SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE NAME : 23EET206 CONTROL SYSTEMS AND INSTRUMENTATION

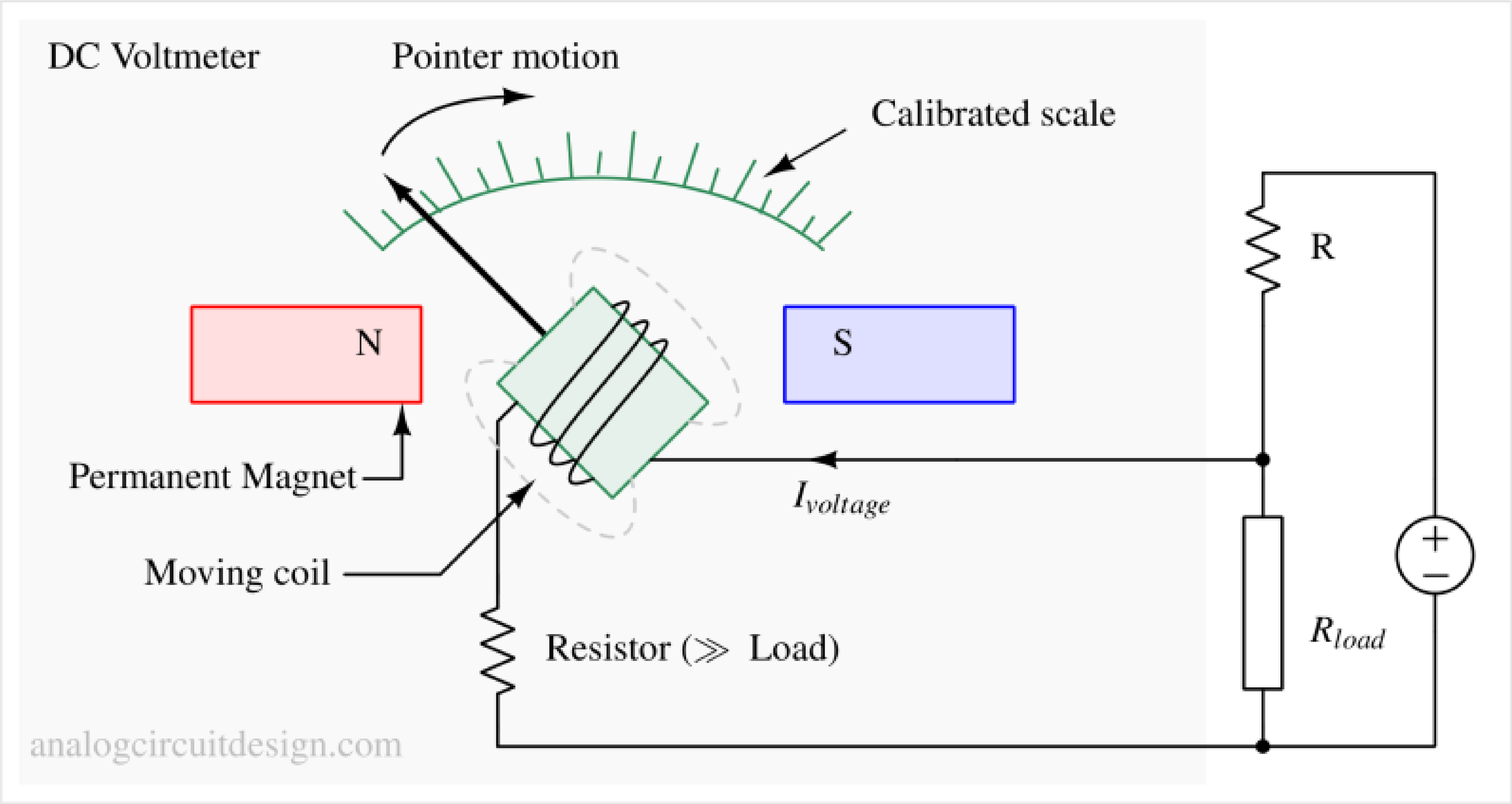
II YEAR ECE /III SEMESTER

Unit 4- Electronic Instruments & Transducers

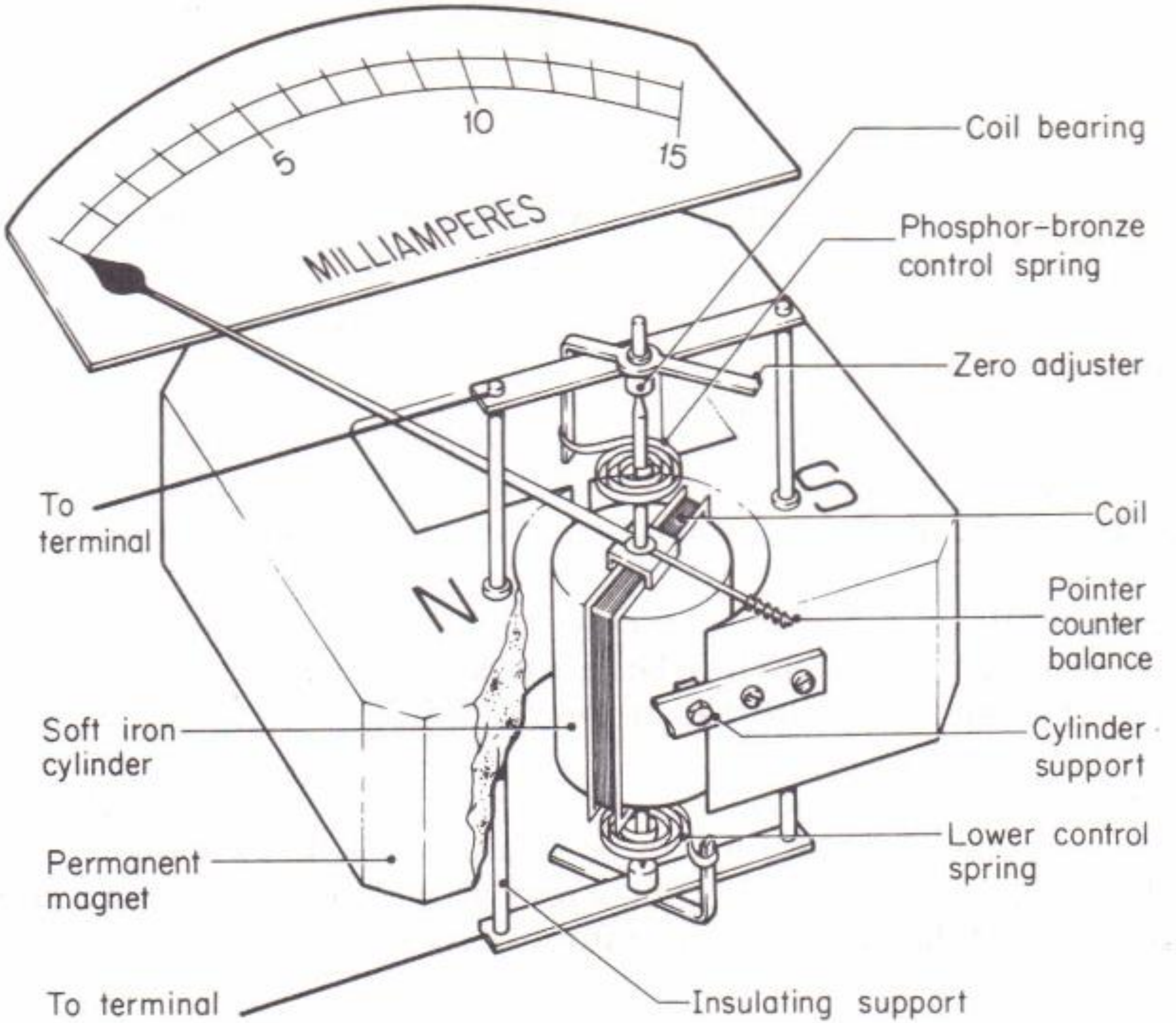
Topic 3 : Voltmeter, Multi-range Voltmeter, True RMS Voltmeter

VOLTMETER

- DC voltmeter is a measuring instrument, which is used to measure the DC voltage across any two points of electric circuit.
- A Series resistor is connected in series with the PMMC Galvanometer.



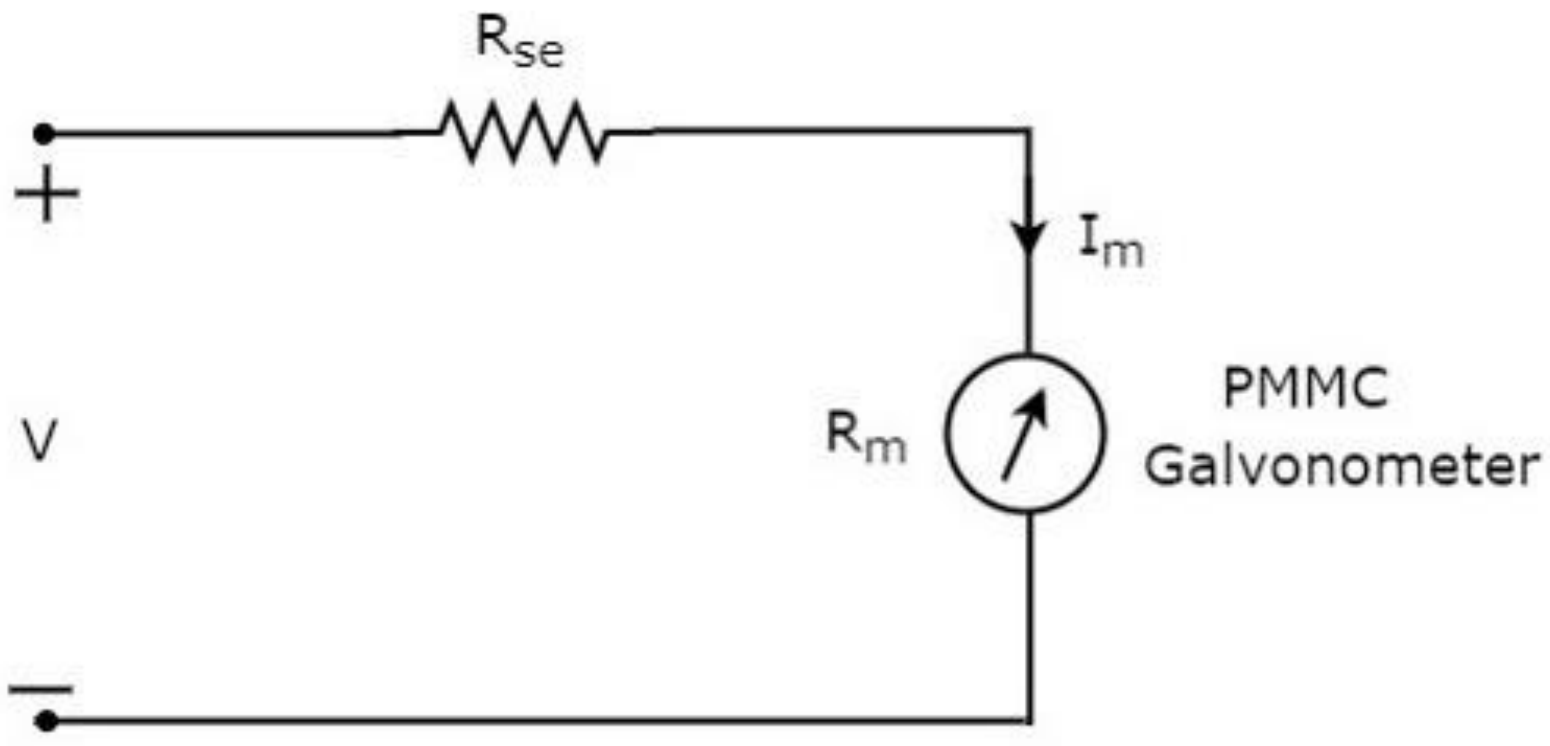
VOLTMETER



5
10
15
MILLIAMPERES
Coil bearing
Phosphor-bronze control spring
Zero adjuster
To terminal
S
Coil
N
Pointer counter balance
Soft iron cylinder
Cylinder support
Lower control spring
Permanent magnet
To terminal
Insulating support

VOLTMETER

- DC voltmeter is a measuring instrument, which is used to measure the DC voltage across any two points of electric circuit.
- A Series resistor is connected in series with the PMMC Galvanometer.
- The series resistance, which is used in DC voltmeter is also called series multiplier resistance or simply, multiplier. It basically limits the amount of current that flows through galvanometer in order to prevent the meter current from exceeding the full scale deflection (FSD) value.



