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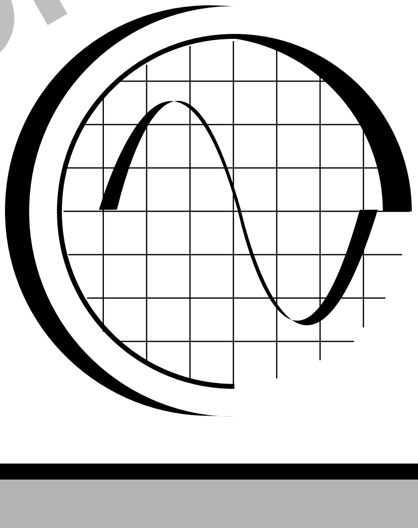
ELECTRICAL MEASURING INSTRUMENTS

Lesson One

Principles of Meter Operation



TPC Training Systems

204.101

Lesson

1 Principles of Meter Operation

TOPICS

Meter Principles
General Digital Meter Design
Integrating ADCs
Digital Displays
Sensitivity, Accuracy, and Resolution
Introduction to Analog Meters
The D'Arsonval Movement
Electrodynamometer Movements
Moving-Vane Meters
Magnetic Shielding
Parallax Error
Analog Instrument Sensitivity
Analog Accuracy

OBJECTIVES

After studying this lesson, you should be able to…

- Define the terms *digital meter* and *analog meter.*
- Describe the purpose of the analog-to-digital converter in a digital meter.
- Identify and label graphs of integrator output from a dual-slope integrating meter.
- Explain how time is related to voltage measurement in an integrating digital meter.
- Differentiate among the terms *accuracy*, *sensitivity*, and *resolution.*
- Explain how a D'Arsonval meter movement works.
- Describe the parallax effect, and explain how to avoid it when using an analog meter.
- State the sensitivity formula for an analog meter.

KEY TECHNICAL TERMS

Resolution	1.06	the ability to distinguish one measurement from another; closely related to significant digits; the greater the number of significant digits in a meter's measurement, the greater (or finer) the meter's resolution
BCD	1.13	binary-coded decimal
LCD	1.27	liquid crystal display
Galvanometer	1.44	an instrument used to detect very small electric currents
FSD	1.48	full-scale deflection; as far as the pointer can move to display its maximum reading
Armature	1.51	the moving component in an electric motor or analog instrument
μA	1.52	abbreviation for micro ampere, or 1 millionth of an ampere (Greek letter mu, followed by a capital A)
Induced magnetism	1.57	magnetic field produced by current flowing in a wire
RMS	1.58	root mean square; the effective value of a current or voltage, 70.7% of peak value
Reluctance	1.64	a measure of the opposition a magnetic material has to the conduction of magnetic flux; similar to resistance in a conductor
Parallax	1.66	the apparent movement of an object against a background caused by changing one's viewing position

To begin this course on electrical measurements, you will be introduced to the two basic kinds of electric meters—digital and analog. Although you need not know all the ins and outs of electronic circuits to understand these meters, it will help if you can at least recognize the symbols used in electronic schematics. For a refresher, you might want to look at TPC Courses 101 and 102. Even if you do not have access to these publications, the explanations in this lesson should be understandable just by reading and following along in the diagrams.

This lesson presents the principles behind both kinds of meters. You will see some of the basic circuitry in digital meters and find out how those instruments work. You will also get clarification of the meaning of certain terms you often see associated with meters. In the next lesson, you will see the practical "how-to" application of these ideas in actual electrical measuring devices. Take your time as you go through these pages so that you do not miss any important concepts. Later lessons will build on these ideas.

Meter Principles

1.01 Working with electricity requires making accurate measurements. The meter is the most common measuring instrument, as it has been for quite some time. Basic meters are used for measuring current, potential difference (voltage), resistance, frequency, and capacitance, just to name a few of their functions.

1.02 All meters have one thing in common. They all have an internal standard to which measured values are compared. In this respect, an electrical meter is much like a mechanical balance that compares an unknown mass to a standard mass.

1.03 This lesson addresses both analog meters and digital meters. Most of the analog meters described here use magnetic fields to induce movement of a pointer on a scale. These are the older, traditional meters that will be covered in the second half of the lesson.

1.04 In the first half, you will learn about the most common meters found in electrical maintenance departments today, the digital meters. These meters all compare an input voltage to an internal reference voltage. The result is a set of digits displayed on a small screen that often looks like the display of a hand-held calculator or memo-pad computer.

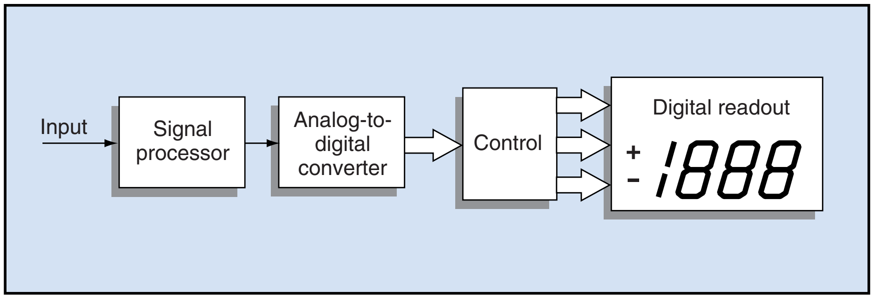
General Digital Meter Design

1.05 Many of the meters you use on the job will be digital meters, like the one shown in Fig. 1-1. They convert measurements into digital signals, then display them as numerals on a small screen. Some people mistakenly think that these meters are called "digital" because they display their measurements as "digits." But the name actually comes from the fact that, like your computer, all data are transferred and processed as discreet 1s and 0s.

1.06 No digital meter can display all possible values of a quantity. The reading must increase in steps, even though the steps can be very small. For example, a voltmeter may be able to display values to the nearest tenth of a volt. But this means that when a voltage is steadily increasing from 221.3 V to 221.4 V, the meter cannot display the intermediate values of 221.32 V, 221.34 V, 221.35 V, and so on. It must jump from 221.3 to 221.4 when the measured quantity

Fig. 1-1. Hand-held digital measuring instrument

Fig. 1-2. Basic functions of a digital meter



becomes large enough. How finely a meter can distinguish between one value and another is called *resolution*.

1.07 In order to generate a display, a digital meter must convert a continuously variable measured signal to a stepped output. To do this, a digital meter needs three main components. It needs a signal processor, an analog-to-digital converter (ADC), and a readout control. These three basic elements are shown as a simple block diagram in Fig. 1-2.

