LECTURE NOTES

ON

EI1202 – MEASUREMENTS AND INSTRUMENTATION

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Curriculum

B.E. ELECTRICAL AND ELECTRONICS ENGINEERING

SEMESTER III

S. No.	Subject Code	Subject	L	T	P	C
Theory						
1	**MA1201**	Transforms and Partial Differential Equations	3	1	0	4
2	**EI1202**	Measurements and Instrumentation	3	0	0	3
3	**EE1201**	Electromagnetic Theory	3	1	0	4
4	**HS1201**	Environmental Science and Engineering	3	0	0	3
5	**EC1209**	Electron Devices and Circuits	3	0	0	3
6	**CS1201**	Data Structures	3	0	0	3
Practical						
7	**EC1210**	Electron Devices and Circuits Laboratory	0	0	3	2
8	**CS1203**	Data Structures Laboratory	0	0	3	2
9	**EI1203**	Measurements and Instrumentation Laboratory	0	0	3	2
					Total	**26**

SYLLABUS

UNIT I FUNDAMENTALS
Functional elements of an instrument – Static and dynamic characteristics – Errors in measurement– Statistical evaluation of measurement data – Standards and calibration

UNIT II ELECTRICAL AND ELECTRONICS INSTRUMENTS
Principle and types of analog and digital instruments –Voltmeters – Ammeters - Multimeters – Single and three phase wattmeters and energy meters – Magnetic measurements – Determination of B-H curve and measurements of iron loss – Instrument transformers – Instruments for measurement of frequency and phase.

UNIT III COMPARISON METHODS OF MEASUREMENTS
D.C and A.C potentiometers – D.C and A.C bridges – Transformer ratio bridges – Self-balancing bridges – Interference and screening – Multiple earth and earth loops – Electrostatic and electromagnetic interference – Grounding techniques.

UNIT IV STORAGE AND DISPLAY DEVICES
Magnetic disk and tape – Recorders, digital plotters and printers – CRT display – Digital CRO, LED, LCD and dot-matrix display – Data Loggers

UNIT V TRANSDUCERS AND DATA ACQUISITION SYSTEMS
Classification of transducers – Selection of transducers – Resistive, capacitive and inductive transducers – Piezoelectric, optical and digital transducers – Elements of data acquisition system – A/D, D/A converters – Smart sensors.

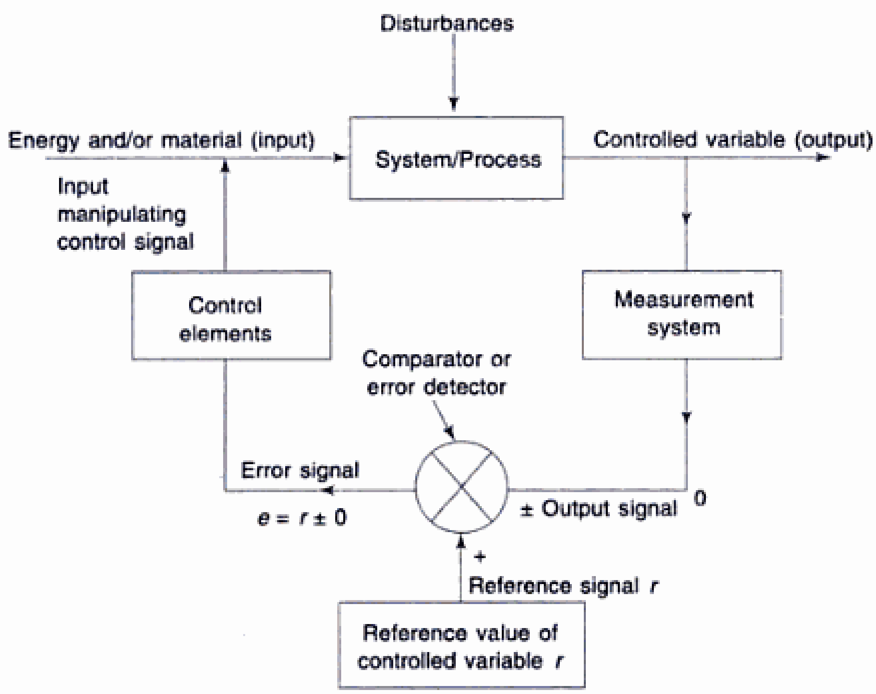
TEXT BOOKS
1. Doebelin, E.O., “Measurement Systems – Application and Design”, Tata McGraw Hill Publishing Company, 2003.
2. Sawhney, A.K., “A Course in Electrical and Electronic Measurements and Instrumentation”, Dhanpat Rai AND Co, 2004