VOLTMETER

Apply **KVL** around the loop of above circuit.

$$V - I_m R_{se} - I_m R_m = 0 \qquad \text{(Equation 1)}$$

$$\Rightarrow V - I_m R_m = I_m R_{se}$$

$$\Rightarrow R_{se} = \frac{V - I_m R_m}{I_m}$$

$$\Rightarrow R_{se} = \frac{V}{I_m} - R_m \qquad \text{(Equation 2)}$$

Where,

R_{se} is the series multiplier resistance

V is the full range DC voltage that is to be measured

I_m is the full scale deflection current

R_m is the internal resistance of galvanometer

VOLTMETER

The ratio of full range DC voltage that is to be measured, V and the DC voltage drop across the galvanometer, V_m is known as **multiplying factor**, m. Mathematically, it can be represented as

$$m = \frac{V}{V_m} \quad \text{(Equation 3)}$$

Full range DC voltage that is to be measured, V

$$V = I_m R_{se} + I_m R_m \quad \text{(Equation 4)}$$

The **DC voltage drop** across the galvanometer, V_m is the product of full scale deflection current, I_m and internal resistance of galvanometer, R_m. Mathematically, it can be written as

$$V_m = I_m R_m \quad \text{(Equation 5)}$$

VOLTMETER

Substitute, Equation 4 and Equation 5 in Equation 3.

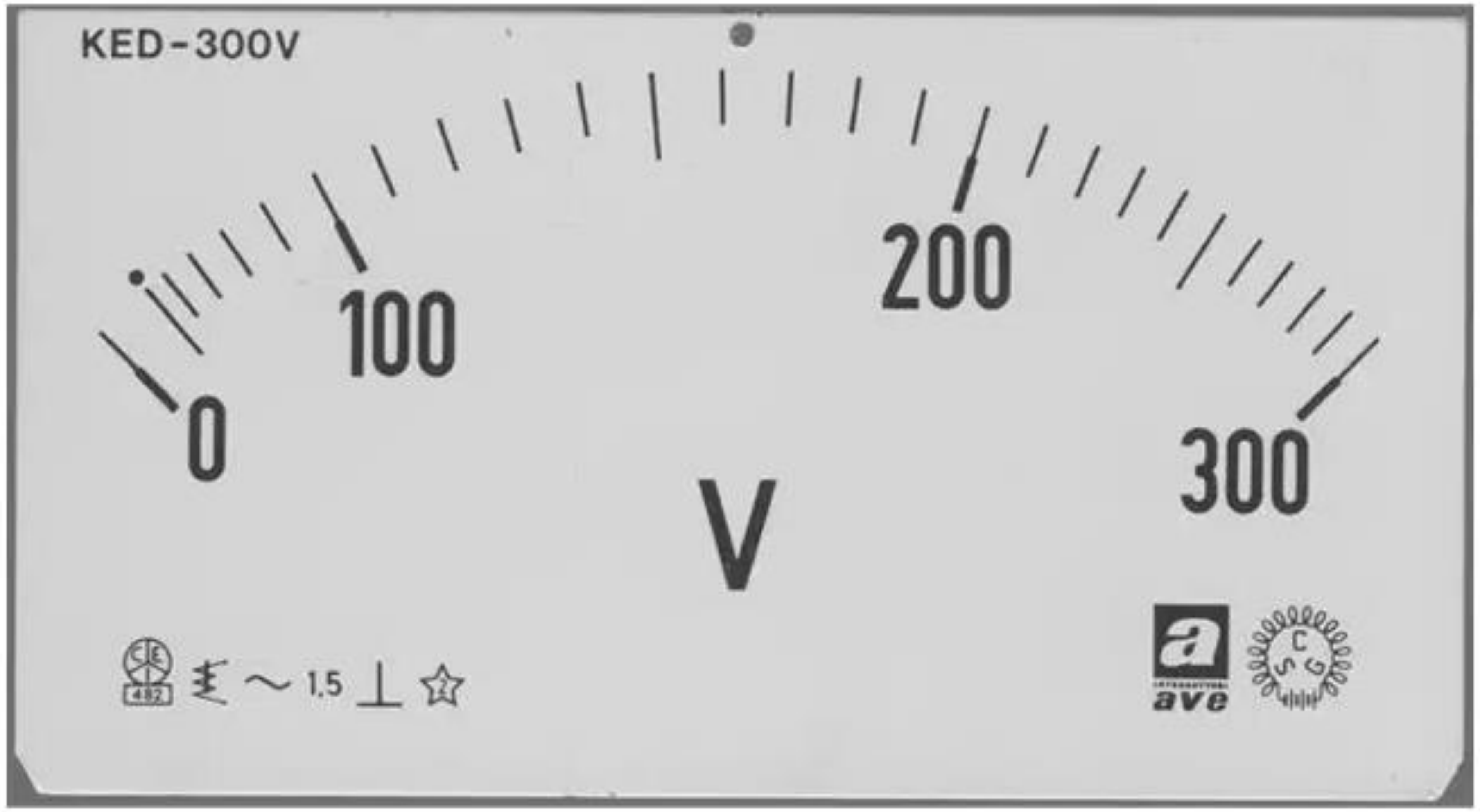
$$m = \frac{I_m R_{se} + I_m R_m}{I_m R_m}$$

$$\Rightarrow m = \frac{R_{se}}{R_m} + 1$$

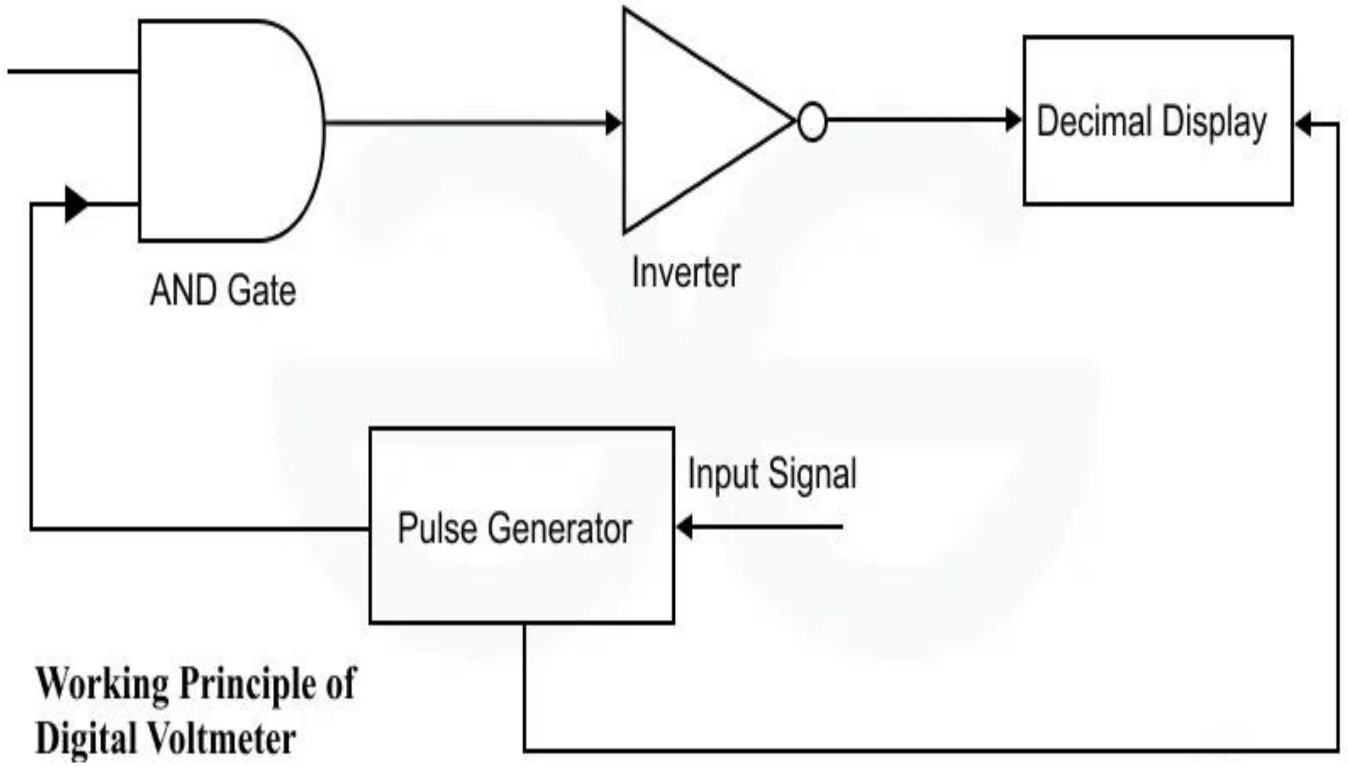
$$\Rightarrow m - 1 = \frac{R_{se}}{R_m}$$

$$R_{se} = R_m \left(m - 1\right)$$ (Equation 6)