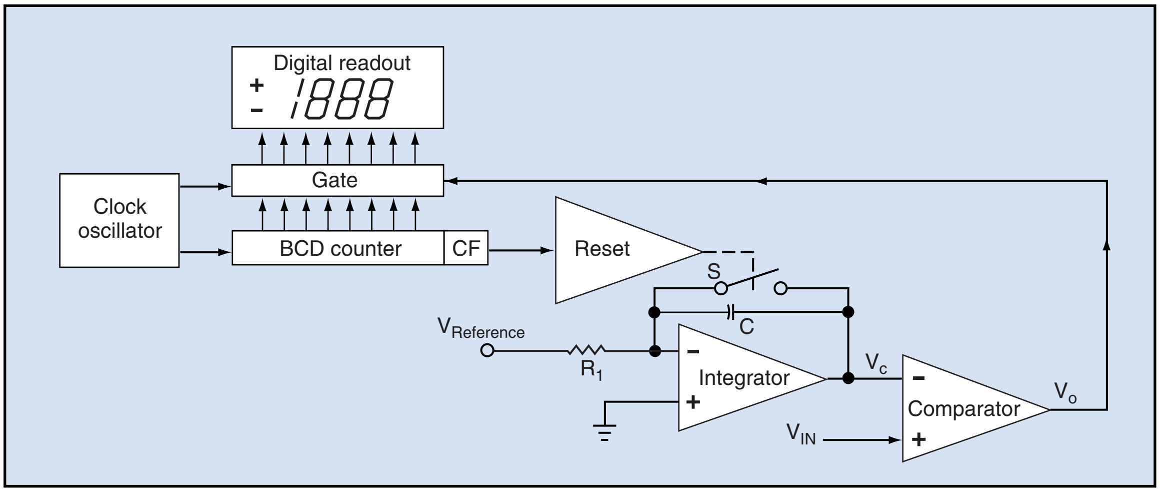
1.08 The first block represents the signal processor. This component must convert the measured signal to a form usable by the ADC. Since most ADCs can only use dc voltages within a very small range, the signal processor may need to either attenuate (reduce the size) of the measured signal or amplify it (make it larger). Then it must convert the measured signal from ac to dc, and change current to voltage.

1.09 The signal processor may be resident within the meter itself, or it may be part of some kind of exterior probe connected to the meter. When resistances are measured, the signal processor must also provide a current source.

1.10 The ADC performs just one function. It accepts the dc voltage from the signal processor and converts it to a readable digital number. Since all ADCs are single-range devices (more about range in the next lesson), all input signals to the ADC must be within the proper range. Two basic methods are used by ADCs to make the analog-to-digital conversion. One is an integrating technique, the other is referred to as nonintegrating. Each of these techniques has several design variations to accomplish the same desired purpose.

1.11 All integrating ADCs use capacitors. In one way or another, they count the time it takes to charge or discharge a capacitor to a reference voltage. Since

Fig. 1-3. Single-slope integration



the counting time is made to vary with the voltage of the incoming signal, time becomes the actual measured variable, and the dc voltage is, therefore, indirectly evaluated. The system is highly accurate.

Integrating ADCs

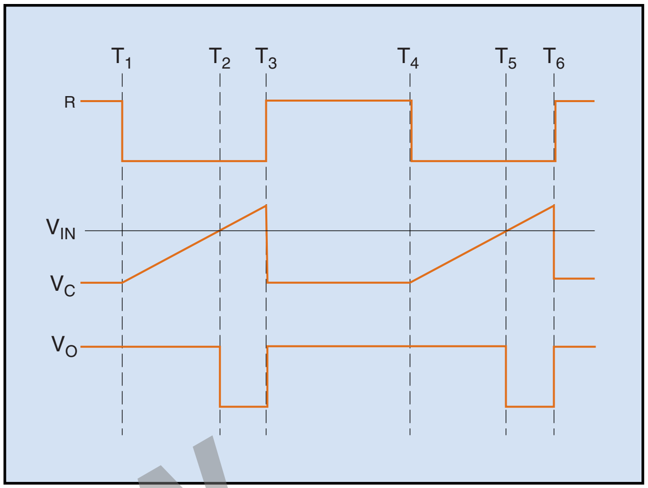
1.12 **Single-slope integration.** In a single-slope integrating digital meter, the ADC has a silicon crystal *oscillator* for a clock, and a precise reference voltage. It also has a precision capacitor and a resistance, with a very exactly determined value. All three of these components must be extremely stable, or the meter will suffer a loss of accuracy.

1.13 As you can see in Fig. 1-3, a binary-coded decimal (*BCD*) counter is connected directly to the oscillator. The counter receives pulses from the oscillator until the counter is "full." This triggers the CF (*counter-full flip-flop*) to change its state, which sends a pulse to the reset amplifier, and the counter begins to fill up again. Two different signals are sent alternately from the CF, first HIGH then LOW.

1.14 The *reset amplifier* resets the state of switch S, which is shown in the diagram as a manual switch. It is actually an electronic ON-OFF switch. When the CF sends HIGH the reset signal closes S. When CF sends LOW, the reset amplifier opens the switch.

1.15 When the switch is closed, the capacitor drops its charge. When it is open, the reference voltage supplies the current to charge capacitor C. This causes V_C to increase at a constant rate. Note that V_C is fed into the inverting side of the *comparator.*

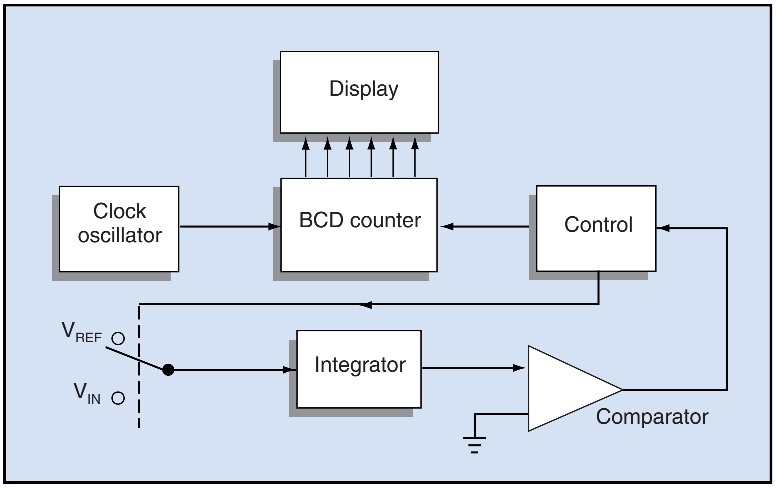
Fig. 1-4. Graphs of signal states in a single-slope integration meter



1.16 Meanwhile, the unknown voltage (V_{IN}) is fed to the noninverting side of the comparator. As soon as V_C equals and surpasses V_{IN}, the comparator output switches from HIGH to LOW. This change in signal triggers the gate to release the stored count to the digital display.

