Lecture 11B – Meters

The moving iron meter. The electrodynamic meter (wattmeter). The ohmmeter. Electronic meters. The analog AC voltmeter. The differential voltmeter. The digital meter.

The Moving Iron Meter

There are two types of moving iron meter – attraction and repulsion type. The attraction type works by having one piece of soft iron attracted by the magnetic field produced by a current through a coil. The soft iron will be attracted to where the field is greatest.

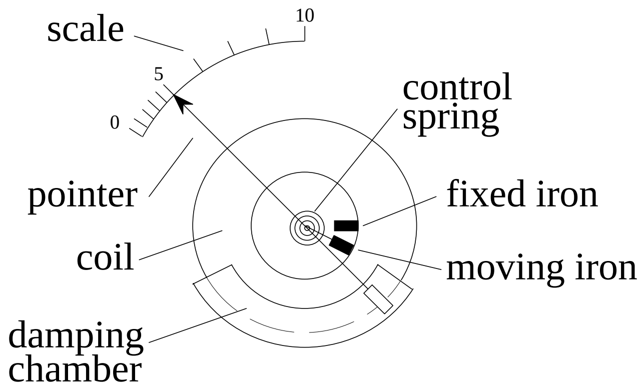

Figure 11B.1

For the repulsion type meter, two pieces of soft iron are placed inside a coil. Both fixed and moving irons are magnetized with the same polarity. The field is produced by the current I being measured.

The deflecting torque is:

$$T_d = \frac{i^2}{2}\frac{dL}{d\theta} \tag{11B.1}$$

With alternating current, the torque fluctuates but is always in the same direction.

The movement takes a position determined by the average torque:

$$T_{d_{AV}} = \frac{1}{T}\int_0^T T_d dt = \frac{1}{2}\frac{dL}{d\theta}\frac{1}{T}\int_0^T i^2 dt$$
$$= \frac{1}{2}\frac{dL}{d\theta}\left(i^2\right)_{AV} \tag{11B.2}$$

Therefore, the moving iron meter responds to $(i^2)_{AV}$ or $(i_{RMS})^2$ and reads RMS. It can be directly calibrated in RMS values. At balance:

$$T_d = T_r$$
$$\frac{i^2}{2}\frac{dL}{d\theta} = K_r\alpha \tag{11B.3}$$

The shape of the irons is designed to give:

up to 10% of scale - $\frac{dL}{d\theta} = K_1$ $\quad \alpha = K'i^2$ (square law) (11B.4a)

rest of scale - $\frac{dL}{d\theta} = \frac{K_2}{\alpha}$ $\quad \alpha = K''i$ (linear scale) (11B.4b)

Advantages

- An RMS meter
- Simple
- Robust
- Cheap

Disadvantages

- Affected by frequency
- Affected by hysteresis (descending *I* or *V* readings > ascending readings)

The Electrodynamic meter (wattmeter)

The principle of operation of an electrodynamic meter is similar to a moving coil meter. All coils are air-cored (the main field B_2 is small, but there is no hysteresis). The fixed coils set up an almost uniform field, in which a moving coil is placed. The moving coil also has a current through it, and so the Lorentz force law applies.

