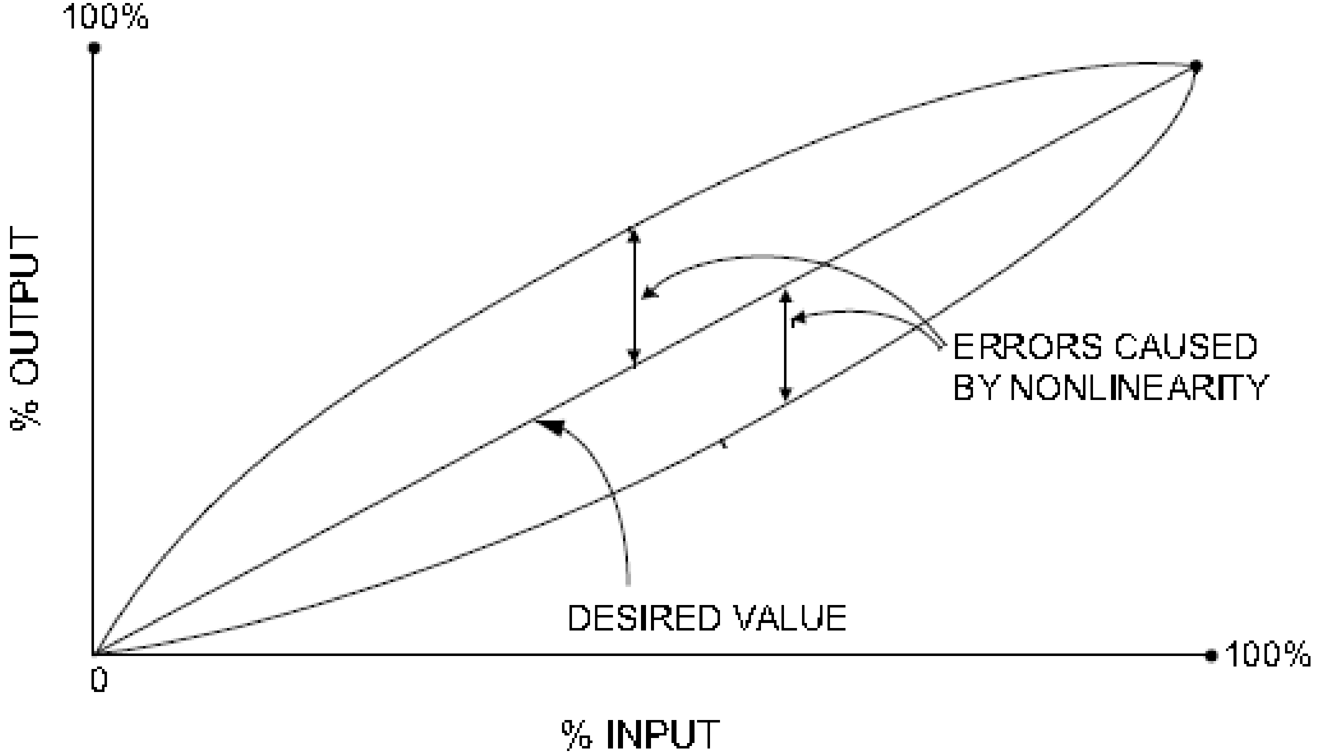


Zero error



Span error

Linearization Error



- Zero and span errors are corrected by performing a calibration.
- Most instruments are provided with a means of adjusting the zero and span of the instrument, along with instructions for performing this adjustment.
- The zero adjustment is used to produce a parallel shift of the input-output curve.
- The span adjustment is used to change the slope of the input-output curve.
- Linearization error may be corrected if the instrument has a linearization adjustment.
- If the magnitude of the nonlinear error is unacceptable and it cannot be adjusted, the instrument must be replaced.

- To detect and correct instrument error, periodic calibrations are performed.
- Even if a periodic calibration reveals the instrument is perfect and no adjustment is required, we would not have known that unless we performed the calibration.
- And even if adjustments are not required for several consecutive calibrations, we will still perform the calibration check at the next scheduled due date.
- Periodic calibrations to specified tolerances using approved procedures are an important element of any quality system.

- A Control System Technician (CST) is a skilled craftsperson who knows pneumatic, mechanical, and electrical instrumentation.
- He or she understands process control loops and process control systems, including those that are computer-based.
- Typically, he or she has received training in such specialized subjects as theory of control, analog and/or digital electronics, microprocessors and/or computers, and the operation and maintenance of particular lines of field instrumentation.
- A CST performs calibration, documentation, loop checks, troubleshooting, and repair or replacement of instrumentation.
- These tasks relate to systems that measure and control level, temperature, pressure, flow, force, power, position, motion, physical properties, chemical composition and other process variables.

CHARACTERISTICS OF A CONTROL SYSTEM TECHNICIAN

1. **Honesty and Integrity:**

- A Control System Technician (CST) must possess honesty and integrity above all else.
- Most technicians work independently much of the time.
- Calibrations must be performed in accordance with procedures and must be properly documented.
- Additionally, the calibration department may be understaffed and production schedules may demand unrealistic completion requirements.
- These factors can have a real impact on proper performance and documentation of calibrations.
- Remember: Nobody can take away your integrity; only you can give it away.

2. Attention to Detail:

- Calibrations should be performed in accordance with detailed instructions.
- Each different make/model instrument is adjusted differently.
- Each instrument is installed in a different physical and loop configuration.
- Because of these and many other differences, attention to detail is very important.
- The minute a technician is not paying attention to detail, safety and proper performance are jeopardized.

3. Excellent Documentation Practices:

- In many facilities, the impression of quality is determined by the content and appearance of documentation.
- Many technicians complain the paperwork is 90% of the work.
- In today's world quality standards, documentation is essential.
- If it isn't documented, it wasn't done.
- Calibration Data Sheets must be neat, complete, signed and, if required, reviewed in a timely manner.
- When changes occur, all related documentation, such as drawings, manuals, specifications and databases must also be updated.

4. Understanding of Processes:

- One thing that sets technicians apart is an understanding of the process, particularly how the instruments monitor and control the process.
- There is a difference between calibrating an individual component and calibrating an instrument as part of the bigger process control loop.
- For example, knowing when a controller can be placed in manual without affecting the process and what to do while that controller is in manual, requires an understanding of the process.
- Additionally, when an operator says there is a problem with his indication, a technician who knows the instrument loop and process will be more capable of identifying the cause of the problem.

- Some basic concepts on how calibrations should be performed need to be discussed before we go on.
- Some of these practices are industry dependent.
- Although calibrations are generally performed the same, some different practices have developed.
- These practices are:
    1. Loop Calibration vs. Individual Instrument Calibration
    2. Bench Calibration vs. Field Calibration
    3. Classification of Instruments as Critical, Non-Critical, For Reference Only, etc.

LOOP CALIBRATION VS. INDIVIDUAL INSTRUMENT CALIBRATION

- An individual instrument calibration is a calibration performed only on one instrument.
- The input and output are disconnected.
- A known source is applied to the input, and the output is measured at various data points throughout the calibration range.
- The instrument is adjusted, if necessary, and calibration is checked.

Loop Calibration vs. Individual Instrument Calibration …

- In some cases, it is best practice to perform individual instrument calibration to achieve maximum accuracy.
- However, there are viable methods where a loop can be tested end-to-end and if readings are within acceptable tolerances, there is no need to break into the loop for individual instrument testing.
- To be effective, a common sense approach is required with the goal to minimize downtime, maximize technician efficiency while ensuring reliable control and maintaining a safe work environment.
- In practice, a loop is simply a group of instruments that in combination make a single measurement or effect a control action in a process plant.

BENCH CALIBRATION VS. FIELD CALIBRATION

- A bench calibration or in-shop is a procedure where the instrument is calibrated at a calibration bench using calibration devices to simulate the process, rather than calibrating the device in the field using the actual process itself as the input means.
- The instrument is disconnected from the process, cleaned, and taken to the shop where it is mounted on a test stand at the calibration bench.

Bench Calibration Vs. Field Calibration …

- Field calibration refers to a company sending trained staff to a client's facility and performing calibration on-site rather than the client sending their equipment to a lab.
- These mobile technicians will bring the right equipment to help them perform their on-site duties appropriately.
- Calibrating in the field assures that the instrument is calibrated in the same actual field conditions where it is also used.
- Sometimes the actual field conditions can be very challenging/harsh to perform calibration in, and in that case it is better to make it in workshop.

