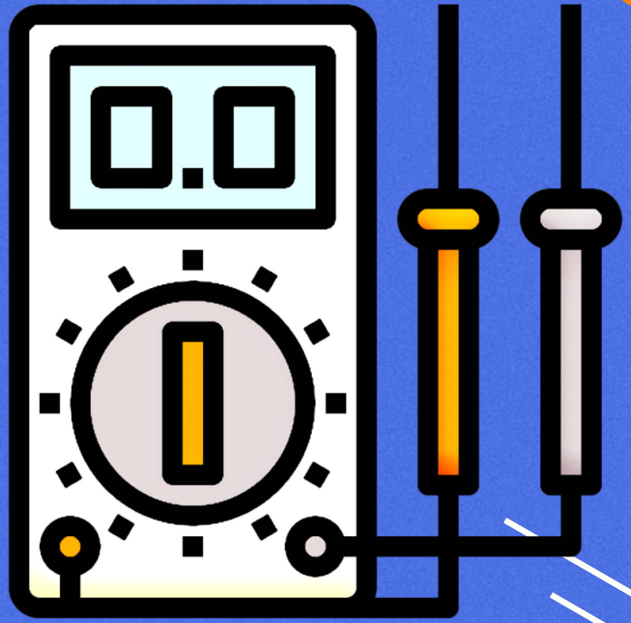
Electronics and Electrical Communications Engineering Dep.

2nd Year / 2nd Term

Electronic Measurements (2)

Lecture (2)



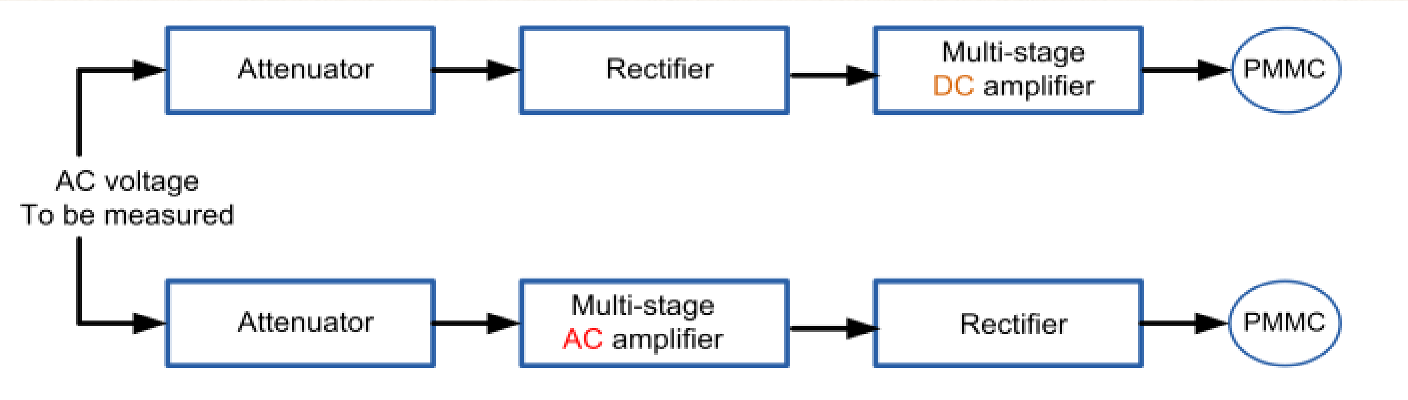
By Dr. Hager Fouda

Lecture Content

- AC Voltmeter
- AC Voltmeter Reading
- AC Voltmeter using Rectifier
- Rectifier basic Type AC Voltmeter
- Average Responding Voltmeter
- Peak Responding Voltmeter
- True Rms Responding Voltmeter
- Quasi Rms Detection
- AC Differential Voltmeter

Ac Voltmeter

❑ Electronic Analog Ac Voltmeter



- ❑ The main difference between AC voltmeter circuit and DC voltmeter circuit is **the usage of a rectifier.**
- ❑ The rectifier is used in order to transform the AC voltage into DC voltage.

Ac Voltmeter

AC Electronic Analog Voltmeter

- ❑ AC Voltmeter Using Rectifier
  - ▪ Rectification before Amplification
  - ▪ Amplification before Rectification
  - ▪ Using Half Wave Rectifier (HWR)
  - ▪ Using Full Wave Rectifier (FWR)
- ❑ Average Responding Voltmeter
- ❑ Peak Responding Voltmeter
- ❑ True RMS Voltmeter
- ❑ Quasi RMS Detection
- ❑ AC Differential Voltmeter

Ac Voltmeter Reading

1. Peak value (V_m)

It is the maximum value attained by the AC waveform either in the positive half cycle or negative half cycle. It is also known as **amplitude.**

2. Average value

- ❑ It is the average of all the instantaneous value over a period of **a half one complete cycle**.
- ❑ For **symmetrical** AC quantity, the average value over a complete cycle is zero. Hence average value is calculated over a half cycle.
- ❑ If the AC quantity is continuous then average value can be expressed mathematically using an integration.