1.17 The graphs in Fig. 1-4 show these relationships. Note how V_O goes LOW when V_C crosses the V_{IN} line at Time 2. At Time 3, the CF sends the signal to the Reset to close switch S. The capacitor dis-

Fig. 1-5. Circuit diagram, dual-slope integrator



charges and remains discharged between T_3 and T_4, at which time the switch opens.

1.18 Because the counter counts at a constant rate and the capacitor charges at a constant rate, an accurate reading of V_{IN} is obtained. In other words, the counter starts counting from zero voltage upward until its count exactly equals the voltage in.

1.19 **Dual-slope integration.** Many digital meters use a dual-slope converter. A block diagram of one such type is shown in Fig. 1-5, on the previous page. The key component in the operation of this meter is an integrator that produces an increasing voltage. The rate of increase is determined by the input voltage. A high input voltage produces a rapid increase in the output of the integrator.

1.20 The integrator starts from zero and produces an increasing voltage for a fixed length of time. The voltage at the end of this time period depends on how fast the voltage increases, which in turn depends on the voltage across the meter terminals.

1.21 At the end of the fixed length of time, the integrator starts decreasing its output. The rate of decrease is fixed, because it is determined by a fixed reference voltage built into the meter circuit. Thus, the length of time for the integrator to return to zero varies. It takes longer to return to zero if it starts from a higher voltage.

1.22 The meter's clock measures how long it takes for the output of the integrator to return to zero. The longer it takes, the higher the voltage at the start of the decrease, which indicates a higher voltage across the meter terminals (input voltage).

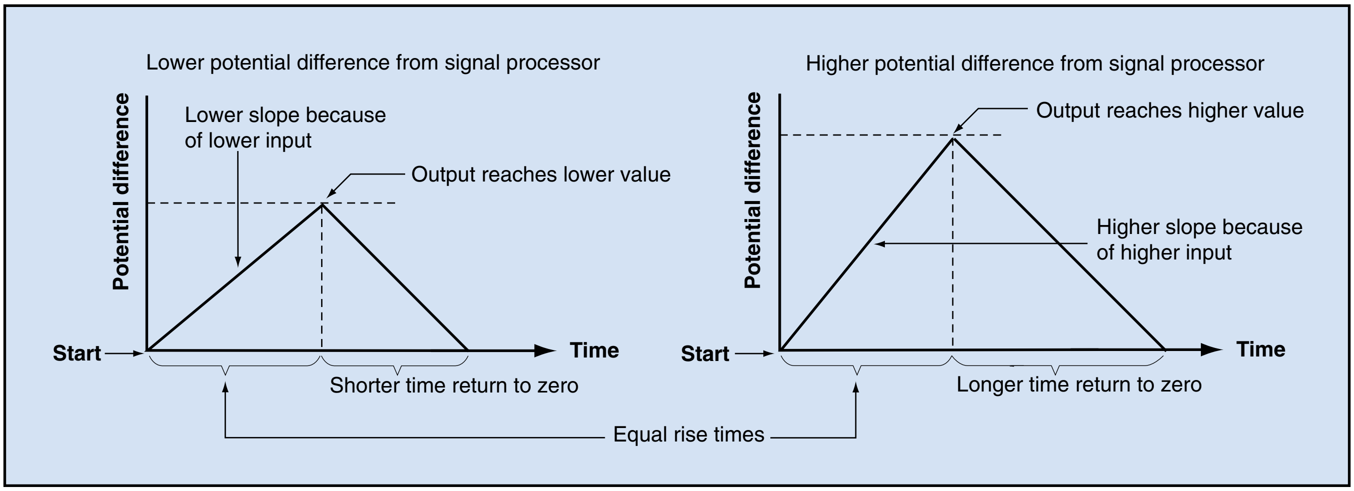
1.23 The two graphs in Fig. 1-6 show how the dual-slope integrator measures two different voltages. The graph on the left shows measurement of a lower voltage than the one on the right. Please note the following:

- The output of the integrator increases slowly (a gradual slope), because its rate is produced by a low voltage across the meter terminals.
- The integrator increases its output for a fixed length of time, reaching a value determined by the rate of increase.
- The output is then allowed to return to zero at a fixed (predetermined) rate (the downward slope is always the same pitch).
- The control keeps track of how long it takes the integrator to return to zero. The number of clock pulses determines the value that will be posted on the digital display.

1.24 The diagram at the right in Fig. 1-6 shows the measurement of a higher voltage.

- The output of the integrator rises faster than before, because of the higher voltage across the meter terminals.

Fig. 1-6. Output of a dual-slope integrator



- The increase continues for the same amount of time as before, so the output of the integrator reaches a higher value.

- The output of the integrator then begins to decrease at the same rate as before.

- The integrator takes longer to return to zero, because it starts from a higher value.

1.25 Other nonintegrating design modes can be found in digital meters, but all of them work on the same principle of converting a voltage into a time period, feeding the time period into a digital counter, and then displaying the "count" as a measured quantity. Although you will probably never be called upon to break open a meter and work on its circuits, you should nevertheless appreciate the precise engineering that goes into making one, and why they are so accurate. Also, since they have no moving parts, you can imagine they are much more rugged and durable than nondigital meters. Still, you should keep them away from dust and moisture at all times.

Digital Displays

1.26 Early digital meters had LEDs (light-emitting diodes) making up the display. These were easy to read, even in low ambient light. But they placed a high demand on their power source.

1.27 Then came the *LCD* (liquid crystal display). These displays use much less power, but are often difficult to read when lighting conditions are poor. To remedy this, meter makers have included low-power background lighting in the meter display.

1.28 The numerals themselves usually consist of seven segments, each of which can be independently energized. In various combinations, these seven segments can show you all ten digits, 0 to 9. Fig. 1-7 shows a detail of the seven segments. A backward 3 can also be formed to indicate an ERROR (E). Displays that include alphabetic characters need more than seven segments.

1.29 When specifications are given for digital meter displays, you will often see the terms $3^1/2$ digits or $4^1/2$ digits. These designations mean that reading from the right side of the display, the meter has the capability of displaying any of the ten digits in the first three or four places, but that it can only display a "1" in the final place, right to left. So the maximum value that a $3^1/2$ digit meter can display would be 1,999. It cannot display 2,000.

