ANALOG AND DIGITAL INSTRUMENTS

Digital Voltmeter (DVM)

- Used to measure the ac and dc voltages and displays the result in digital form.

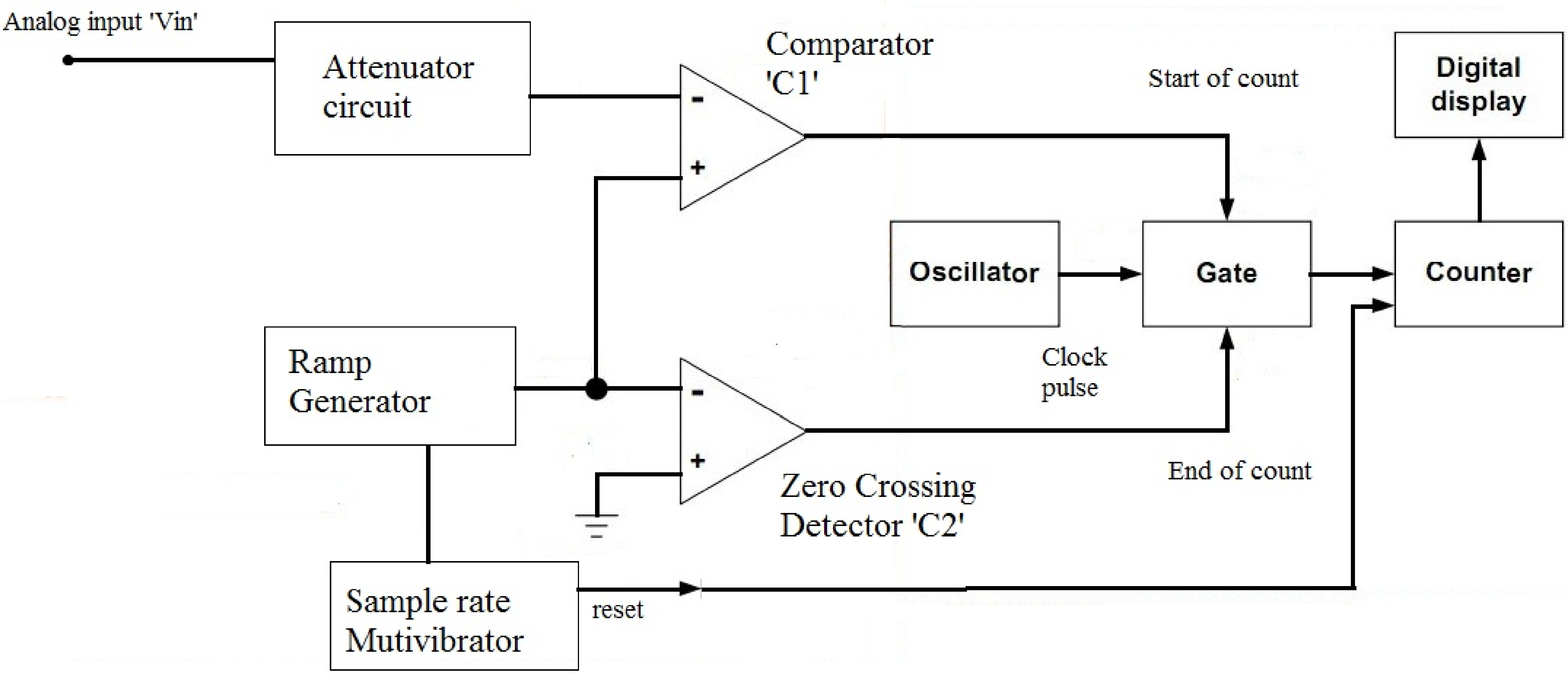
Types:

- Ramp type DVM
- Integrating type DVM
- Potentiometric type DVM
- Successive approximation type DVM
- Continuous balance type DVM

Advantages:

1. Errors on account of parallax and approximations are entirely eliminated
2. Operating speed is increased
3. Data can be fed to memory devices for storage and future computation.
4. Size reduced after the advent of ICs and easily portable.

Block Diagram - Ramp type DVM



Ramp type DVM

Principle:

Input voltage is converted into digital equivalent by counting the time taken for the ramp wave to decrease from the magnitude of input voltage to 0V.

Construction:

The block diagram of the Ramp-type ADC can be divided into two sections as follows:

1. Voltage to time conversion section
2. Time measurement section

Voltage to time conversion section

- In the voltage to time conversion section, the analog input voltage is fed to the attenuation circuit. The attenuated signal is compared with the the ramp signal generated by the ramp generator given in the block diagram by the input comparator 'C1'. Similarly, The ramp signal generated is compared with 0V via a zero-crossing detector 'C2'. A sample rate multivibrator is connected to the ramp generator whose purpose is to provide an initiating pulse for the ramp generator to start the next ramp voltage for the next measurement. It is also used to reset the counter before generating the next ramp voltage.

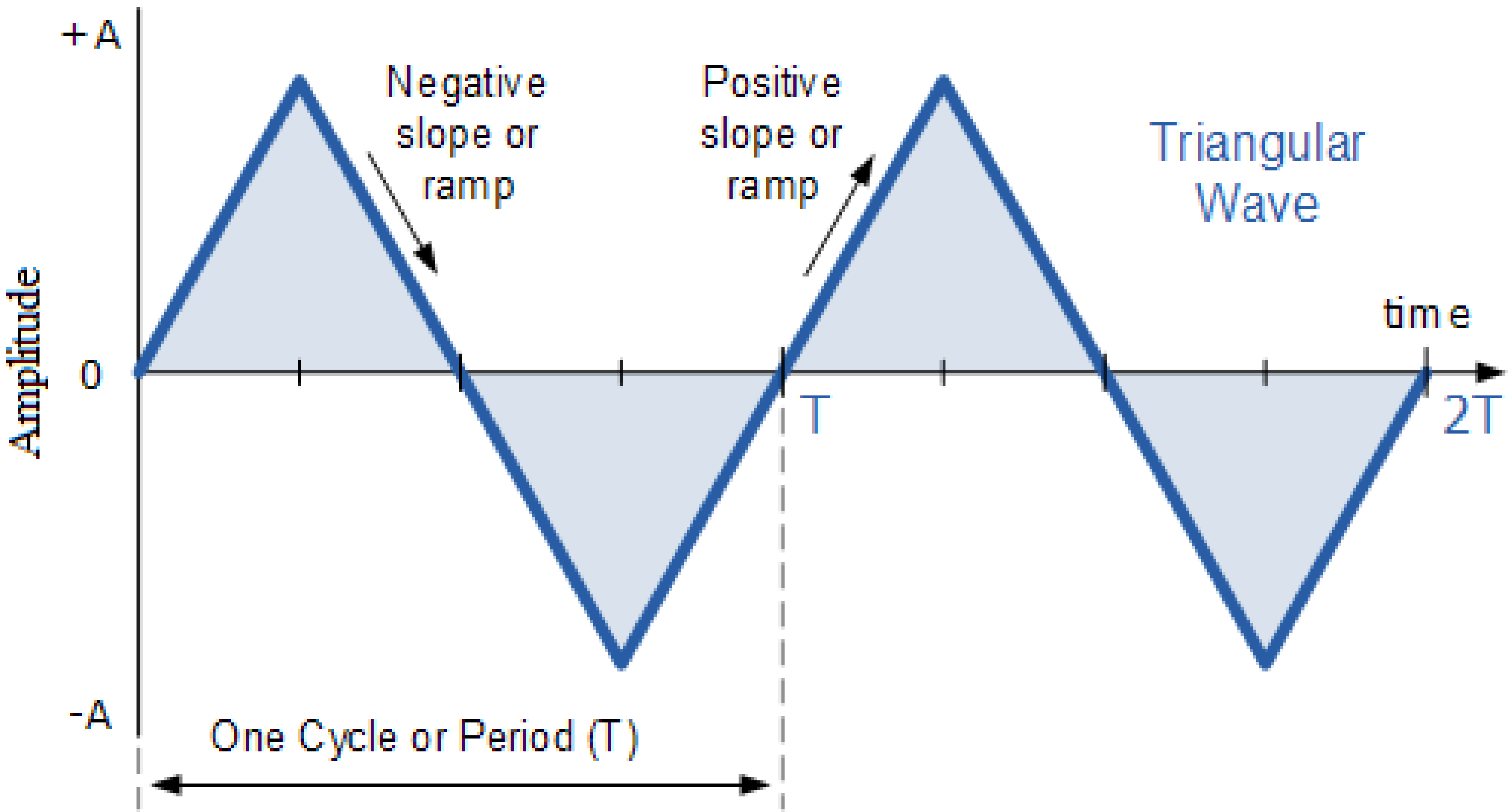
Time measurement section

- In the time measurement section, there is counter which is triggered by a gating pulse. The inputs of the gating pulse are (i) Output of 'C1' (ii) Output of 'C2' (iii) Clock pulse from the oscillator. The counter is reset after each successful completion of time measurement by a control signal from the sample rate multivibrator. The count produced is displayed by connecting suitable display device.

