Test & Measuring Instruments

Testing and measuring instruments — the moving coil meter and its use in measuring voltage, current and resistance — the multimeter or VOM — the electronic voltmeter, VTVM or SSVM — the cathode-ray oscilloscope, CRO or "scope" — oscillators and signal generators — measuring bridges — other less common instruments.

In many of the preceding chapters we have had occasion to mention a number of test and measuring instruments, such as the multimeter, the oscilloscope and the signal generator. It would therefore seem wise at this stage to spend a little time looking at the various measuring instruments used in electronics, to give the reader some idea of their operation and use.

A basic component in many measuring instruments is the moving-coil meter. This is a device which has an indicating pointer so arranged that, when a current is passed through the meter, the pointer moves along a scale by an amount which is directly proportional to the amount of current flowing.

Figure 1 gives the general idea, and may be used to explain how the moving-coil meter works. The heart of the meter is a rectangular coil of fine insulated wire, pivoted at opposite ends on jewelled bearings so that it can rotate. Current is fed through the coil via two delicate spiral springs, one at each pivot. The springs also supply what is known as the "restoring torque," which will be explained in a moment.

Attached to the coil is a long but extremely light and delicate pointer, along with a set of three short arms and small weights. These are used to counterbalance the pointer so that the whole rotating assembly remains balanced, irrespective of the position in which the meter is mounted. The pointer moves over a dial plate having a measuring scale printed upon it.

Behind the dial plate is a strong "horseshoe" shaped permanent magnet; this is fitted with two pole-pieces which concentrate its magnetic field through the movable coil. There is also a cylindrical soft iron core arranged to be within the coil, but not to rotate. It is fixed, and serves to ensure that, no matter where the coil is, it always moves perpendicular to the magnetic field. This must be done if an evenly-spaced or "linear" scale is required.

In an early chapter, you may recall, we saw that a current flowing in a coil of wire produces a magnetic field; this is precisely what happens when current flows through the meter coil. Two magnetic fields are thus present around the coil — that due to the permanent magnet, and that produced by the current being passed through the coil.

The two fields interact, and the coil experiences a turning force or torque; it therefore tends to rotate and, in so doing, to move the pointer needle along the indicating scale. When it does this, the spiral springs begin to have an effect; coil rotation compresses one spring and expands the other, so that both springs tend to resist such movement. The further the coil rotates, the greater the force of "resistance" produced by the springs, which are all the time trying to restore the coil to its original position. Hence we say that the springs provide "restoring torque"

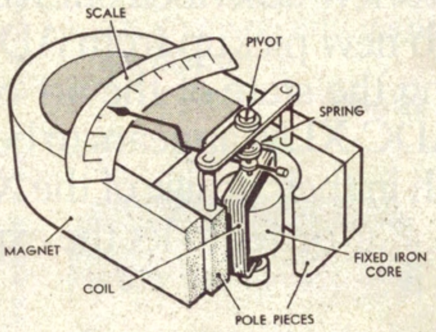
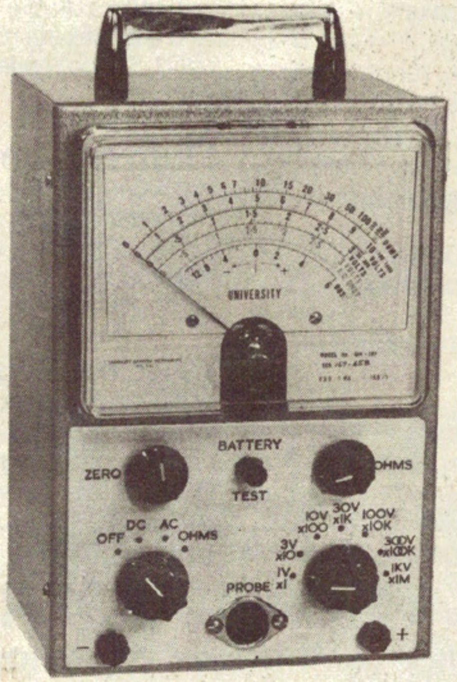


Fig. 1: A basic moving-coil meter.