TYPES OF VOLTMETER



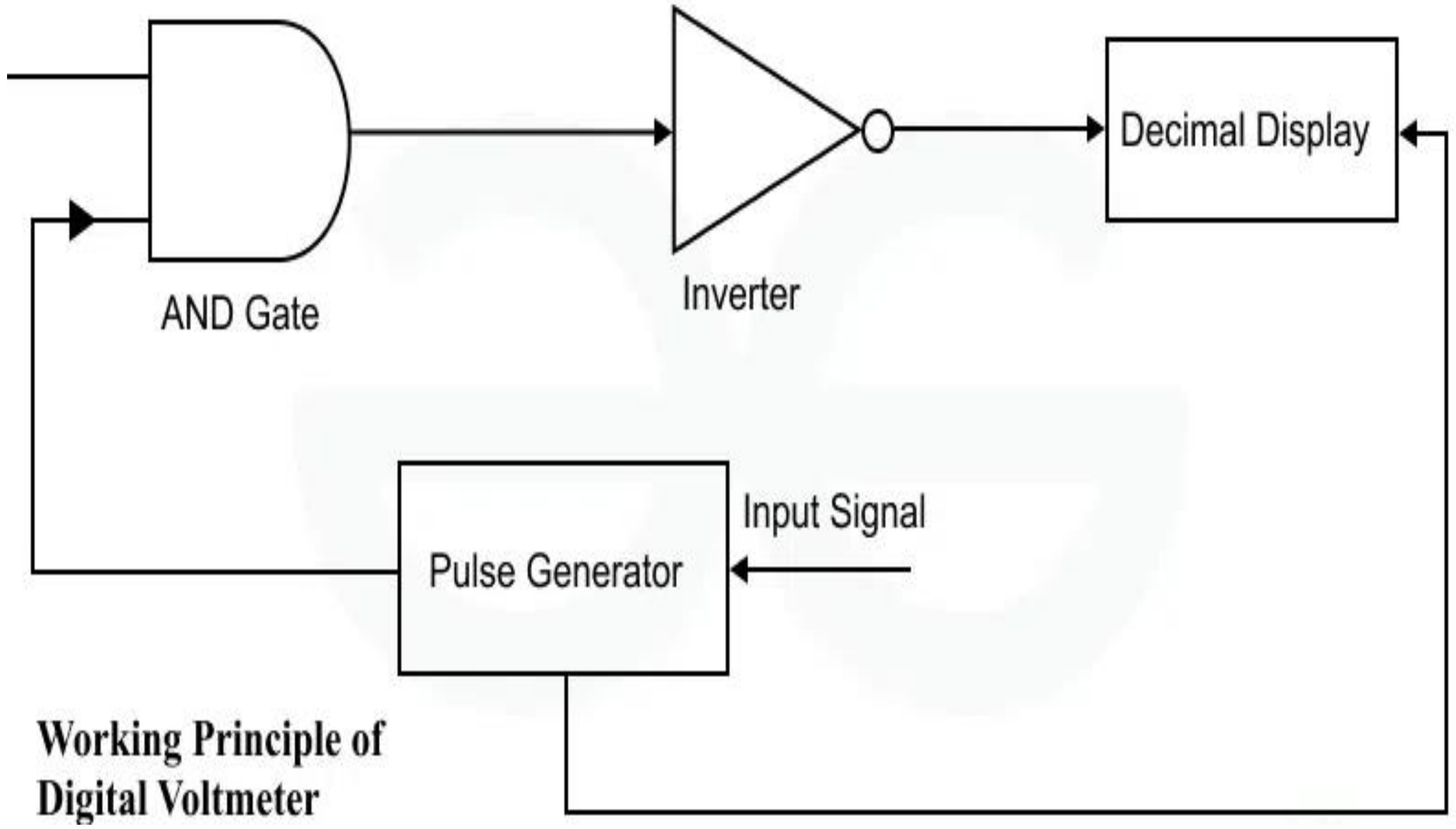
DIGITAL VOLTMETER (DVM)



Working Principle of Digital Voltmeter

- The input signal is fed as the input to the pulse generator. The pulse generator generates rectangular pulses of width as that of input signal.
- The output of the pulse generator acts as the input the AND gate whose another input is a sequence of pulses. This creates a positive triggered switch resulting in positive triggered sequence of pulses having width same as the pulses generated by the pulse generator.
- The positive triggered pulses i.e. the output of AND gate is fed to invertor which inverts the output of AND gate.

DIGITAL VOLTMETER (DVM)

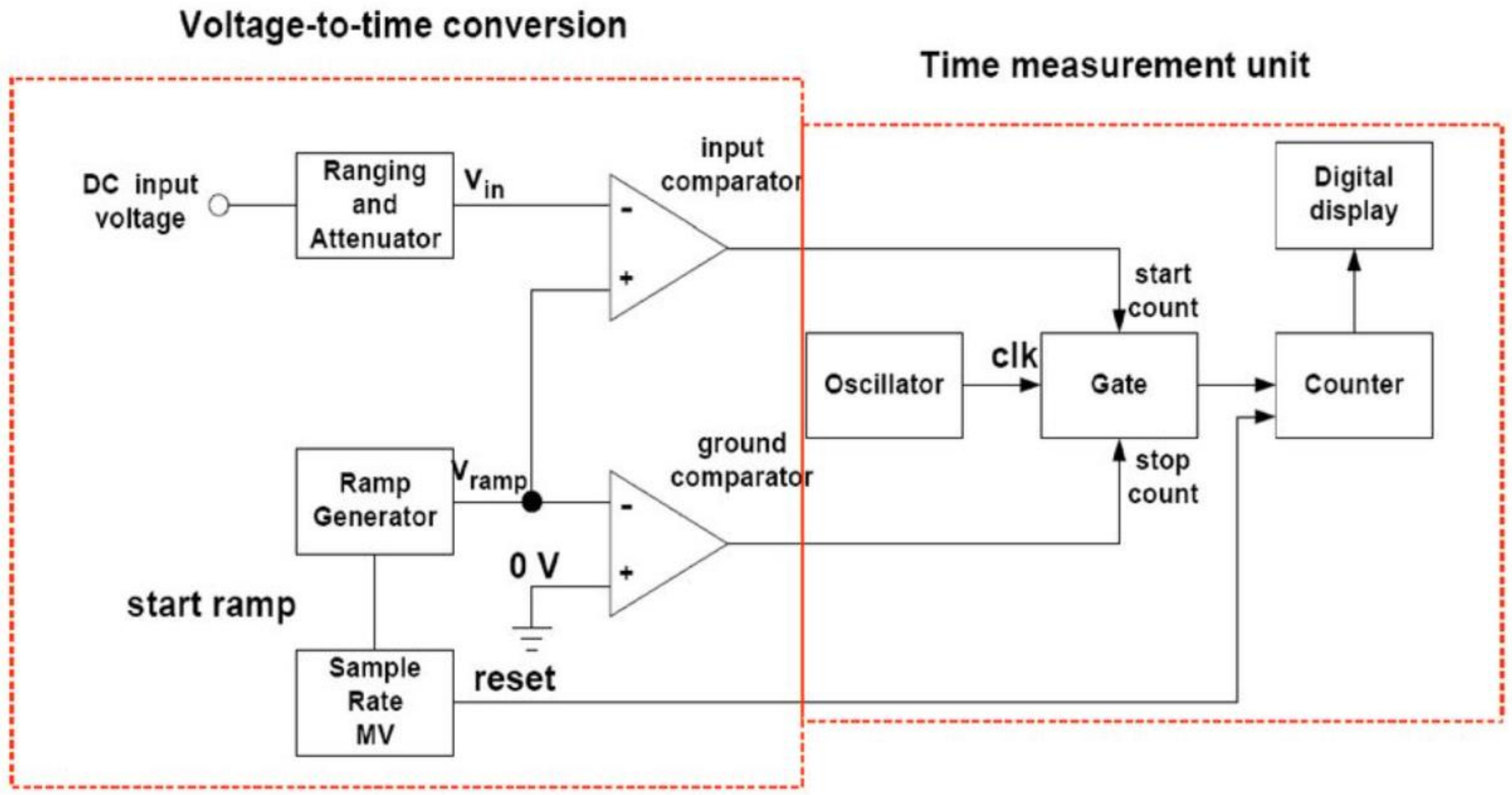


- The output of invertor is fed as an input to the counter which counts the total pulses and time duration between the pulses.
- The last step involves showing the precise output mainly on LED and the reading is calibrated and shown in Volts.

TYPES OF DIGITAL VOLTMETER (DVM)

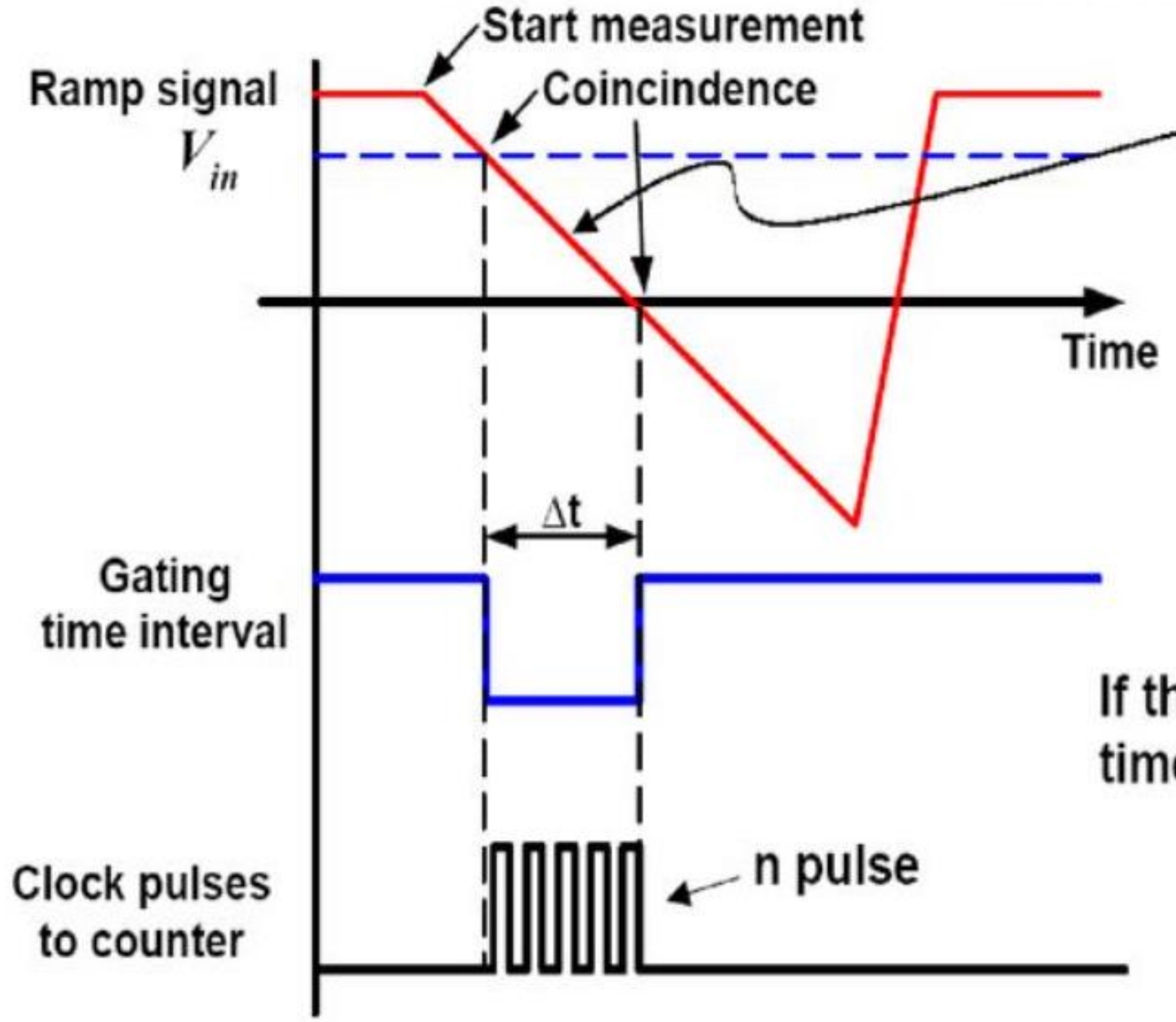
- Ramp Type Digital Voltmeter
- Integrating Type Digital Voltmeter
- Successive Approximation Digital Voltmeter
- Dual Slope Integrating Digital Voltmeter

LINEAR RAMP TYPE DVM



LINEAR RAMP TYPE DVM

Operation principle: The measurement of the time it takes for a linear ramp voltage to rise from O V to the level of the input voltage, or to decrease from the level of the input voltage to zero. This time interval is measured with an electronic time-interval counter.