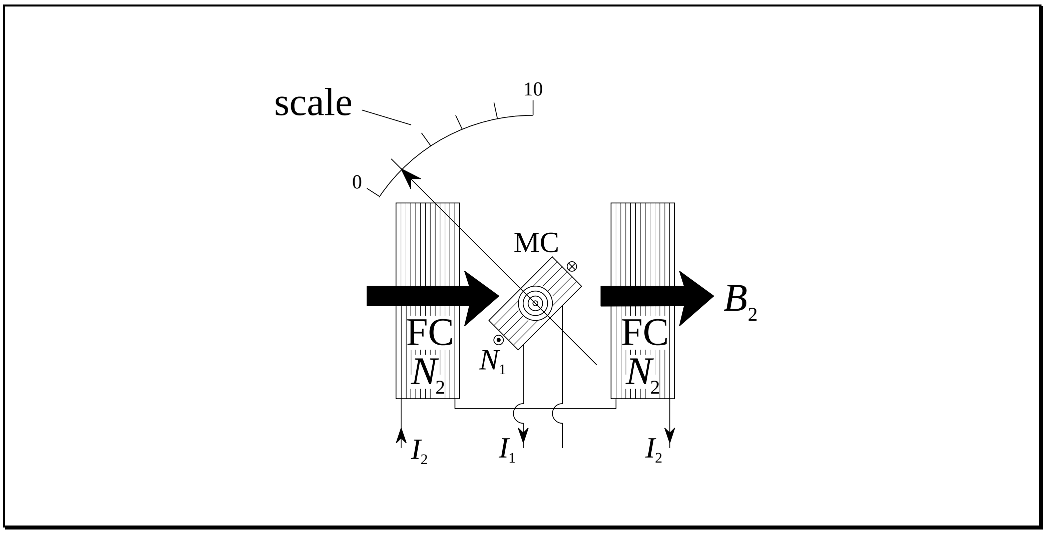

Figure 11B.2

If the moving coil radius is very small compared to the fixed coil radius, then the field at the moving coil, due to the fixed coils, is given by:

$$B_{12} = \frac{\mu_0 I_2 R_0{}^2 N_2}{\left(R_0{}^2 + D^2\right)^{3/2}} \tag{11B.5}$$

where the various dimensions are:

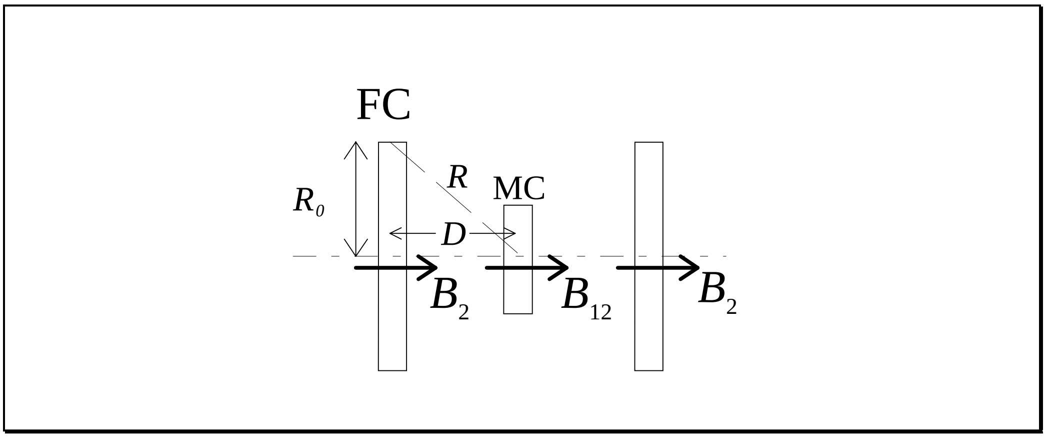

Figure 11B.3

The deflecting torque is then:

$$T_d = KI_1B_{12}\cos\theta = K_d I_1 I_2 \cos\theta \tag{11B.6}$$

Ammeter

To use the meter as an ammeter, connect the moving coil and fixed coils in series. Then I_1 and I_2 are equal and:

$$T_{d\,AV} \propto \left(i^2\right)_{AV} \tag{11B.7}$$

Voltmeter

A voltmeter can be made from any ammeter by placing a large resistor in series with it to limit the current. Therefore it will be an RMS voltmeter.