A modern solid-state voltmeter or SSVM, using FET devices.

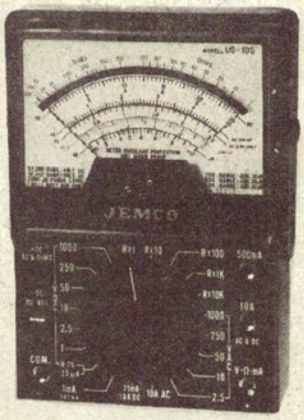
as well as providing flexible connections to the coil.

The springs are thus fundamental to the operation of the meter. Because of their "proportional-to-angle-turned" restoring force, the coil and pointer are brought to rest at a point where the pointer needle indicates a value directly proportional to the actual current flowing.

If a strong current flows through the coil, its forward torque will be large and the coil will be able to rotate through quite a large angle before the restoring torque of the springs is able to counteract the current torque and bring it to a halt. On the other hand, a small current will only produce a small forward torque and the coil will only be able to move through a small angle before the springs are able to stop it.

For every value of coil current there will thus be a corresponding coil and pointer position, providing that the meter is not "overloaded" by passing through it a current greater than it is designed to handle.

The moving-coil meter can be used to measure very small orders of current. It can also be used to measure larger currents, as well as voltage and resistance, as we shall explain.



A typical modern multimeter or VOM. It features more than 20 ranges.

In passing, however, it should be noted that there are other types of basic meter movement beside the moving-coil type. These types are not as common as the moving-coil meter and, for this reason, they need not concern us here. It is sufficient merely to mention that they exist.

When we discussed Ohm's Law in an earlier chapter, we saw that resistances in parallel share any current which may be flowing. In fact, the proportion of the total current which flows through each of a number of resistances in parallel is inversely — and exactly — proportional to their resistance. The lowest resistance will take most of the current, while the highest resistance will take least current, and so on.

Because of this fact, a moving-coil meter may be arranged to measure large currents. Its coil has a certain value of resistance and, by placing in parallel with it a smaller resistance called a "shunt," the meter coil will receive only a known minor part of the current.

A typical meter movment giving full-scale deflection of the pointer needle with only 1 milliamp through its coil can thus be arranged to read as a 1 amp meter, by wiring it in parallel with a shunt which takes 999/1000ths of the current flowing through the two. The shunt would simply have a resistance of 1/999 that of the meter coil so that, when 1 amp flows through the two, the shunt takes 999 milliamps and the meter receives its correct 1 milliamp.

If the total current should be less than 1 amp, the meter will read the same proportion of 1 milliamp. Thus ½-amp of total current would read half-scale on the meter.

When we discussed Ohm's Law we also saw that, when a voltage is applied to a resistance, a current flows which is proportional to the applied voltage and inversely proportional to the resistance. It is this fact which permits us to use the moving-coil meter to measure voltage.

All we have to do is connect the meter coil in the series with a resistor, which is called the "multiplier." The multiplier is made to have a resistance which, when added to that of the meter coil, will draw the full-scale meter current when the intended full-scale voltage is applied to the two.

An example should again make this clear: Suppose we have a 1-milliamp meter and we want to use it to read from 0 to 100 volts. All we need do is work out from Ohm's Law the resistance which draws 1 milliamp when 100 volts is applied, which works out to be 100k (100 divided by 1/1000, giving 100,000). To find the multiplier resistor value, we simply subtract the resistance of the meter coil from this figure. Thus, if the meter coil has a resistance of 100 ohms (a typical figure) we will need a multiplier of 99,900 ohms in series with the meter to convert it into a 0-100 voltmeter.

In practice, if subtracting the meter resistance only affects the multiplier resistor value by the small amount shown above, it would be neglected. An accurate 100k resistor would be quite close enough as the multiplier.

In these circumstances, 100 volts applied to the combination would make the meter read full scale. With 50 volts applied it would read half-scale and with 25 volts, quarter-scale. By marking the meter scale in volts to 100, any voltage up to 100 can be read directly.