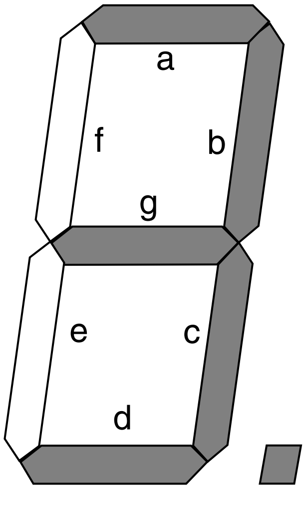
1.30 By switching the range selector, you move the decimal point in the display. So the same $3^1/2$ digit meter can display up to 199.9, if measuring to the nearest tenth, or up to 19.99 if measuring to the nearest hundredth. In some meters, the "1" in the half-digit spot indicates that you have exceeded the range of the meter (over-range).

1.31 Some meters have digital LCD displays that are not numerals. Instead, you may find bar graphs displayed on a grid, or a thick, segmented line, made to look like a mercury column in a thermometer. The line moves, extending or retreating, as segments are added to or taken away from the end of the line. On still other meters, both the moving bar and its digital equivalent appear on the screen.

1.32 You may even find an LCD display that mimics an analog meter dial, with a very small replica of a pointer, comprised of LCD dots. All of these meters with moving LCD elements in their displays, instead of numbers, are still considered digital meters, because all their internal signals are digital in nature. Furthermore, their displays still increment to a higher or lower value in steps. They are often referred to as *analog/digital meters*.

1.33 The most sophisticated digital meter displays resemble small TV screens. On them, you can see plotted graphs and curves, verbal advisories, and

Fig. 1-7. Seven-element digit display



other useful information, as well as the usual numerical measurements. These meters are the *graphical multimeters*. They will be covered in Lesson Four.

Sensitivity, Accuracy, and Resolution

1.34 Before leaving digital meters and going on to discuss the analog variety, it might be wise to clarify the meanings of three similar terms. They are sensitivity, accuracy, and resolution. Often people get confused and incorrectly use these three terms interchangeably. Although they are related, you should recognize that these terms have three distinct meanings.

1.35 *Sensitivity* is an indication of how small a signal can be detected by a meter. It is the smallest change in current or voltage to which a meter can respond. The smaller the signal that will still register on the meter, the greater the sensitivity of the meter. In today's meters, we are talking about one ten-thousandth of a volt or ampere. Electrical meters, if made to measure circuits in solid-state electronic equipment, must be extremely sensitive.

1.36 On the other hand, those meters that are designed to measure massive potentials or massive energy flows are not sensitive in the usual sense. They do not need to be. When you are dealing with kilovolts and megawatts, measuring to the nearest tenth of a volt does not make a lot of sense. A value to the nearest whole ampere or volt would certainly be sensitive enough for most purposes. Later, you will learn a handy formula for finding the sensitivity of an analog meter.

1.37 *Accuracy* is an index of how sure you are that the meter is displaying the correct value for the measured quantity. Accuracy is expressed as a number that tells the maximum error that can be expected, between the actual voltage, for example, and the value indicated on the meter. You have probably seen and heard this term used many times in other situations. For example, a public opinion poll's accuracy may be ±4%. Or, the estimated crowd at the auto race was 55,000, ±2,000 people.

1.38 Accuracy is usually expressed as "plus or minus" some percentage. If a meter measures 440 V, with an accuracy of ±5%, you know the actual value could be anywhere between 418 V and 462 V. The designation "±5%" tells you the total range of possible error is 10%, or 5% in either direction from the displayed value. Sometimes accuracy is expressed as ± the actual units of measurement, as in ±0.05 V.

1.39 *Resolution*, as mentioned before, deals with how finely the meter can distinguish between two values. In other words, it is the ability of a meter to display the differences between values. Resolution is closely related to the concept of significant digits. If a meter provides a reading of 121.346 V, its resolution is greater than one that reads the voltage as 121.3 V. A meter with greater resolution obviously has a greater sensitivity as well.

The Programmed Exercises on the following page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of your book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The degree to which a meter can distinguish one value from another is referred to as the meter's ________.	1-1. RESOLUTION Ref: 1.06
1-2. The circuit component in a digital meter that changes a smoothly variable signal to a stepped signal is the ________.	1-2. ADC or ANALOG TO DIGITAL CONVERTER Ref: 1.10
1-3. A digital meter measures voltage by counting the time it takes to charge or discharge a(n) ________ to a reference voltage.	1-3. CAPACITOR Ref: 1.11
1-4. In single-slope integration, the Reset Switch changes its state when it receives a pulse that was generated by the ________.	1-4. CF or COUNTER-FULL FLIP-FLOP Ref: 1.13, 1.14
1-5. LCDs are easier to read in low lighting conditions when they also have ________.	1-5. BACKGROUND LIGHTING Ref: 1.27
1-6. A single numeral in an LCD digital display consists of how many segments?	1-6. SEVEN Ref: 1.28
1-7. What is the largest number you can see displayed on a $3^{1}/_{2}$ digit meter?	1-7. 1999 Ref: 1.29
1-8. Accuracy is usually expressed as a(n) ________.	1-8. PERCENT Ref: 1.38

Introduction to Analog Meters

1.40 In the past, electrical training courses devoted a great deal of time to the study of analog meters, and much less to digital meters. Today, however, most test meters in the field are digital. Few analogs are left. Nevertheless, it is a good idea to know something about these devices, so they have been included here.

1.41 Analog meters do have some distinct advantages. They transition smoothly, as the measured variable rises and falls, instead of displaying the measurement in steps. You can easily follow the swing of a pointer. Therefore, it is easier to spot a trend visually and to "eyeball" the rate of change on an analog meter. Furthermore, analogs are basically less affected by extreme temperature changes.

1.42 What constitutes an analog measuring instrument? The output of an analog instrument is typically a pointer, as seen in Fig. 1-8. The pointer does not move in steps, but moves smoothly in response to a steady change in the measured variable. Most analog meters have a mechanical movement that drives a pointer, which moves across a printed scale. The motive power behind these mechanical movements may be electromagnetic or, in a few cases, thermal. We will look at some of these meter movements in detail.

The D'Arsonval Movement

1.43 Perhaps the most common analog meter movement is the D'Arsonval movement. It is named for its inventor, D'Arsonval Deprez. This movement is similar in operation to an electric motor, in that it uses the interaction between a magnet and a current-carrying coil of wire. The basic parts of a D'Arsonval meter movement are shown in Fig. 1-9.