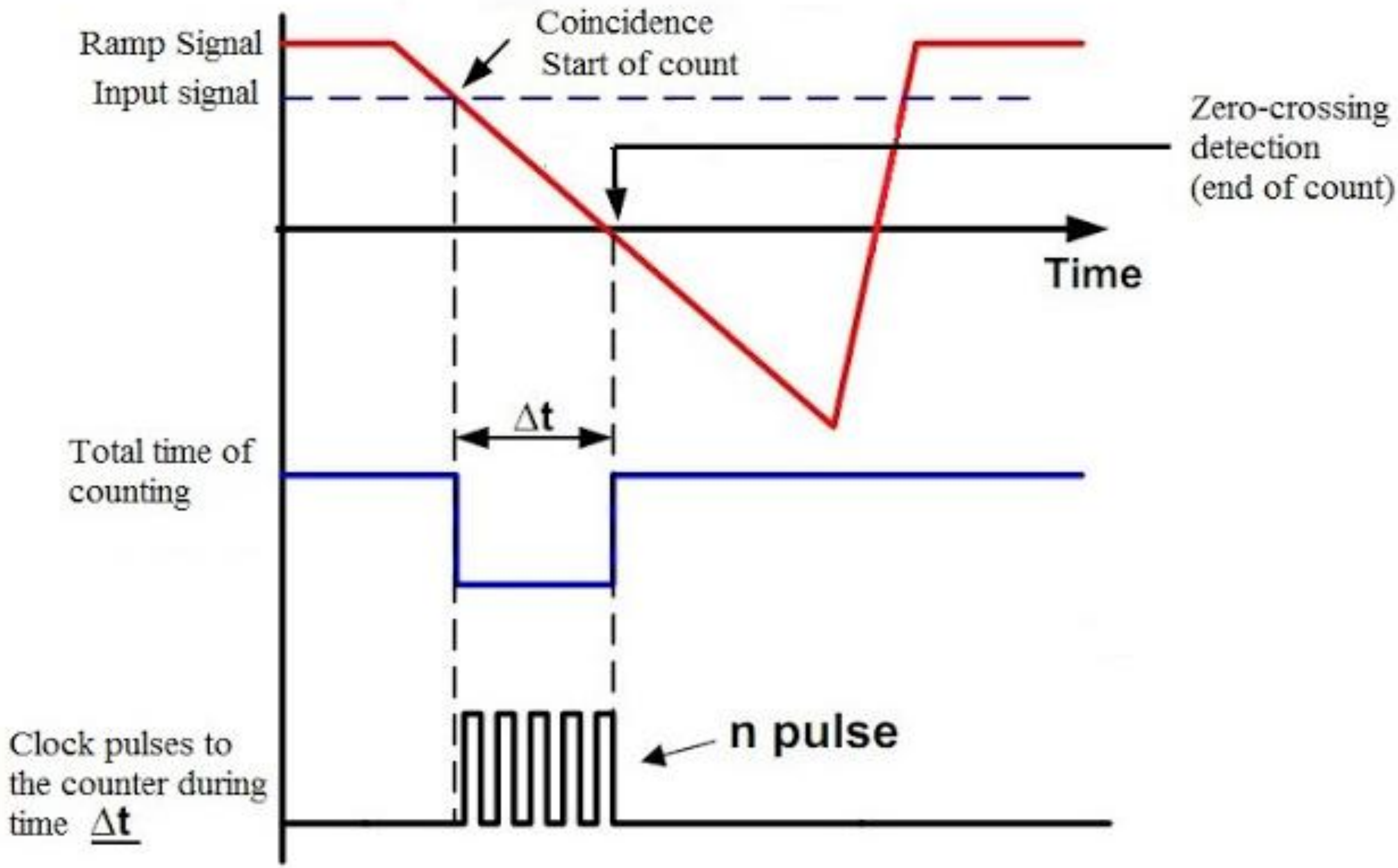
Operation

- Initially, the attenuated signal is compared with a negative going ramp signal generated by the ramp generator. When the ramp voltage coincides with the input signal, the output of 'C1' becomes low. This point is called coincidence point. This initiates the counting process (start of count). The counter continues to count until the ramp voltage reduces and crosses zero (0V). This is detected by zero crossing detector 'C2'. The output of 'C2' becomes high which ends the counting process (end of count).

Triangular wave displaying Ramp type



Waveform Analysis



Waveform

- The count displayed is the count of number of clock pulses produced by the oscillator during the time in which the ramp signal is less than the input signal and greater than 0V (ie) |input signal| > ramp > 0V. This count gives the digital equivalent of input analog voltage.

DVM

Equations Involved:

$(\Delta)t = t2 - t1 = Vin/m = nT$;

Hence, $Vin = nmT$;

where

t1-> start of count

t2-> end of count

Vin-> input analog voltage

m-> slope of the ramp curve

n-> number of clock pulses to counter

T-> clock period

DVM

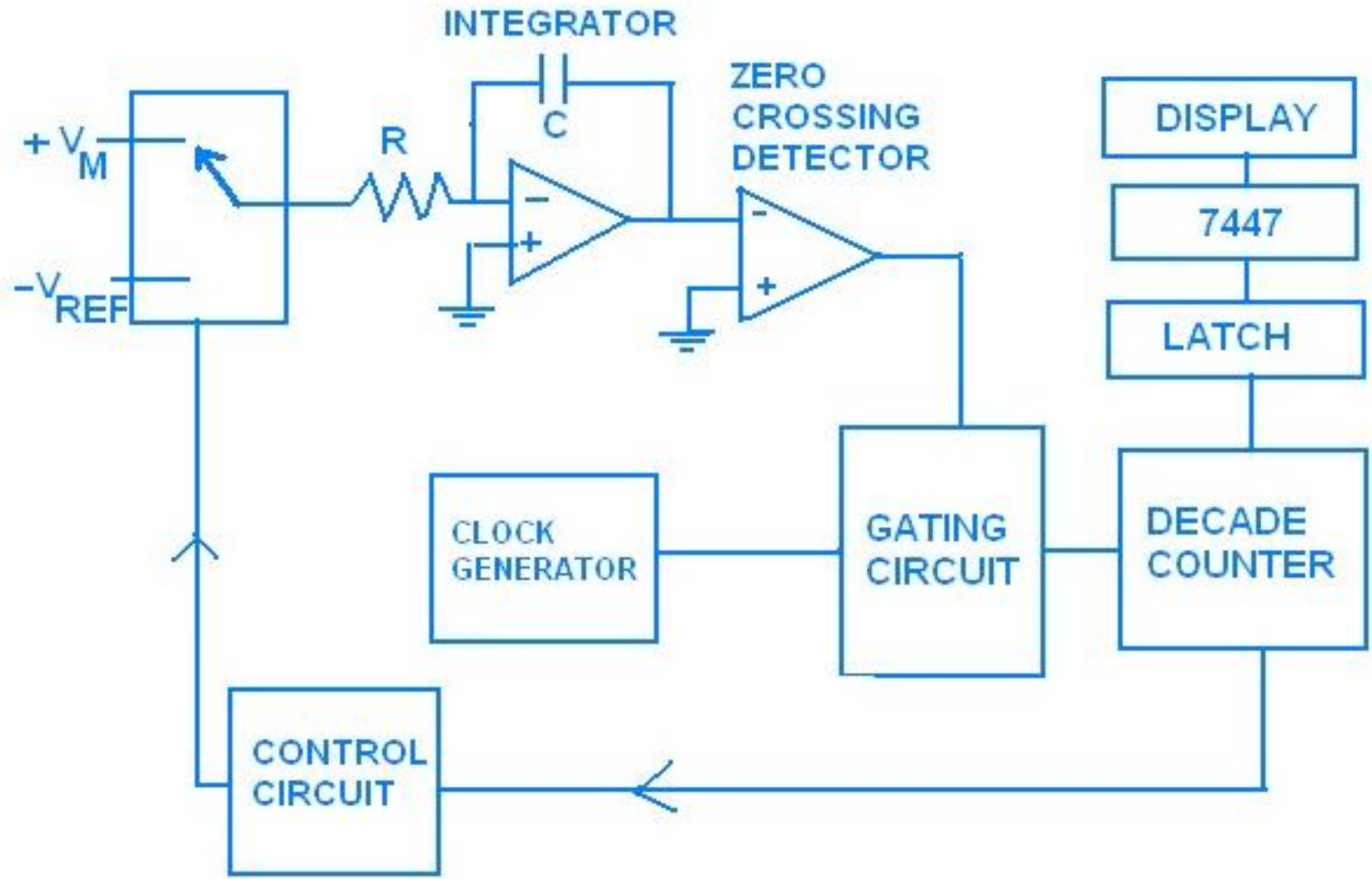
Merits:

- low cost
- simple, easy to design
- long distance transmission of output pulse is possible