Different voltage ranges may be provided simply by selecting different values of multiplier resistance.

There are a number of different arrangements whereby the moving-coil meter may be used to measure resistance. The resistance-measuring circuit most often used is basically little more than a battery wired in series with the meter.

When an unknown resistance is connected into the circuit between the appropriate terminals, it completes the circuit and a current flows through the meter. The amount of current (and hence the meter reading) will depend upon the value of the resistance. Small resistors will produce a large current, and large resistors a small current; thus the scale of the meter can be marked in terms of resistance.

The moving-coil meter may also be used to measure AC, with the aid of a small rectifier circuit to change the AC into DC. Multiplier resistors may be added to the meter-rectifier combination to measure alternating voltage, while a small transformer is used to allow the combination to be used to measure heavy alternating currents.

The common "multimeter" or "VOM" (short for Volt-Ohm-Milliameter) is simply a meter movement fitted into a case along with a variety of current shunts, multiplier resistors and resistance measuring circuits, to enable it to be used to perfom a wide variety of measuring tasks.

It is usually provided with switches to select the various shunts or multipliers, etc. Alternatively it may have a series of pin-jacks or terminals to which the test leads may be connected by the user, depending on the measuring job to hand.

The multimeter is one of the most useful instruments in electronics. A modern instrument of the type shown in the photograph may provide thirty or more different measuring ranges, covering voltages (AC and DC) from a fraction of a volt to many thousands of volts; currents

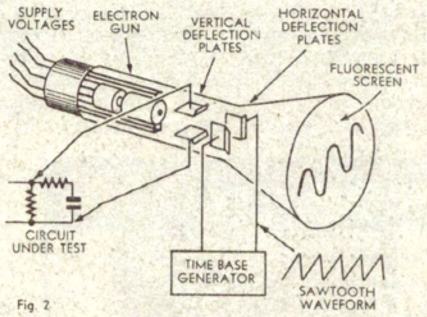


Fig. 2: (above) Basic operation of the CRO or "scope". At right is a typical small instrument of this type.

from microamps to amps; resistance from a fraction of an ohm to many megohms. It may also provide built-in protection for the meter, to guard against damage due to improper setting of the controls.

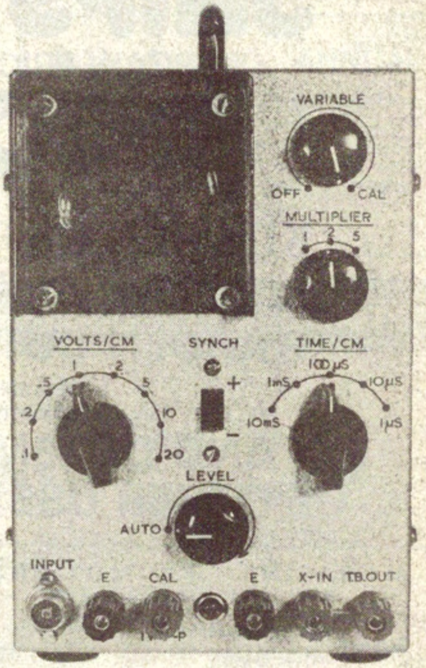
Because the moving-coil meter is essentially a current reading device, the multimeter always draws a small current when being used to measure voltage. With modern, sensitive meter movements this metering current may be as low as 10 or 20 microamps for full-scale deflection, but even this current can load some circuits unduly and produce reading errors.

It was principally because of the loading imposed by the moving-coil multimeter that electronic voltmeters and multimeters were developed. These use either valves, bipolar transistors or FETs to increase the sensitivity of the basic moving-coil meter, at the same time giving it a very high effective input resistance so that it does not seriously load even high resistance circuits being tested. Typically the input resistance of an electronic voltmeter is around 10 megohms, while special types may go as high as several hundred megohms.

The first type of electronic voltmeter to be developed was the vacuum-tube voltmeter or "VTVM", also called the valve voltmeter. This generally used two triode valves, or a twin triode, in a balanced circuit. Electronic voltmeters and multimeters using valves are still available, but most modern instruments of this type use either bipolar transistors or FETs, and thus go under the name of solid-state voltmeter or "SSVM".