Voltage-to-time conversion using gated clock pulses.

$$V_{ramp}(t) = V_o - m\,t$$

Where m is the ramp rate

$$V_{ramp}(t_1) = V_{in} = V_o - m\,t_1$$

$$V_{ramp}(t_2) = 0 = V_o - m\,t_2$$

$$\Delta t = t_2 - t_1 = V_{in}/m$$

If the period of the clock is T, then during the time interval Δt_1, the number of pulses is

$$\Delta t \approx nT \text{ or } V_{in} \approx nmT$$

- Accuracy depends on both the ramp rate and clock period.

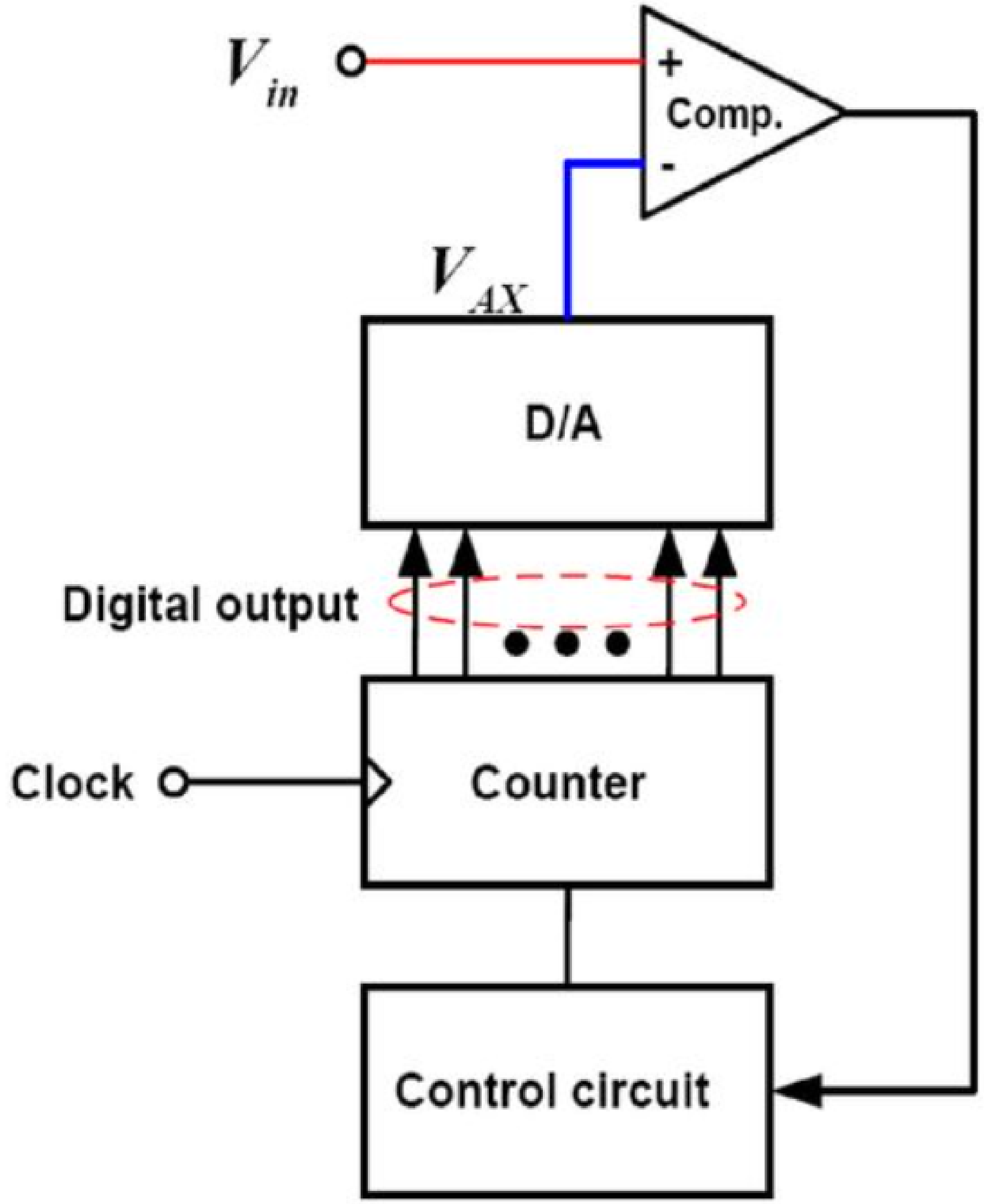
LINEAR RAMP TYPE DVM

- The voltage is measured by providing an unknown input signal to the ranging and attenuation. Depending on the needs, the signal is attenuated or made stronger by amplification.
- The ramp generator is a device which generates a positive or a negative ramp and our unknown signal is compared to it.
- The comparator compares input signal to the ramp signal. If the input voltage matches with ramp voltage then gate is opened with the pulse and after the ramp signal reaches 0 ,the gate is closed.
- The time period between two events is called **gating time interval.** This generates the ramp voltage

STAIRCASE RAMP TYPE DVM

(also called digital ramp)

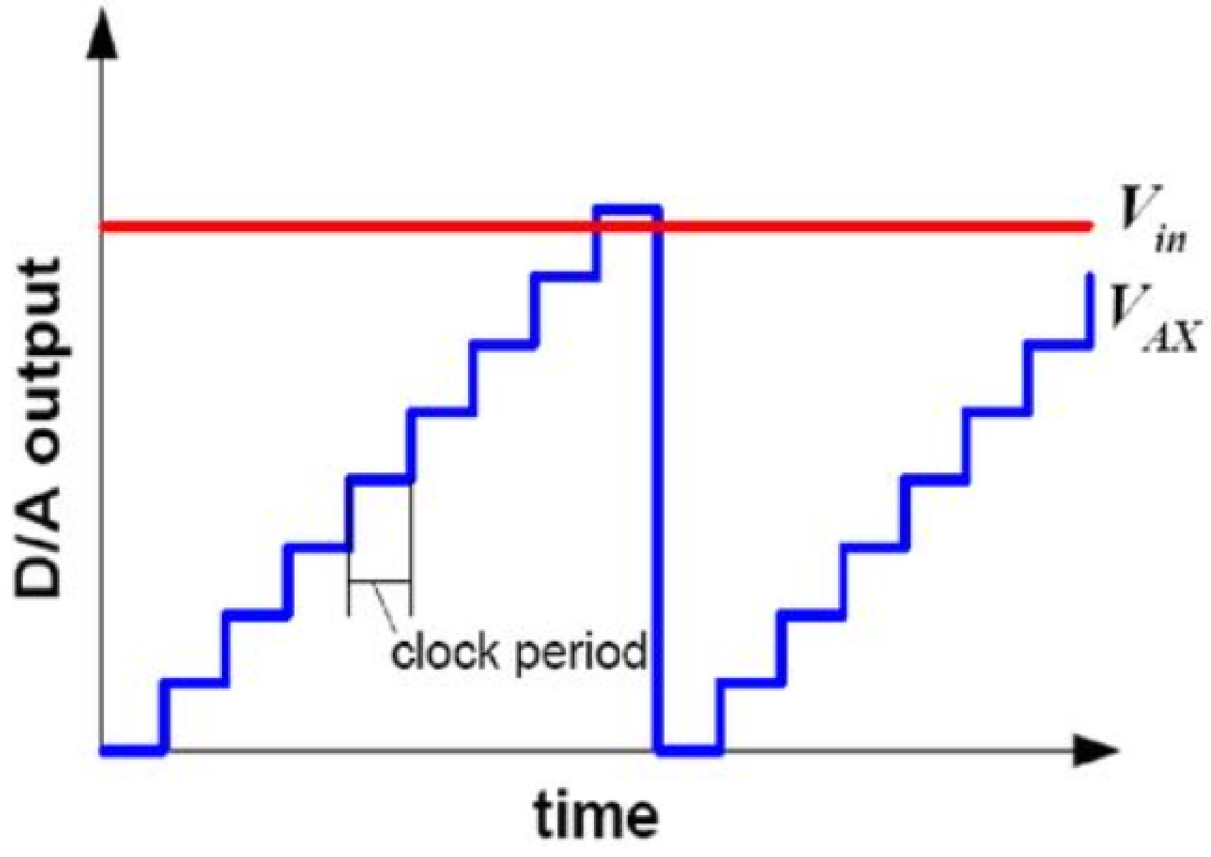
Compare the input voltage to the internally generated stair case ramp.