Electromechanical Wattmeter

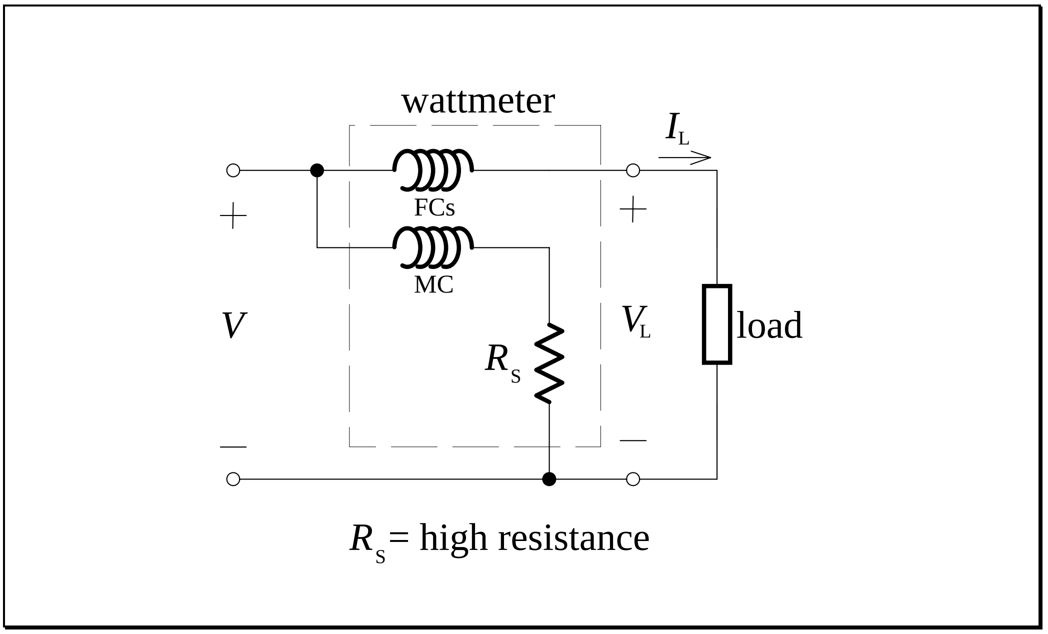

Figure 11B.4

If the coils are connected as shown then:

$$I_2 = I_L \tag{11B.8a}$$

$$I_1 = \frac{V}{R_{MC} + R_S} \propto V \tag{11B.8b}$$

Also:

$$\alpha_{AV} \propto (I_1 I_2)_{AV} \tag{11B.9a}$$

$$\alpha_{AV} \propto (VI_L)_{AV} \tag{11B.9b}$$

But:

$$\begin{aligned} V &= V_L + R_F I_L \\ VI_L &= V_L I_L + R_F I_L^{\,2} \\ &= \text{load power} + \text{fixed coil heat loss} \end{aligned} \tag{11B.10}$$

Therefore, as connected, $\alpha_{AV} \propto (\text{load power} + \text{fixed coil heat loss})$. With the moving coil connected across just the load, the meter reads (load power + moving coil heat loss).

For sinusoidal voltages and currents:

$$v = \hat{V}\cos\omega t$$

$$i = \hat{I}_L \cos(\omega t + \theta)$$

$$\alpha \propto \frac{\hat{V}\hat{I}_L}{2}\{\cos\theta + \cos(2\omega t + \theta)\}$$

$$\alpha_{AV} \propto \frac{\hat{V}\hat{I}_L}{2}\cos\theta = V_{RMS} I_{L_{RMS}} \cos\theta \qquad \text{(11B.11)}$$

The Ohmmeter

An ohmmeter consists of a moving coil meter, a battery, and a number of resistors that determine the range of the measurement.