$$\boxed{V_{ave} = \frac{2}{T}\int_0^{T/2} v_{in}\, dt}$$

Ac Voltmeter Reading

3. Root mean squared (RMS) value

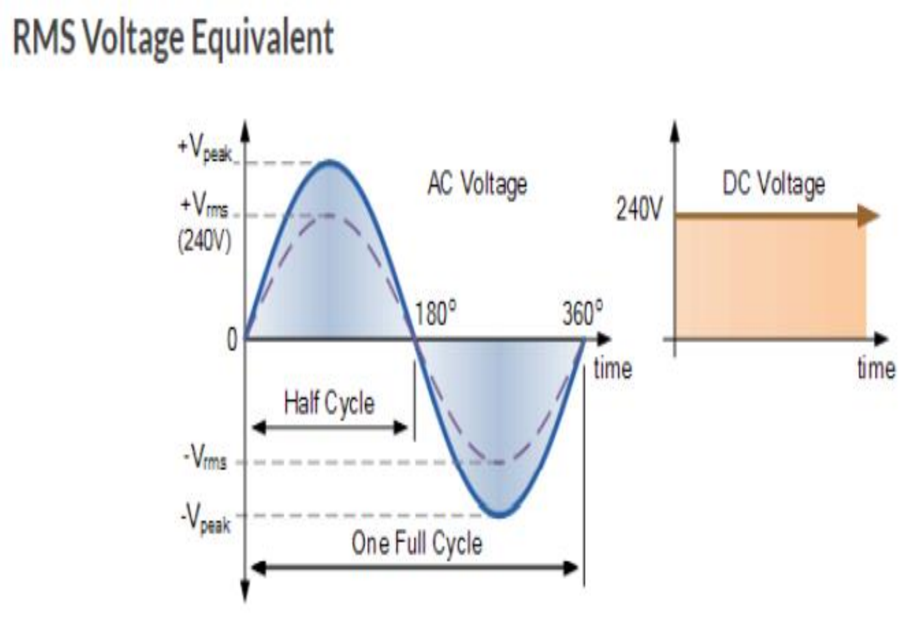
- RMS" stands for Root Mean Square, and is a way of expressing an AC quantity of voltage or current in terms functionally equivalent to DC.
- For example, 10 volts AC RMS is the amount of voltage that would produce **the same** amount of heat dissipation across a resistor of given value as a 10 volt DC power supply.
- The RMS value is the effective value of a varying voltage or current.
- It is the equivalent steady DC (constant) value which gives the same effect.
- For example, a lamp connected to a 6V RMS AC supply will shine with the same brightness when connected to a steady 6V DC supply.

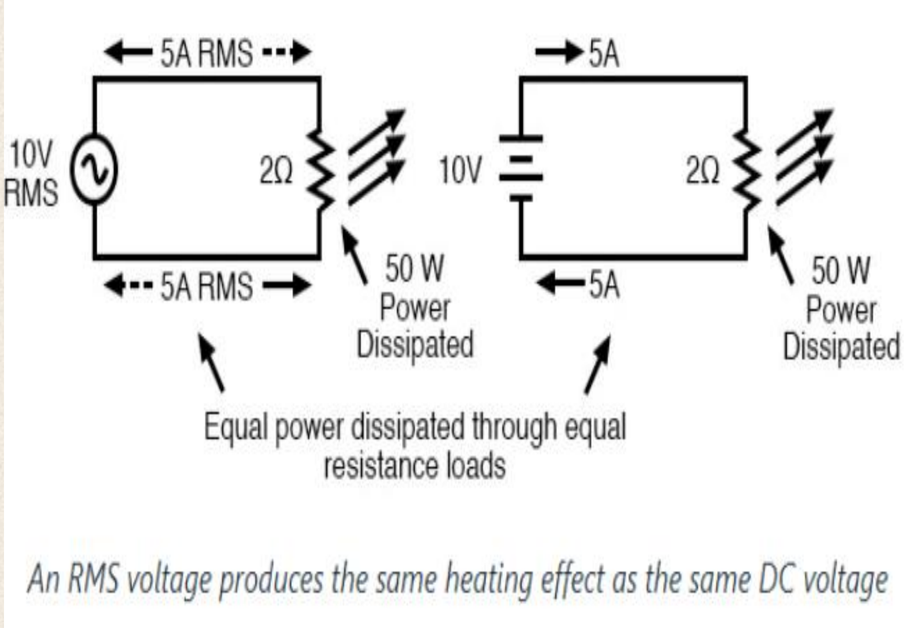
$$\boxed{V_{rms} = \sqrt{\frac{1}{T}\int_0^T \boldsymbol{v_{in}}^2 \, dt}}$$