Block diagram

- The most simple A/D
- Slow conversion and conversion time depends on the magnitude of input signal.

$$T_{C,max} = (2^N - 1) \times \text{Clock period}$$



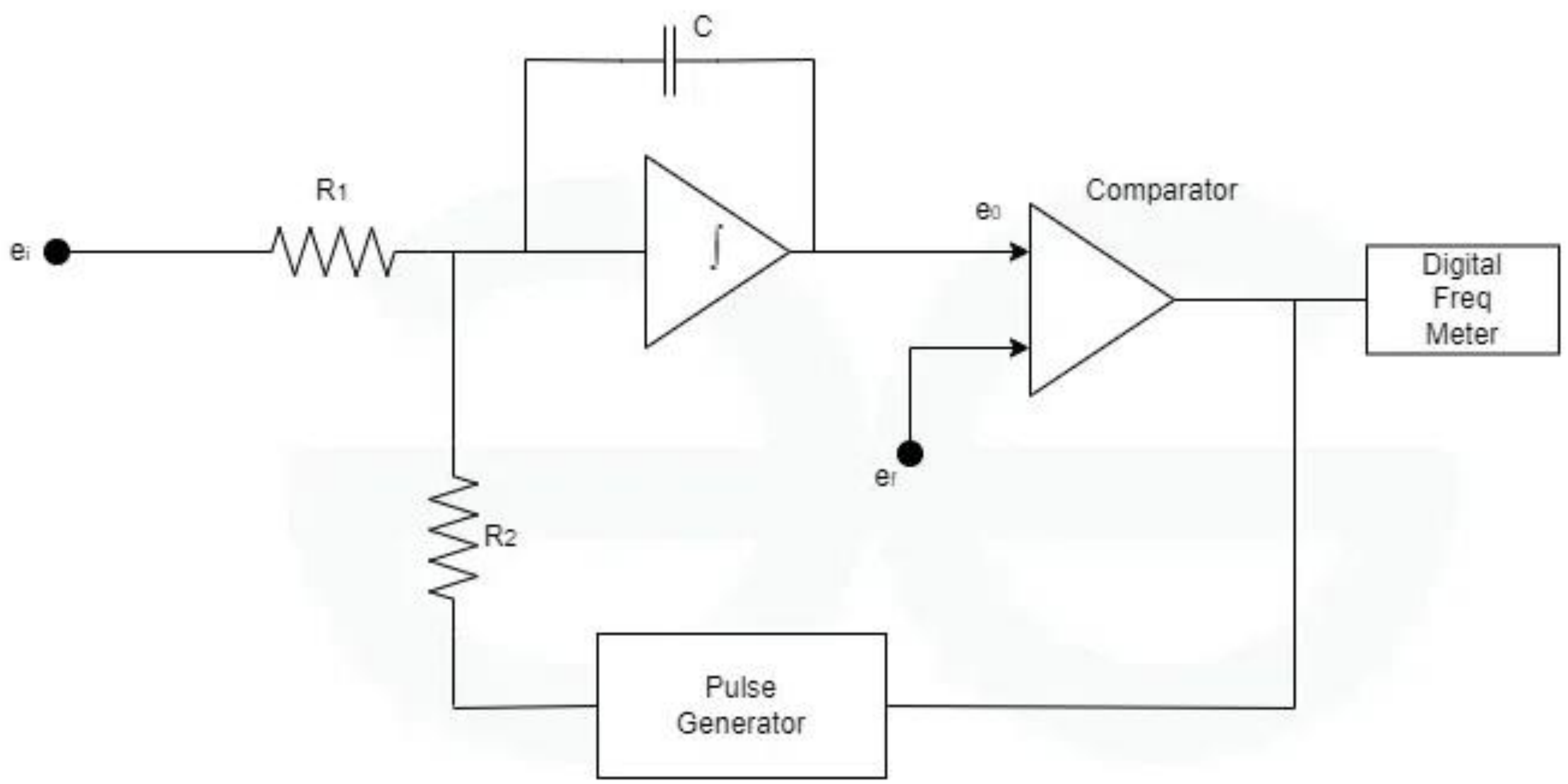
STAIRCASE TYPE DVM

- The clock generates pulses continuously. At the start of a measurement, the counter is reset to 0 at time t_1 so that the output of the digital to analog converter (DAC) is also 0.
- If V_i is not equal to zero, the input comparator applies an output voltage that opens the gate so that clock pulses are passed on to the counter through the gate.
- The counter starts counting and the DAC starts to produce an output voltage increasing by one small step at each count of the counter. The result is a staircase voltage applied to the second input of the comparator.

STAIRCASE TYPE DVM

- This process continues until the staircase voltage is equal to or slightly greater than the input voltage V_i. At that instant t_2, the output voltage of the input comparator changes state or polarity, so that the gate closes and the counter is stopped. The display unit shows the result of the count.
- As each count corresponds to a constant dc step in the DAC output voltage, the number of counts is directly proportional to V_c and hence to V_i. By appropriate choice of reference voltage, the step height of the staircase voltage can be determined.

INTEGRATING TYPE DVM

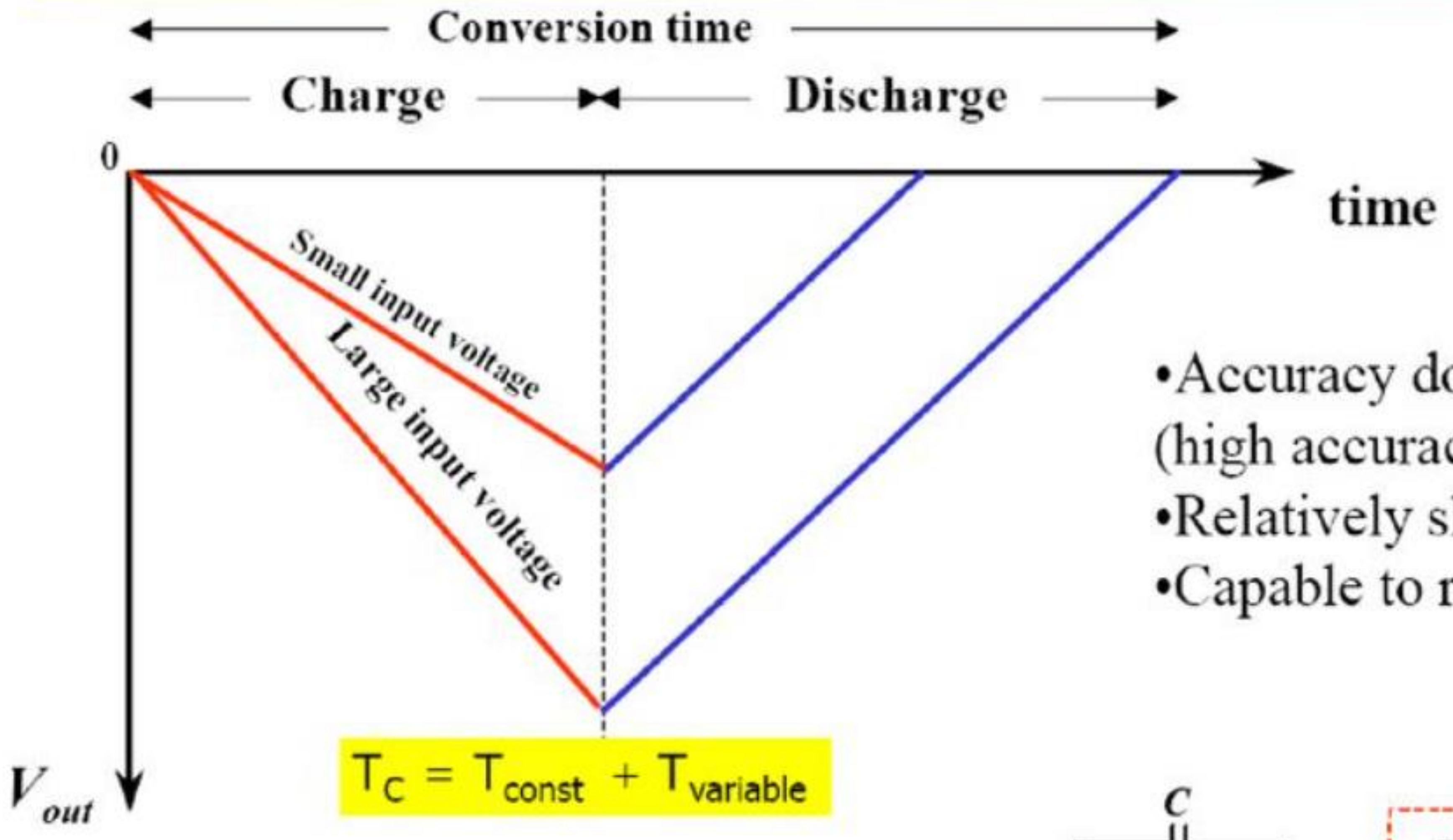


- This voltmeter measures exact value of input corresponding to the constant of time.
- This circuit usually uses a voltage-to-frequency converter device which works on the feedback control system.
- The main characteristic of this voltmeter is that the output from the integrator is compared with the fixed level voltage of reference source.

INTEGRATING TYPE DVM

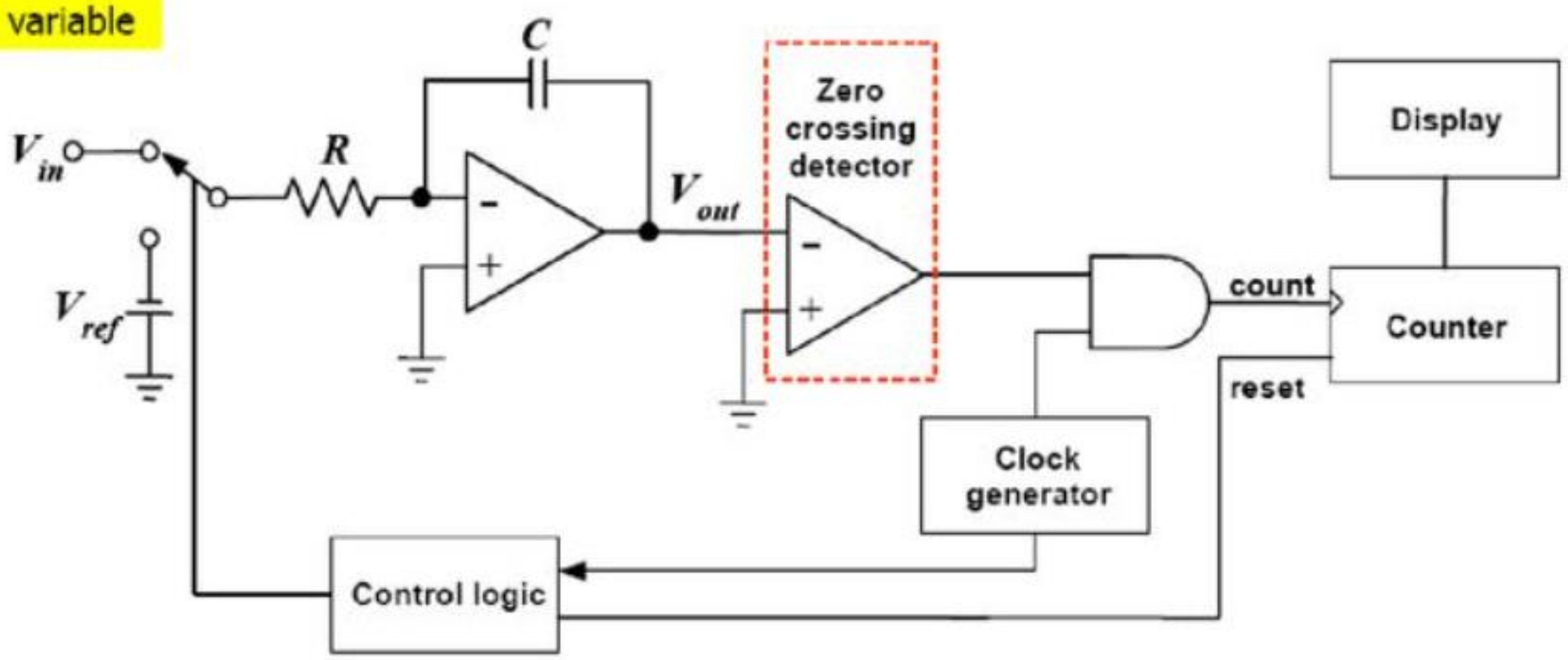
- The input voltage is applied, the output voltage begins to increase which fed to level detector. After the output voltage reaches a certain value, detector sends a pulse to pulse generator gate.
- The integrator output is compared to fixed level voltage of the internal reference source resulting in an output pulse. This output pulse from level detector.
- This pulse opens gate which passes pulse from oscillator to pulse generator. The pulse generator like a **Schmitt trigger**, generates pulses with fixed width and amplitude.
- So for each wave a pulse is generated which helps to determine the input voltage.