Classification of Instruments as Critical, Non-Critical

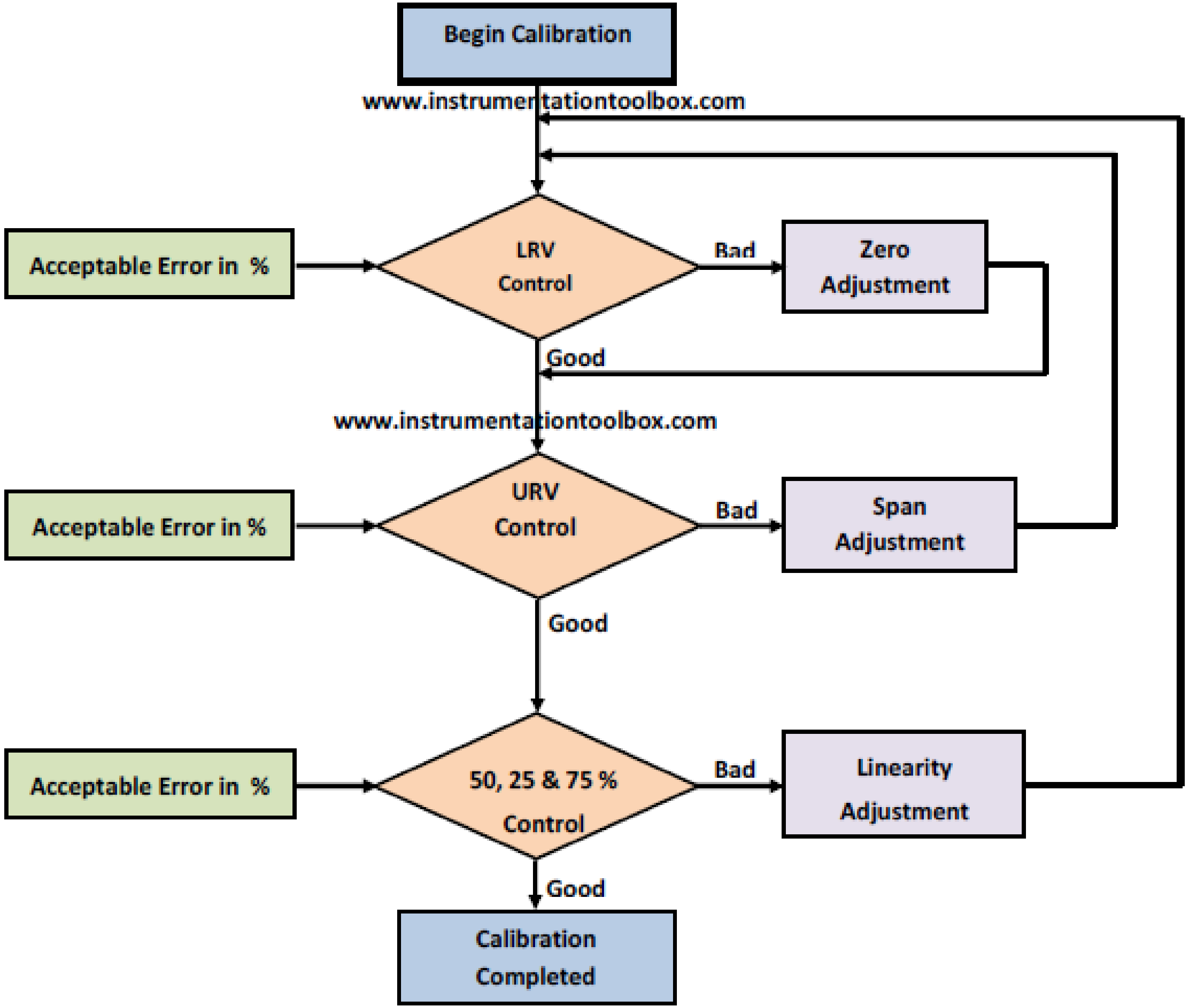
- List all instruments and indicate whether or not they are critical equipment.
- An instrument is critical if the measurements of that instrument significantly affect the safety, quality or proper operation of an installation.
- Critical instruments must be calibrated.
- Non-critical instruments can also be calibrated, but calibration is not always necessary as critical instruments.

Calibration procedures

Linear Instruments

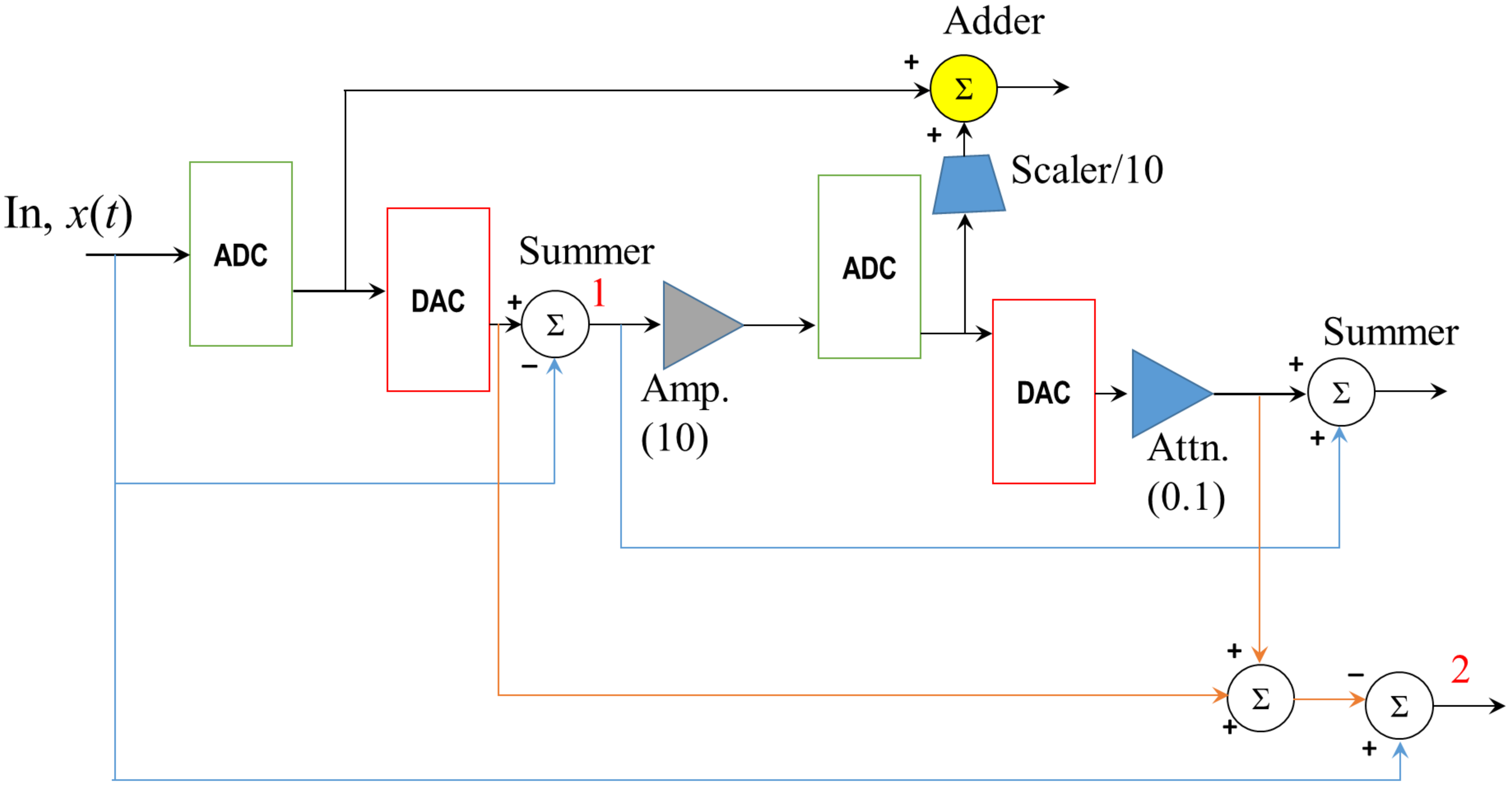
1. Apply the lower-range value stimulus to the instrument, wait for it to stabilize
2. Move the “zero” adjustment until the instrument registers accurately at this point
3. Apply the upper-range value stimulus to the instrument, wait for it to stabilize
4. Move the “span” adjustment until the instrument registers accurately at this point
5. Repeat steps 1 through 4 as necessary to achieve good accuracy at both ends of the range

- An improvement over the procedure is to check the instrument's response at several points between the lower- and upper-range values.
- A common example of this is the so-called five-point calibration where the instrument is checked at:
    a) 0% (LRV),
    b) 25%,
    c) 50%,
    d) 75%, and
    e) 100% (URV) of range.
- A variation on this theme is to check at the five points of 10%, 25%, 50%, 75%, and 90%, while still making zero and span adjustments at 0% and 100%.


Begin Calibration
www.instrumentationtoolbox.com
Acceptable Error in %
LRV
Control
Bad
Zero
Adjustment
Good
www.instrumentationtoolbox.com
Acceptable Error in %
URV
Control
Bad
Span
Adjustment
Good
Acceptable Error in %
50, 25 & 75 %
Control
Bad
Linearity
Adjustment
Good
Calibration
Completed

Assignment-1:
Using SIMULINK, analyze the point-performance (accuracy) of the following system at point-1 and point-2.
Submission date: 04th December 2023 before Noon.