The principal disadvantage of VTVMs and other electronic meters using valves is that considerable power is needed to run the valves, so that they must generally be operated from the AC mains. This limits their versatility compared with a simple moving-coil multimeter. Solid state voltmeters are less subject to this limitation, however, as they can operate for quite long periods on a small battery supply. Modern SSVMs are in fact fast becoming used for many of the jobs formerly handled by the multimeter, because of their higher input resistance.

Multimeters and electronic voltmeters permit the measurement of voltages, currents and resistances in circuits, but they do not allow us to see the ways in which



currents or voltages may be changing — unless the changes are taking place very slowly. The cathode-ray oscilloscope or CRO, also called the "scope", is an instrument which allows both fast and slow changes to be seen. It may also be arranged to measure voltages and frequencies.

The heart of the CRO is the cathode-ray tube, which is a small-scale version of the picture tube used in television receivers. In addition to the size difference, the cathode-ray tube used in most oscilloscopes uses what is termed electrostatic deflection, rather than the magnetic deflection used by television picture tubes, and has no "yoke" mounted on its neck.

Fig 2 should help in understanding how the cathode-ray oscilloscope works. The tube consists of three main parts — a group of electrodes called the "electron gun," two pairs of flat electrodes called the deflection plates, and a fluorescent screen.

It is the screen which is visible at the front of the oscilloscope, and it is on the screen that a "picture" of circuit voltage or current changes appears. Repeating changes, like those of alternating voltages and currents, produce fixed wave-like patterns on the screen — hence the use of the term "waveform" to describe the screen patterns and the circuit variations which they represent.

The purpose of the electron gun is to produce a fine stream of electrons aimed at the flurorescent screen. The gun has a heated cathode similar to that in a normal valve, and a system of cylindrical and disc electrodes used to control and guide the electrons into a narrow beam.

If the deflection plates were not there, or if they were not connected to anything, the electron beam from the gun would strike the centre of the fluorescent screen and cause the phosphor powder at that spot to glow. All that would be visible would be a small bright dot at the centre of the screen.

Consider what happens to the beam when one of the pairs of plates — say the pair marked "vertical deflection" — is connected into a circuit so that a changing circuit voltage appears across the two plates.

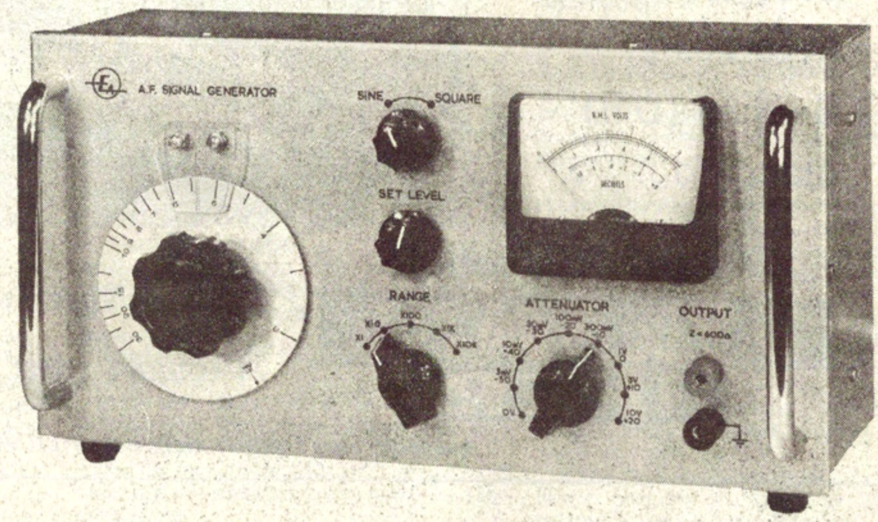
The two deflection plates are in effect a parallel-plate capacitor, and the voltage difference between them will set up an electric field in the space between them — through which the electron beam is travelling. As the voltage of the circuit varies, the electron beam will therefore find itself in a varying electric field.