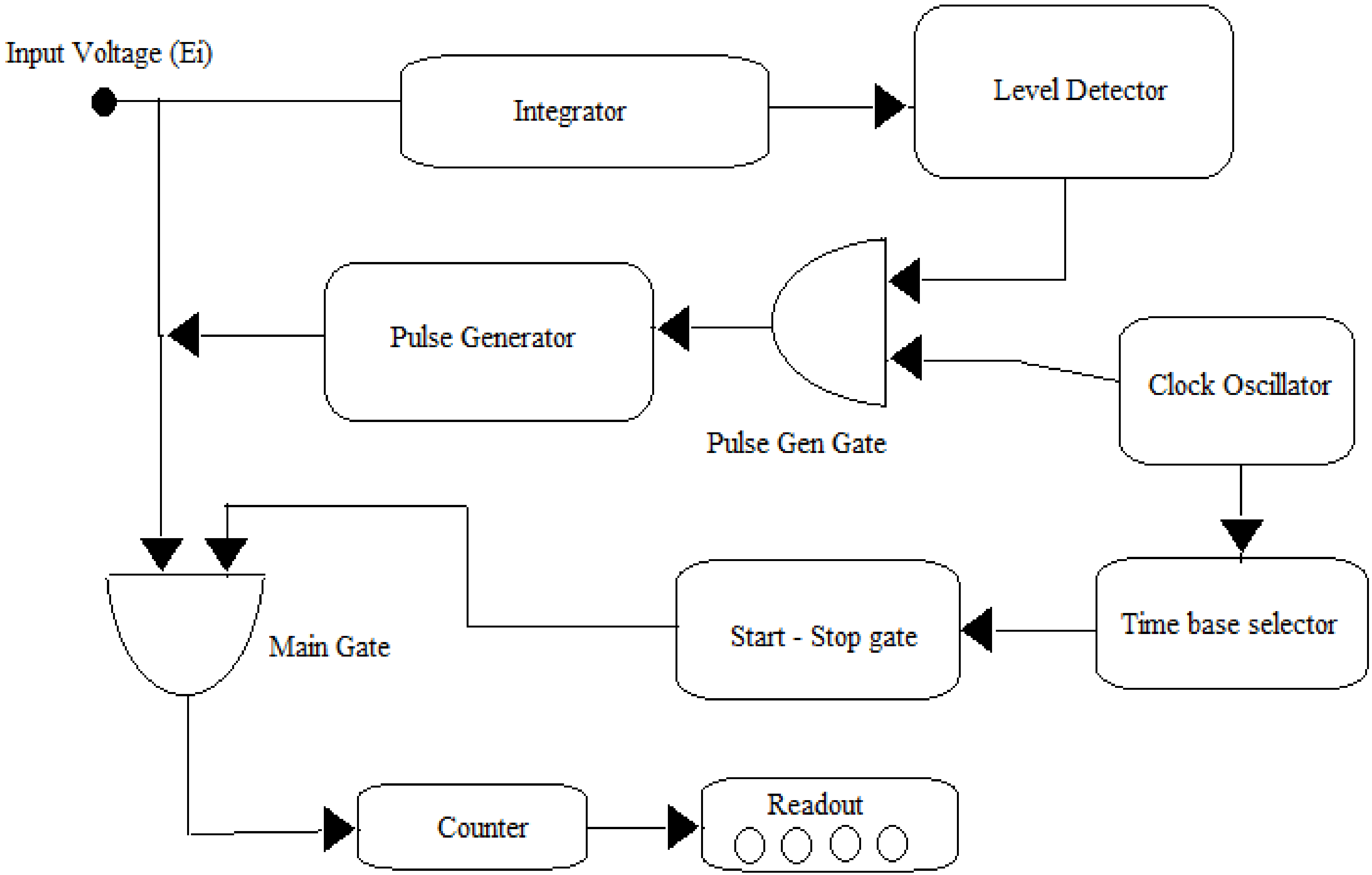
Demerits:

- accuracy of output greatly depends on linearity of the ramp.(since only one ramp is used)
- input filter are needed for filtering noise from input signal.