- Maximum input signal = 12 V
- ADC = 8-bits output
- Voltage amplifier gain = 10
- Attenuator = 0.1

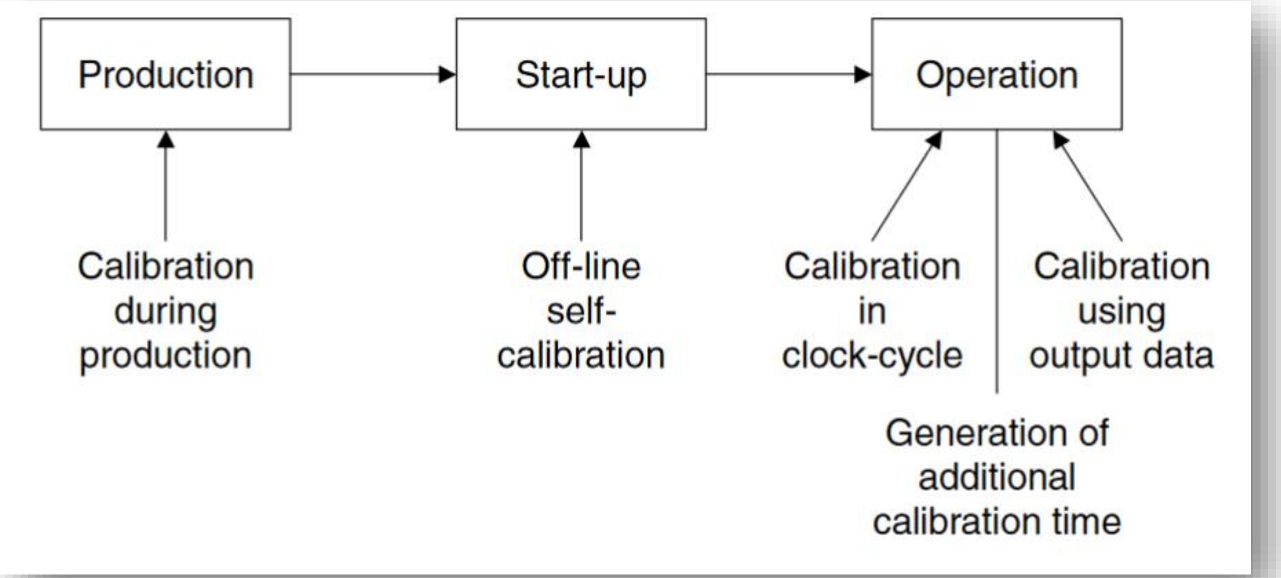


Adder
Scaler/10
In, $x(t)$
ADC
DAC
Summer
1
Amp.
(10)
ADC
DAC
Summer
Attn.
(0.1)
2

Medical Instruments Calibration

- In most medical instrumentation systems, some form of calibration is necessary at regular intervals during operation.
- The calibration signal is usually applied to the sensor input or as early in the signal conditioning chain.

- The calibration can be performed at several ‘moments’ during the lifetime of an A/D converter, as shown in figure below.



Calibration during production

- The most straightforward method of calibration is carried out off-line during fabrication.
- When this method of calibration is used the process needs a type of programming facility on-chip, like read-only memory (ROM) programming.
- These values are used for compensating the errors in the analog or in the digital domain.

Off-line self-calibration

- The analog error correction can be stored in a (P)ROM at fabrication, but when random-access memory (RAM) is used an additional IC-processing step is not required.
- The RAM is programmed during a calibration cycle at start-up, but this can also be done during operation in a time interval when the instrument is idle or not in use.
- This type of calibration is generally known as self-calibration (or calibration at start-up).
- During self-calibration, a known input signal is applied or the A/D converter is put in a known state, such that the output of the A/D converter is a known digital signal.

- Due to mismatches in the used components, e.g. capacitors, the resulting digital signal deviates from the wanted signal.
- The difference in the wanted and the resulting digital signal is used to calibrate the errors.
- The calibration can be performed by shifting the references applied during conversion, which depends on the raw data generated by the A/D converter.
- The code-dependent correction terms, which are also derived by applying known signals to the A/D converter, are stored in a digital register or a ROM.
- During normal operation these correction terms are added to the conversion results to calibrate the errors.

- A more flash-type converter-specific calibration method involves assigning more than one comparator to each level.
- The trip points of the comparators are distributed because of transistor mismatch.
- By selecting the comparators closest to each trip point, powering down, and ignoring the others.
- This can only be satisfied when sufficient comparators are available for each decision point, which requires an overhead in the silicon area.

- Calibration at start-up offers the advantage over calibration during fabrication because each time the instrument is powered up, or even during a non-operation time period, the A/D converter is calibrated.
- This means that mismatch effects due to aging are compensated.
- However, the calibration has to be performed repetitively upon request to ensure that mismatch effects like temperature drift or supply variations are compensated for.
- Calibration in the analog domain results in an A/D converter with nearly perfect analog circuitry.
- However, calibration in the digital domain requires sufficient resolution.
- This is necessary because due to digital adding and subtraction, quantization errors are generated.

- Using more bits (typically one or two) in the calibration process and truncating the raw data to N bit reduces this effect sufficiently.
- This does, however, mean that for an N-bit A/D converter, N+1 or N+2 -bit raw data has to be generated by the A/D converter, which involves additional power and area.

Calibration in clock cycle

- Instead of calibrating the A/D converter only during fabrication, at start-up, or at a calibration request, the calibration can take place every clock cycle.
- The main advantage of these techniques is that the offset is calibrated every clock cycle and changes over time are therefore calibrated as well.
- However, the major disadvantage is that the available settle time for the signal processing phase is halved since the other half is used for the offset canceling phase.
- In general, this means that the power is increased by the same factor.

Examples of production calibration process

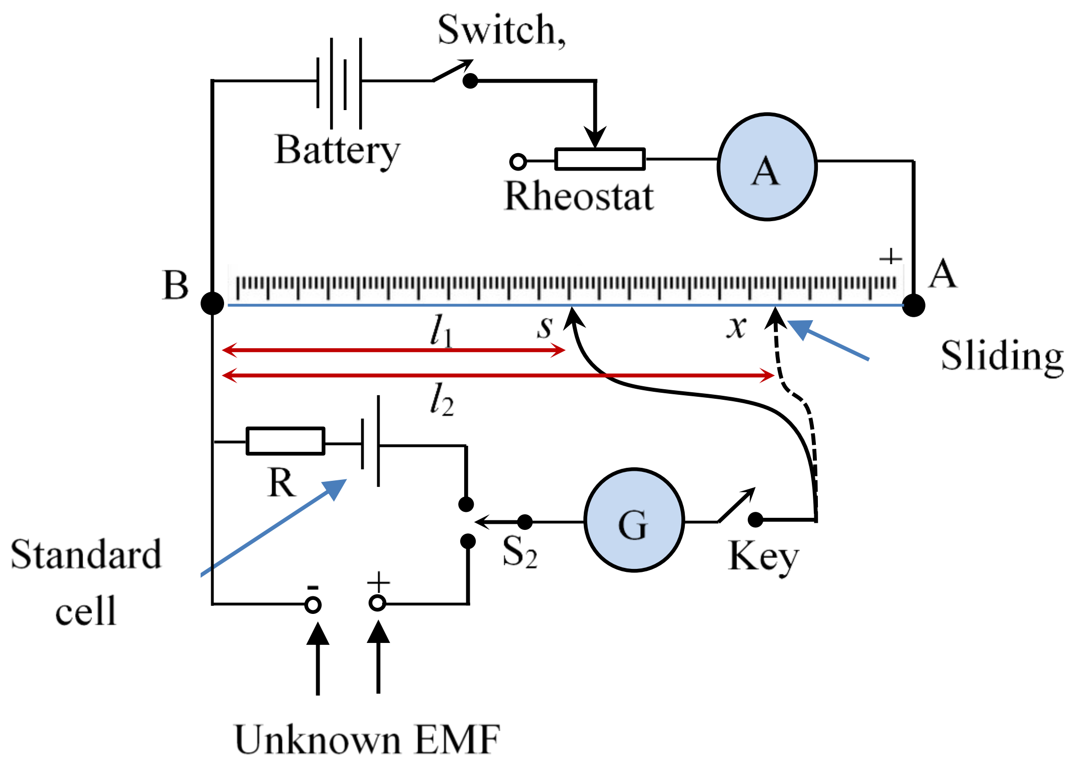
- Fuel level measurement
- Define the set of readings such as volume versus voltage:
- Express the equation related to the data observed
- Calibrate the scale.
- Note that other parameters such as power supply, environmental conditions, and others may affect the scale reading.
- Averaging and other algorithms may be utilized during the improvement of the accuracy of measuring instruments.

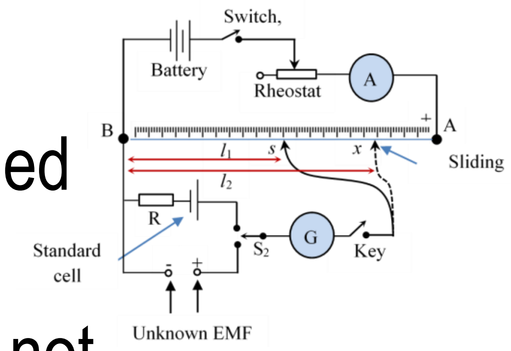
Potentiometers

- A potentiometer (POT) is an instrument used for measuring potential difference or electromotive force (e.m.f.) by performing a comparison with a known voltage.
- It works by varying the position of a sliding contact across a uniform resistance.
- The standard cell or any other known voltage reference source can be used for comparison.
- The accuracy of measurements does not depend upon the actual deflection of a pointer, but upon the accuracy of the known voltage of the reference source.

Construction of Basic Potentiometer

- The construction of a simple slide-wire potentiometer is shown in Figure below.