REFERENCES
1. Bouwens, A.J., “Digital Instrumentation”, Tata McGraw Hill, 1997.
2. Moorthy, D.V.S., “Transducers and Instrumentation”, Prentice Hall of India, 2007.
3. Kalsi, H.S., “Electronic Instrumentation”, 2nd Edition, Tata McGraw Hill, 2004.
4. Martin Reissland, “Electrical Measurements”, New Age International (P) Ltd., 2001.
5. Gupta, J.B., “A Course in Electronic and Electrical Measurements”, S.K.Kataria and Sons, 2003.

UNIT I FUNDAMENTALS

Functional elements of an instrument – Static and dynamic characteristics – Errors in measurement– Statistical evaluation of measurement data – Standards and calibration

Control of a certain process or operation Another important application of measuring instruments is in the field of automatic control systems. The measurement system forms an integral part of such systems (Fig. 1.1) which in turn provides deliberate guidance or manipulation to maintain them at a set point or to change it according to a pre-set programme.



mass production, easy maintenance and repairs, the current particle is to have modular type of instruments in which the various functional elements are fabricated in the form of modules or as a combination of certain sub-modules. The brief descriptions of the various functional elements are as follows.

Transducer Element Normally, a transducer senses the desired input in one physical form and converts it to an output in another physical form. For example, the input variable to the transducer could be pressure, acceleration or temperature and the output of the transducer may be displacement, voltage or resistance change depending on the type of transducer element. Sometimes the dimensional units of the input and outnut signals may be same. In such cases, the functional element is termed a *transformer*. Some typical examples of transducer elements commonly used in practice are mentioned in Table 1.1.

S.No.	*Input variable to transducer*	*Output variable of transducer*	*Principle of operation*	*Type of device*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
1.	Temperature	Voltage	An emf is generated across the junctions of two dissimilar metals or semiconductors when that junction is heated	Thermocouple or Thermopile
2.	Temperature	Displacement	There is a thermal expansion in volume when the temperature of liquids or liquid metals is raised and this expansion can be shown as displacement of the liquid in the capillary	Liquid in Glass Thermometer
3.	Temperature	Resistance change	Resistance of pure metal wire with positive temperature coefficient varies with temperature	Resistance Thermometer
4.	Temperature	Pressure	The pressure of a gas or vapour varies with the change in temperature	Pressure Thermometer
5.	Displacement	Inductance change	The differential voltage of the two secondary windings varies linearly with the displacement of the magnetic core	Linear Variable Differential Transducer (LVDT)
6.	Displacement	Resistance change	Positioning of a slider varies the resistance in a potentiometer or a bridge circuit	Potentiometric Device
7.	Motion	Voltage	Relative motion of a coil with respect to a magnetic field generates a voltage	Electrodynamic Generator

element is incorporated in the signal conditioning element which may be one of the following depending on the type of transducer signal.

1. *Mechanical Amplifying Elements* such as levers, gears or a combination of the two, designed to have a multiplying effect on the input transducer signal.
2. *Hydraulic/Pneumatic Amplifying Elements* employing various types of valves or constrictions, such as venturimeter/orificemeter, to get significant variation in pressure with small variation in the input parameters.
3. *Optical Amplifying Elements* in which lenses, mirrors and combinations of lenses and mirrors or lamp and scale arrangement are employed to convert the small input displacement into an output of sizeable magnitude for a convenient display of the same.
4. *Electrical Amplifying Elements* employing transistor circuits, integrated circuits, etc. for boosting the amplitude of the transducer signal. In such amplifiers we have either of the following:

$$\text{Voltage amplification} = \frac{\text{output voltage}}{\text{input voltage}} = \frac{V_o}{V_i} \tag{1.1}$$

or

$$\text{Current amplification} = \frac{\text{output current}}{\text{input current}} = \frac{I_o}{I_i} \tag{1.2}$$

or

$$\text{Gain} = \frac{\text{output power}}{\text{input power}} = \frac{V_o I_o}{V_i I_i} \tag{1.3}$$

Signal filtration The term signal filtration means the removal of unwanted noise signals that tend to obscure the transducer signal. The signal filtration element could be any of the following depending on the type of situation, nature of signal, etc.