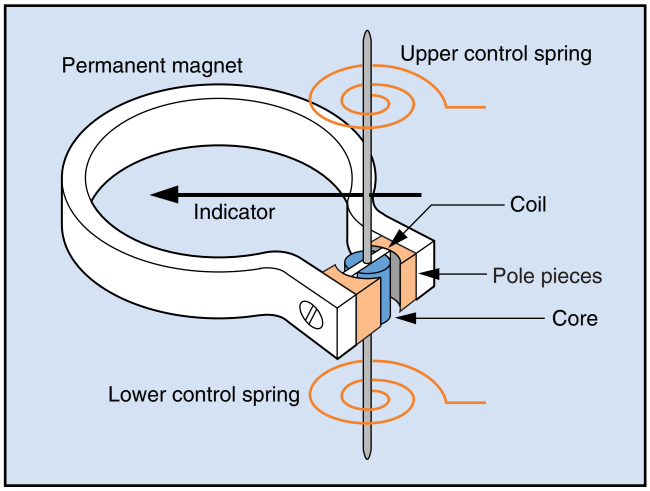
1.44 As you can see, this meter is really quite simple: nothing more than a permanent magnet, a moving coil of wire, a pointer, and a scale. This meter also has another name. It is sometimes called a permanent-magnet, moving-coil galvanometer, or a PMMC galvanometer, for short. The term *galvanometer* refers to any sensitive device used to detect the presence of an electric current. Many galvanometers can swing either way, positive or negative, with the zero mark in the middle of the scale.

1.45 Galvanometers are used in laboratory measurements of extremely small currents. However, they are usually not portable, and they are neither compact nor rugged enough for industrial use. The D'Arsonval movement has a kind of galvanometer that is portable, compact, and relatively sturdy.

1.46 The operation of the D'Arsonval movement is quite simple. A coil is wound around a shaft, which is mounted on two jewel bearings to keep friction to an absolute minimum. Near each end of the shaft are two precisely made coil springs. These springs conduct the current to the coil. They also dampen the rotation of the coil and return the pointer to zero when the current is removed.

Fig. 1-8. Analog meter

Fig. 1-9. D'Arsonval meter movement



1.47 When the coil carries current, the coil's electromagnetic field interacts with the magnetic field of the permanent magnet, resulting in a torque being applied to the movable coil. The torque causes the coil to rotate, making the pointer move toward the right (toward full-scale deflection). The springs resist this motion.

1.48 Maximum pointer deflection occurs when the current reaches the maximum value of the meter's range. In instruments of conventional design, this usually means 90 to 100° of full-scale deflection (*FSD*). In instruments designed to measure current in both directions, the balance springs are set so that the zero position of the pointer is straight up, and the coils are centered on the magnet faces.

1.49 The diagram on the left in Fig. 1-10 shows an instrument with its zero mark on the left side of its scale. There is no current passing through the coils, and the coils are at rest positioned at a 45° angle to the permanent magnetic field. There is no deflection, so the pointer points to zero on the scale.

1.50 The drawing on the right in Fig. 1-10 shows the same instrument with current flowing in the coil. The magnetic field exerts a torque that turns the shaft, clockwise in this case. The stronger the field produced by the coils, the greater the torque, and the farther to the right it will turn. The direction of this torque follows the left-hand rule, and will always continue in the same direction, as long as the current flows in the same direction. As the current increases, the coil will rotate still farther in a clockwise direction, until it reaches the limit of its movement.

1.51 The moving coil (sometimes called the *armature*) has a fixed number of turns of wire. The field strength of the permanent magnets is also constant. Therefore, the deflecting force on the coil is directly proportional to the current flowing through it. These conditions make it possible to calibrate the scale of the instrument to give accurate readings.

1.52 Meter movements are rated by the amount of current that must flow through them to produce FSD. The 50 μA meter movement is one of the most commonly used D'Arsonval movements. By definition, these movements have only 50 μA of current flowing through them when they are at FSD. This is a very, very small current. You can see how a meter movement such as this could easily be burned out, if you are not careful. You can also find D'Arsonval movements of 10 μA, 20 μA, 100 μA, and 200 μA.

1.53 Another caution about these movements: they are not designed to accept ac current. If you do apply ac to this meter, each time the current reverses, the coil will attempt to turn in the opposite direction, too. If the current reverses more than a few times per second, the coil cannot keep up. So, you must use this meter movement with dc only, unless the meter has a rectifier, which you will learn more about in the next lesson.

Fig. 1-10. Deflection of the movable coil as current is applied

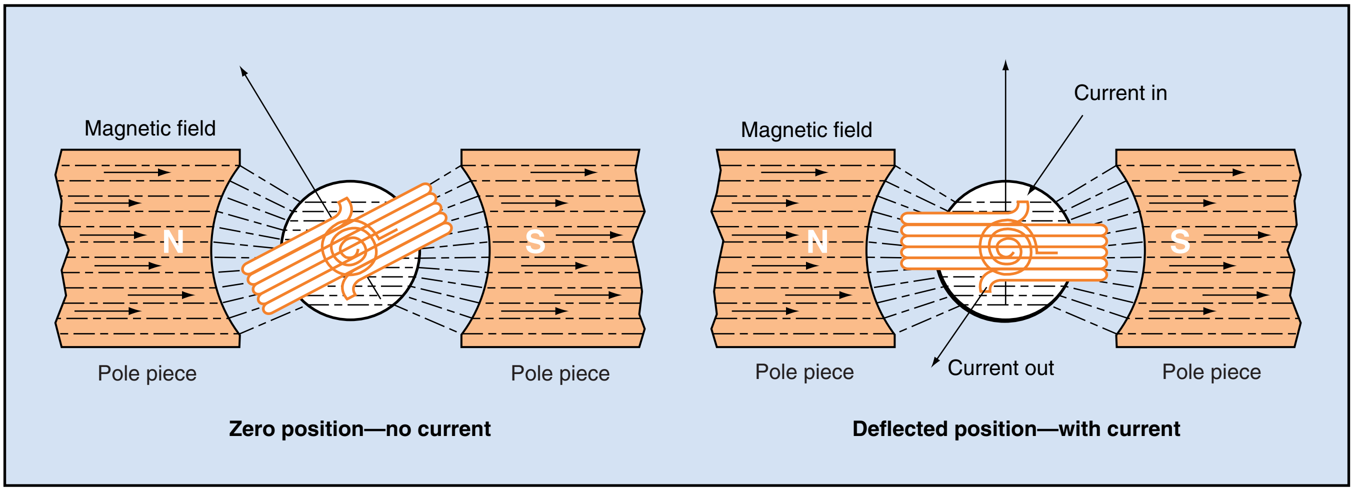
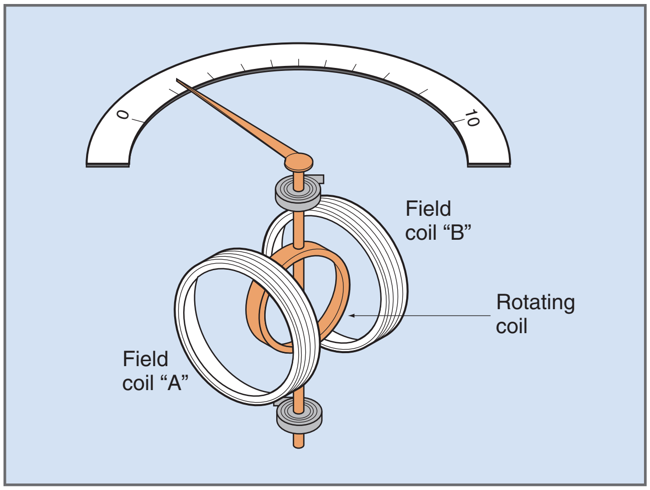