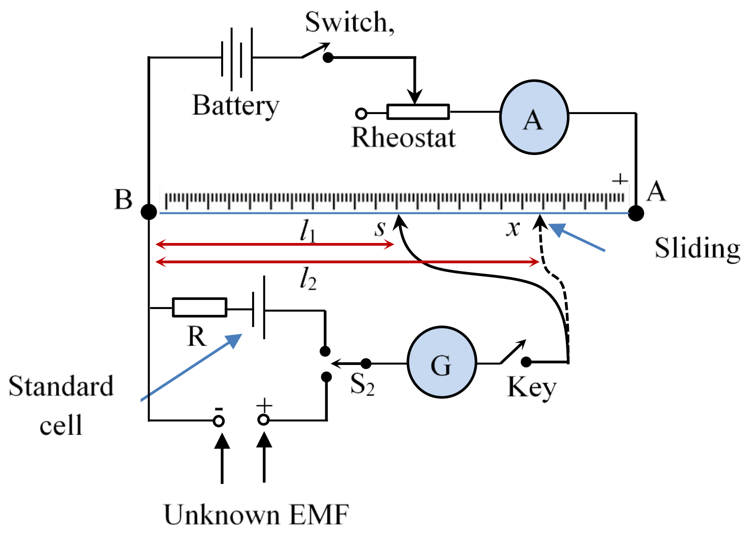


- It consists of manganin wire or German silver, or other materials like constantan with uniform cross-sectional area (A) and length (l) stretched between terminal A and B.
- These materials hold a special property by which the resistance does not show much variation with the temperature change.
- A meter scale is fixed on the wooden board parallel to the length of the wire.
- The terminal A and B is also connected to the external power supply having known voltage through rheostat (Rh), switch (S1) and ammeter to form an auxiliary circuit.
- The rheostat is used to control the level of current through the auxiliary circuit.
- The positive terminals of the standard cell and unknown source, V_x are connected to point A of the potentiometer wire through a two-way switch (S2), key (K), resistor (R) and galvanometer (G) to form a secondary circuit.

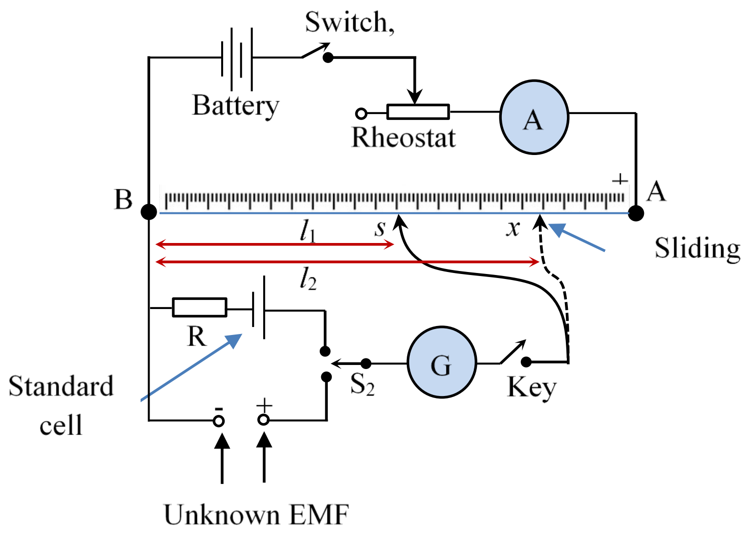
- A galvanometer is used to detect a null point.
- The resistor R is used to protect the standard cell against excessive current flow.

Working Principles

- Initially, the sliding contact is set in the mid of the slide wire.
- Then press the switch, S1 to complete the auxiliary circuit.
- Adjust the rheostat to obtain the constant current through the potentiometer wire.
- The potentiometer is calibrated by connecting the standard cell to the galvanometer through switch, S.



- Now, move the sliding contact on the slide wire, until a position s is reached when the galvanometer shows zero deflection.
- The zero or null deflection of the galvanometer shows that the potential of the standard cell and the voltage drops across the sliding wires l_1 (Bs) are equal.
- The EMF of a Weston standard cell is in absolute volts of 1.01864 at 20 °C.
- Suppose that the resistance wire is exactly 1 m (100 cm) in length, and the position s from point B (the null position of the cell standard) is 40 cm, then the constant of proportionality of the resistance is expressed as

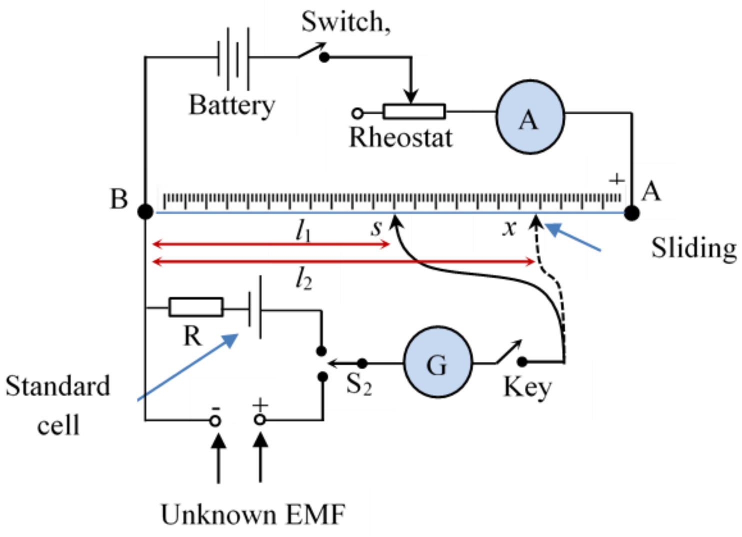


$$k(\text{volt/unit-length}) = \frac{\text{Standard cell voltage}}{l_1} = \frac{1.01864\ \text{V}}{40\ \text{cm}} = 25.47\ \text{mV/cm}$$

V_x

$$\text{Standard cell voltage} = k \times l_1$$

- Since the sliding contact is set to an accuracy of 1 mm, the resolution of this potentiometer per mm is 2.547 mV.
- If there are no other sources of errors, the instrument is said to have a precision of ±2.547 mV.
- Now, connect the unknown EMF to the galvanometer through the switch, and move the sliding contact on the slide wire, until the galvanometer shows zero deflection.
- Note the length l_2 (Bx) at position x is reached.
- Then unknown EMF is proportional to l_2.

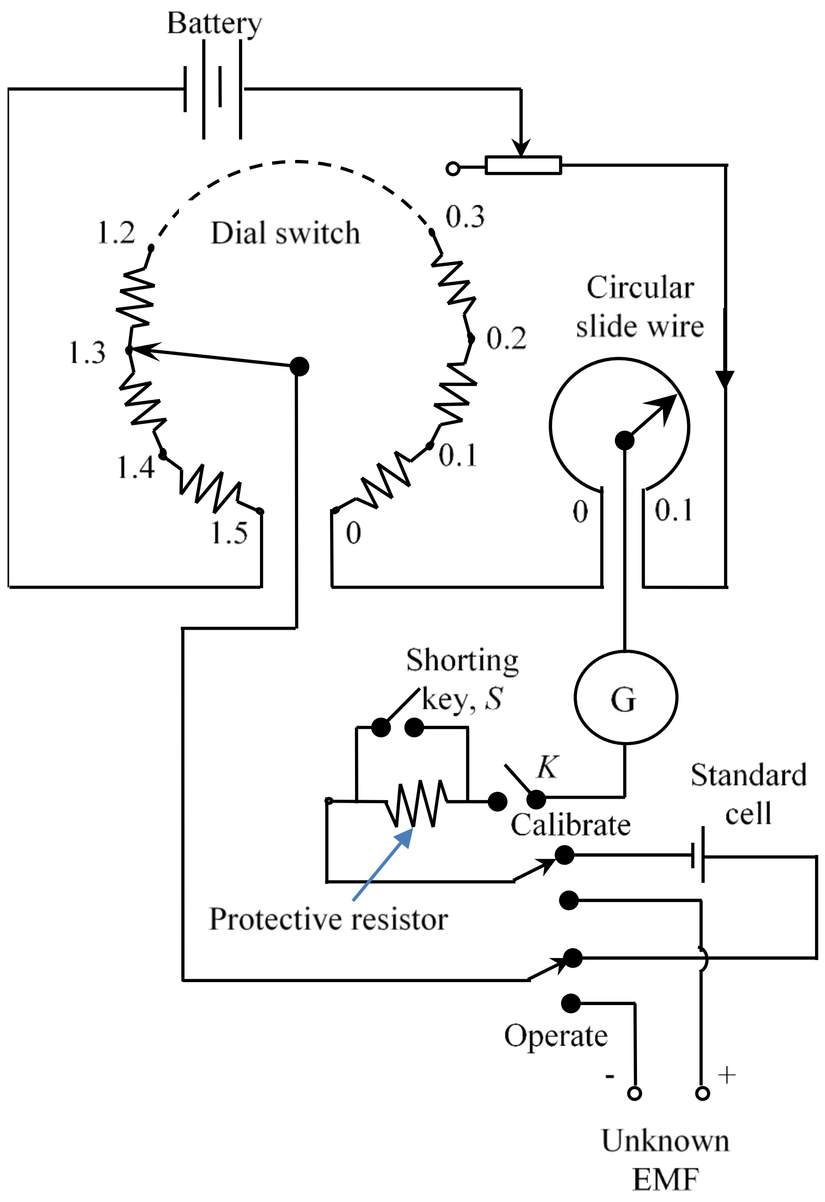


$$\text{Unknown EMF} = k \times l_2$$

Construction Laboratory Type Potentiometer

- The accuracy of the basic potentiometer discussed earlier is limited by the division on the sliding rule, say 1 mm.
- Besides, the length shown cannot be read to a very great degree of precision.
- Modern laboratory-type potentiometers use calibrated dial resistors and a small circular wire of one or more turns.
- This type of potentiometer is known as the laboratory-type potentiometer or DC Crompton's potentiometer.