Ac Voltmeter Reading

- For purely **sinusoidal** quantity

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$





Ac Voltmeter Reading

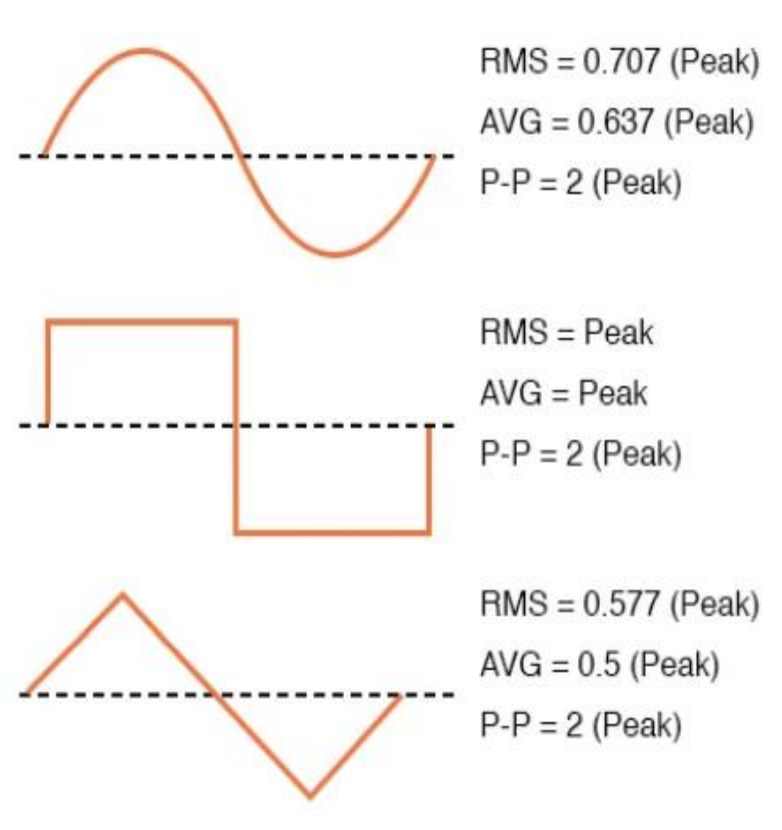
- The scale on AC voltmeters are ordinarily **calibrated** in rms values of a sinusoidal wave form.

$$\boldsymbol{Form\ Factor = \frac{rms\ \ value}{average\ value}}$$

$$\boldsymbol{Peak\ Factor = crest\ factor = \frac{peak\ \ value}{rms\ value}}$$

- For purely sinusoidal quantity

$$\boldsymbol{Peak\ Factor = \sqrt{2} = 1.414}$$



Sensitivity of Voltmeters

$$\boxed{Sensitivity\ (S) = \frac{1}{I_{FSD}}\ \Omega/V}$$

- where I_{FSD} is the full scale deflection current

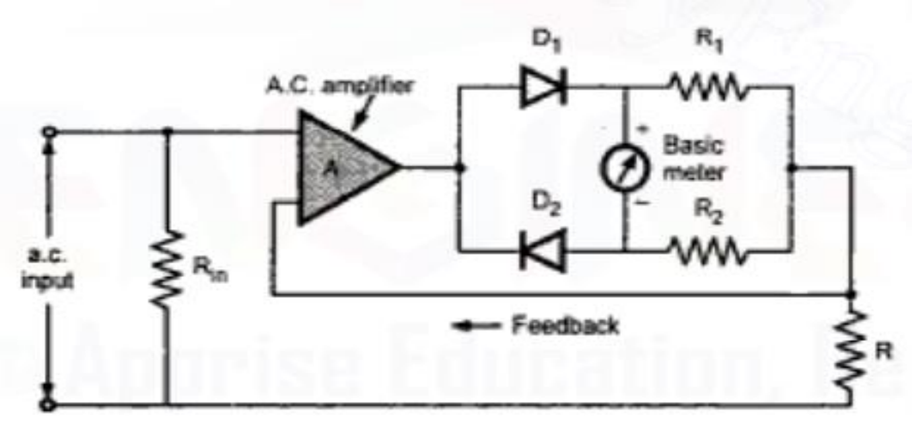
- It is also called **the ohm per volt rating** of the voltmeter.
- Internal resistance of the voltmeter can be obtained by:

$$\boxed{R_m = Maximum\ Voltage\ range \times\ sensitiviy\ \ in\ \Omega/V}$$

- The sensitivity is useful in calculating **the multiplier resistance** values, **required for multi-range voltmeter.**

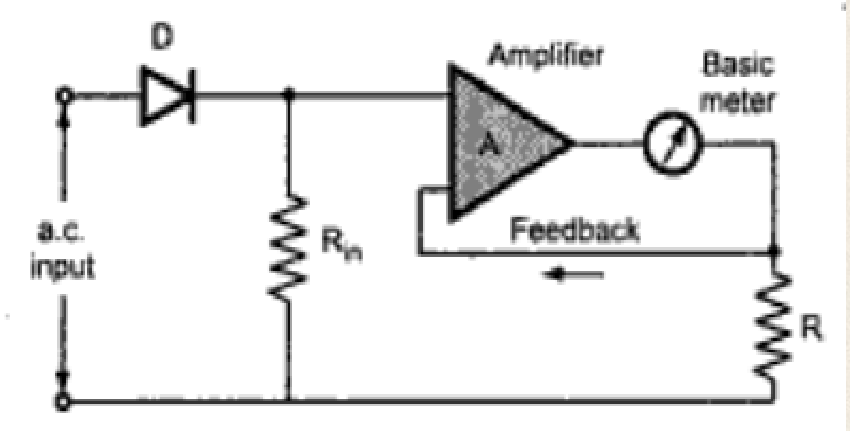
AC Voltmeter Using Rectifier

AC Voltmeter with First Amplification



- The AC amplifier requires a high open loop gain and large amount of negative feed back to **overcome the non-linearity** of the rectifier diodes

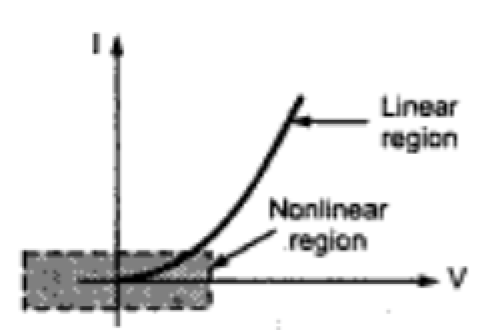
AC Voltmeter with First Rectification



- This approach ideally requires a DC amplifier **with zero drift** characteristics and a DC meter movement with high sensitivity.