Fig. 1-11. Electrodynamometer movement



Electrodynamometer Movements

1.54 A similar type of meter movement is the electrodynamometer movement. One major difference is that this meter can indicate both dc and ac. Fig. 1-11 shows the components of an electrodynamometer movement (or just dynamometer movement). It is much like the D'Arsonval movement, except that it has no permanent magnets. Instead, the operational magnetic field is produced by two stationary field coils, which become energized when the meter is attached to the circuit being tested.

1.55 When measuring current, all three coils are connected in series, as shown in Fig. 1-12. Although this instrument is not as sensitive as the D'Arsonval movement, because of the extra resistance imposed by the field coils, it is equally accurate. And the pointer moves right to left across the scale, regardless of the polarity of the external meter leads. This is why the dynamometer can measure ac or dc equally well. It is often used to measure power, as well as current and voltage.

Fig. 1-12. All three electrodynamometer coils in series

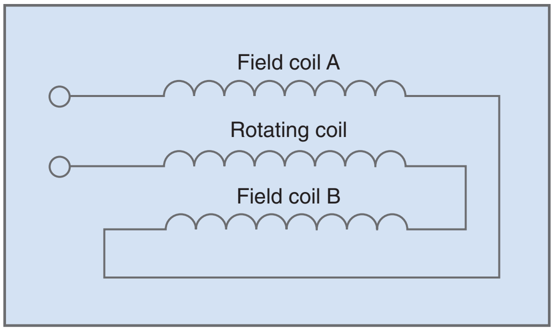
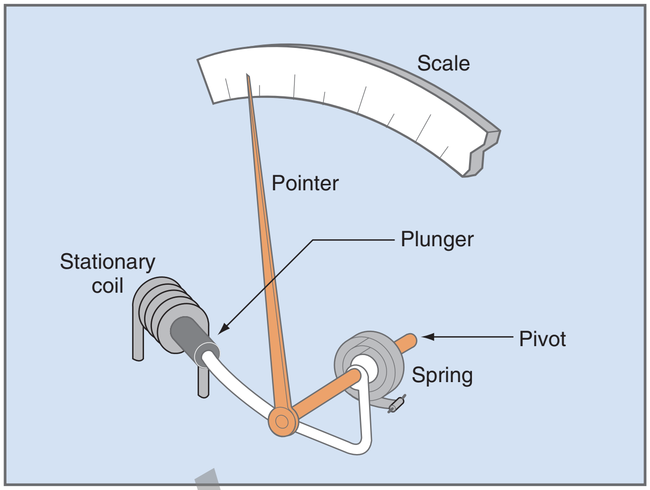


Fig. 1-13. Plunger-style moving-vane meter movement



Moving-Vane Meters

1.56 Another kind of analog meter more commonly employed for measuring ac values is the moving-vane meter. Panel board meters, both voltage- and current-measuring, often have this type of meter movement. In some ways, a moving-vane movement is just the opposite of a D'Arsonval movement. The coils are stationary, and a magnetized armature moves.

1.57 But unlike the D'Arsonval meter, which has permanent magnets, the moving-vane meter depends on *induced magnetism* from its coils (as does the electrodynamometer). The magnetic interaction between a movable piece of iron and the magnetic field of a stationary coil produces rotation of the indicator shaft.

1.58 Moving-vane meter movements do a good job of measuring RMS (effective) current. One type, shown in Fig. 1-13, uses a coil of wire, with a soft iron plunger attached to the pointer assembly. This particular style of moving-vane meter movement is also called a *moving-iron* meter.

1.59 When current flows through the coil, the induced magnetic field draws the iron core toward the center of the coil. The spring opposes this

Fig. 1-14. Radial-vane meter movement

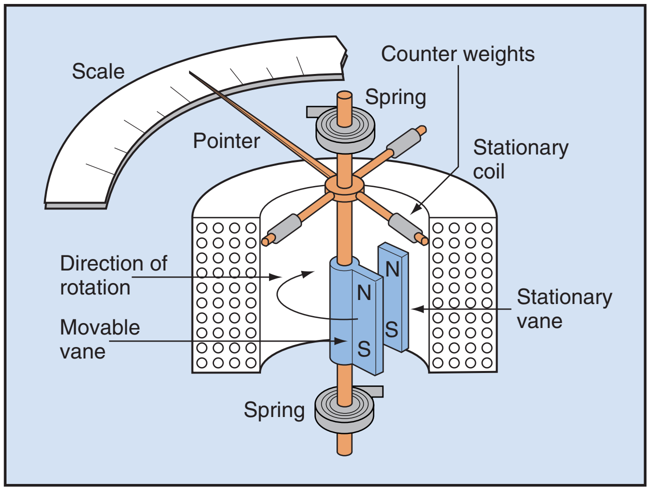
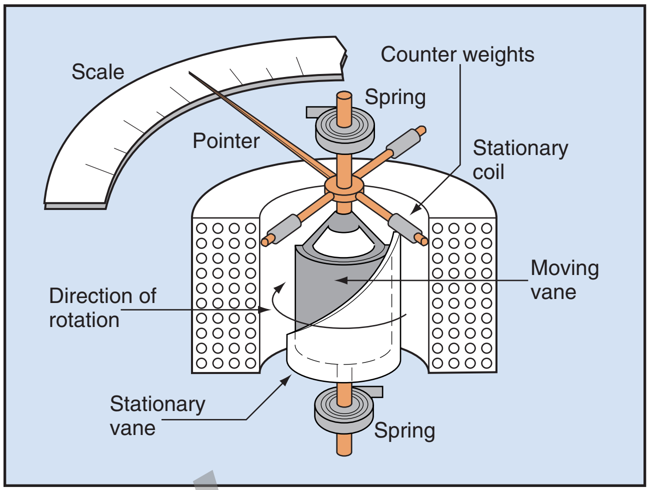


Fig. 1-15. Concentric-vane meter movement



motion, and tries to hold the pointer at the zero position. But the stronger the current, the more the magnetic field stresses the spring, and the greater the pointer deflection toward the right.