1. *Mechanical Filters* that consist of mechanical elements to protect the transducer element from various interfering extraneous signals. For example, the reference junction of a thermocouple is kept in a thermos flask containing ice. This protects the system from the ambient temperature changes.
2. *Pneumatic Filters* consisting of a small orifice or venturi to filter out fluctuations in a pressure signal.
3. *Electrical Filters* are employed to get rid of stray pick-ups due to electrical and magnetic fields. They may be simple R–C circuits or any other suitable electrical filters compatible with the transduced signal.

Other signal conditioning operators Other signal conditioning operators that can be conveniently employed for electrical signals are:

1. Signal Compensation /Signal Linearisation.
2. Differentiation/Integration.
3. Analog-to-Digital Conversion.
4. Signal Averaging/Signal Sampling, etc.

Data Presentation Element This element gathers the output of the signal conditioning element and presents the same to be read or seen by the experimenter. This element should:

1. have as fast a response as possible,
2. impose as little drag on the system as possible, and
3. have very small inertia, friction, stiction, etc. (hence using light rays and electron beams is advantageous).

This element may be either of the visual display type, graphic recording type or a magnetic tape. In the visual display type element, devices such as pointer and scale/panel meter, multi-channel CRO, storage CRO, etc. may be employed. The graphic recording type of element gives a permanent record of the input data. The device in this element may be pen recorders using heated stylus, ink recorders on paper charts, optical recording systems such as mirror galvanometer recorders or ultraviolet recorders on special photosensitive paper. Further, a magnetic tape may be used to acquire input data which could be reproduced at a later date for analysis.

In case the output of the signal conditioning element is in digital form, then the same may be displayed visually on a digital display device. Alternatively, it may be suitably recorded either on punched cards, perforated paper tape, magnetic type, typewritten page or a combination of these systems for further processing.

1.6 STANDARDS AND CALIBRATION

Basically, measurement is an act of a quantitative comparison between a predefined standard and the unknown magnitude of a physical quantity. In order that the results are meaningful, the following two requirements must be met in the act of measurement:

1. The standard that is used for comparison must be well-established, highly accurate and reproducible; and
2. The measurement devices and the calibration procedures adopted in the act of measurement must have proven reliability.

1.6.1 Standards of Measurements

A standard of measurement is defined as the physical representation of the unit of measurement. A unit of measurement is generally chosen with reference to an arbitrary material standard or to a natural phenomenon that includes physical and atomic constants. For example, the S.I. unit of mass, namely kilogram, was originally defined as the mass of a cubic decimetre of water at its temperature of maximum density, i.e. at 4°C. The material representation of this unit is the International Prototype kilogram which is preserved at the International Bureau of Weights and Measures at Sévrés, France, Further, prior to 1960, the unit of length was the carefully preserved platinum–iridium bar at Sévrés, France. In 1960, this unit was redefined in terms of optical standards, i.e. in terms of the wavelength of the orange-red light of Kr^{86} lamp. The standard metre is now equivalent to 1 650 763.73 wavelengths of Kr^{86} orange-red light. Similarly, the original unit of time was the mean solar second which was defined as 1/86400 of a mean solar day. However, the current internationally recognised unit of universal time is based on a cesium clock. It is now defined in terms of frequency of the cesium transition to its hyperfine state unperturbed by external fields, which occurs at 9 192 631 770 Hz. The use of cesium clock gives an accuracy exceeding 1 μs per day. Therefore, it is considered as the primary time and the frequency standard. In fact, a number of standards have been developed for other units of measurements including standards for fundamental as well as dervied quantities which may include mechanical, electrical, thermal, optical, etc. parameters (Appendix A 1).