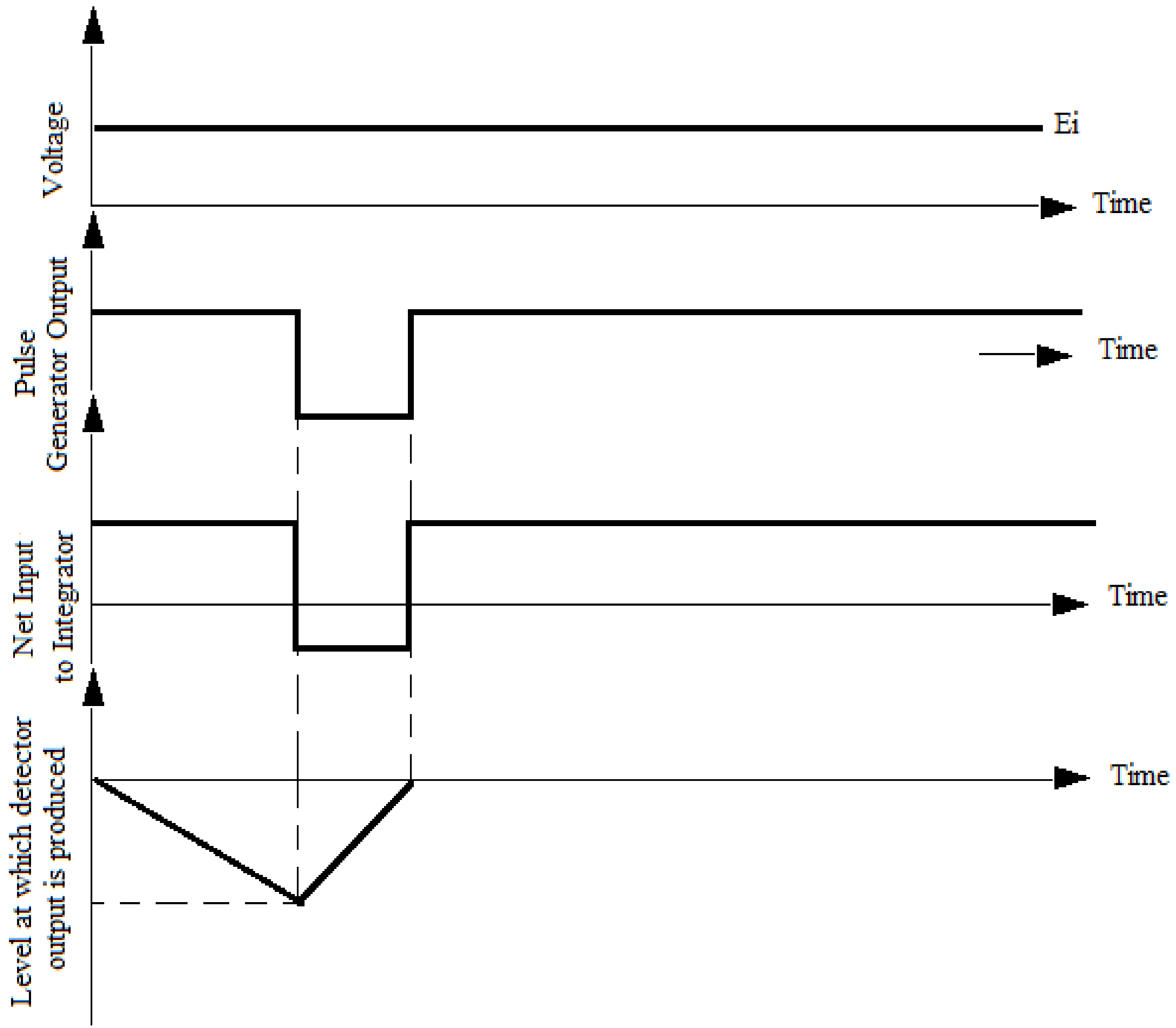
Dual Slope Integrating type DVM



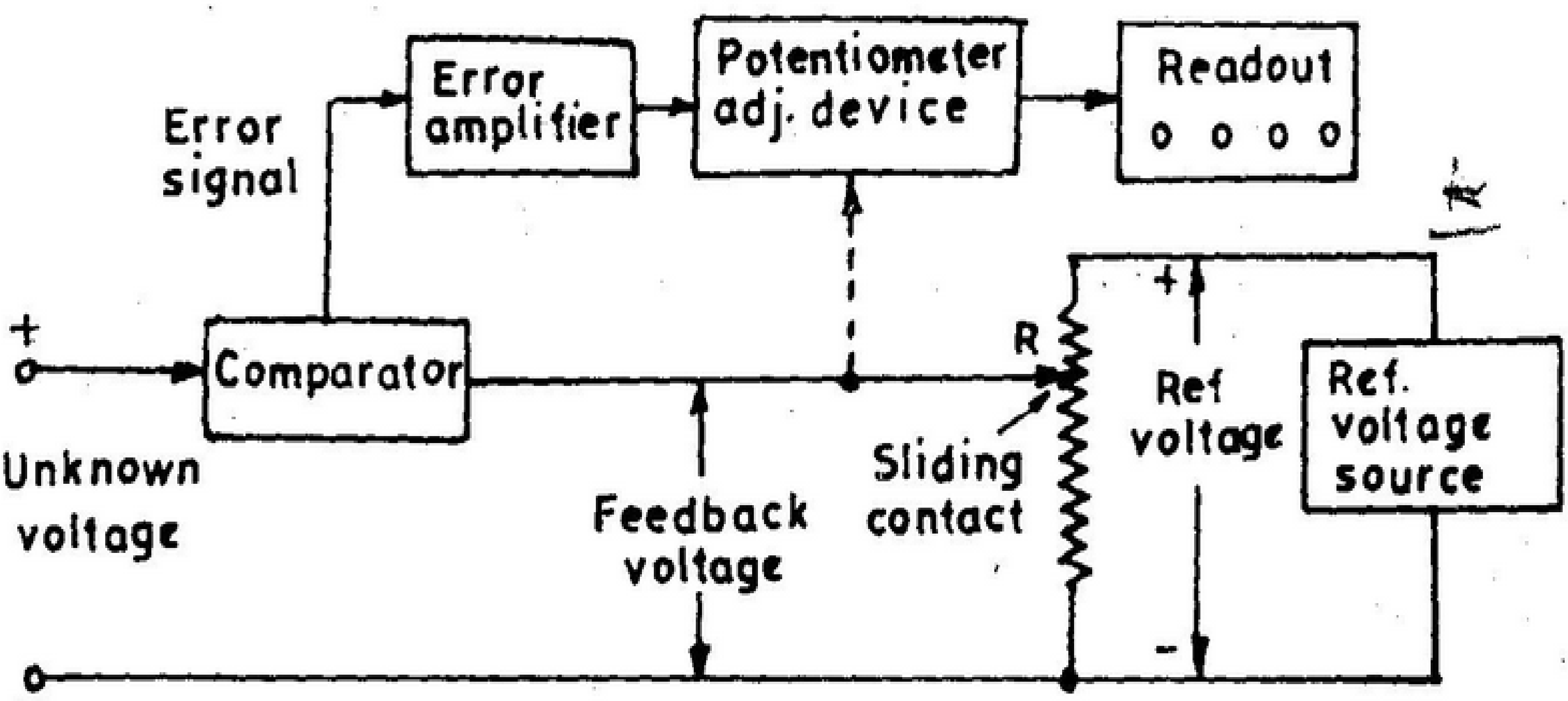
Block Diagram of Integrator type DVM



Waveform of output voltage



Potentiometric type Digital voltmeter



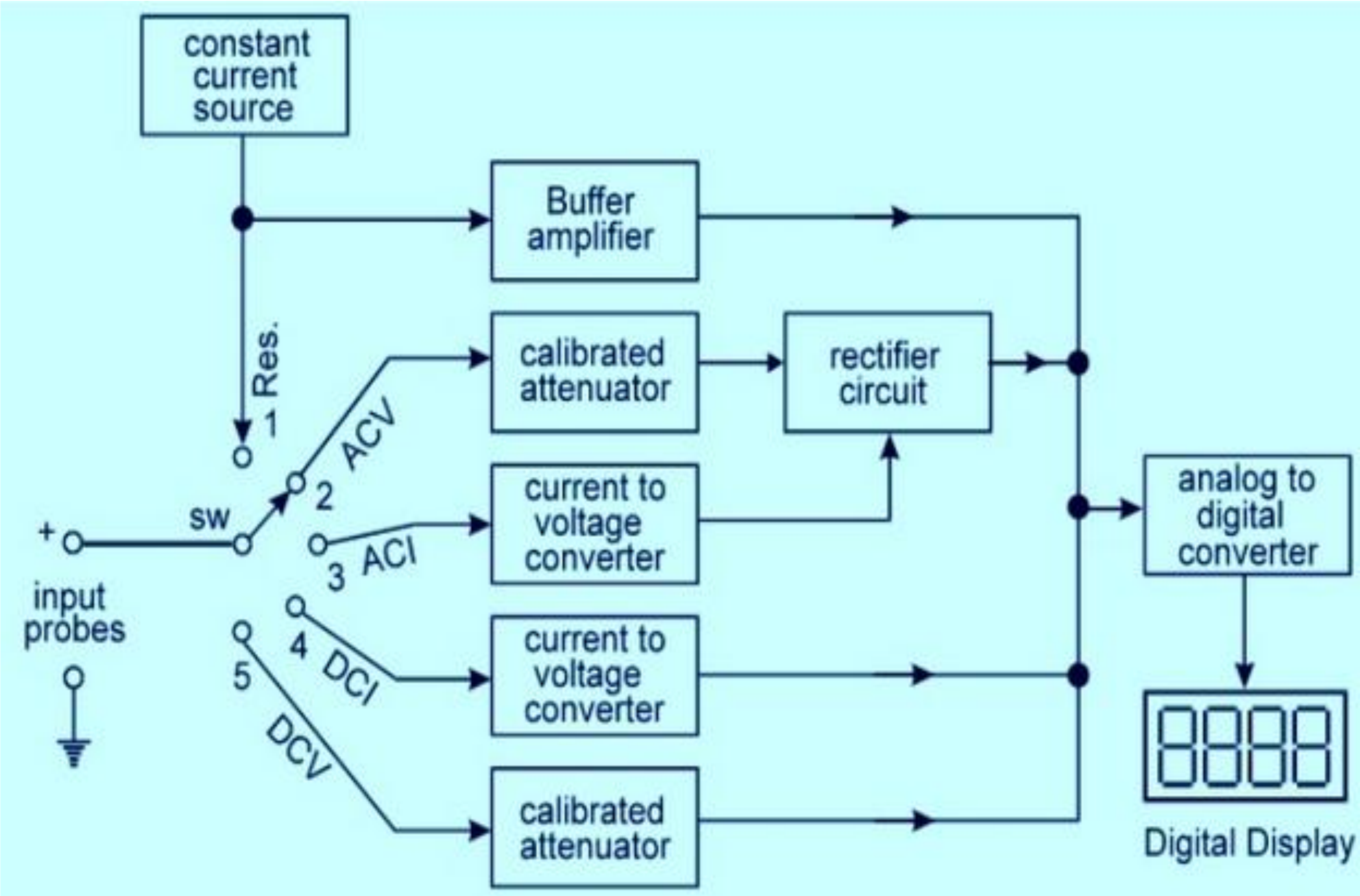
DIGITAL MULTIMETER

- Digital multimeter is an instrument used to measure voltage, current and resistance and display the measured voltage using LCD or LED to display the results in floating point format

Special characters

- DMM has a variety of special features that are designed for a wide number of applications
- Frequency
- Temperature
- Capacitance
- Continuity check
- Diode check

Block diagram



Parts of a DMM

Integrator:

The integrator stabilizes the voltage as a first step in measuring it. It takes a brief time sample, integrates it and outputs a proportional voltage. Integrating a time sample makes the voltmeter more immune to noise in the signal.

A/D converter:

The analog/digital converter is a clocked circuit that takes the sampled input voltage and outputs a number representing the voltage value. Since it is clocked, we get a steady stream of numbers that change when the input voltage changes.

Zeroing & Sampling:

A digital voltmeter needs to know where zero is in order to give a true reading. This is done with a precision zero reference voltage provided either internal to the ADC chip or externally.

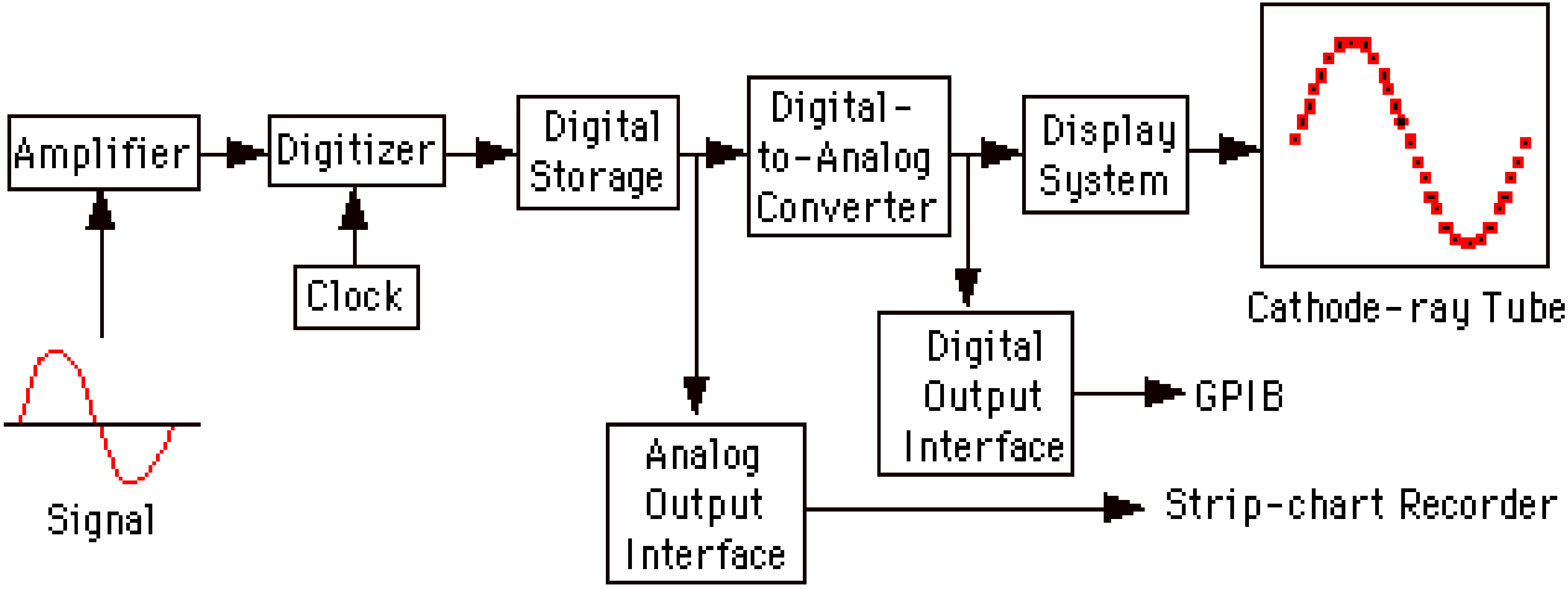
Display:

The digital display requires a river circuitry to handle the drive current. An ADC chip converts the generated analog signal to digital data and is displayed in the LCD.