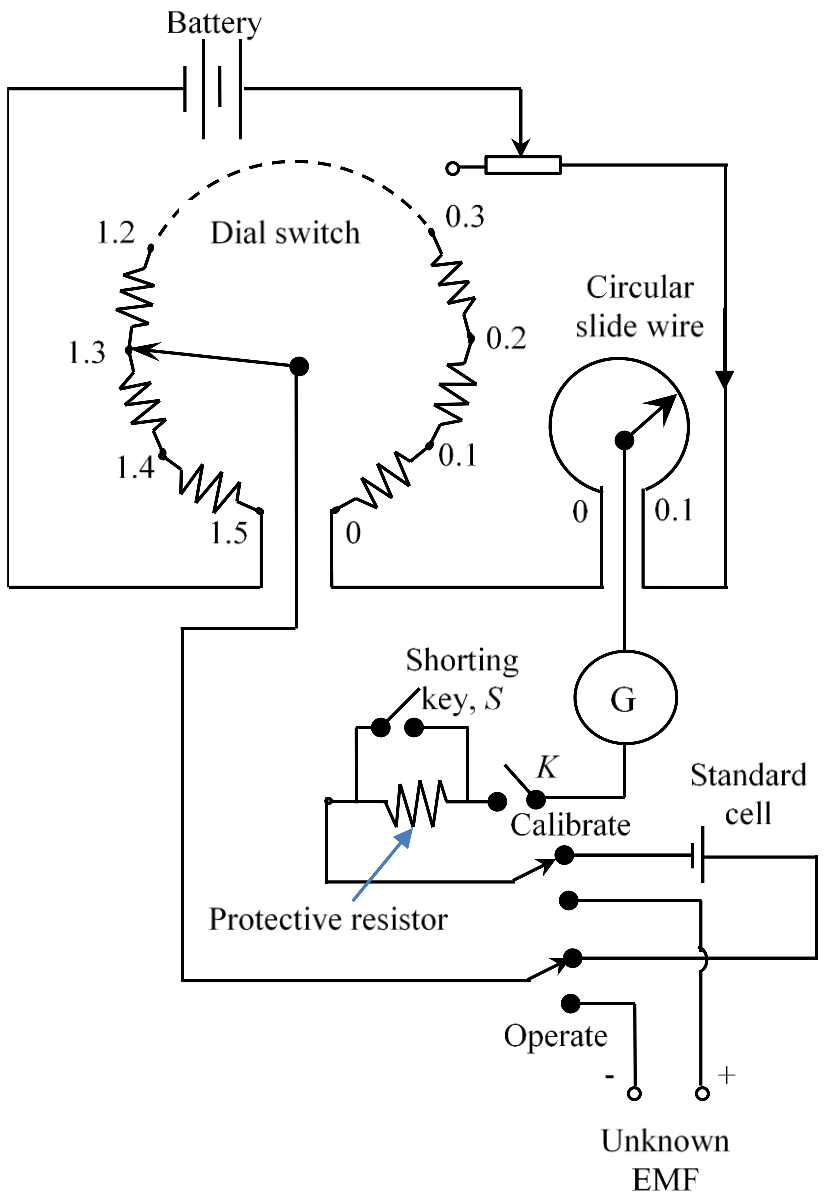
- The circuit of a simple DC Crompton's potentiometer theory is shown in the Figure below.



- Laboratory-type potentiometer has one dial switch with fifteen steps, each having a precision resistor of 10 Ω and a single 10 Ω turn circular slide wire.
- A double-throw switch is provided for calibration and measuring the unknown EMF.
- A protective resistance is connected in series with the galvanometer to protect the galvanometer and is shorted when the galvanometer reaches the balanced condition.

Operation of laboratory-type Potentiometer

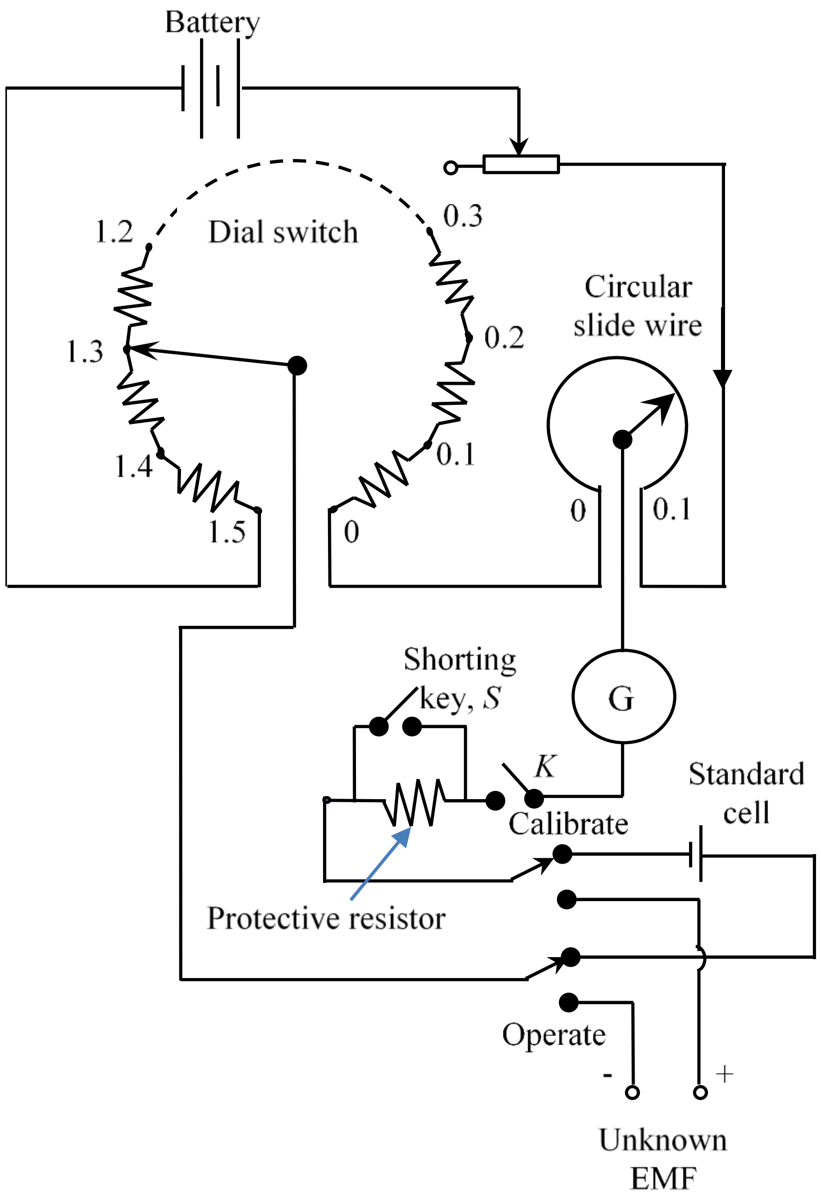
- The working current of the potentiometer provided by the battery is 10 mA, then each step of the dial switch corresponds to 0.1 V.
- The circular slide wire has 200 divisions corresponding to the resolution of 0.5 mV.
- It is quite possible to interpolate readings up to one-fifth of a scale division. Therefore, it is possible to estimate reading readings up to 0.1 mV.



In order to measure unknown EMF using laboratory type potentiometer, use the following steps:

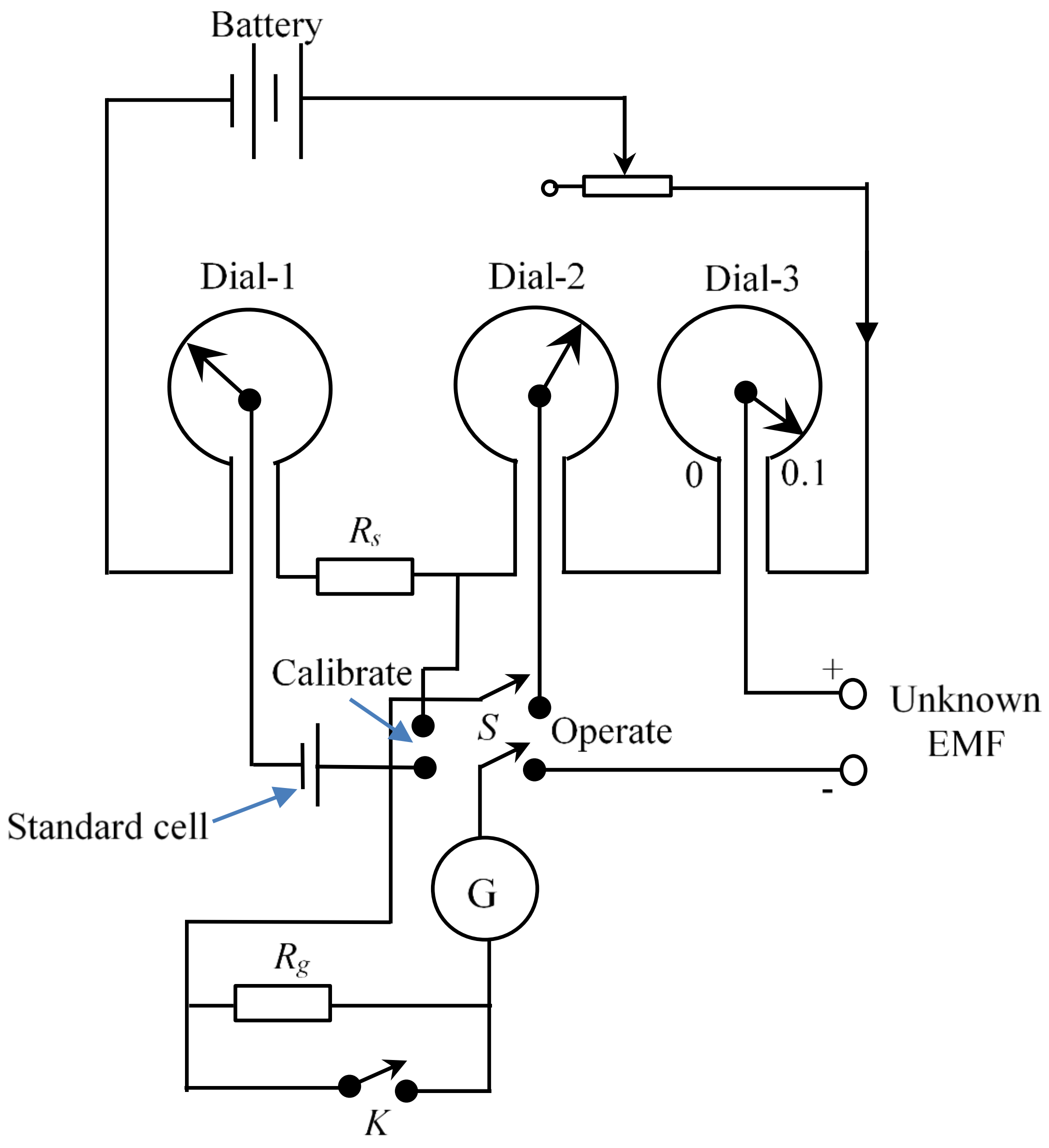
- Supposing the value of EMF of the standard cell is 1.0186 V, first calibrate the potentiometer by adjusting the dial switch at 1.0 V and slide wire at 0.0186.
- While protective resistor is in the circuit, the galvanometer key, *K* is short-circuited.
- The double-throw switch is set to the calibrated position to connect the standard cell and galvanometer to the dial switch and slide wire.
- Adjust the rheostat until the galvanometer shows null deflection.
- Close the shorting key, *S*, and the rheostat is adjusted until the galvanometer shows null deflection.
- Now, the potentiometer is standardized to the voltage of a standard cell.

- Set the double-throw switch to operate-position to connect the unknown EMF to the potentiometer circuit.
- With the protective resistance in the circuit, balance the potentiometer (galvanometer reads zero point) by adjusting the main dial and the slide wire.
- When the potentiometer is approaching the balance point, the protective resistance is shorted, and final adjustments are made to obtain true balance.
- Now, the value of the unknown EMF is read off directly measured from the dial switch and circular slide wire.
- This method has better precision than using a basic potentiometer.

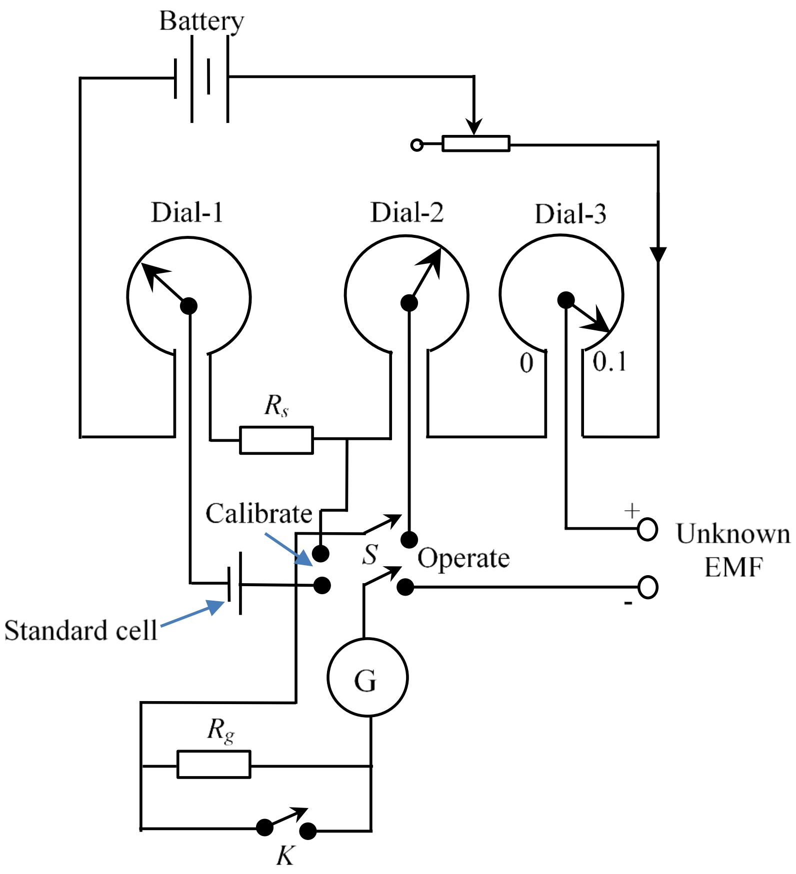


Modern Potentiometer

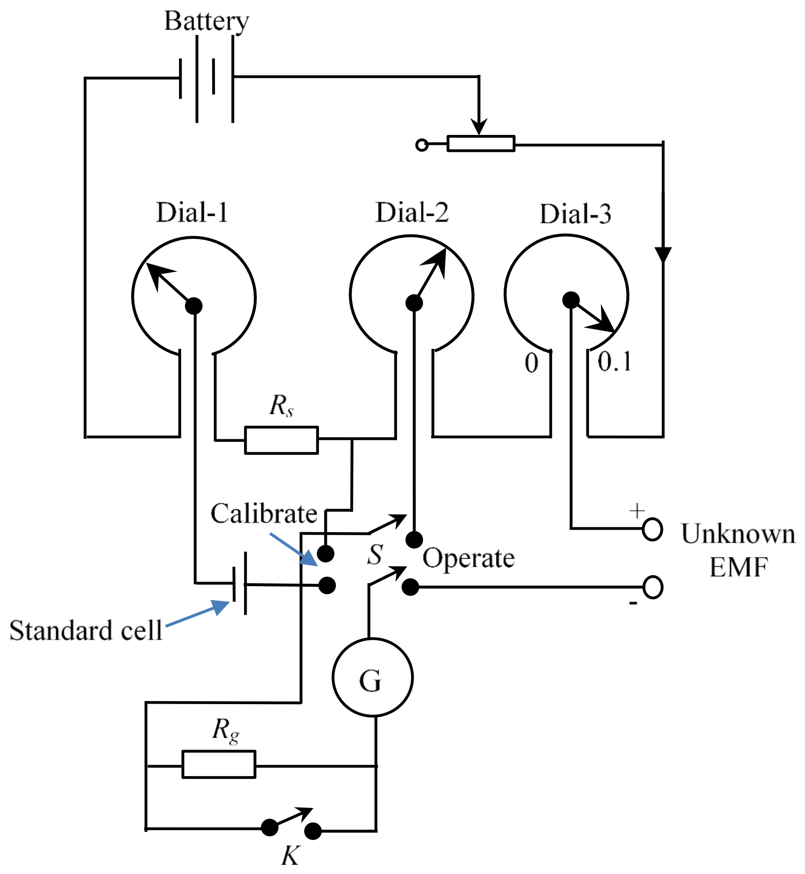
- Modern potentiometers, shown Figure below, consist of a separate or independent standard cell dial circuit comprised of a standard cell, standard resistor R, and dial-1.
- This separate standard cell dial circuit enables operators to check the standard cell balance during measurements without disturbing the potentiometer settings.
- This independent standardizing circuit can be set on any range of standard cell EMF from 1.016 V to 1.020 V.



- A drop of 1.016 V is provided by resistance, Rs and the remaining drop of 0.004 V is provided by the slide-1.
- The protective resistance and shorting key are used to protect the galvanometer.
- Initially, the slide-1 is set to read the EMF of the standard cell.
- The selector switch S, Double Pole Double Throw (DPDT), is set to calibrate position and the rheostat is adjusted to balance the galvanometer.
- This fixes the working current to its proper value.



- The switch S is then thrown to the operate position and unknown EMF is read by adjusting the dial-2 and dial-3.
- The standardizing circuit can be checked for the consistency of working current, anytime during the measurements by simply throwing the switch S back to calibrate position.
- This process does not disturb the measuring circuit. Besides it is convenient and increases the speed of measurements.