There are different types of standards of measurements. They can be classified according to their function and type of application. They are briefly described as follows:

International standards International standards are devices designed and constructed to the specifications of an international forum. They represent the units of measurements of various physical quantities to the highest possible accuracy that is attainable by the use of advanced techniques of production and measurement technology. These standards are maintained by the International Bureau of Weights and Measures at Sévrés, France. For example, the International Prototype kilogram, wavelength of Kr^{86} orange–red lamp and cesium clock are the international standards for mass, length and time, respectively. However, these standards are not available to an ordinary user for purposes of day-to-day comparisons and calibrations.

Primary standards Primary standards are devices maintained by standards organisations/national laboratories in different parts of the world. These devices represent the fundamental and derived quantities and are calibrated independently by absolute measurements. One of the main functions of maintaining primary standards is to calibrate/check and certify secondary reference standards. Like international standards, these standards also are not easily available to an ordinary user of instruments for verification/calibration of working standards.

Secondary standards Secondary standards are basic reference standards employed by industrial measurement laboratories. These are maintained by the concerned laboratory. One of the important functions of an industrial laboratory is the maintenance and periodic calibration of secondary standards against primary standards of the national standards laboratory/organisation. In addition, secondary standards are freely available to the ordinary user of instruments for checking and calibration of working standards.

Working standards These are high-accuracy devices that are commercially available and are duly checked and certified against either the primary or secondary standards. For example, the most widely used industrial working standard of length are the precision gauge blocks made of steel. These gauge blocks have two plane parallel surfaces a specified distance apart, with accuracy tolerances in the 0.25–0.5 micron range (1 micron = 10^{-6} m). Similarly, a standard cell and a standard resistor are the working standards of voltage and resistance, respectively. Working standards are very widely used for calibrating general laboratory instruments, for carrying out comparison measurements or for checking the quality (range of accuracy) of industrial products.

2.2 ERRORS AND UNCERTAINTIES IN PERFORMANCE PARAMETERS

The various static performance parameters of the instruments are obtained by performing certain specified tests depending on the type of instrument, the nature of the application, etc. Some salient static performance parameters are periodically checked by means of a static calibration. This is accomplished by imposing constant values of 'known' inputs and observing the resulting output. Quite often, we experience difficulty in obtaining known constant values of the input quantity. Further, we also come across the following difficulties:

1. The change in sensitivity of instruments due to certain perturbations results in influencing all output values, generally equally by a particular quantity. These are caused due to worn out parts, effect of changes in the environment on the equipment or the user, etc.
2. Failure of the instrument to have the same output for repeated applications of any particular value of the input. This effect, i.e. the *scatter* in output values, within a given range, is caused due to random variations in the parameter or in the system of measurement.

No measurement can be made with perfect accuracy and precision. Therefore, it is instructive to know the various types of errors and uncertainties that are in general, associated with measurement system. Further, it is also important to know how these errors are propagated. This is because if an error is detected, then it can be eliminated or its effect can be accounted for in the form of a suitable correction. On the other hand, if an error goes unrecognised, then it would make experimental data unreliable.

2.2.1 Types of Errors

Error is defined as the difference between the measured and the true value (as per standard). The different types of errors can be broadly classified as follows.

Systematic or Cumulative Errors Such errors are those that tend to have the same magnitude and sign for a given set of conditions. Because the algebraic sign is the same, they tend to accumulate and hence are known as cumulative errors. Since such errors alter the instrument reading by a fixed magnitude and with same sign from one reading to another, therefore, the error is also commonly termed as *instrument bias*. These types of errors are caused due to the following:

Instrument errors Certain errors are inherent in the instrument systems. These may be caused due to poor design/construction of the instrument. Errors in the divisions of graduated scales, inequality of the balance arms, irregular springs tension, etc, cause such errors. Instrument errors can be avoided by (i) selecting a suitable instrument for a given application, (ii) applying suitable correction after determining the amount of instrument error, and (iii) calibrating the instrument against a suitable standard.

Environmental errors These types of errors are caused due to variation of conditions external to the measuring device, including the conditions in the area surrounding the instrument. Commonly occurring changes in environmental conditions that may affect the instrument characteristics are the effects of changes in temperature, barometric pressure, humidity, wind forces, magnetic or electrostatic fields, etc. For example, change in ambient temperature causes errors due to expansion of the measuring tape. Similarly, buoyant effect of the wind causes errors on weights of a chemical balance.