AC Voltmeter Using Rectifier

Diode using limitation

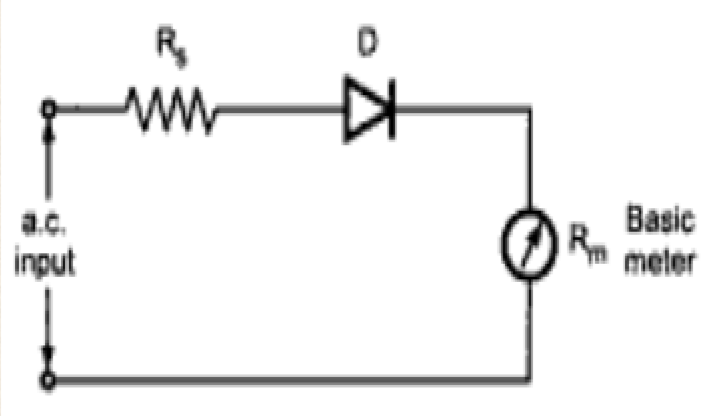


1. The diode are **nonlinear** device particularly at low values of the forward current. Due to this nonlinearity, the meter scale is also nonlinear and is crowded at the **lower end of a low range voltmeter**. In this region, the meter sensitivity is also very low because of **high** forward resistance of the diode.
2. Depending of diode characteristics on **temperature** is also an important factor in AC voltmeters.
3. The rectifier shows the **capacitance properties** under reverse biased and tends to bypass **high** frequencies. The meter reading may have error due to such effect of the order of 0.5% decrease for every $1KHz$ rise in the frequency.

Basic Rectifier Type AC Voltmeter

AC Voltmeter Using HWR

- ❑ The diode conducts only for half cycle and meter movement is **bypassed** for another cycle.
- ❑ The rectified DC is a pulsating DC, hence the meter will deflect proportional to the **average value**.
- ❑ The pointer will deflect for a full scale if 10 V dc is applied and $4.5\ V$ when a $10\ V_{rms}$ sinusoidal signal is applied.
- ❑ This means that an ac voltmeter is less sensitive than a dc voltmeter. As $V_{ave} = V_{dc} = \frac{V_m}{\pi} = 0.45\ V_{rms}$
- ❑ For half wave, the value of **the multiplier resistor** is obtained as:



$$\boxed{\boldsymbol{R_S = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45\ E_{rms}}{I_{dc}} - R_m}}$$

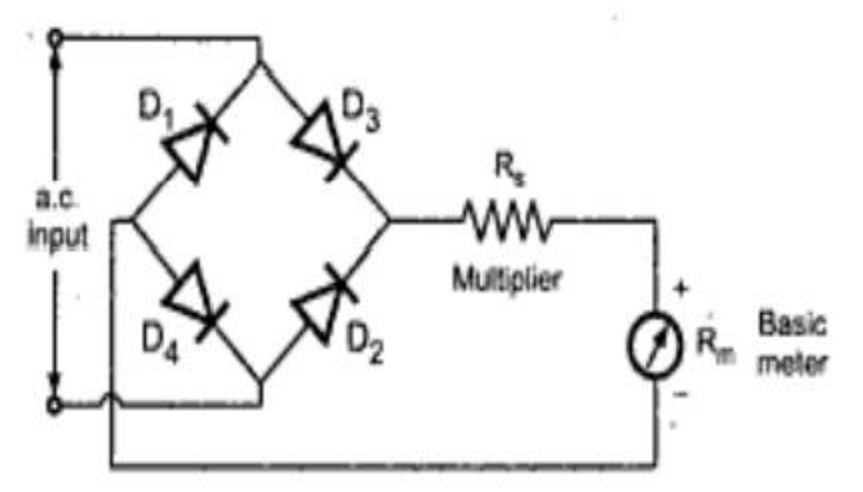
- where $I_{dc} = I_{FSD}$ is the full scale deflection current.

Basic Rectifier Type AC Voltmeter

AC Voltmeter Using FWR

- As $V_{ave} = V_{dc} = \frac{2V_m}{\pi} = 0.9\,V_{rms}$: we can see that a $10\,V_{rms}$ voltage is equal to a $9\,V_{dc}$ for full scale deflection, i.e. the pointer will deflect to 90% of full scale.