Advantages

- Easy to handle
- Very accurate
- Noise signals absent
- Portable
- Has very good resolution

Digital Storage Oscilloscope



A.C BRIDGE MEASUREMENTS

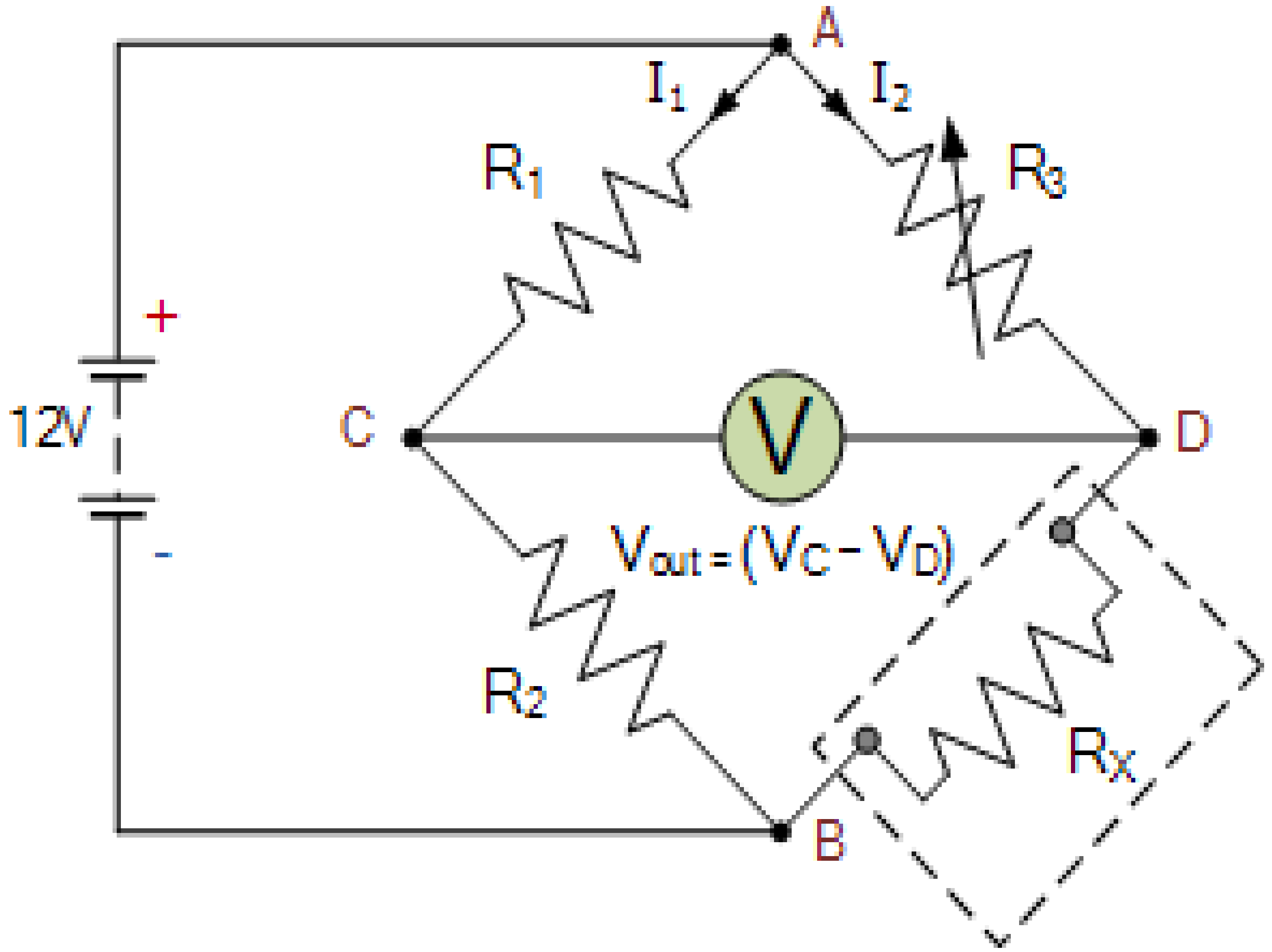
Measurement of resistance

- Wheatstone bridge
- Kelvin bridge

Wheatstone bridge

The Wheatstone Bridge was originally developed by Charles Wheatstone to measure unknown resistance values and as a means of calibrating measuring instruments, voltmeters, ammeters, etc, by the use of a long resistive slide wire. Although today digital multimeters provide the simplest way to measure a resistance, The Wheatstone Bridge can still be used to measure very low values of resistances down in the milli-Ohms range.

Wheatstone Bridge Circuit



By replacing R_4 above with a resistance of known or unknown value in the sensing arm of the Wheatstone bridge corresponding to R_X and adjusting the opposing resistor, R_3 to "balance" the bridge network, will result in a zero voltage output. Then we can see that balance occurs when:

$$\frac{R_1}{R_3} = \frac{R_2}{R_X} = 1\ (\text{Balanced})$$

The Wheatstone Bridge equation required to give the value of the unknown resistance, R_X at balance is given as:

$$V_{OUT} = \left(V_C - V_D\right) = \left(V_{R2} - V_{R4}\right) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

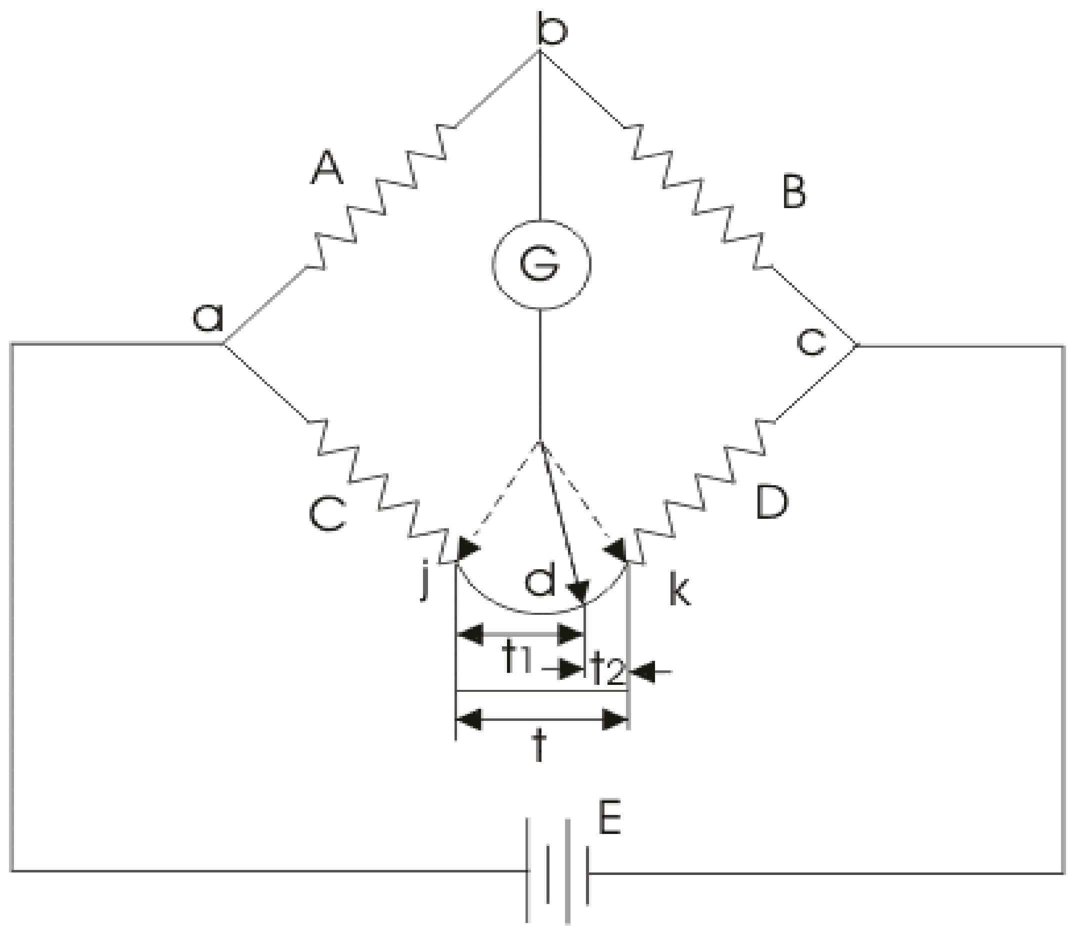
$$\text{At Balance: } R_C = R_D \quad \text{So, } \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

$$\therefore\ R_2\left(R_3 + R_4\right) = R_4\left(R_1 + R_2\right)$$

$$R_2 R_3 + \cancel{R_2 R_4} = R_1 R_4 + \cancel{R_2 R_4}$$

$$\therefore\ R_4 = \frac{R_2 R_3}{R_1} = R_X$$

Kelvin bridge



Here, t is the resistance of the lead.

C is the unknown resistance.

D is the standard resistance (whose value is known).

Derivation

Let us connect the galvanometer to point d such that it divides d into t_1 and t_2

$$\frac{t_1}{t_2} = \frac{A}{B}$$

Then also the presence of t_1 causes no error, we can write,

$$C + t_1 = \frac{A}{B}(D + t_2)$$

$$Also\ we\ have\ \frac{t_1}{t_2} = \frac{A}{B} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$So,\ \frac{t_1}{t_1 + t_2} = \frac{A}{A + B} \Rightarrow t_1 = \frac{A}{A + B} \times t$$