Assignment-2

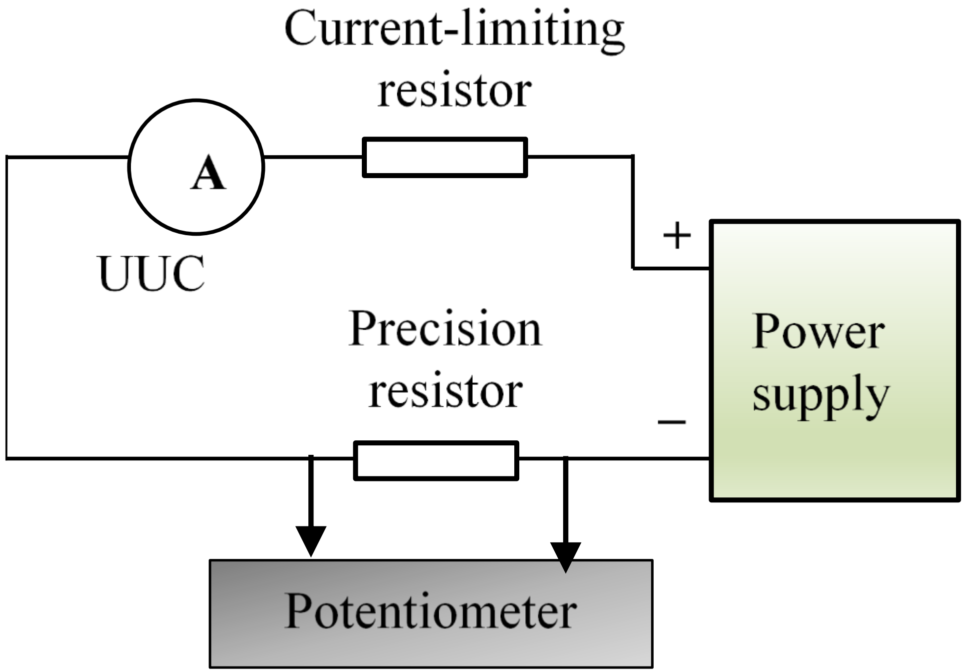
- Design the display system to show the readings of the potentiometer and the respective flow of data (signals).

Potentiometer Calibration Method

DC Ammeter Calibration

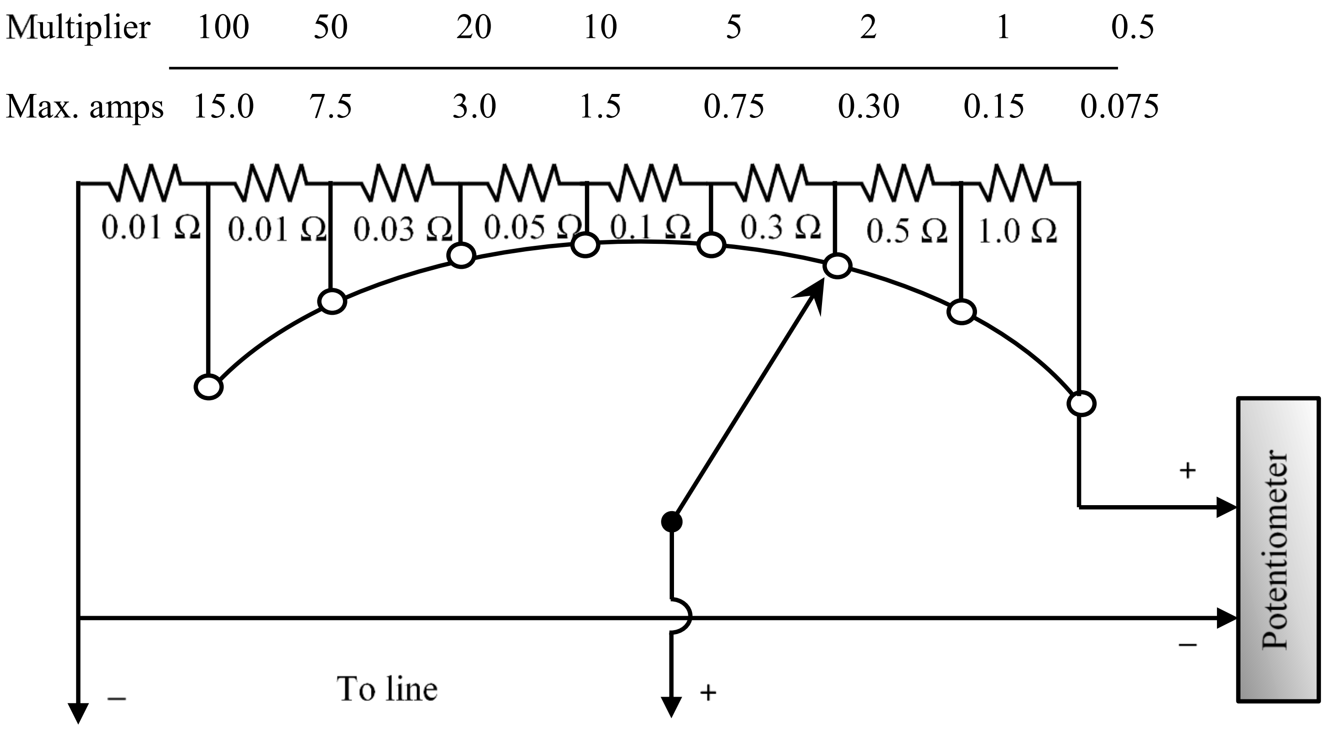
- The calibration of the ammeter using a potentiometer starts by measuring the voltage across the precision resistor.
- Precision resistors are very precise resistors with very low tolerance value closely near its nominal value.
- They are used in applications requiring a high degree of accuracy of the components.
- Examples precision resistors have tolerance between ±0.005%, and ±1%.
- The measured voltage drops across the precision resistor, measured by the potentiometer, divided by the value of the resistor is used to calibrate an ammeter connected in series.

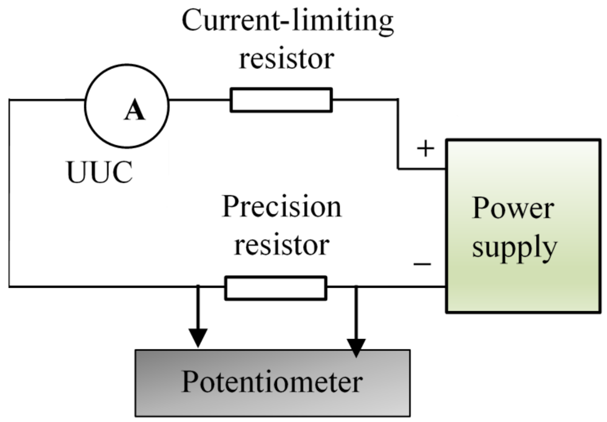
- Figure below shows the potentiometer connection used to calibrate an ammeter.



Shunt Box Resistors

- Shunt resistors are solely available in shunt boxes used to measure electric current.
- The figure below is a set of precision series-connected resistors.
- This type of device is commonly used in potentiometer calibration of ammeters.
- The line terminals of the shunt resistor are connected in series with the ammeter as discussed earlier.



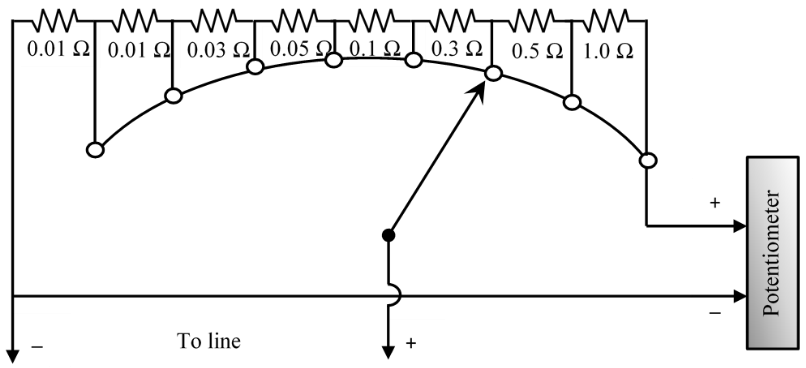


- For example the shunt-box shown in Figure has the 100, 50, 20, 10, 5, 2, 1 and 0.5 multipliers.
- At the 100 multiplier, if the maximum current is 15 A, we select 0.01 Ω resistor.
- The resistor is selected to minimize the power dissipated in the resistor and the resultant temperature error.
- Therefore the output voltage is 15 A × 0.01 Ω = 0.15 V.
- The resistance at the 50 multiplier is given as

$$R_{50} = \frac{0.15\ \text{V}}{50\%(15\ \text{A})} = \frac{0.15\ \text{V}}{7.5\ \text{A}} = 0.02\ \Omega$$

that is (0.01 Ω + 0.01 Ω)

Multiplier	100	50	20	10	5	2	1	0.5
Max. amps	15.0	7.5	3.0	1.5	0.75	0.30	0.15	0.075



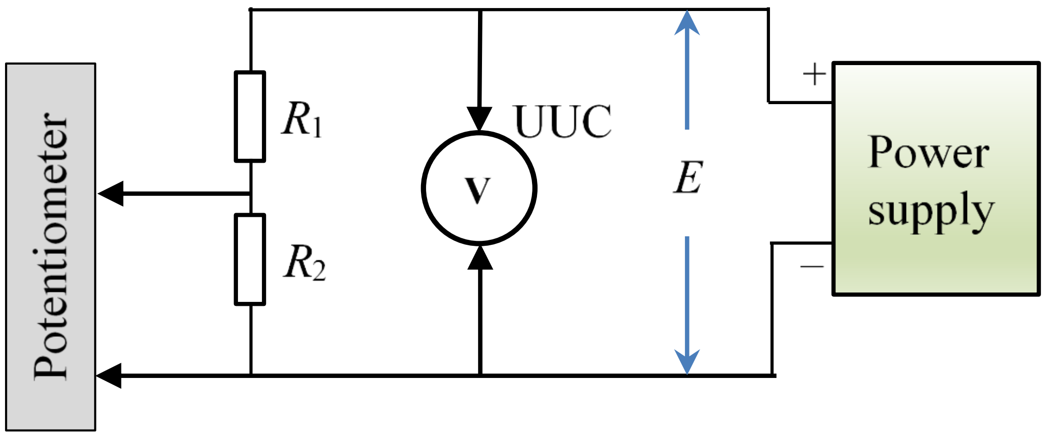
$$R_{20} = \frac{0.15 \text{ V}}{20\%(15 \text{ A})} = \frac{0.15 \text{ V}}{3.0 \text{ A}} = 0.05\ \Omega$$

$$R_{10} = \frac{0.15 \text{ V}}{10\%(15 \text{ A})} = \frac{0.15 \text{ V}}{1.5 \text{ A}} = 0.1\ \Omega$$

- that is (0.01 Ω + 0.01 Ω + 0.03 Ω)
- that is (0.01 Ω + 0.01 Ω + 0.03 Ω + 0.05 Ω) and so forth.