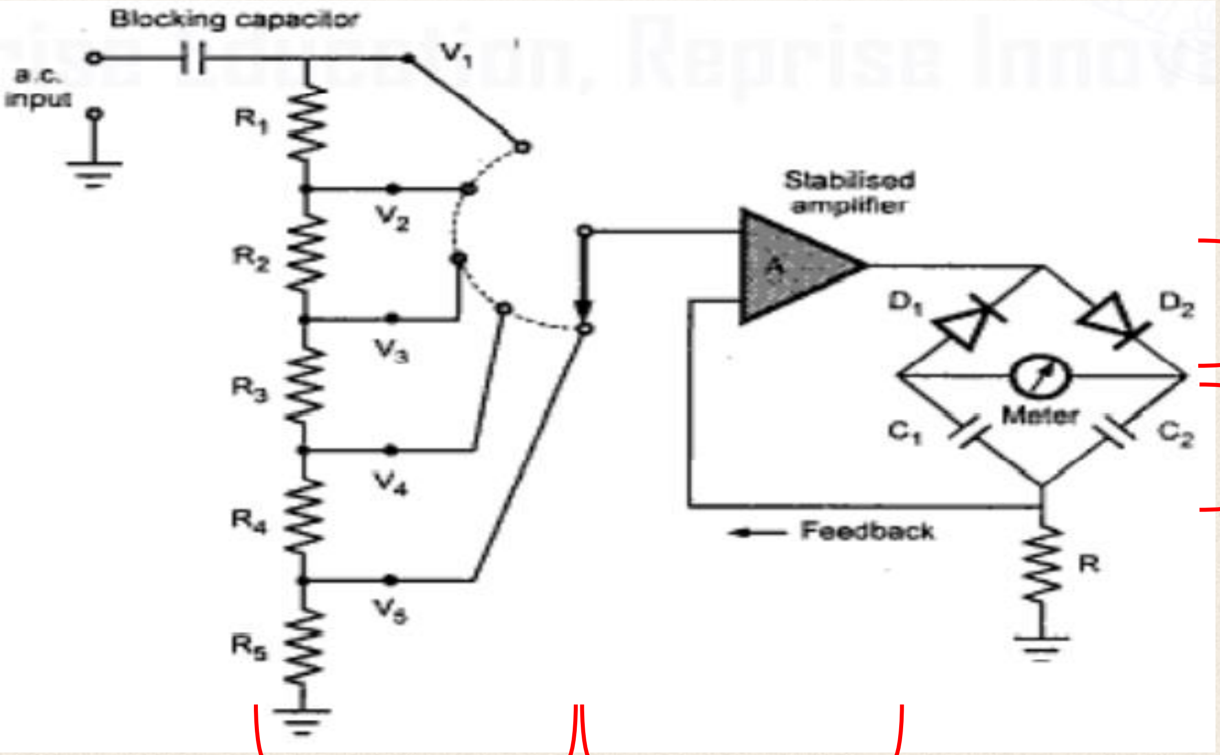
$$\boldsymbol{Sensitivity\ of\ AC\ voltmeter = 0.9 \times Sensitivity\ of\ DC\ voltmeter}$$



- **For full wave**, the value of the multiplier resistor is obtained as:

$$\boldsymbol{R_S = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.9\,E_{rms}}{I_{dc}} - R_m}$$

Average Responding Voltmeter



Rectification

Integration

Range selection

Amplification

Average Responding Voltmeter

- Blocking capacitor used at the input side **blocks** any dc component in the input voltage.
- The ac input applied is **first amplified** with the help of high gain stabilized amplifier.
- This voltage is then **rectified** using diodes D1 and D2.
- The rectified voltage is fed to a **dc milliammeter** used as a measuring meter.
- The current obtained from the rectifier is **averaged** by using **a filter** to produce a steady state deflection of the meter pointer.
- The dc milliammeter is **calibrated in term of rms value** of the input voltage.
- The meter responds to **the average reading** of the input, hence called the average responding meter.
- The capacitor C1 and C2 in the rectifier circuit act as **filter** capacitors. These capacitors also act as the **coupling capacitors** in the feedback path.

Average Responding Voltmeter

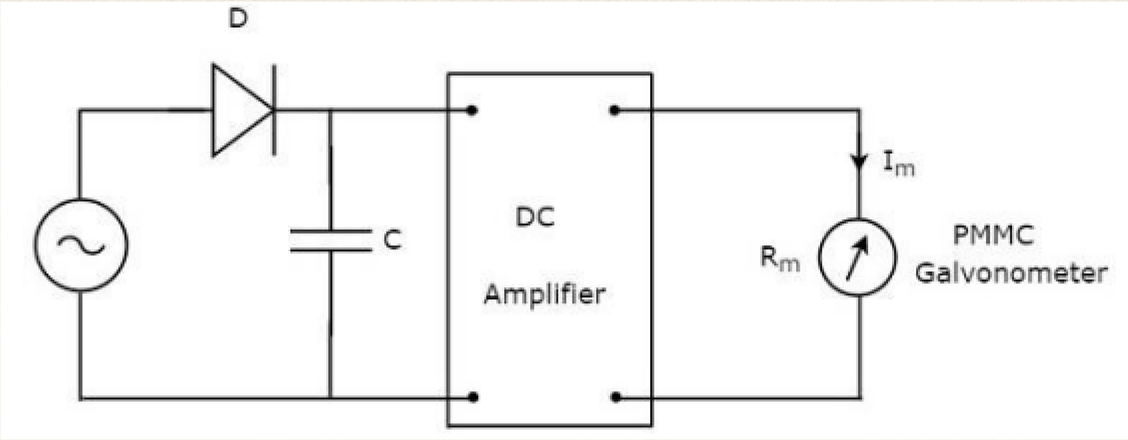
- Large amount of **negative feedback** is used for the amplifier to:
  - Ensure stability for measurement accuracy.
  - Increase the frequency range of the instrument.
  - Minimize the effect of diode nonlinearity.
  - Compensate any changes in the meter impedance.