Loading errors Such errors are caused by the act of measurement on the physical system being tested. Common examples of this type are: (i) introduction of additional resistance in the circuit by

voltage in the range of ±0.1 V, which is equal to the resolution of the instrument. The voltmeter would still indicate 100 V as the instrument is incapable of registering a change up to or below the resolution of the instrument. Therefore, it would be reasonable to say, in this case, that the measured value of 100 V has the external estimate of uncertainty U_E equal to ±0.1 V.

2.4.2 Precision

Precision is defined as the ability of the instrument to reproduce a certain set of readings within a given accuracy. For example, if a particular transducer is subjected to an accurately known input and if the repeated read outs of the instrument lie within say ±1%, then the precision or alternatively the precision error of the instrument would be stated as ±1%. Thus, a highly precise instrument is one that gives the same output information, for a given input information when the reading is repeated a large number of times.

Precision of an instrument is in fact, dependent on the repeatability. The term repeatability can be defined as the ability of the instrument to reproduce a group of measurements of the same measured quantity, made by the same observer, using the same instrument, under the same conditions. As mentioned before, the deviations in repeatability or the inconsistencies in the measured values are caused due to random or accidental errors. Therefore, the precision of the instrument depends on the factors that cause random or accidental errors. As mentioned before, the extent of random errors of alternatively the precision of a given set of measurements can be quantified by performing the statistical analysis (Chs. 20 and 21 of the measured data).

2.4.3 Resolution (or Discrimination)

It is defined as the smallest increment in the measured value that can be detected with certainty by the instrument. In other words, it is the degree of fineness with which a measurement can be made. The least count of any instrument is taken as the resolution of the instrument. For example, a ruler with a least count of 1 mm may be used to measure to the nearest 0.5 mm by interpolation. Therefore, its resolution is considered as 0.5 mm. A high resolution instrument is one that can detect smallest possible variation in the input.

2.4.4 Threshold

It is a particular case of resolution. It is defined as the minimum value of input below which no output can be detected. It is instructive to note that resolution refers to the smallest measurable input above the zero value. Both threshold and resolution can either be specified as absolute quantities in terms of input units or as percentage of full scale deflection.

Both threshold and resolution are not zero because of various factors like friction between moving parts, play or looseness in joints (more correctly termed as backlash), inertia of the moving parts, length of the scale, spacing of graduations, size of the pointer, parallax effect, etc.

2.4.5 Static Sensitivity

Static sensitivity (also termed as scale factor or gain) of the instrument is determined from the results of static calibration. This static characteristic is defined as the ratio of the magnitude of response (output signal) to the magnitude of the quantity being measured (input signal), i.e.

$$\text{Static sensitivity,} \quad K = \frac{\text{change of output signal}}{\text{change in input signal}} \tag{2.31}$$

$$= \frac{\Delta q_0}{\Delta q_i} \tag{2.32}$$

where q_o and q_i are the values of the output and input signals, respectively.