DUAL SLOPE INTEGRATING TYPE DVM



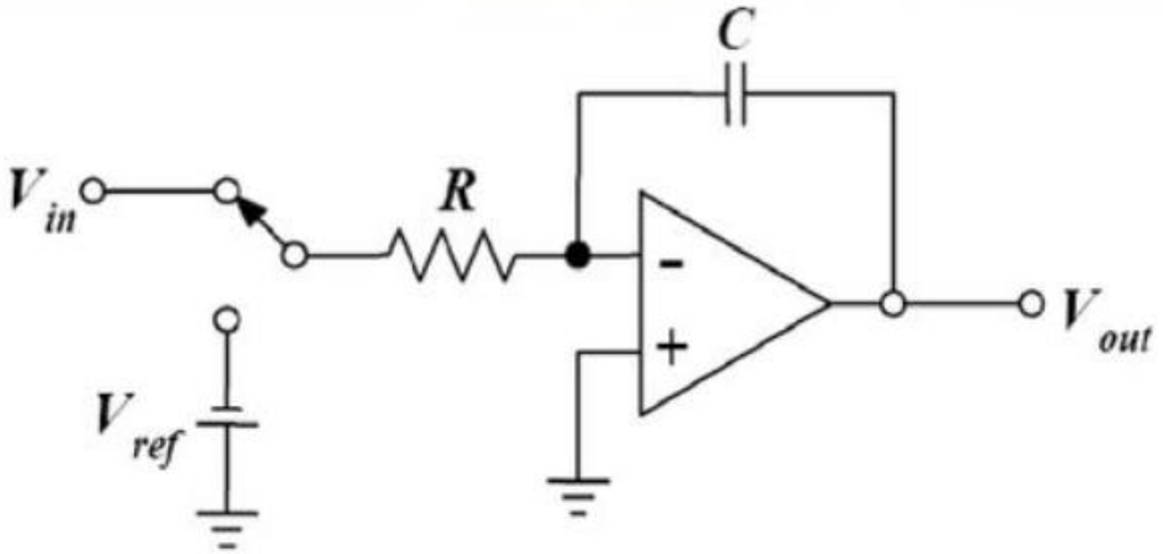
- Accuracy does not depend on ***R C*** and Clock (high accuracy)
- Relatively slow
- Capable to reject noise

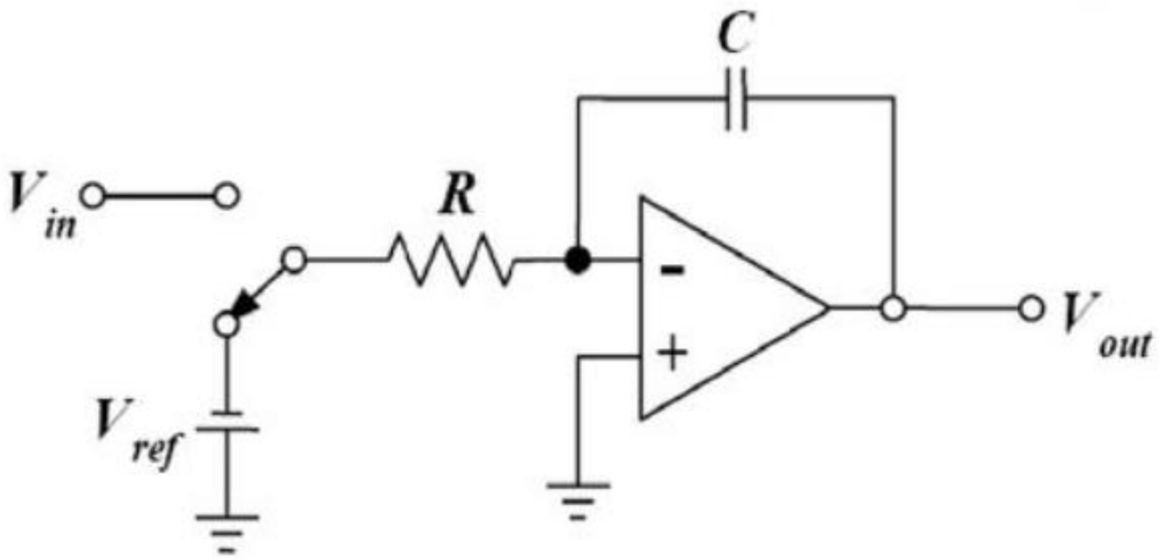
$$T_C = T_{const} + T_{variable}$$



Vi = Vref (T1 /T2)

DUAL SLOPE INTEGRATING TYPE DVM





Phase 1: charging C with the unknown input for a given time.

Phase 2: discharging *C* with the reference voltage until the output voltage goes to zero.

Assume $V_c(0) = 0$

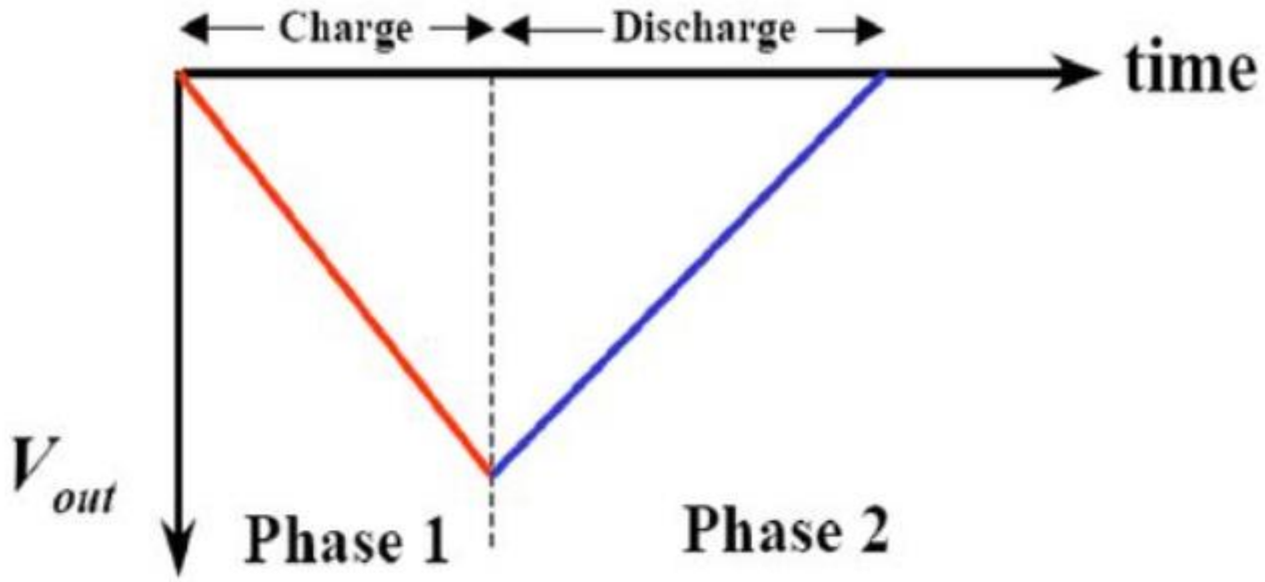
$$V_{out1} = -\frac{V_{in}T}{RC}$$

where *T* is the charging time

$$V_{out} = \frac{V_{ref}T_x}{RC} + V_{out1}$$

find T_x at which V_{out} becomes zero

$$T_x = \frac{V_{in}T}{V_{ref}}$$

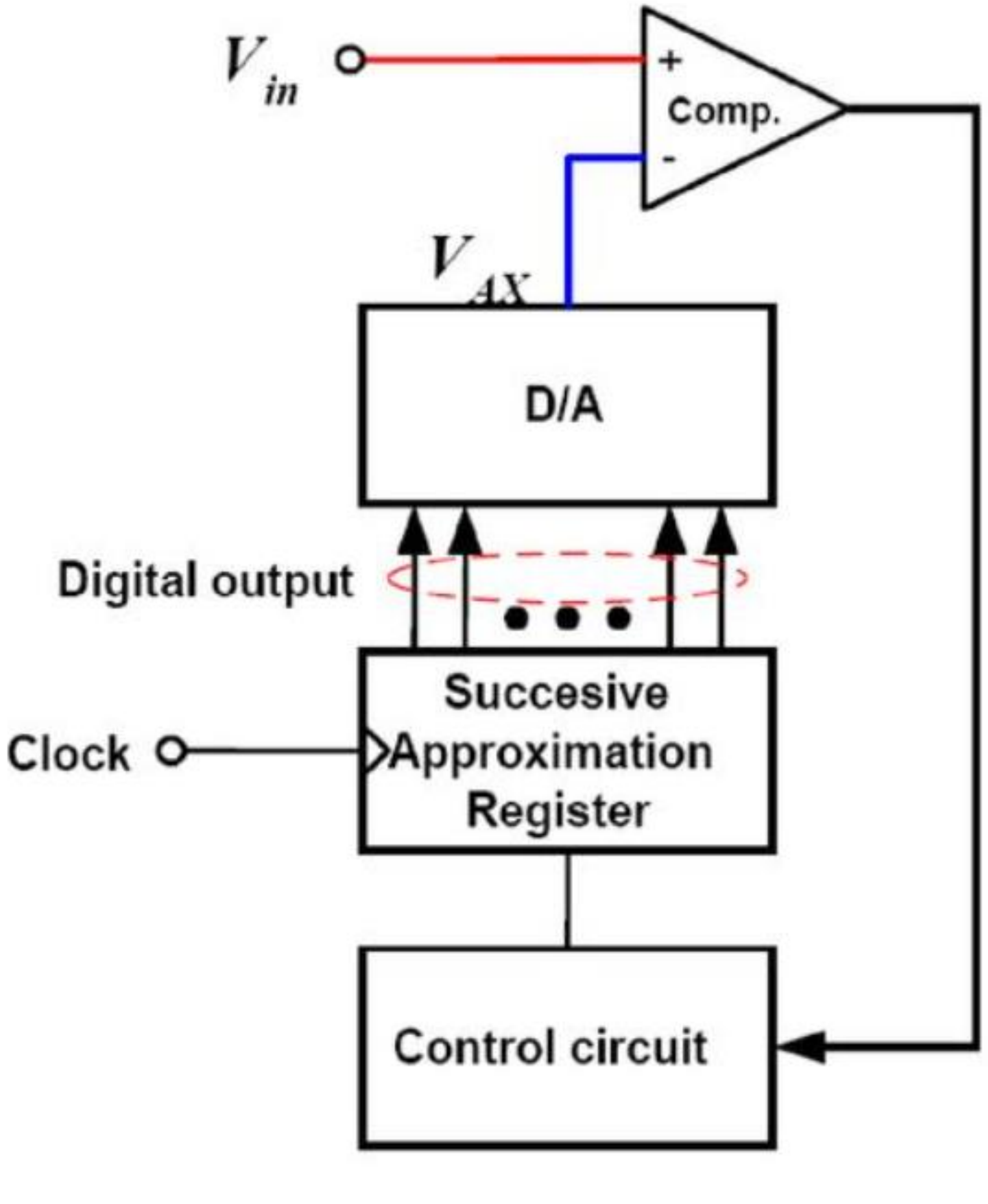


DUAL SLOPE INTEGRATING TYPE DVM

- It consist of an integrator circuit which takes the unknown input for certain time measured using a clock. The circuit consist of comparators ,capacitors ,clock and counters which generate the reference voltage with time. In this way we can measure the required voltage.
- In this, the integrator circuit receives an input signal for a specific period of time which is measured using clock frequency. During this time, the capacitor gets charged and the charge is proportional to the input voltage.
- At the end of this time, the switch is shifted from input voltage to a reference voltage and the charging of capacitor decreases creating a downward linear ramp voltage. This generates the required voltage.