$$As\ t_1 + t_2 = t\ and\ t_2 = \frac{B}{A + B} \times t$$

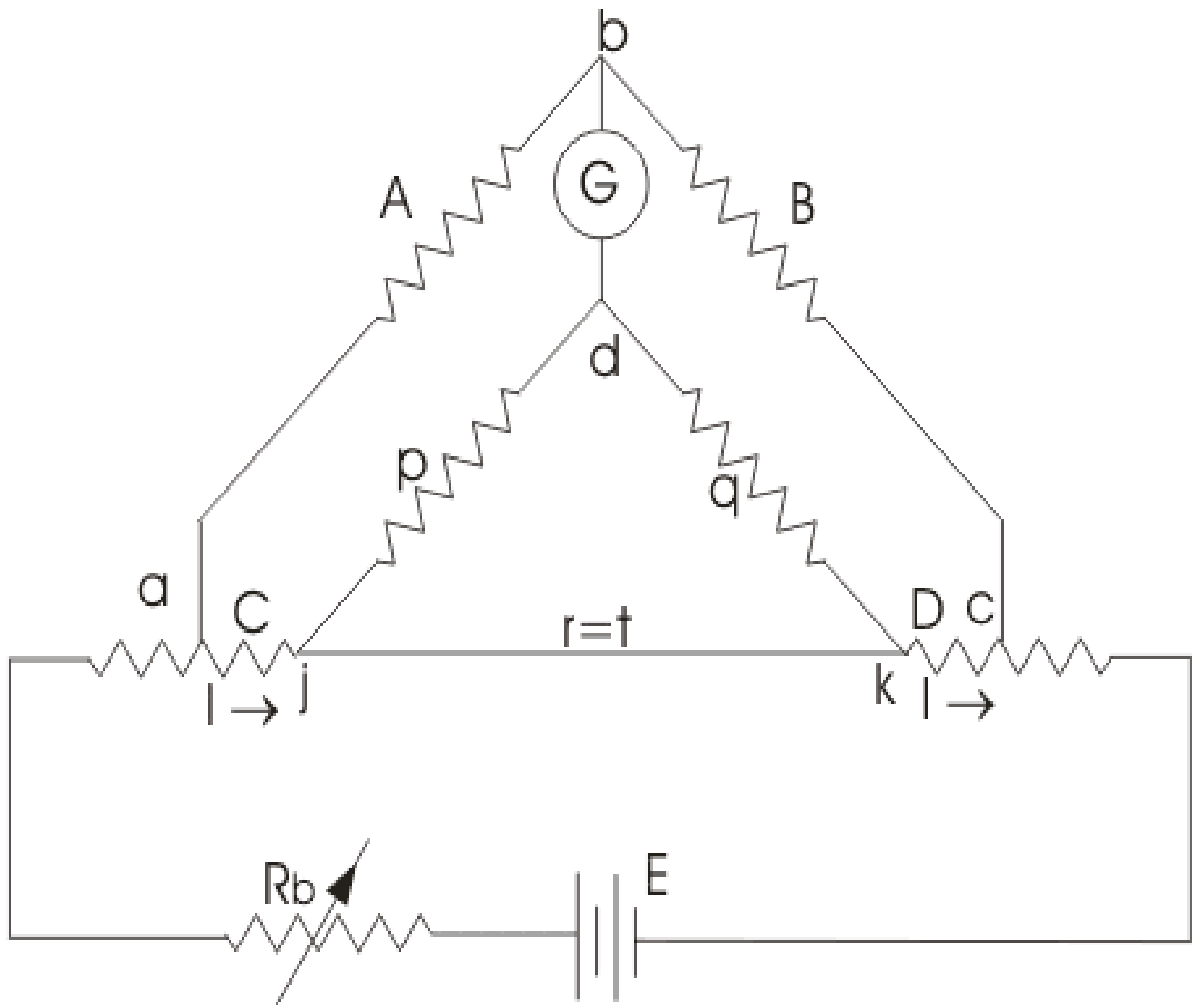
We can write equation (1) as

$$C + \frac{A}{A + B} \times t = \frac{A}{B} \times \left(D + \frac{B}{A + B} \times t\right)$$

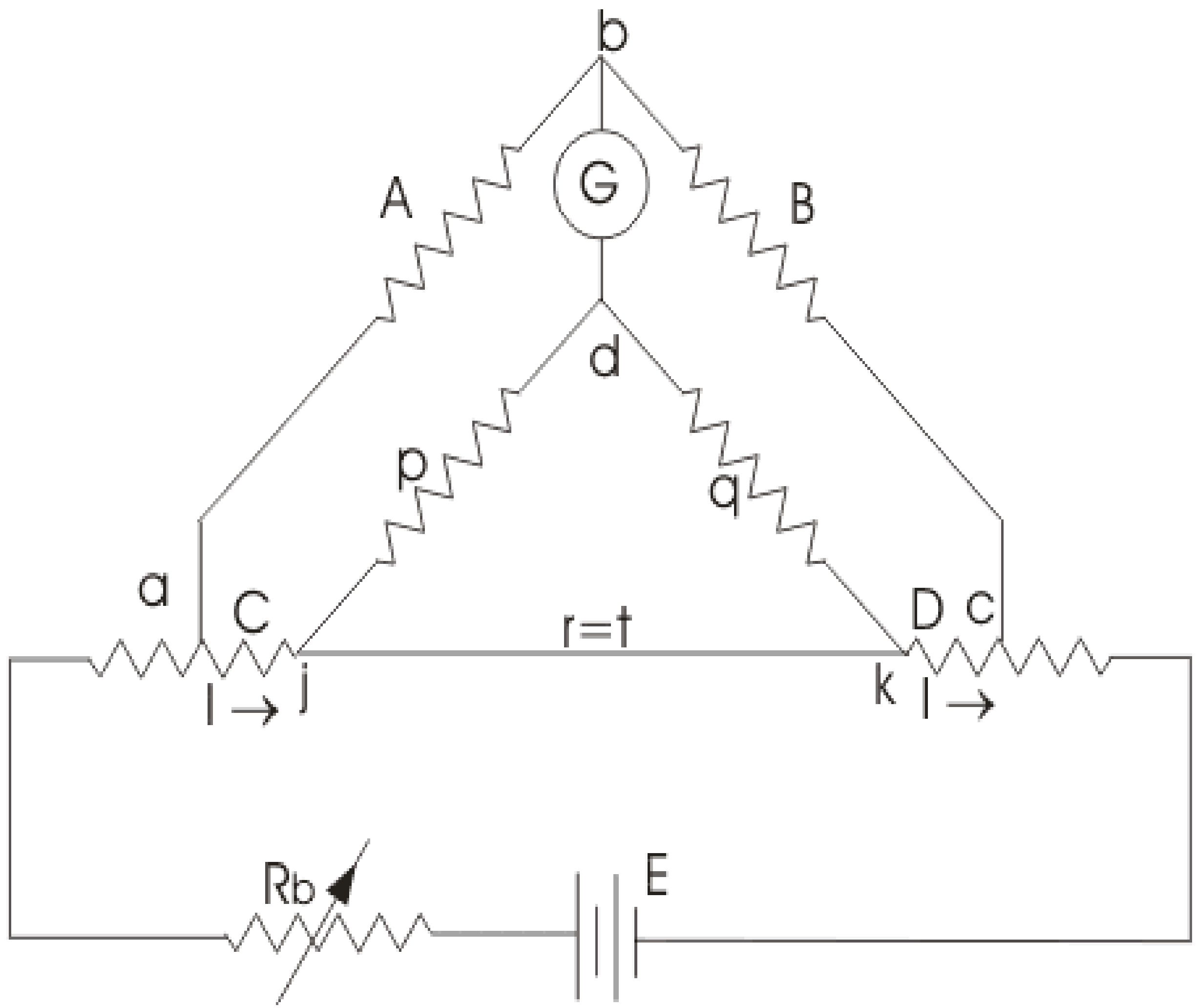
$$It\ implies\ that\ C = \frac{A}{B} \times D$$

Thus we can conclude that there is no effect of t (i.e. resistance of leads). Practically it is impossible to have such situation however the above simple modification suggests that the galvanometer can be connected between these points j and k so as to obtain the null point.

Kelvin Double Bridge



Kelvin Double Bridge



Derivation

In this the ratio arms p and q are used to connect the galvanometer at the correct point between j and k to remove the effect of connecting lead of electrical resistance t. Under balance condition voltage drop between a and b (i.e. E) is equal to F (voltage drop between a and c)

$$Hence,\ E = \frac{A}{A+B} \times F$$

$$\Rightarrow F = I \times \left(C + D + \frac{p+q}{p+q+t} \times t\right)$$

$$Hence,\ G\ i.e.\ (voltage\ drop\ between\ a\ and\ d) = I \times \left(C + \frac{p \times t}{p+q+t}\right)$$

For zero galvanometer deflection, E = F

$$or\ \frac{A}{A+B} \times I\left(C + D + \frac{p+q}{p+q+t} \times t\right) = I \times \left(C + \frac{p}{p+q+t} \times t\right)$$

$$\Rightarrow C = \frac{A}{B} \times D + \frac{q}{p+q+t}\left(\frac{P}{Q} - \frac{p}{q}\right) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$If\ \frac{A}{B} = \frac{p}{q}\ then\ C = \frac{A}{B} \times D$$

Again we reaches to the same result i.e. t has no effect. However equation (2) is useful as it gives error when,