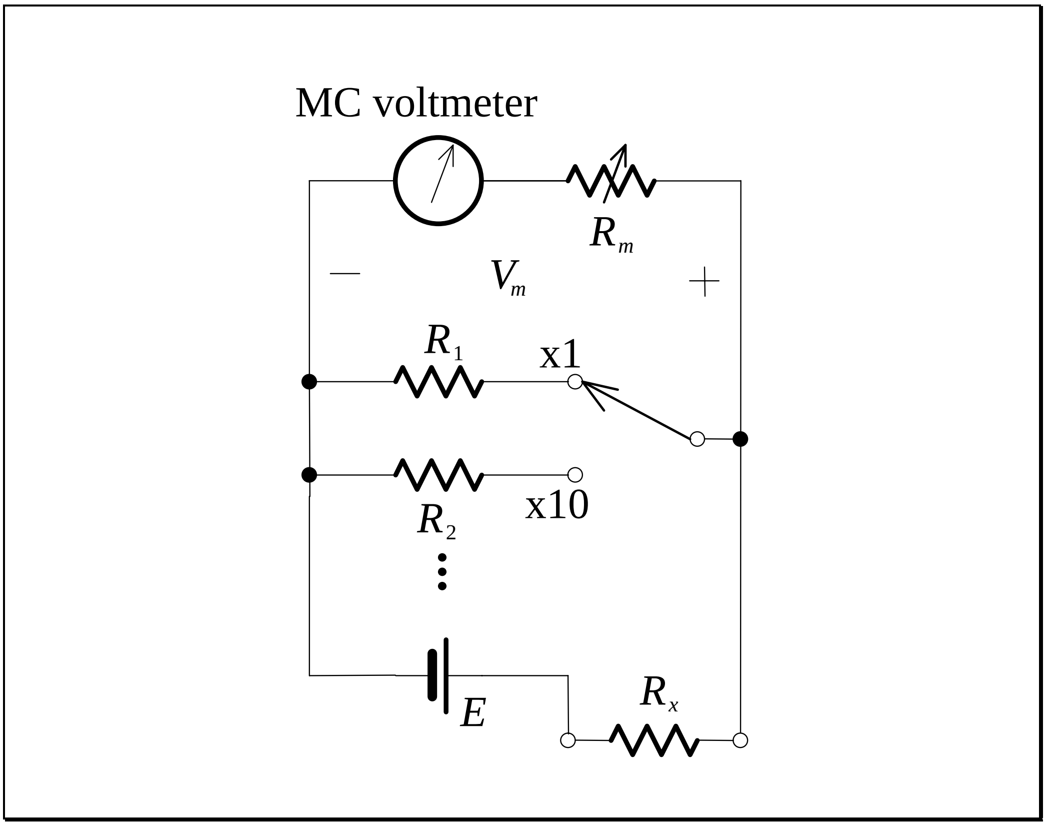

Figure 11B.5

R_m is the moving coil resistance, plus the current limiting resistance, plus the zero adjust resistance. It limits the current in the moving coil to full scale deflection (FSD) current I_{FS} when the test leads are shorted. Therefore:

$$R_m = \frac{E}{I_{FS}} \tag{11B.12}$$

Also:

$$V_m = \frac{R_1 \| R_m}{R_1 \| R_m + R_{x1}} E \tag{11B.13}$$

The lowest range (x1, say) shunt resistance R_1 is chosen so that a specific resistance R_{x1} gives half scale deflection (HSD):

$$V_m = \frac{I_{FS}}{2} R_m = \frac{E}{2} \tag{11B.14}$$

or, from Eq. (11B.13):

$$\begin{aligned} R_{x1} &= R_1 \| R_m \\ R_1 &= \frac{R_{x1} R_m}{\left(R_m - R_{x1}\right)} \end{aligned} \tag{11B.15}$$

To determine the shunt R_3 for the x100 range we use the previous equation with $R_{x3} = 100 R_{x1}$.

R_m, R_1, R_2, ... and E are all constant. The meter deflection, using Eq. (11B.13), is:

$$\alpha = K V_m = \frac{K_1}{K_2 + R_x} \propto \frac{1}{R_x} \tag{11B.16}$$

Therefore, the meter scale is not uniform.

Electronic Meters

Some of the existing type of electronic meter are:

Analog – quantity to be measured is converted to DC or DC proportional to heating energy of input wave, which then drives a DC moving coil electromechanical meter (usually taut-band suspension).