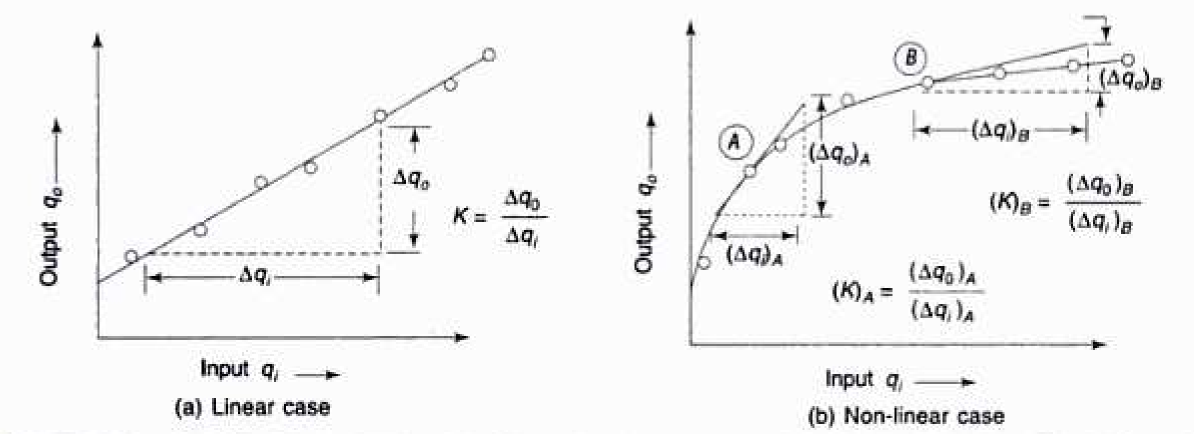


Fig. 2.3 *Static sensitivity of linear and non-linear instruments*

The sensitivity of a typical linear spring, whose extension is directly proportional to the applied force can be defined as say, 450 N/mm. Similarly, the sensitivity of a non-linear type of copper/Constantan thermocouple is found to be maximum at 350 °C and is 60 μV/°C.

It may be noted that in certain applications, the reciprocal of the sensitivity is commonly used. This is termed inverse sensitivity or the deflection factor.

2.4.6 Linearity

A linear indicating scale is one of the most desirable features of any instrument. Therefore, manufacturers of instruments always attempt to design their instruments so that the output is a linear function of the input. However, linearity is never completely achieved and the deviations from the ideal are termed as linearity tolerances. In commercial instruments, the maximum departure from linearity is often specified in one of the following ways.

Independent of the input If the deviations of the output of the instrument from the best fitting straight line (drawn through the calibration points) does not vary with the input [Fig. 2.4(a)], then non-linearity is specified in the terms of higher value of the maximum deviation that occurs on the positive and negative sides of the best fitting or idealised straight line. This value is usually expressed as ± percentage of full-scale deflection.

Proportional to input If the deviations of the output of the instrument from the idealised straight line vary with the input [Fig. 2.4(b)], then non-linearity is specified as a function of the input. In such cases, the maximum deviation points on the positive and negative sides of the idealised straight line are joined with the origin and their slopes are determined. The higher value of the percentage change in slope with respect to the idealised line is usually expressed as ± percentage non-linearity with respect to the magnitude of input values.

Combined independent and proportional to the input In certain cases, the deviations of the output may not vary with the input for a part of the range and may show proportional variation for the rest of the range. In Fig. 2.4(c), a typical calibration curve shows an independent deviation at the lower range and proportional variations at the higher range with respect to the idealised straight line. In this case, the maximum deviations at the lower range is taken care of by specifying say $\pm y\%$ of full scale deflection and by say $\pm x\%$ of the input value.

QUESTIONS

FUNCTIONAL ELEMENTS OF AN INSTRUMENT

PART – A

1. What are the functional elements of an instrument? (2)
2. What is meant by accuracy of an instrument? (2)
3. Define international standard for ohm? (2)
4. What is primary sensing element? (2)
5. What is calibration? (2)
6. Define the terms precision & sensitivity. (2)
7. What are primary standards? Where are they used? (2)

8. When are static characteristics important? (2)
9. What is standard? What are the different types of standards?(2)
10. Define static error. Distinguish reproducibility and repeatability. (2)
11. Distinguish between direct and indirect methods of measurements.
12. With one example explain “Instrumental Errors”. (2)
13. Name some static and dynamic characteristics. (2)
14. State the difference between accuracy and precision of a measurement. (2)
15. What are primary and secondary measurements? (2)
16. What are the functions of instruments and measurement systems? (2)
17. What is an error? How it is classified? (2)
18. Classify the standards of measurement? (2)
19. Define standard deviation and average deviation. (2)
20. What are the sources of error? (2)
21. Define resolution. (2)
22. What is threshold? (2)
23. Define zero drift. (2)
24. Write short notes on systematic errors. (2)
25. What are random errors? (2)

PART – B

1. Describe the functional elements of an instrument with its block diagram. And illustrate them with pressure gauge, pressure thermometer and D'Arsonval galvanometer. (16)
2. (i) What are the three categories of systematic errors in the Instrument and explain in detail. (8)

   (ii) Explain the Normal or Gaussian curve of errors in the study Of random effects. (8)
3. (i) What are the basic blocks of a generalized instrumentation system.