Advantages

Disadvantages

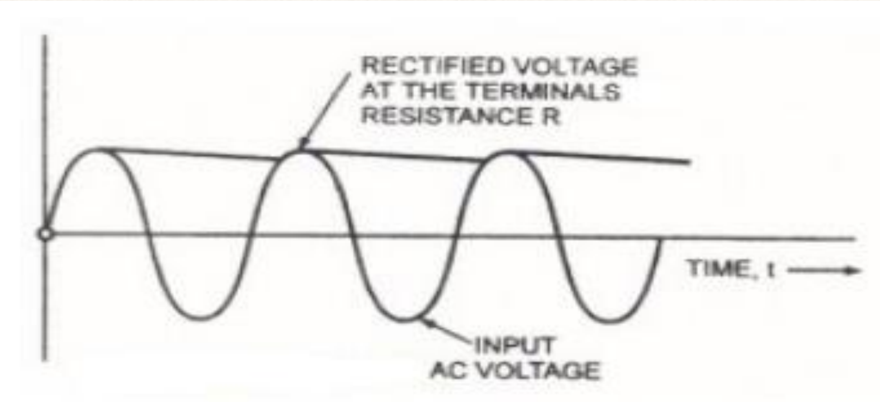
- Waveforms which are distorted, nonuniform, nonsinusoidal including hum or noise, **produce errors** in the reading.
- Accuracy of the meter depends not only on the amplitude but also on the phase of the harmonic contents at the input side.

Peak Responding Voltmeter



- The primary difference between the peak-responding voltmeter and the average responding voltmeter is **the usage of a storage capacitor** with the rectifying diode.
- The diode present in the above circuit is used for rectification purpose. So, the diode converts AC voltage signal into a DC voltage signal.
- The capacitor charges to the peak value of this DC voltage signal.

Peak Responding Voltmeter



- During positive half cycle of AC voltage signal, the diode conducts and the capacitor **charges to the peak value** of AC voltage signal.
- When the value of AC voltage signal is less than this value, the diode will be reverse biased.
- Thus, the capacitor will discharge through the resistor R of DC amplifier till the next positive half cycle of AC voltage signal.
- When the value of AC voltage signal is greater than the capacitor voltage, the diode conducts and the process will be repeated.

Peak Responding Voltmeter

- We should select the component values in such a way that the capacitor **charges fast and discharges slowly.**
- As a result, the meter always responds to this capacitor voltage, i.e. the peak value of AC voltage.
- The condition is: $RC >> T$

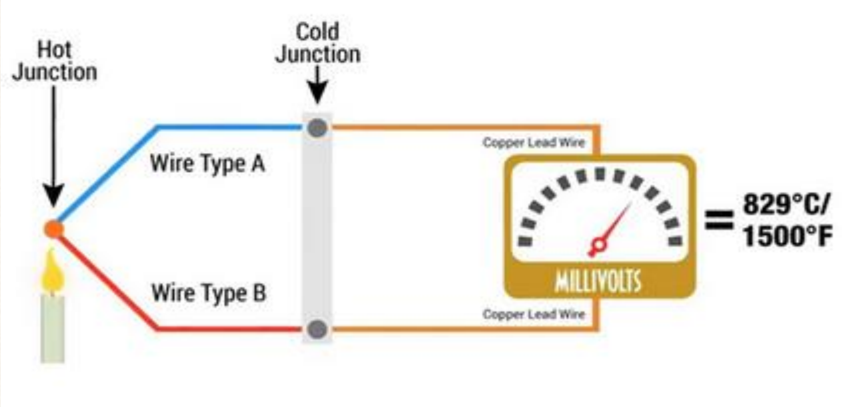
Disadvantages

- Harmonic distortion in the input causes errors.
- The instrument has limited sensitivity due to imperfect and nonlinear diode characteristics.
- Error is introduced if the input waveform is not symmetrical.

True RMS Responding Voltmeter

Thermocouple

- A Thermocouple is a sensor used **to measure temperature.**
- It consist of two wire legs made from different metals.
- The wires legs are welded together at one end, creating a junction.
- This junction is put where the temperature is measured.
- When the junction experiences a change in temperature, **a voltage is created.**