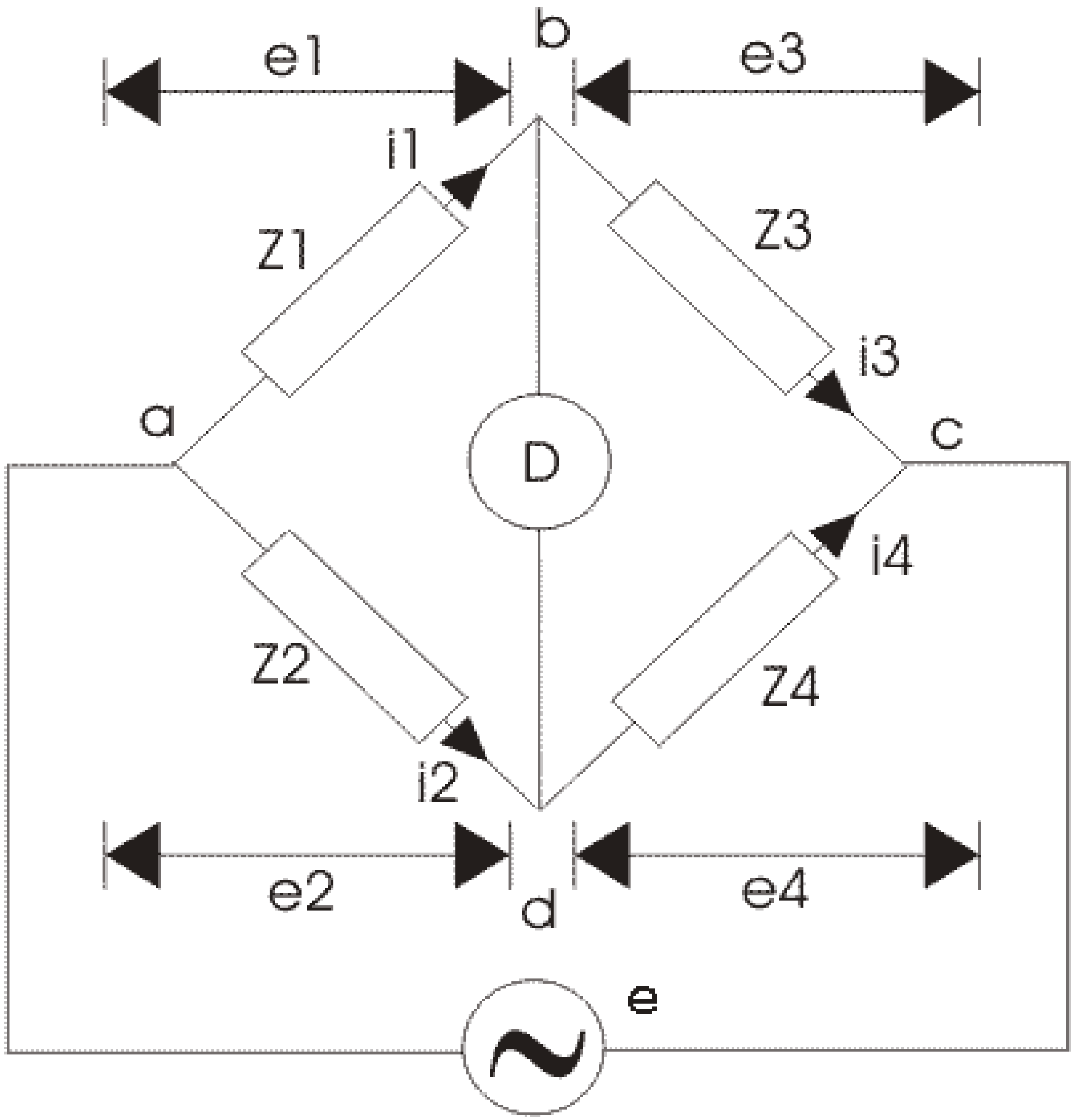
$$If\ \frac{A}{B} = \frac{p}{q}$$

D.C BRIDGE MEASUREMENTS

Inductance can be measured by,

- Maxwell Bridge
- Anderson Bridge

AC Bridge



Derivation

Here Z_1, Z_2, Z_3 and Z_4 are the arms of the bridge.

Now at the balance condition, the potential difference between b and d must be zero. From this, when the voltage drop from from a to d equals to drop from a to b both in magnitude and phase.

Thus, we have from figure $e_1 = e_2$

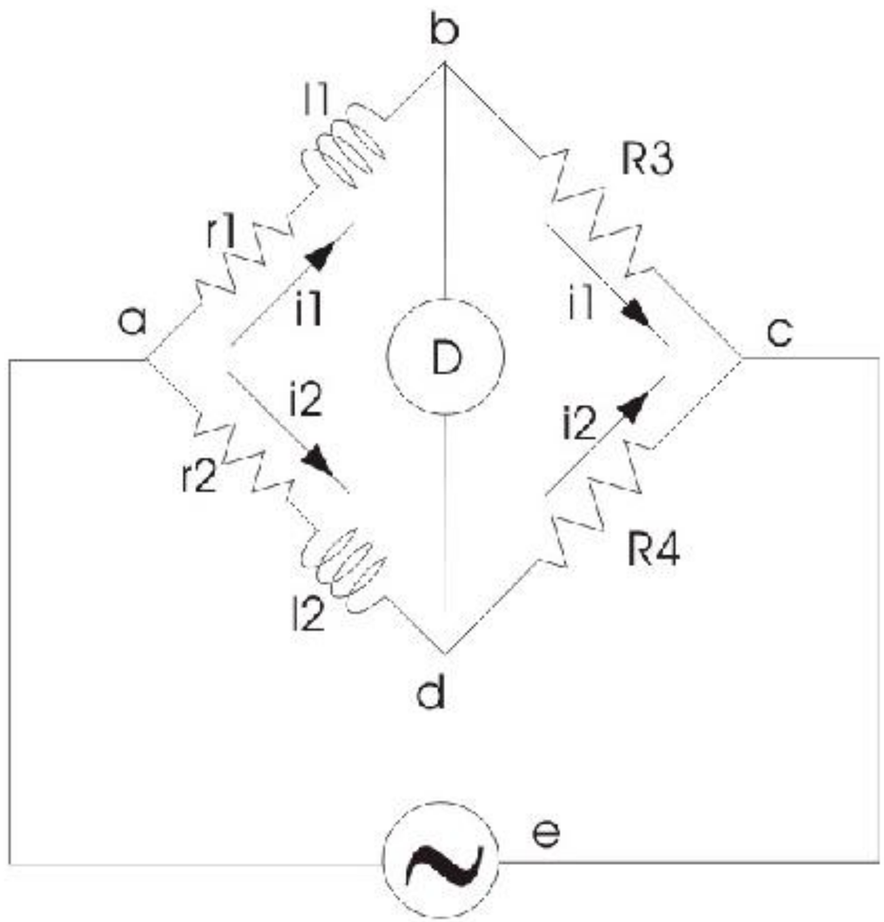
$$i_1 \cdot Z_1 = i_2 \cdot Z_2 \cdots\cdots\cdots (1)$$

$$i_1 = i_2 = \frac{e}{Z_1 + Z_3} \cdots\cdots\cdots (2)$$

$$i_2 = i_4 = \frac{e}{Z_2 + Z_4} \cdots\cdots\cdots (3)$$

From equation 1, 2 and 3 we have $Z_1.Z_4 = Z_2.Z_3$ and when impedance are replaced by admittance, we have $Y_1.Y_4 = Y_2.Y_3$.

AC bridge



In this circuit R_3 and R_4 are pure electrical resistances.

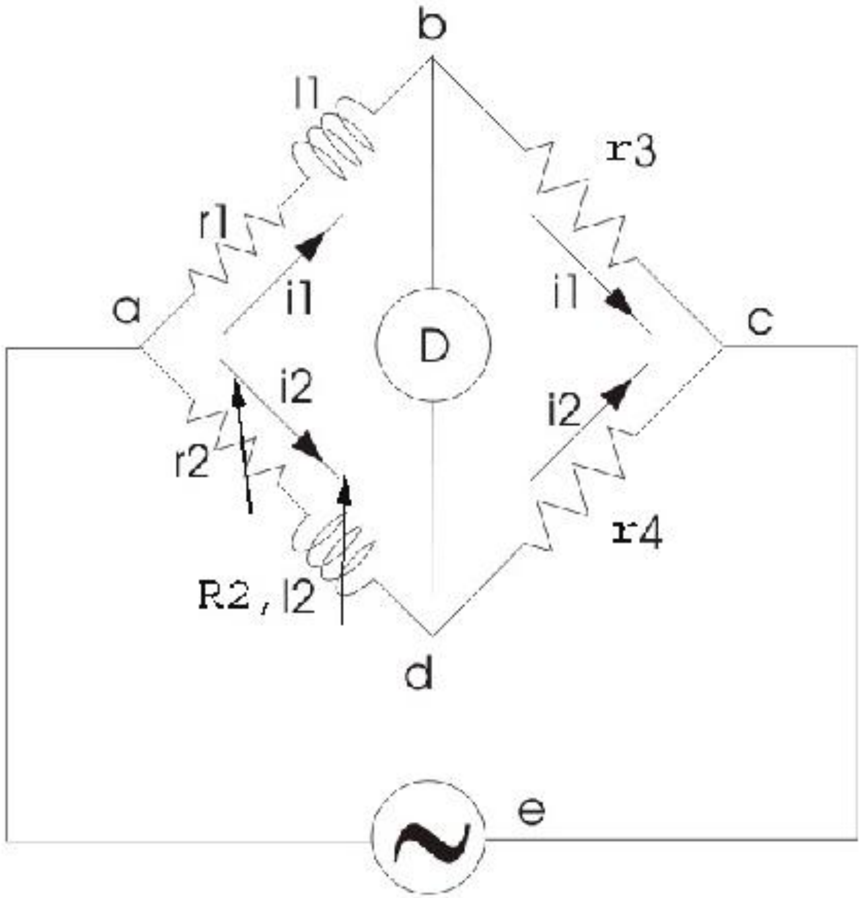
Putting the value of Z_1, Z_2, Z_3 and Z_4 in the equation that we have derived above for AC bridge.

$$We\ get\ (r_1 + j\omega l_1) \cdot R_4 = (r_2 + j\omega l_2) \cdot R_3$$

Now equating the real and imaginary parts we get

$$r_1 = \frac{R_3}{R_4} \cdot r_2\ and\ l_1 = \frac{R_3}{R_4} \cdot l_2$$

Maxwell Inductance bridge



In this bridge the arms bc and cd are purely resistive while the phase balance depends on the arms ab and ad.

Here l_1 = unknown inductor of r_1.

l_2 = variable inductor of resistance R_2.