   Draw the various blocks and explain their functions. (10)

   (ii) Explain in detail calibration technique and draw the Calibration curve in general. (6)
4. (i) Discuss in detail various types of errors associated in Measurement and how these errors can be minimized? (10)

   (ii) Define the following terms in the context of normal Frequency distribution of data (6)

a) Mean value

b) Deviation

c) Average deviation

d) Variance

e) Standard deviation.

5. (i) Define and explain the following static characteristics of an instrument. (8)
   a) Accuracy
   b) Resolution
   c) Sensitivity and
   d) Linearity

   (ii) Define and explain the types of static errors possible in an instrument. (8)

6. Discuss in detail the various static and dynamic characteristics of a measuring system. (16)

7. (i) For the given data, calculate
   a) Arithmetic mean
   b) Deviation of each value
   c) Algebraic sum of the deviations (6)

   X1 = 49.7, X2 = 50.1, X3 = 50.2, X4 = 49.6, X5 = 49.7

   (ii) Explain in detail the types of static error. (7)

   (iii) Give a note on dynamic characteristics. (3)

8. (i) What is standard? Explain the different types of standards(8)

   (ii) What are the different standard inputs for studying the Dynamicresponse of a system. Define and sketch them. (8)

UNIT II ELECTRICAL AND ELECTRONICS INSTRUMENTS

Principle and types of analog and digital instruments –Voltmeters – Ammeters - Multimeters –Single and three phase wattmeters and energy meters – Magnetic measurements – Determinationof B-H curve and measurements of iron loss – Instrument transformers – Instruments formeasurement of frequency and phase.

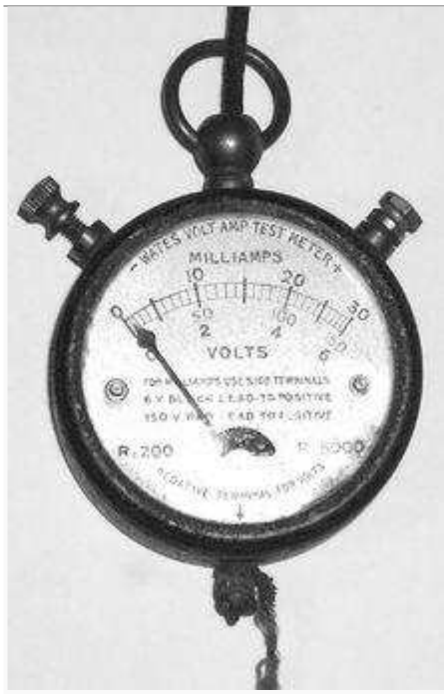
Principle and types of analog and digital instruments

A **multimeter** ora **multitester**, also known as a **volt/ohm meter** or **VOM**, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. Multimeters may use analogor digital circuits—**analog multimeters** and **digital multimeters** (often abbreviated **DMM** or **DVOM**.) Analog instruments are usually based on amicroammeter whose pointer moves over a scale calibration for all the different measurements that can be made; digital instruments usually display digits, but may display a bar of a length proportional to the quantity measured.

A multimeter can be a hand-held device useful for basic fault finding and field service work or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.

Multimeters are available in a wide ranges of features and prices. Cheap multimeters can cost less than US$10, while the top of the line multimeters.

History



The first moving-pointer current-detecting device was the galvanometer. These were used to measure resistance and voltage by using a Wheatstone bridge, and comparing the unknown quantity to a reference voltage or resistance. While useful in the lab, the devices were very slow and impractical in the field. These galvanometers were bulky and delicate.

The D'Arsonval/Weston meter movement used a fine metal spring to give proportional measurement rather than just detection, and built-in permanent field magnets made deflection independent of the 3D orientation of the meter. These features enabled dispensing with Wheatstone bridges, and made measurement quick and easy. By adding a series or shunt resistor, more than one range of voltage or current could be measured with one movement.

Multimeters were invented in the early 1920s as radio receivers and other vacuum tube electronic devices became more common. The invention of the first multimeter is attributed to United States Post Office (USPS) engineer, Donald Macadie, who became dissatisfied with having to carry many separate instruments required for the maintenance of the telecommunications circuits.[1] Macadie invented an instrument which could measure amperes (aka amps), volts and ohms, so the multifunctional meter was then named Avometer.[2] The meter comprised a moving coil meter, voltage and precision resistors, and switches and sockets to select the range.