Electrons, it will be recalled, are negatively charged, and the electrons of the beam will thus tend to be moved or "deflected" by the electric field toward the more positive plate. The beam is travelling quite fast, so the electrons will not actually be able to reach the more positive plate, but the beam will be bent in the direction of the plate and the electrons will hit the fluorescent screen at a new spot somewhat removed from the centre of the screen. The exact distance moved will depend upon the voltage applied to the two plates.

As the voltage of the circuit varies, the bending of the beam will also vary and the glowing spot on the screen will move up and down in sympathy. Whenever the top plate is more positive than the lower plate, the beam will bend upward and the spot will move up. Conversely, when the lower plate is more positive than the upper plate, the beam will be deflected downward and the spot will move below the centre of the screen.

The amount of beam deflection produced at any instant will be proportional to the circuit voltage present at that instant, and so the distance moved by the spot on the screen will be directly proportional to the circuit voltage at all times. If too much voltage is applied to the plates, the beam will be deflected right into the glass neck of the tube, and the spot will disappear off the top or bottom of the screen.

So far, the cathode-ray tube is simply acting like a meter with an electron-beam indicator "needle". But here is where the second set of plates come in — those marked "horizontal deflection." These are very similar to the first set, but are closer to the screen (for mainly physical reasons) and are turned sideways so that any voltages applied to them will tend to move the beam and spot horizontally.



An audio signal generator of modern design, using solid-state circuitry.

A circuit called the "timebase generator" applies to this second set of plates a voltage which changes linearly (smoothly) for a certain period then drops back to its initial value, then changes linearly again, and so on. The waveform of this voltage is thus shaped like the teeth of a rip-saw, and is accordingly called a sawtooth sweeping voltage.

The effect of this sweeping voltage is to move the beam and spot smoothly across the screen from one side to the other, then quickly back again, then smoothly across again, and so on. The speed at which this occurs can be adjusted over a wide range by controls in the timebase generator circuit.

By this horizontal movement of the beam and spot, the timebase waveform "spreads out" the up-and-down spot motion produced by the signal so that it can be seen.

In effect, the cathode-ray tube plots a graph of the test voltage compared with time; the time represented by one sweep of the time base waveform can be worked out or measured.

The cathode-ray oscilloscope thus allows us not only to see the circuit voltages changing, but to measure by how much they change — given by the height of the pattern — and how long they take in changing — which may be deduced from a knowledge of the period of time represented by one sweep of the timebase waveform. It is thus an extremely useful instrument.

Most modern oscilloscopes include an amplifier (called the "Y" or "vertical" amplifier) to enable very small circuit voltages to be made large enough to produce a visible deflection of the spot. The amplifier has a switch to allow the selection of various amounts of amplification, and the switch is marked directly in terms of the amount of input voltage which is represented by 1 centimetre of vertical spot deflection. Voltages can thus be measured quite easily.

The speed of the timebase generator is adjustable by means of other switches, and these again are marked directly in terms of the period of time (in seconds, milliseconds or microseconds) represented by 1 centimetre of screen width. Time duration and frequency can thus also be measured quite easily.

In passing, it should be noted that some oscilloscopes, notably the older types and the simpler modern types, do not have such "calibrated" vertical amplifier and timebase controls. They often have just a variable gain control on the vertical amplifier and have timebase controls either unmarked or marked in terms of the approximate timebase sweeping frequency (in Hertz). Such instruments are intended mainly for "looking" at circuit goings-on, and are not really suitable for making measurements.

Most oscilloscopes have knobs to control the brightness and focus of the spot, and to set the spot to the centre of the screen when voltages having a large steady component are being measured. These latter are called the "shift" or "centering" controls.

Oscilloscopes are also fitted with circuits to enable the timebase to be locked or "synchronised" with the voltage under inspection so that the screen pattern is held steady. Depending upon the exact type of circuit used, the controls associated with this feature may be marked "synch." or "triggering" or "locking" adjustments.