SUCCESSIVE APPROXIMATION TYPE DVM

Compare the input voltage to the internally generated voltage

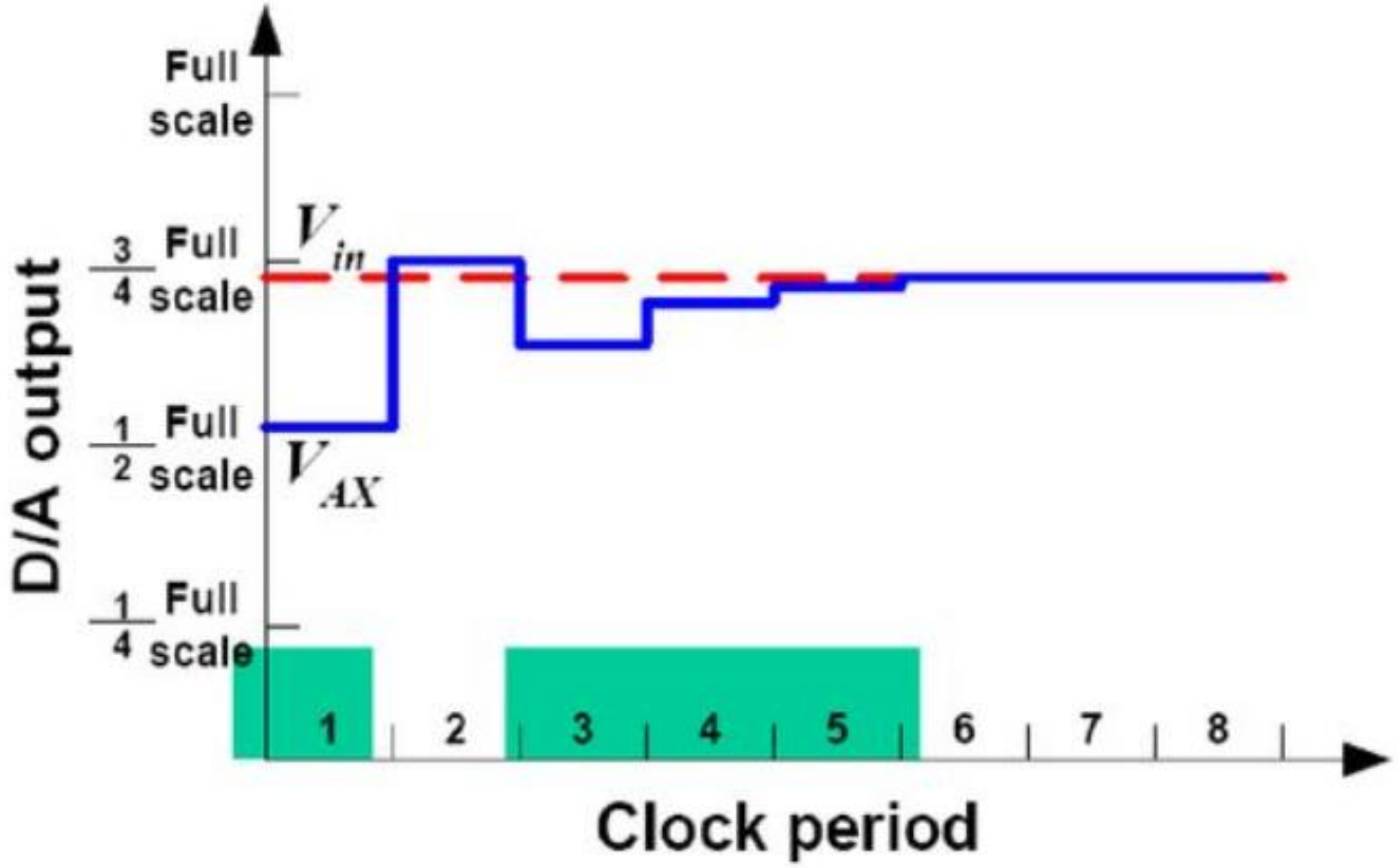


Block diagram

- The most common A/D for general applications
- Conversion time is fixed (not depend on the signal magnitude) and relatively fast

$$T_C = N \times \text{Clock period}$$

where N is the number of bits



SUCCESSIVE APPROXIMATION TYPE DVM

Ex. To determine a number between 0 – 511 (9 bit binary), given, the number to be determined is 301

No.	Estimate		Results
1	256	1 0000 0000	$V_{in} > V_{AX}$
2	256+128 = 384	1 1000 0000	<
3	256+64 = 320	1 0100 0000	<
4	256+32 = 288	1 0010 0000	>
5	288+16 = 304	1 0011 0000	<
6	288+8 = 296	1 0010 1000	>
7	296+4 = 300	1 0010 1100	>
8	300+2 = 302	1 0010 1110	<
9	300+1 = 301	1 0010 1101	Finished

ADVANTAGES OF DVM

- Since it does not involve reading from a pointer, it eliminates the human error that are caused by reading at an angle. This means gross errors are now removed giving precise results.
- They are more reliable and stable as compared to analog voltmeters which are comparatively unreliable while making readings.
- The output from DVMs can be provided to memory devices for the purpose of storage. This means that we can directly store the result of digital voltmeter in devices like flip flops.
- User don't require any extra manuals for using digital voltmeters as they are easy to read and give precise and accurate readings.
- Digital voltmeters are more durable than analog voltmeters. We say this because they provide accurate readings without being affected by external factors like atmosphere, temperature and moisture.

DISADVANTAGES OF DVM

- They are comparatively fragile than Analog voltmeters and need to be handled with care. They can get heated up on prolonged use and give wrong readings in that case.
- The speed of digital voltmeters is dependent on digitizing circuit being used .This might reduce the operational speed of the voltmeters making them slow.
- There is a certain threshold value associated with digital voltmeter and exceeding that value can damage the voltmeter without any prior warnings.
- In case of fluctuations in the output, digital voltmeter fails to detect them and can even give wrong readings in that case giving wrong output.
- Due to the designing of digital voltmeter in a certain way, it becomes almost impossible to measure transient voltage using this device. Hence measuring transient spikes through this meter is a difficult process.

CHARACTERISTICS OF DVM

Redesigning Common Mind & Business Towards Excellence

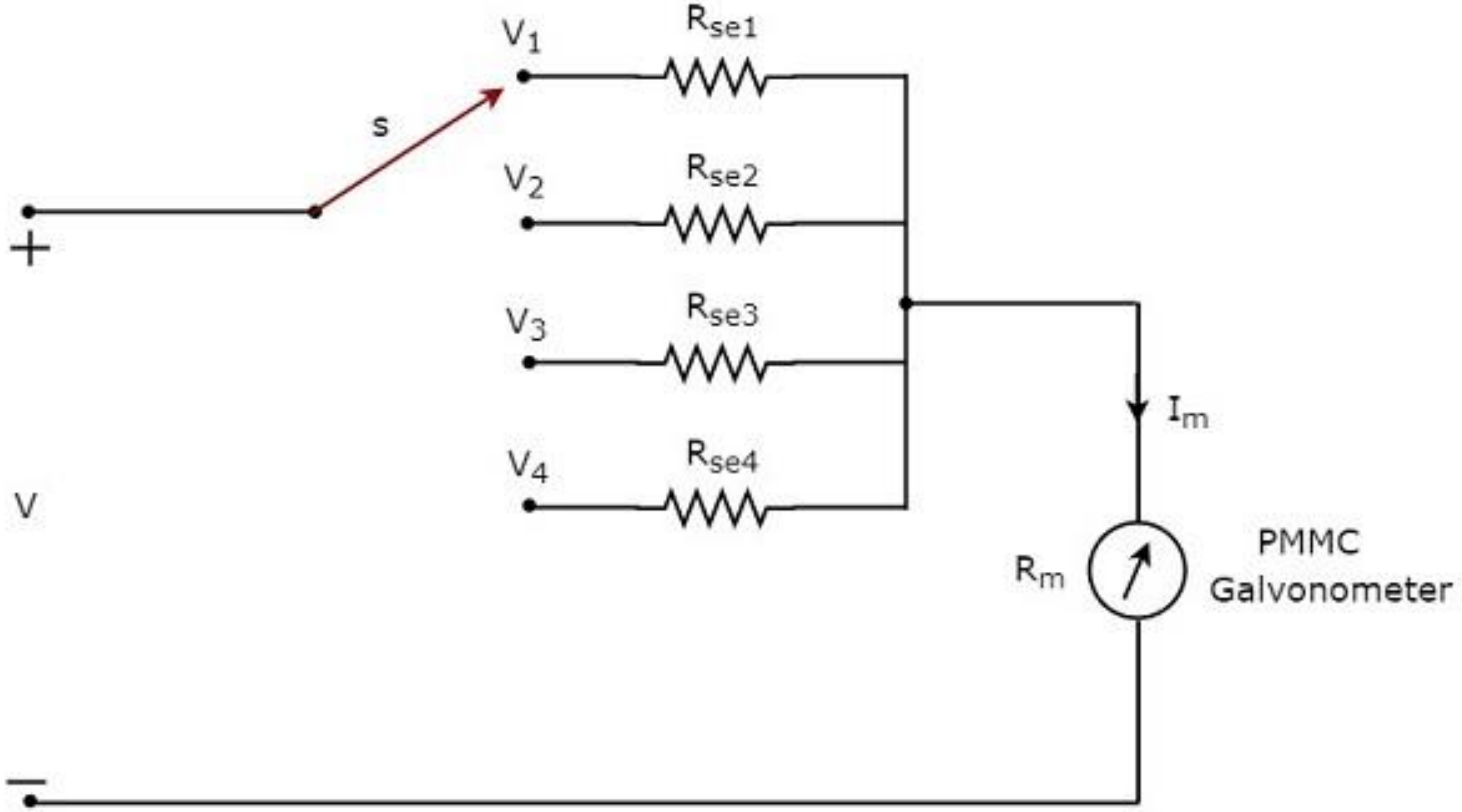
Build an Entrepreneurial Mindset Through Our Design Thinking FrameWork

- Input Range: From ±1.000 to ±1000V with automatic range selection and overload indication
- Absolute accuracy: As high as ±0.005% of the reading
- Resolution: 1 part in 10^6
- Stability: Short term – 0.002% of the reading for a 24-hr period

  Long term – 0.008% of the reading for a 6 month period
- Input resistance: Typically 10 MΩ
- Input capacitance: 40 pF
- Output signals: BCD form

MULTIRANGE VOLTMETER

- The DC voltmeter for measuring the DC voltages of **multiple ranges**, then use of multiple parallel multiplier resistors instead of single multiplier resistor and this entire combination of resistors is in series with the PMMC galvanometer.