Differential – quantity to be measured is compared to a reference voltage.

Digital – analog input is converted to digital form. The display is also digital.

In all cases the basic "building blocks" are:

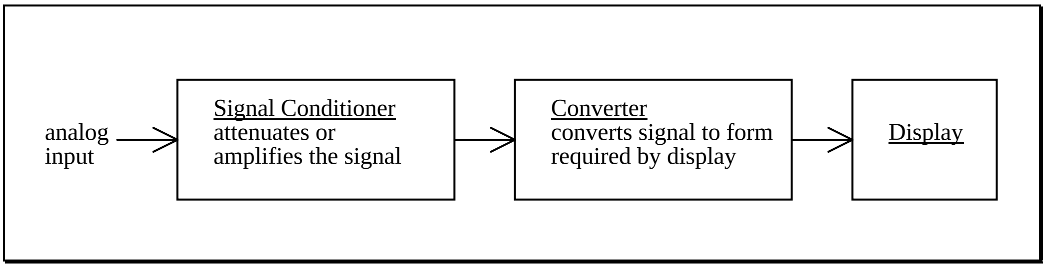

Figure 11B.6

The Analog AC Voltmeter

A basic AC voltmeter circuit is the following:

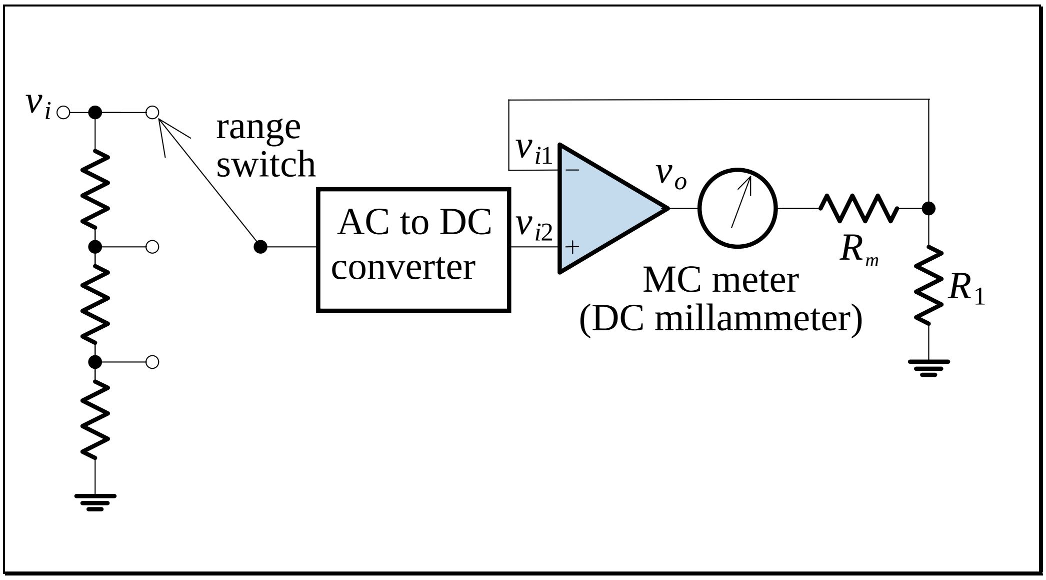

Figure 11B.7

The input consists of a series connection of resistors. A voltage is selected from this potential divider using a physical switch that corresponds to a voltage range. The input resistance is seen to be a constant, no matter where the switch is positioned.

The voltage waveform is then applied to an AC to DC converter circuit of some sort. The DC voltage resulting from the conversion is applied to the noninverting terminal of an op amp so as not to load the measured circuit.

A moving coil meter (which responds to the average) is placed in the feedback loop of the amplifier. In order to stabilize the output, a proportion of the output is fed back to the input. The operational amplifier has a very high gain, very high input impedance and a very low output impedance.