In some of the preceding chapters, we have referred to sources of RF alternating voltage, called variously modulated RF oscillators or RF signal generators depending upon their degree of refinement. It was explained that such devices are basically valve or transistor type oscillators, provided with a tuning capacitor and various coils to set the desired frequency band.

They usually include provision for modulating the RF voltage with a fixed audio tone (usually 400 or 1,000 Hz), and with a reliable control over the amount of output voltage delivered — the so-called "attenuator."

In laboratory parlance, the name "Signal Generator" is usually reserved for instruments which have a meter to monitor the output voltage and the degree of modulation present, and an output voltage attenuator capable of setting the output to a known level between a fraction of a microvolt and a few volts.

Just as there is a need for instruments able to supply RF voltage, there is a similar need for instruments able to supply low- and audio-frequency alternating voltages. Such instruments are known as audio oscillators or audio generators, the latter being the counterpart of the RF signal generator in terms of accuracy and refinement.

One early type of audio oscillator was the so-called "beat frequency oscillator" or "BFO", so named because it generated the desired audio signal by beating together two RF signals. This type is now rarely used because it tended to have poor frequency stability and a rather high distortion level. Most modern instruments are based on oscillators which generate the audio signal directly, a common type being based on the so-called "Wien -bridge" network. This consists of a network of resistors and capacitors connected in a feedback loop around a high-gain audio amplifier.

Modern instruments of this type can typically deliver audio signals from as low as 1Hz to above 200kHz, at levels from a fraction of a millivolt to many tens of volts. The output waveform may be either a sinewave, with perhaps a distortion level as low as .01%, or other waveforms such as square wave or triangular wave.

There are many occasions when resistors, capacitors and inductors must be accurately measured to determine their value of resistance or reactance. While a reasonably accurate measurement can be made using various circuits provided on a multimeter or electronic multimeter, it is usually necessary to employ what is known as a measuring bridge in order to make really accurate measurements.

Basically, a measuring bridge is a device which balances the unknown resistor, capacitor or inductor against a known or standard unit, to give an indication of the relative value of the unknown component. This type of measurement is accurate because the bridge simply performs a comparison between the unknown unit and a highly accurate standard unit; it does not rely upon the voltage of an internal battery or oscillator, or the accuracy of a meter. If a meter is used in the bridge, it is simply used as a balance indicator and not used as a measuring device.

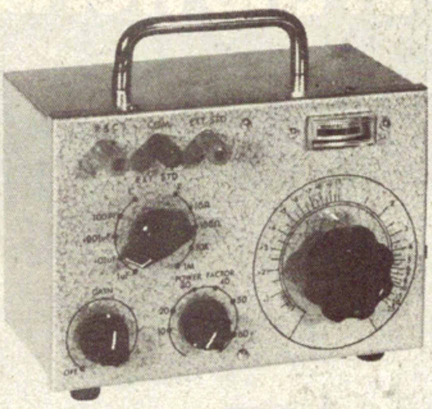
For the measurement of inductance a rather elaborate bridge is required, whereas quite a simple bridge can measure resistance and capacitance fairly accurately. For this reason most of the simpler measuring bridges are called R-C bridges to signify that they are really only suitable for measuring resistance and capacitance.

The R-C bridge shown in the photograph has inbuilt standard resistors and capacitors for six comparison ranges, with a pair of terminals provided so that additional standard resistors or capacitors may be connected if desired. The comparison is carried out at a frequency of 50Hz and a small meter used to indicate when a balance is achieved. On older bridges this function was served by a special valve known as a "magic eye" or electron-ray indicator which indicated balance by means of two overlapping fan-shaped glowing segments on a fluorescent screen.

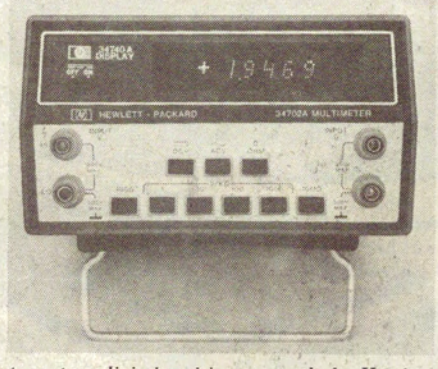
The bridge is adjusted for a balance by means of the large dial knob, which effectively "tries out" various ratios between the unknown and standard components. When it finds the ratio which produces a balance, the dial reading gives the value of the unknown component relative to the standard. If it reads "0.5" when the standard is 100pF, for instance, the unknown capacitance is 50pF. If it reads "3.4" with the same standard, the unknown would be 340pF.