1.60 A second kind of moving-vane analog meter movement is shown in Fig. 1-14. Here, the stationary coil is wrapped around the central axis, with a flag-shaped vane attached to the pointer axle. Another vane is embedded in the coil. When current flows through the coil, the two vanes are magnetized in such a way that they repel each other. The greater the current, the greater the repulsion. Thus, the shaft rotates and the pointer indicates a value on the scale. This meter is also known as a *radial-vane* meter.

1.61 A third type of moving-vane meter movement is also called a *concentric-vane* movement. Its name comes from the fact that two curved pieces of metal, one inside the other, fit within the coil and encircle the pointer axle. Fig. 1-15 shows this arrangement. When current flows through the coil, the induced magnetic field passes through the two concentric vanes, causing them to be magnetized.

1.62 However, because the edge of the stationary vane is tapered (like a torn-off piece of cardboard mailing tube), the magnetic field is not passed uniformly to the movable vane inside. Less magnetic force comes from the short end of the stationary vane than from the tall end. Therefore, the tall end of the vane becomes more strongly magnetized than the short end. This means that the greatest repulsion occurs between the tall end of the stationary vane and the movable vane. Thus, the movable vane is forced to rotate toward the short end of the stationary vane, against the torsional resistance of the spring. The result is that the pointer rotates upscale.

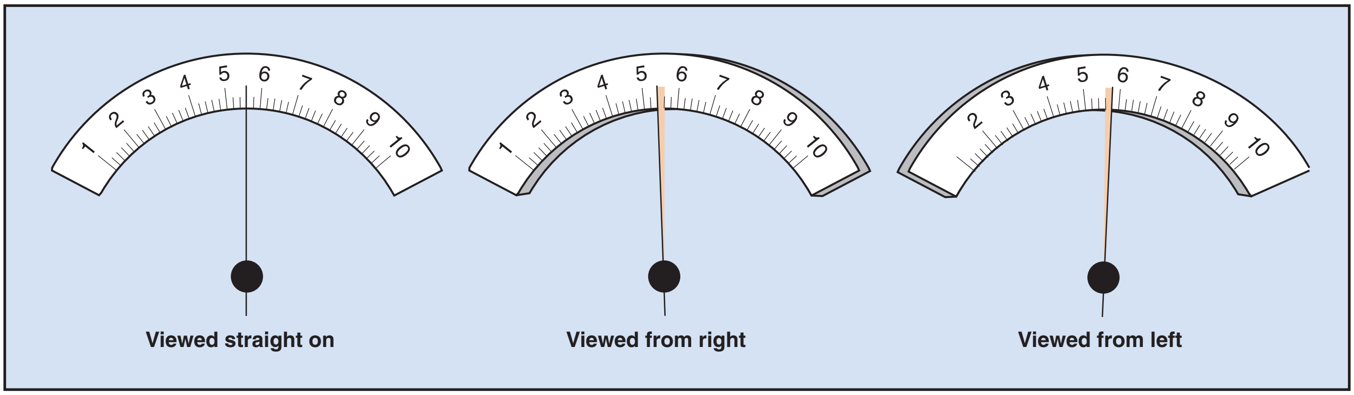
Magnetic Shielding

1.63 If an analog instrument is to rely on its moving coil to measure accurately, outside interference must be avoided. Stray magnetic fields would add to or subtract from the instrument's own magnetic field. For example, a nearby mass of magnetic material, such as that found in a large transformer, could very well distort the instrument's magnetic field. The properties of the resulting distorted field would differ from those of the original field, leading to an incorrect deflection of the pointer.

1.64 Such interference can be avoided by shielding the instrument. To do this, the instrument needs to be surrounded by an enclosure (housing) made of soft iron or other material with high magnetic permeability. This case should provide a low-reluctance path for outside magnetic fields to follow to ground, thus preventing them from affecting the accuracy of the instrument.

1.65 Magnetic shielding also confines the magnetic field of the instrument, preventing it from affecting other magnetic analog instruments nearby. Shielded

Fig. 1-16. The parallax effect



Viewed straight on

Viewed from right

Viewed from left

instruments can be grouped closely together, without danger of affecting one another's readings.

Parallax Error

1.66 One problem that you have with analog meters that you do not have with digitals is parallax error. *Parallax* is caused by looking at the meter at an angle other than straight on. By having your head slightly off the perpendicular to the meter scale, the pointer will appear to be slightly to the left or right of its true position.

1.67 Fig. 1-16 shows how erroneous readings result from parallax. When the eye is dead-center, directly in front of the pointer, the true reading is obtained. However, when you move your head slightly to the right, the apparent reading is lower than the correct reading. When you move to the left, the pointer appears to be indicating a higher reading. This effect is similar to what happens when you weigh yourself on an analog bathroom scale. You can add or subtract a pound or two, simply by moving your head to the left or right.

1.68 Meter manufacturers have devised various ways to combat parallax error. One way is to have a mirror on the scale of the instrument. The operator is given instructions to view the meter, with one eye closed, so that the pointer and its image coincide as one. Then you know you are perpendicular to the pointer. Of course, with digital meters, there is no possibility for parallax error.

Analog Instrument Sensitivity

1.69 The lower the current an analog meter movement requires for full-scale deflection, the greater the sensitivity of the meter. The sensitivity of an analog meter is defined as the reciprocal of the FSD current.

$$\text{Sensitivity} = 1/\text{FSD current}$$

1.70 The units of sensitivity are the reciprocal of the units for current. According to Ohm's Law, the unit *ampere* is the same as the unit *volts per ohm*.