The meter scale can be calibrated in terms of the RMS value of a sine wave. The meter response is given by:

$$
\begin{aligned}
V_{i1} &= \frac{R_1}{R_1+R_m}V_o = \beta V_o \\
V_o &= A\left(V_{i2} - \beta V_o\right) \\
&= \frac{A}{1+A\beta}V_{i2} \qquad \text{(11B.17a)}
\end{aligned}
$$

$$V_m = \frac{R_m}{R_m+R_1}V_o \approx \frac{R_m}{R_1}V_{i2} \qquad \text{(11B.15b)}$$

11B.10

Some basic AC to DC converter circuits are:

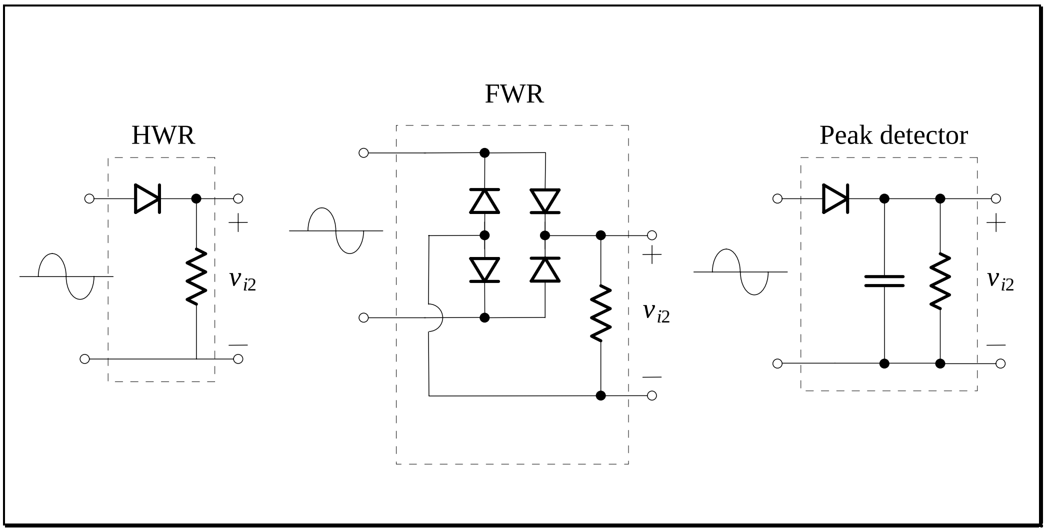

Figure 11B.8

For the full wave rectifier converter circuit, the moving coil meter reads $1.11V_{\mathrm{AV}}$. For the peak detector, it reads $0.707V_{\mathrm{AV}}$.

If the signal needs to be amplified, then rectification takes place after amplification:

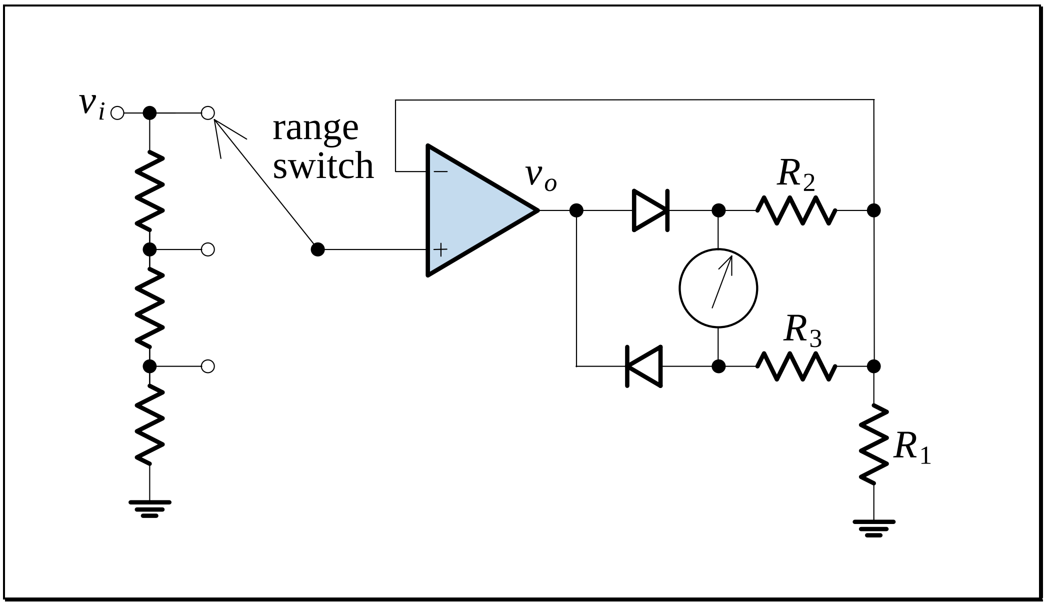

Figure 11B.9

The diodes are placed in the feedback loop so that their nonlinear characteristic is of no consequence.

The Differential Voltmeter

The differential voltmeter compares the unknown voltage to a standard reference voltage by using a precision divider:

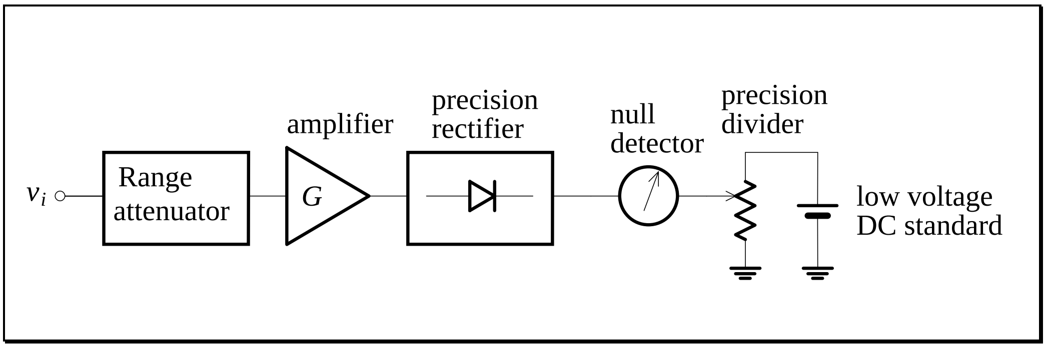

Figure 11B.10

It is accurate but slow.

The Digital Meter

Digital instruments have a good readability (not prone to human error) and are more accurate than analog meters. They have a greater resolution and thus have less ranges than analog meters (they are often auto ranging).

A digital meter contains digital circuitry to obtain a measurement. The converter block of the general electronic meter is therefore:

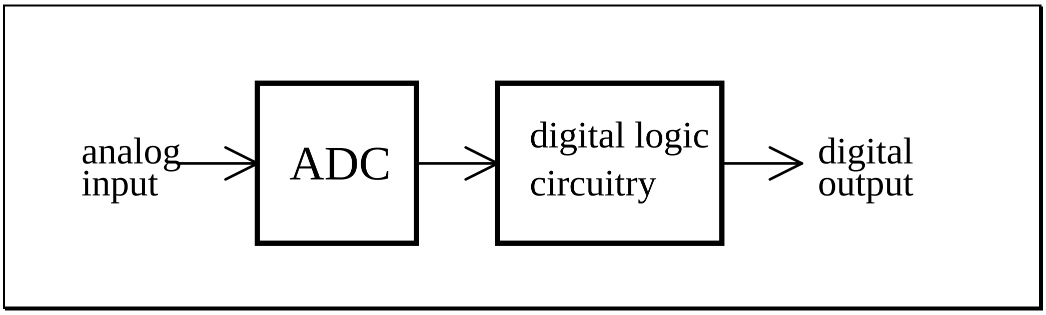

Figure 11B.11

There are two main types of analog to digital converter (ADC), integrating and non-integrating. Integrating ADCs are mainly associated with discrete circuitry. Non-integrating ADCs are more common in integrated circuits (ICs) and microcontrollers.