The instruments which we have looked at so far are perhaps the most common types which are met in electronics. Before we leave this topic, however, it might be worthwhile briefly mentioning a few of the many not-so-common instruments.

The sweep and marker generator is an instrument used in the alignment of TV receivers and similar applications. It is in effect two RF oscillators or signal generators in one. The sweep section generates an RF signal which is swept back and forth in frequency, and may be used in conjunction with a CRO to show how tuned circuits and amplifiers behave over the band of frequencies being swept. The marker is a fairly normal RF oscillator used to identify or "mark" the various frequencies being swept through.



A typical small R-C measuring bridge. The value of an unknown component is read on the large dial.



A modern digital multimeter made by Hewlett-Packard. Readout is by light-emitting idodes or LEDs.

Valve testers and transistor testers are intruments used to check valves and transistors for proper operation. Simple types may only indicate the difference between useless or very poor units and those which should operate more or less normally. The more elaborate instruments place the valve or transistor being tested under its correct operating conditions and measure just how well it performs.

Distortion meters are audio testing instruments which may measure one or more of a number of different types of signal distortion. They are often combined in the one case with an instrument called a millivoltmeter — which, as the name suggests, measures very small alternating voltages. The millivoltmeter is very useful for measuring the performance of microphones and gramophone pick-ups, as it can measure their output voltage directly.

Dip oscillators are small RF oscillators which have externally-mounted resonance coils and a meter which indicates their strength of oscillation. They are used to determine the tuning frequency of resonant circuits in receivers and other equipment. When the coil of the dip oscillator is brought near the coil of the unknown tuned circuit, the frequency is varied until the meter indicates that the test circuit is absorbing some of the oscillation energy — this shows as a "dip" in the meter reading. The dip oscillator dial then indicates the resonant frequency of the unknown circuit.

The first dip oscillators used valves, and were called "grid-dip oscillators" or "GDOs" because the strength of oscillation was monitored by measuring the oscillator valve's grid current. Nowadays most dip oscillators use either a bipolar transistor or a FET in the oscillator, resulting in a smaller and more flexible instrument.

The signal tracer is effectively a sensitive radio receiver fitted with a switch which permits signals to be fed into it at any of the various points along the signal path. It is used to follow the path of radio signals through a receiver under test, in order to find out speedily the section of the receiver which is faulty.

Digital counters or digital frequency meters (DFMs) are instruments used to measure frequencies and time periods, and to count pulses. They operate by converting the input signals into a stream of rectangular pulses, and counting the number of these pulses occurring in a known period of time. The counting is performed by groups of circuit modules known as "flip-flops", which are bi-stable circuits capable of flipping from one stable state to the other when triggered by a pulse. Readout of the count is in the form of glowing numbers, usually from either special gas discharge tubes or from arrays of light-emitting semiconductor diodes or "LEDs".

Digital voltmeters or "DVMs" are electronic voltmeters which, like digital counters, operate by counting rectangular pulses and displaying their reading in the form of glowing numbers. However in a DVM an input circuit is used to produce a group of pulses whose number is directly proportional to input voltage, so that when they are counted the reading may be arranged to indicate the input voltage. The voltage-to-pulses conversion is generally performed by a circuit which generates a voltage "ramp" which is linearly rising or falling from zero or a set value, and opens a digital "gate" to pass the pulses until the ramp voltage just equals the voltage to be measured.

Although we may seem to have looked at quite a number of test and measuring instruments in this chapter, there are a great many more that we have not been able to mention. All sorts of test and measuring instruments have been developed in order to make the job of the electronics worker a little easier, faster and surer.