Table 1-1. Comparison of mechanical meter movements

Type of meter movement	Sensitivity	Accuracy	Durability	AC measurement	Frequency range	Cost	Remarks
D'Arsonval	Good	Good	Fair	Sine wave*	Fair	Moderate	Rectifier required
Electro-dynamometer	Poor	Good	Fair	RMS any waveform	Poor	High	
Moving vane	Poor	Fair	Very good	RMS	Poor	Low	

*poor at low voltage

Therefore the units of sensitivity are usually expressed as *ohms per volt*. For example, the sensitivity of a 100 μA analog meter movement can be found by taking the reciprocal of 100 μA (1/10,000 A). So the sensitivity is 10,000 Ω per volt.

1.71 Instrument sensitivity is just one criterion to be used when selecting an analog electrical meter. Others are accuracy, durability, and cost. The meters described so far are listed in Table 1-1, along with their evaluations.

Analog Accuracy

1.72 Accuracy is expressed as a percent, taken at FSD. So an instrument measuring 100 mA at FSD, with an accuracy of ±3%, will be accurate to ±3 mA at that reading. However, at midscale, a reading of 50 mA will also have an accuracy of ±3 mA. But here, that figure works out to a practical accuracy of ±6%. Similarly, down at the low end, a reading of 10 mA will have an accuracy of ±3 mA, giving an actual percentage error of ±30%!

1.73 If you have followed the logic presented here, you can understand why an analog meter reading should be taken as close to full-scale deflection as possible. At the same time, you must try to keep the pointer from "pegging out" on the right edge of the scale. It takes a little getting used to, to try to measure quantities in the most advantageous part of an analog meter's range.

1-9. The ________ is an extremely sensitive instrument used only to detect the presence of very small currents.	1-9. GALVANOMETER Ref: 1.44, 1.45
1-10. In a D'Arsonval movement, current is delivered to the rotating coil through the ________.	1-10. SPRINGS Ref: 1.46
1-11. The maximum analog meter reading is taken when the pointer reaches full-scale ________.	1-11. DEFLECTION Ref: 1.48
1-12. An electrodynamometer movement has no ________.	1-12. PERMANENT MAGNET Ref: 1.54
1-13. Nearby magnetic fields can affect an analog meter's own magnetic fields unless the meter movement is ________.	1-13. SHIELDED Ref: 1.63, 1.64
1-14. A mirror built into the meter's printed scale helps to eliminate the problem of ________.	1-14. PARALLAX ERROR Ref: 1.68
1-15. By taking the reciprocal of the FSD current, you find the ________ value of the analog meter.	1-15. SENSITIVITY Ref: 1.69
1-16. Analog meters have their greatest accuracy (smallest error) at what point on their scales?	1-16. FSD or FULL-SCALE DEFLECTION Ref: 1.72, 1.73

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. Every digital electrical measuring device requires a(n)

☐ a. ADC
☐ b. FSD
☐ c. L.E.D.
☐ d. pointer

1-2. Single-slope and dual-slope are two kinds of

☐ a. ADCs
☐ b. analog meters
☐ c. binary counters
☐ d. meter movements

1-3. In a dual-slope integrator, which of the slopes always has the same degree of pitch (slant)?

☐ a. Decreasing comparator output
☐ b. Decreasing integrator output
☐ c. Increasing comparator output
☐ d. Increasing integrator output

1-4. The advantage of LCDs over LEDs is

☐ a. better visibility
☐ b. greater accuracy
☐ c. greater sensitivity
☐ d. lower power consumption

1-5. An analog/digital meter is one that processes digital signals internally, but

☐ a. can be switched to analog processing when needed
☐ b. displays the results in a fake analog format
☐ c. has an electromagnetic movement to provide a higher resolution
☐ d. must also be connected in series to an analog meter

1-6. In a D'Arsonval movement, the pointer's deflection varies in proportion to changes in the

☐ a. current in the coil
☐ b. distance between the magnet's pole pieces
☐ c. number of magnetic poles
☐ d. rotational inertia of the coil

1-7. The analog instrument movement consisting totally of coils, with no permanent magnets nor magnetized iron armatures, is the ________ movement.

☐ a. D'Arsonval
☐ b. electrodynamometer
☐ c. radial-vane
☐ d. vector-displacement

1-8. Shielding protects an analog meter from

☐ a. damage due to careless handling
☐ b. harmful UV rays
☐ c. overcurrent and surges
☐ d. stray magnetic fields

1-9. Parallax error is caused by a(n)

☐ a. instrument detection
☐ b. instrument maintenance failure
☐ c. operator error
☐ d. signal error

1-10. Sensitivity of an analog meter is expressed in

☐ a. amperes per ohm
☐ b. ohms per volt
☐ c. per cent
☐ d. volts per ampere

SUMMARY

You have been introduced to the two main types of electrical instruments. Becoming ever more popular, the digital meters are easy to use and very reliable. You have seen how their measurement functions can be carried out without the aid of several moving parts. You have learned the meaning of a few electronic terms, such as ADC, and you understand the difference between a single-slope and a dual-slope integrating digital meter.

You know now that measuring electrical signals with a digital meter is simply a matter of counting time clicks from a super-accurate clock-oscillator. Voltage levels, for example, are determined by counting how long it takes a capacitor to charge or discharge. You saw that digital displays do nothing more than total the click-counts, then energize various combinations of the seven segments in LCD elements.

Although their use is diminishing, analog meters will still be encountered from time to time in the workplace. You saw that several different kinds of internal mechanisms are possible in these meters, ranging from the simple D’Arsonval movement, to a more complex concentric-vane movement. All of these meters, since they rely on magnetic fields, must be shielded from other magnetic fields in the environment.

Finally, you should have a clearer understanding of the terms sensitivity, accuracy, and resolution. You will be able to use these ideas as you go on to the next lesson, which deals with specific ammeters and voltmeters.

Answers to Self-Check Quiz

1-1. a. ADC. Ref: 1.07

1-2. a. ADCs. Ref: 1.12, 1.19

1-3. b. Decreasing integrator output. Ref: 1.23, 1.24

1-4. d. Lower power consumption. Ref: 1.26, 1.27

1-5. b. Display the results in a fake analog format. Ref: 1.31, 1.32

1-6. a. Current in the coil. Ref: 1.50, 1.51

1-7. b. Electrodynamometer. Ref: 1.54

1-8. d. Stray magnetic fields. Ref: 1.63, 1.64

1-9. c. Operator error. Ref: 1.66

1-10. b. Ohms per volt. Ref: 1.70

Contributions from the following sources are appreciated:

Figure 1-1. Tektronix, Inc.
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Figure 1-8. KTI