True RMS Responding Voltmeter

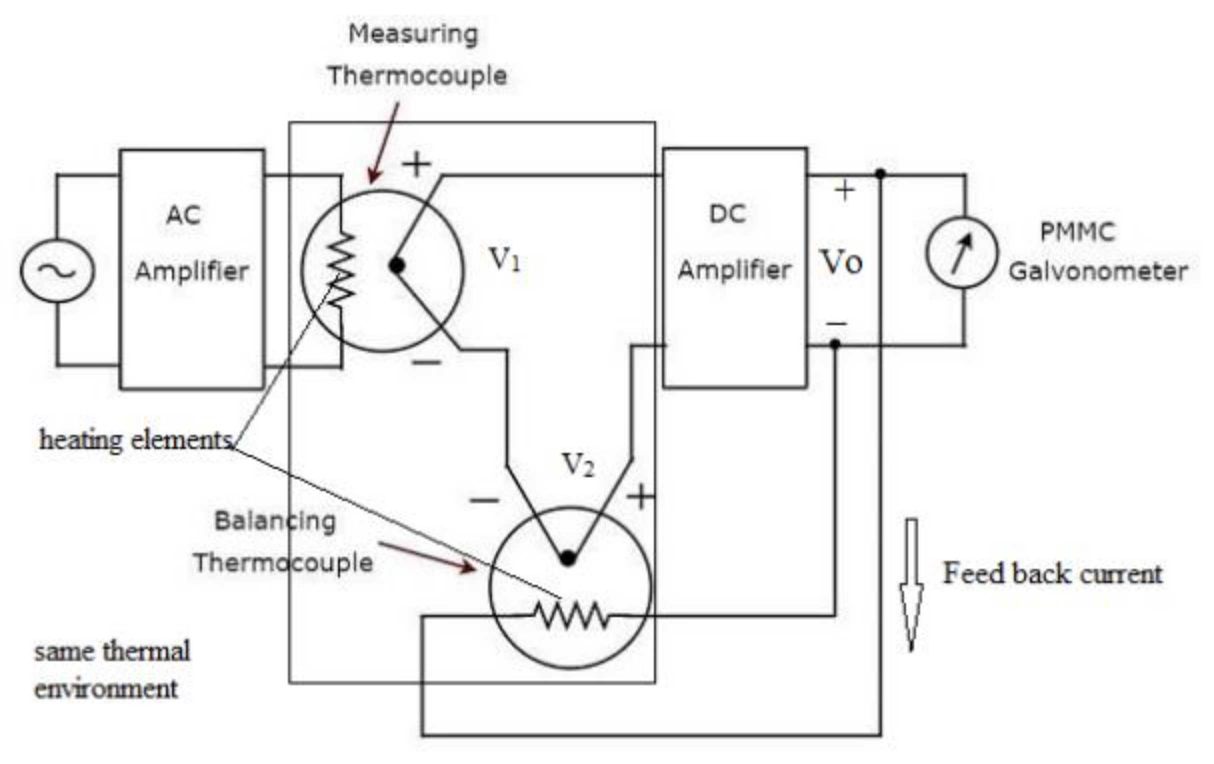
- The heating power $\propto {V_{rms}}^2$
- $\text{Power} = \frac{{V_{rms}}^2}{R_{heater}}$, where R_{heater} is the heater resistance.
- Thermocouple output voltage V_{out} $\propto$ heat $\propto$ power.
- $V_{out} = \frac{k_t {V_{rms}}^2}{R_{heater}}$
- k_t is the proportionality constant depends on the distance between the heater and the thermocouple hot-junction and also on the materials used in the heater and thermocouple.

True RMS Responding Voltmeter

Working Principle of True RMS Responding AC Voltmeter

- **Complex** waveforms are most accurately measured with a **true RMS** responding voltmeter.
- This instrument produces a meter indication (deflection) by: sensing the waveform heating power (usually using a thermocouple) .
- The heating power is proportional to the square of the RMS value of the input waveform (voltage).
- This heating power can be measured by feeding an amplified version of the input waveform to the heater element of a thermocouple whose
- output voltage is then proportional to ${V_{rms}}^2$

True RMS Responding Voltmeter



True RMS Responding Voltmeter

Factors that affect the reading accuracy

- ❑ **Thermal radiation**

Overcome by enclosing the heater and thermocouple **in the same** thermal environment, e.g., glass bubble.

- ❑ **Non-linear characteristics of the thermocouple**

- Overcome using balancing thermocouple where the effect of non-linear behavior of the thermocouple in the input circuit (measuring thermocouple) is **cancelled** by similar non-linear effects of the thermocouple in the feedback circuit (balancing thermocouple).
- Furthermore, the two thermocouples are placed in the same thermal environment. The two thermocouples balancing and measuring form a balanced bridge in the input circuit of the DC amplifier

True RMS Responding Voltmeter

- The unknown ac voltage is amplified and applied to the heating element of the measuring thermocouple.
- The application of heat produces an output voltage (V1) that upsets the balance of the bridge.
- The dc amplifier amplifies the unbalanced voltage.
- The amplified voltage is fed back to the heating element of the balancing thermocouple, which heats the thermocouple to produce (V2), such that the bridge is balanced again, i.e. the outputs of both the thermocouples are the same.
- At this instant, the DC current in the heating element of the feedback thermocouple is equal to the AC current in the input thermocouple.
- This DC current is therefore **directly proportional** to the effective, or RMS, value of the input voltage and is indicated on the meter movement in the output circuit of the DC amplifier.

True RMS Responding Voltmeter

- In balanced condition of the bridge: $V_1 = V_2$.

where V_1 : is the output of the measuring thermocouple. and V_2: is the output of the balancing thermocouple.

- $V_1 = k_1 {V_{rms}}^2$

where V_{rms} is the RMS value of the input waveform.

- $V_2 = k_2 {V_o}^2$

where V_o is the output DC voltage.

- $k_1 = k_2 = \frac{k_t}{R_{heater}}$

- Due to thermal environment used for the two thermocouples:

$${V_{rms}}^2 = {V_o}^2 \rightarrow V_{rms} = V_o$$

- The true RMS value is measured **independent** of the waveform of the ac input provided that, the peak amplitude of the ac input is within the dynamic range of the ac amplifier.