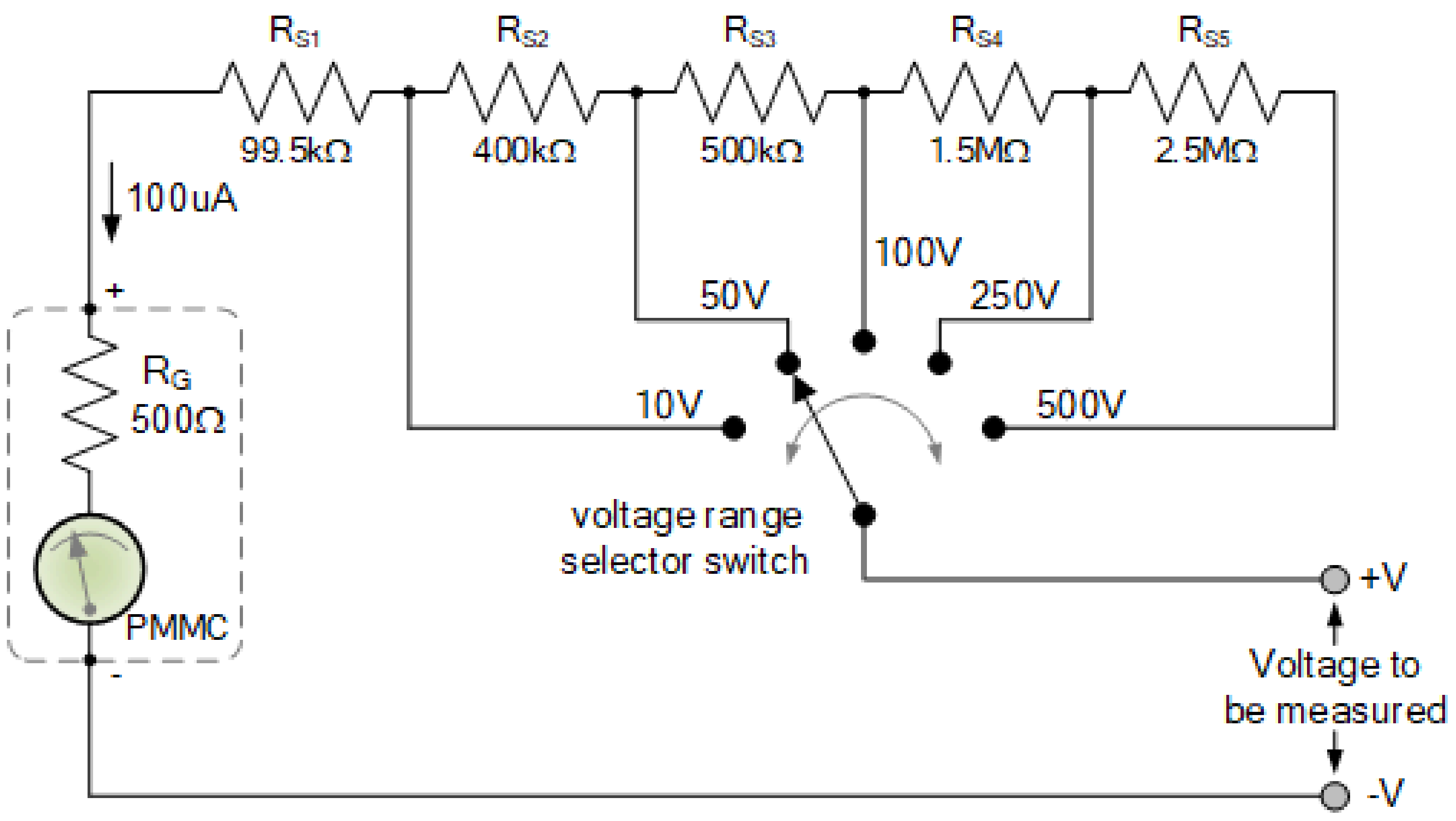
We have to place this **multi range DC voltmeter** across the two points of an electric circuit, where the DC voltage of required range is to be measured. We can choose the desired range of voltages by connecting the switch s to the respective multiplier resistor.

MULTIRANGE VOLTMETER

Redesigning Common Mind & Business Towards Excellence

Build an Entrepreneurial Mindset Through Our Design Thinking FrameWork

Let, m_1,m_2,m_3 and m_4 are the **multiplying factors** of DC voltmeter when we consider the full range DC voltages to be measured as, V_1,V_2,V_3 and V_4 respectively. Following are the formulae corresponding to each multiplying factor.



$$m_1 = \frac{V_1}{V_m}$$

$$m_2 = \frac{V_2}{V_m}$$

$$m_3 = \frac{V_3}{V_m}$$

$$m_4 = \frac{V_4}{V_m}$$

MULTIRANGE VOLTMETER

In above circuit, there are four **series multiplier resistors**, R_{se1},R_{se2},R_{se3} and R_{se4}. Following are the formulae corresponding to these four resistors.

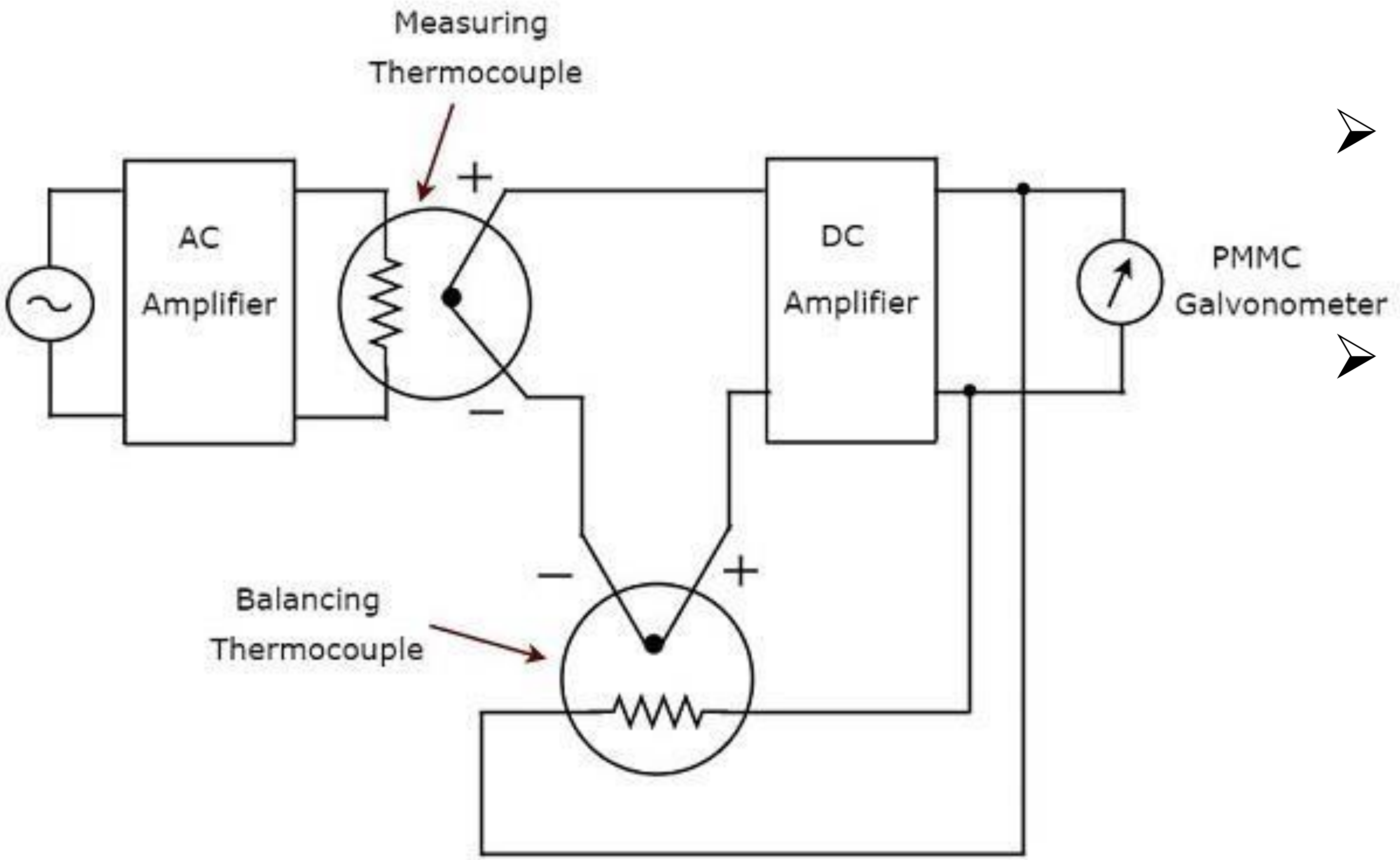
$$R_{se1} = R_m (m_1 - 1)$$

$$R_{se2} = R_m (m_2 - 1)$$

$$R_{se3} = R_m (m_3 - 1)$$

$$R_{se4} = R_m (m_4 - 1)$$

TRUE RMS VOLTMETER



- The true RMS AC voltmeter responds to the true RMS values of AC voltage signal.
- This voltmeter measures RMS values of AC voltages.

TRUE RMS VOLTMETER

- The above circuit consists of an AC amplifier, two thermocouples, DC amplifier and PMMC galvanometer. AC amplifier amplifies the AC voltage signal. Two thermocouples that are used in above circuit are a measuring thermocouple and a balancing thermocouple.
- **Measuring thermocouple** produces an output voltage, which is proportional to RMS value of the AC voltage signal.
- Any thermocouple converts a square of input quantity into a normal quantity. This means there exists a non-linear relationship between the output and input of a thermocouple..

TRUE RMS VOLTMETER

- The effect of non-linear behavior of a thermocouple can be neglected by using another thermocouple in the feedback circuit. The thermocouple that is used for this purpose in above circuit is known as **balancing thermocouple.**
- The two thermocouples, namely measuring thermocouple and balancing thermocouple together form a bride at the input of DC amplifier. As a result, the meter always responds to the **true RMS value** of AC voltage signal.

References

1. Albert D. Helfrick, William D. Cooper, "Modern Electronic Instrumentation and Measurement Techniques", Pearson, 1st Edition, 2016 (Unit IV-V).
2. Sawhney A K., "Course in Electrical, Electronic Measurements and Instrumentation", Shree Hari Publications, 2021(Unit IV-V).
3. Patranabis D, "Principles of Industrial Instrumentation", Mc-Graw Hill Education, 3rd Edition, 2017 (Unit IV-V).

Thank You