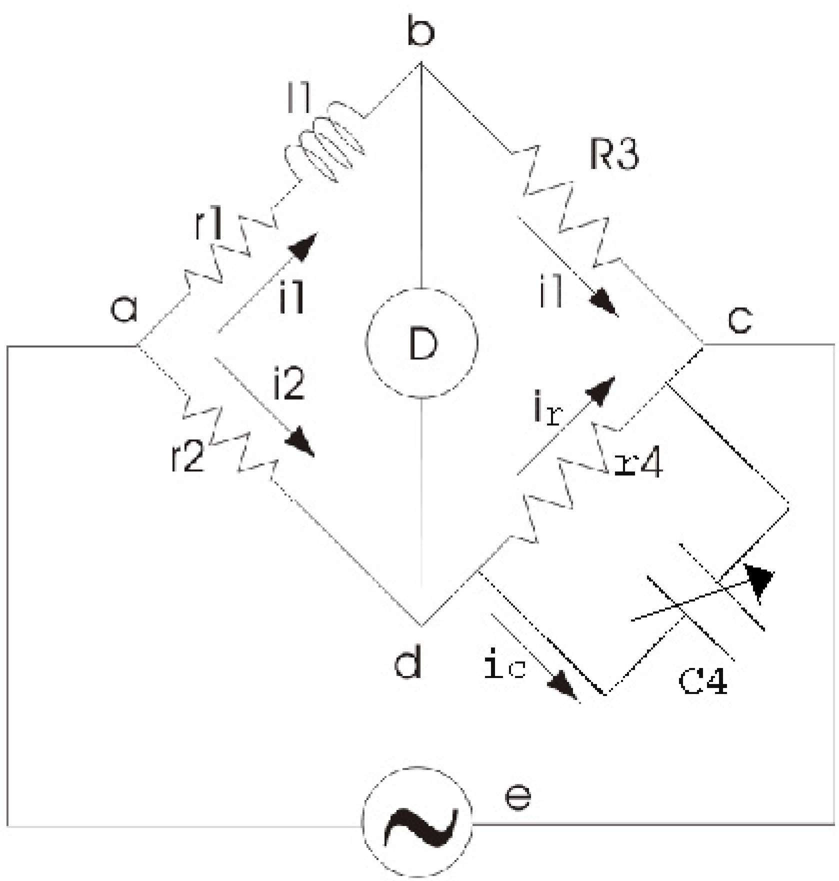
r_2 = variable electrical resistance.

As we have discussed in ac bridge according to balance condition, we have at balance point

$$l_1 = \frac{r_3}{r_4} \cdot l_2 \; and \; r_1 = \frac{r_3}{r_4}(r_2 + R_2)$$

We can vary R_3 and R_4 from 10 ohms to 10,000 ohms with the help of resistance box.

Maxwell Inductance Capacitance Bridge



Here, l_1 is unknown inductance, C_4 is standard capacitor.

Now under balance conditions we have from ac bridge that $Z_1.Z_4 = Z_2.Z_3$

$$(r_1 + j\omega l_1)\frac{r_4}{1 + j\omega C_4 r_4} = r_2 \cdot r_3$$

$$r_1 \cdot r_4 + j\omega l_1 \cdot r_4 = r_2 \cdot r_3 + j\omega r_2 r_3 C_4 r_4$$

Let us separate the real and imaginary parts, the we have,

$$r_1 = r_2 \cdot \frac{r_3}{r_4} \; and \; l_1 = r_2 \cdot r_3 \cdot C_4$$

Now the quality factor is given by,

$$Q = \frac{\omega l_1}{r_1} = \omega C_4 \cdot r_4$$

Advantages

- The frequency does not appear in the final expression of both equations, hence it is independent of frequency.
- Maxwell's inductor capacitance bridge is very useful for the wide range of measurement of inductor at audio frequencies.

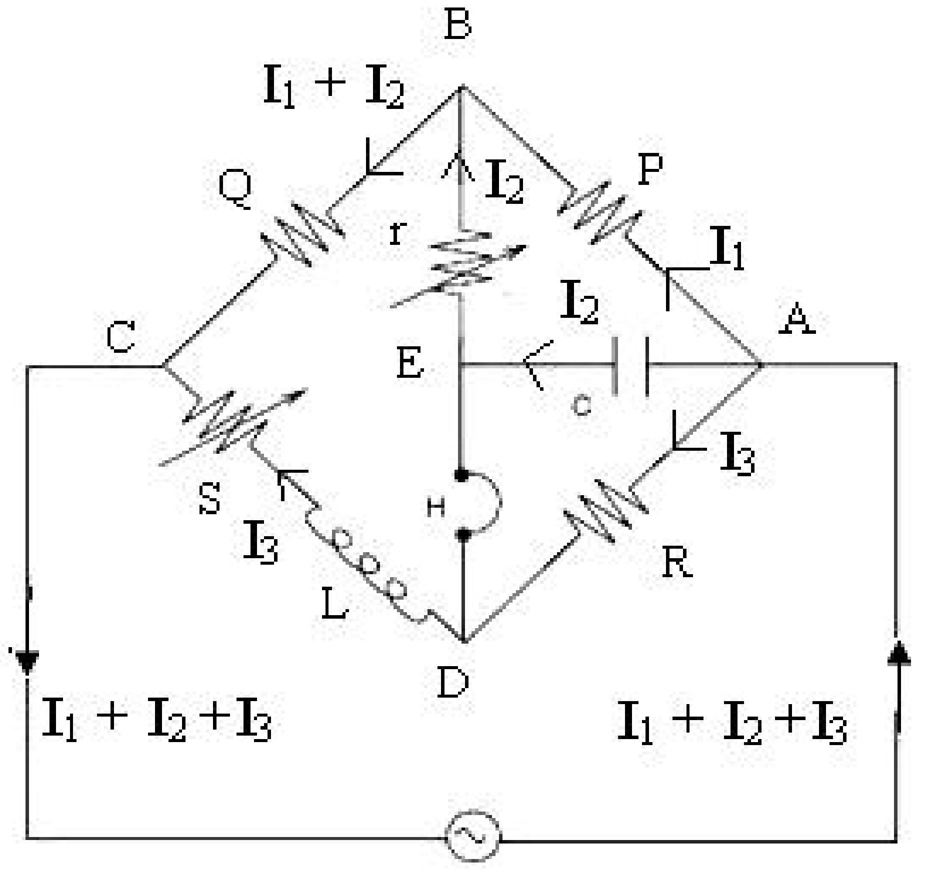
Disadvantages

- The variable standard capacitor is very expensive.
- The bridge is limited to measurement of low quality coils ($1 < Q < 10$) and it is also unsuitable for low value of Q (i.e. $Q < 1$) from this we conclude that a Maxwell bridge is used suitable only for medium Q coils.

Anderson Bridge

- This bridge is the modified version of Maxwell Inductance Capacitance Bridge.
- Double balance can obtained by fixing the value of capacitance and changing the value of electrical resistance only.

Circuit diagram



Derivation

Consider the mesh ABCDA

$$I_1P + (I_1 + I_2)Q - I_3(jL\omega + S) - I_3R = 0$$

$$I_1(P+Q) + I_2Q = I_3(S + R + jL\omega) \qquad (1)$$

This shows that potential drop along ABC is equal to that along ADC.

Consider the mesh ABEA, there is no e.m.f.

$$I_1P - I_2r - \frac{I_2}{jC\omega} = 0$$

$$I_1P - I_2(r + \frac{1}{jC\omega}) = 0 \qquad (2)$$

Consider the mesh AEDA,

$$\frac{I_2}{jC\omega} = I_3R \qquad (3)$$

i.e. potential difference from A to E is equal to that from A to D.
From (3) we get,

$$I_2 = jI_3C\omega R \qquad (4)$$

Derivation

Now substitute the value of I_3 from (1) in (4)

$$I_2\left[\frac{S+R+jL\omega}{jC\omega R}-Q\right]=I_1[P+Q] \qquad (5)$$

Dividing (5) by (2)

$$\frac{I_1(P+Q)}{I_1P}=\frac{I_2\left[\frac{S+R+jL\omega}{jC\omega R}-Q\right]}{I_2\left[r+\frac{1}{jC\omega}\right]}$$

$$\frac{P+Q}{P}\left[r+\frac{1}{jC\omega}\right]=\frac{R+S+jL\omega-jC\omega RQ}{jC\omega R} \qquad (6)$$

Multiply and divide by R in the L.H.S of (6) and rearrange,

$$\frac{(P+Q)R}{P}\left[\frac{rjC\omega+1}{jC\omega R}\right]=\frac{R+S+jL\omega-jC\omega RQ}{jC\omega R}$$

$$PR+RQ+j\Pr C\omega R+jQrC\omega R=PR+PS+jL\omega P-PRjC\omega Q$$

$$RQ+j(P+Q)RC\omega r=PS+j[L\omega-RC\omega Q]P \qquad (7)$$

Derivation

Equating real parts on both sides of (7)

$$\frac{R}{S} = \frac{P}{Q} \qquad (8)$$

Equation (8) represents the condition for balancing of the bridge.

Equating imaginary parts on both sides of (7)

$$L = \frac{RC[\mathrm{Pr} + Qr + PQ]}{P} \qquad (9)$$

Substituting :

$$S = \frac{RQ}{P}$$

From (8) and (9) gives us

$$L = C[RQ + r(R+S)] \qquad (10)$$

At this condition of balancing there is minimum sound in the headphone.
Further we can make P=Q

$$L = CR(P + 2r) \qquad (11)$$

The inductive reactance can be calculated by

$$X_L = 2\pi f L \qquad (11)$$

Advantages

- It is very easy to obtain the balance point in Anderson's bridge as compared to Maxwell bridge in case of low quality factor coils.
- There is no need of variable standard capacitor is required instead of thin a fixed value capacitor is used.
- This bridge also gives accurate result for determination of capacitance in terms of inductance.

Disadvantages

- The equations obtained for inductor in this bridge is more complex as complex as compared to Maxwell's bridge.
- The addition of capacitor junction increases complexity as well as difficulty of shielding the bridge.

Considering all the advantages and disadvantages, Maxwell bridge is preferred over Anderson's bridge whenever use of variable capacitor is permissible.