True RMS Responding Voltmeter

Advantages

- Nonlinear behavior is avoided by using two thermocouples placed **in the same** thermal environment.
- True rms value measured is independent of the waveform of the ac input, if the peak amplitude of the ac input is within the dynamic range of the ac amplifier.
- Voltages through a range of $100\,\mu V$ to $300\,V$ within a frequency range $10Hz$ to $10MHz$ can be measured.

Disadvantages

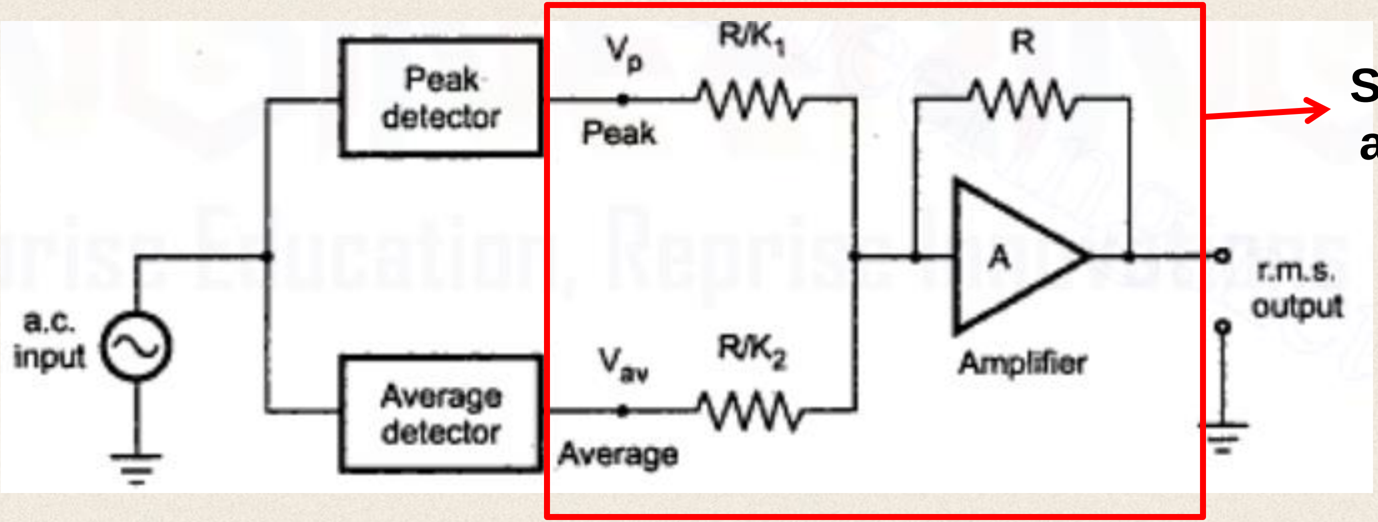
- Response of thermocouples is very slow, hence the overall response of the meter sluggish.
- Meter cost is high compared to average and peak responding meters.

Quasi rms Detection

- Rms value of waveform can be expressed as

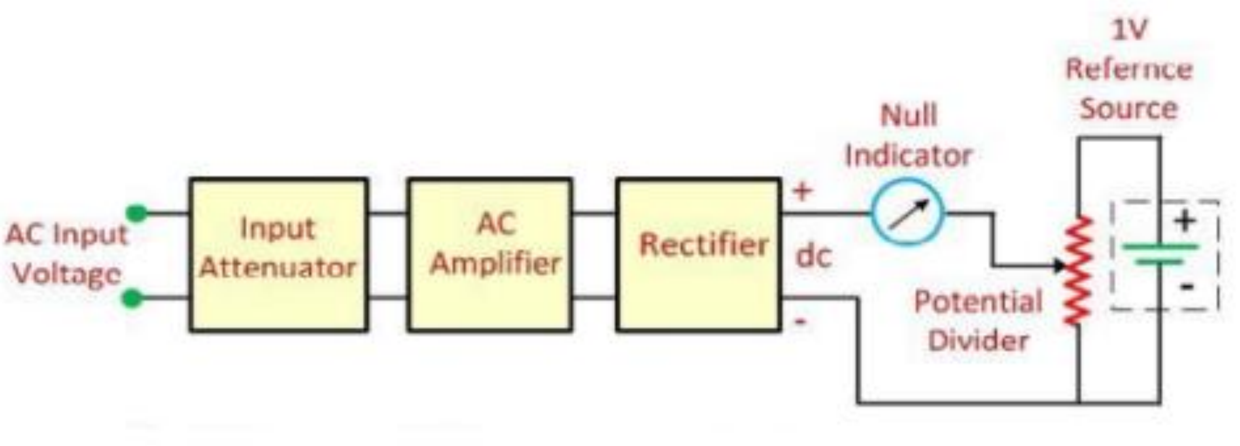
$$\boxed{V_{rms} = K_1\, V_m + K_2\, V_{ave}}$$

- In this technique, rms value of the input waveform is measured by using **average and peak detectors.**



Summing amplifier

AC Differential Voltmeter



- ❑ The rectifying AC voltage compares with the standard DC voltage.
- ❑ The meter shows the null deflection when their magnitudes become equals.

Lecture References

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2. Kishore, K. Lal. Electronic Measurements and Instrumentation. Pearson Education India, 2009.
3. Dr. Nansy El-Shaer. Electronics and Electrical Communications Engineering Faculty of Engineering Tanta University. Electronic Analog Voltmeter lectures.

Thank you!

Any question?

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