DC Voltmeter Calibration

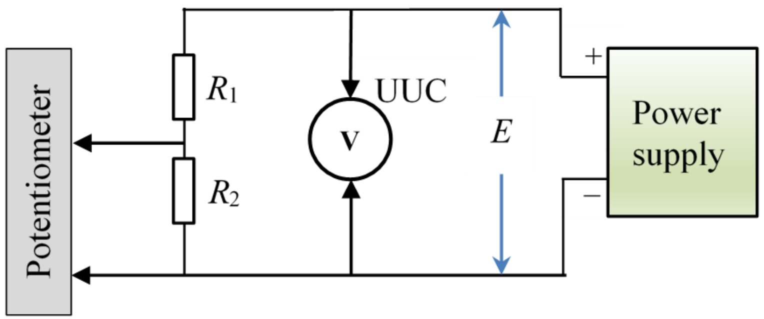
- The potentiometer acts as a standard voltmeter.
- Therefore, the calibration of voltmeter using potentiometer is simply a comparison of potentiometer voltage reading with the voltmeter under calibration reading.
- However, this is possible only is the voltage range is within 1.5 V or lower.
- Higher voltages would require two precision resistors, R1 and R2.
- The voltage across R2, which is within the potentiometer acceptable range, is measured by the potentiometer.



- Then, the precise voltmeter potential is expresses from

$$V_{R_2} = E \times \frac{R_2}{(R_1 + R_2)}$$

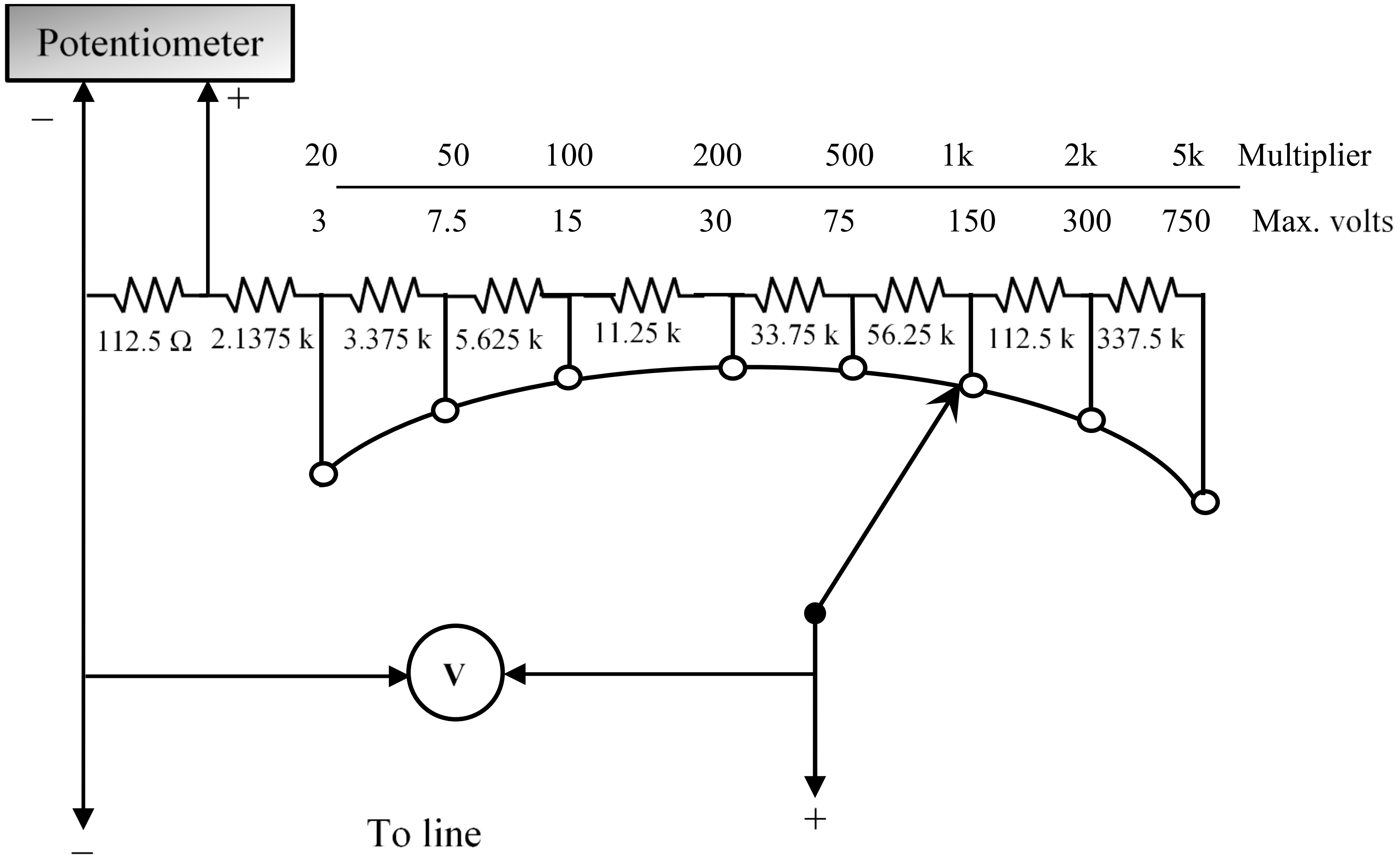
$$E = V_{R_2} \times \frac{(R_1 + R_2)}{R_2}$$



Volt Box

- A volt box, also known as, a resistance potential divider, is a device commonly used to extend the range of a potentiometer to permit of the precise measurement of direct voltages which exceed the limited range of the potentiometer.

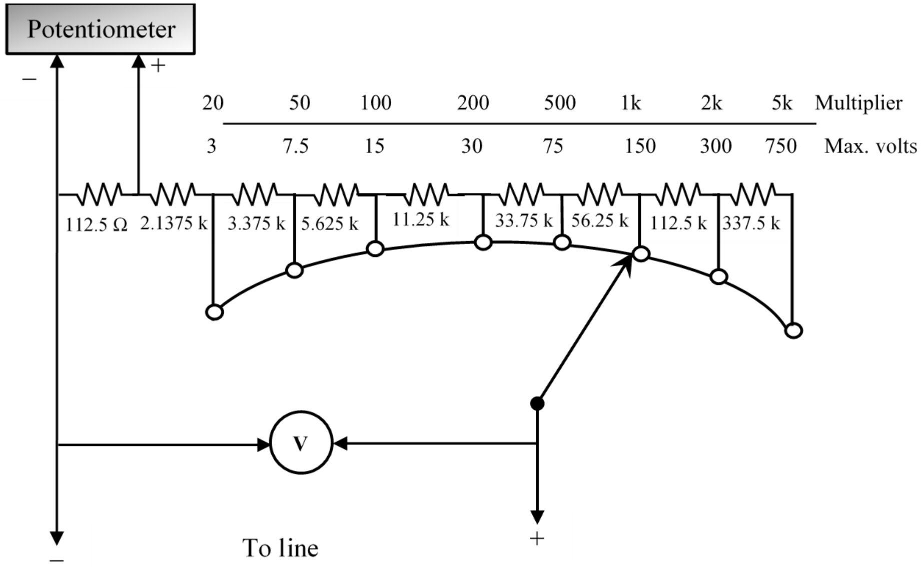
- Figure below is a precision potential divider for use in potentiometer calibration of voltmeter.



- As it is for the shunt-box, when the maximum voltage is applied to the device, the volt-box output to the potentiometer is always 0.15 V.
- Therefore, the ratio of the total resistance to the maximum voltage at any position setting is the sensitivity of the volt-box , given in equation

$$\gamma_{volt-box} = \frac{R_t}{V_{max}}$$

- where, R_t is the total resistance, and V_{max} is the maximum voltage at the given setting and the reciprocal of the sensitivity is the maximum current.



- Consider the volt-box in Figure at 3 V setting, the sensitivity of the volt-box is

$$\gamma_{volt-box} = \frac{(112.5\ \Omega + 2137.5\ \Omega)}{3\ \text{V}} = \frac{2250}{3} = 750\ \Omega/\text{V}$$

- The maximum current is

$$I_{max} = \frac{1}{\gamma_{volt-box}} = 1.33\ \text{mA}$$