Integrating ADC

One example of an integrating ADC is the voltage to frequency integrating ADC (relatively slow, but accurate):

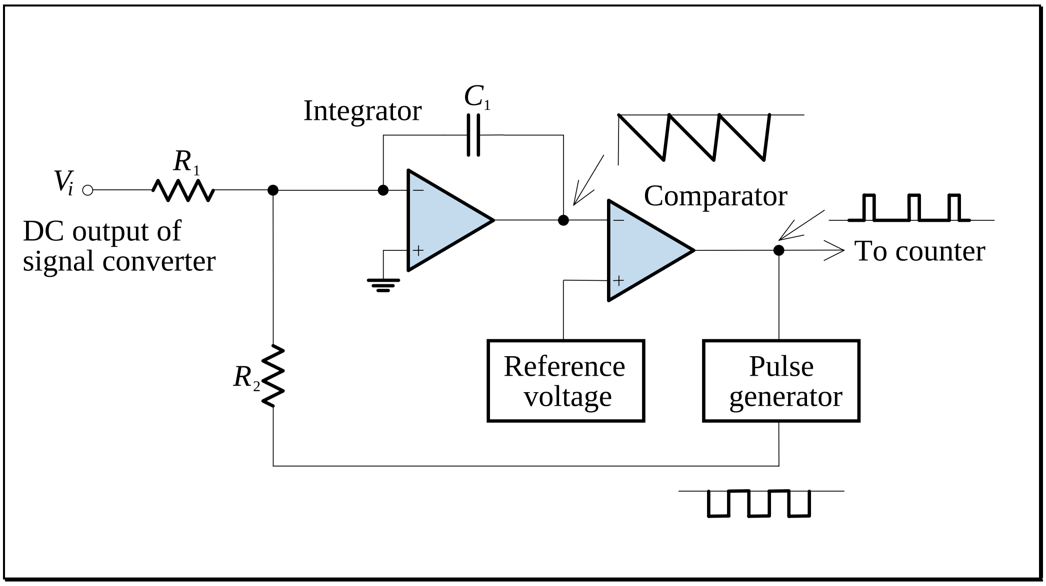

Figure 11B.12

With a DC input to an integrator, we have:

$$\begin{aligned} v_o &= -\frac{1}{R_1 C_1}\int_0^t v_i dt \\ &= -\frac{V_i}{R_1 C_1}t + v_o(0) \end{aligned} \tag{11B.18}$$

Thus the output, for a DC input, is a negative ramp.

When v_o reaches a certain negative level, the comparator triggers the pulse generator which generates a negative voltage step with magnitude > $|V_\mathrm{i}|$ and the integrator output is zeroed. The comparator detects $v_\mathrm{o} < v_\mathrm{ref}$ and turns off the pulse generator.

The process is repeated. The rate of pulse generation is governed by the magnitude of the DC input (V_i). A larger input causes a steeper ramp and a higher pulse rate. The comparator output waveform is fed to a digital counter and the pulse rate (calibrated in volts) is displayed.

Noise tends to average out (the integral of noise is generally zero).

Microprocessor Controlled

A microprocessor based instrument is an "intelligent" instrument. The microprocessor can control such things as a keypad, display, the ADC; other internal circuitry such as oscillators and frequency dividers; the nature of the measurement, e.g. from voltmeter to ohmmeter, etc.

Most of these functions can be incorporated into one integrated circuit (which is mass produced), known as a microcontroller. These meters are therefore cheaper than analog meters.

A disadvantage of microprocessor-based meters is that they can only measure signals below a certain frequency, known as the “foldover frequency”, which is intimately related to how fast digital samples of the analog waveform can be taken. However, with advances in computing speed, this is becoming less of a concern.

References

Jones, D. and Chin, A.: *Electronic Instruments and Measurements*, John Wiley & Sons, Inc., New York, 1983.