Macadie took his idea to the Automatic Coil Winder and Electrical Equipment Company (ACWEEC, founded in ~1923).[2] The first AVO was put on sale in 1923, and although it was initially a DC. Many of its features remained almost unaltered through to the last Model 8.

Pocket watch style meters were in widespread use in the 1920s, at much lower cost than Avometers. The metal case was normally connected to the negative connection, an arrangement that caused numerous electric shocks. The technical specifications of these devices were often crude, for example the one illustrated has a resistance of just 33 ohms per volt, a non-linear scale and no zero adjustment.

The usual analog multimeter when used for voltage measurements loads the circuit under test to some extent (a microammeter with full-scale current of 50ampere, the highest sensitivity commonly available, must draw at least 50 milliamps from the circuit under test to deflect fully). This may load a high-impedance circuit so much as to perturb the circuit, and also to give a low reading.

Vacuum Tube Voltmeters or valve voltmeters (VTVM, VVM) were used for voltage measurements in electronic circuits where high impedance was necessary. The VTVM had a fixed input impedance of typically 1 megohm or more, usually through use of a cathode follower input circuit, and thus did not significantly load the circuit being tested. Before the introduction of digital electronic high-impedance analog transistor and field effect transistor (FETs) voltmeters were used. Modern digital meters and some modern analog meters use electronic input circuitry to achieve high-input impedance—their voltage ranges arefunctionally equivalent to VTVMs.

Additional scales such as decibels, and functions such as capacitance, transistor gain, frequency, duty cycle, display hold, and buzzers which sound when the measured resistance is small have been included on many multimeters. While multimeters may be supplemented by more specialized equipment in a technician's toolkit, some modern multimeters include even more additional functions for specialized applications (e.g., temperature with a thermocoupleprobe, inductance, connectivity to a computer, speaking measured value, etc.).

Quantities measured

Contemporary multimeters can measure many quantities.

The common ones are:

- Voltage, alternating and direct, in volts.
- Current, alternating and direct, in amperes. The frequency range for which AC measurements are accurate must be specified.
- Resistance in ohms.

Additionally, some multimeters measure:

- Capacitance in farads.
- Conductance in siemens.
- Decibels.
- Duty cycle as a percentage.
- Frequency in hertz.
- Inductance in henrys.
- Temperature in degrees Celsius or Fahrenheit, with an appropriate temperature test probe, often a thermocouple

Digital multimeters may also include circuits for:

- Continuity; beeps when a circuit conducts.
- Diodes (measuring forward drop of diode junctions, i.e., diodes and transistor junctions) and transistors (measuring current gain and other parameters).
- Battery checking for simple 1.5 volt and 9 volt batteries. This is a current loaded voltage scale. Battery checking (ignoring internal resistance, which increases as the battery is depleted), is less accurate when using a DC voltage scale.

Various sensors can be attached to multimeters to take measurements such as:

- Light level
- Acidity/Alkalinity(pH)

- Wind speed
- Relative humidityeditResolution

- **Digital**

The resolution of a multimeter is often specified in "digits" of resolution. For example, the term 5½ digits refers to the number of digits displayed on the display of a multimeter.

By convention, a half digit can display either a zero or a one, while a three-quarters digit can display a numeral higher than a one but not nine. Commonly, a three-quarters digit refers to a maximum value of 3 or 5. The fractional digit is always the most significant digit in the displayed value. A 5½ digit multimeter would have five full digits that display values from 0 to 9 and one half digit that could only display 0 or 1.[3] Such a meter could show positive or negative values from 0 to 199,999. A 3¾ digit meter can display a quantity from 0 to 3,999 or 5,999, depending on the manufacturer.

While a digital display can easily be extended in precision, the extra digits are of no value if not accompanied by care in the design and calibration of the analog portions of the multimeter. Meaningful high-resolution measurements require a good understanding of the instrument specifications, good control of the measurement conditions, and traceability of the calibration of the instrument.

Specifying "display counts" is another way to specify the resolution. Display counts give the largest number, or the largest number plus one (so the count number looks nicer) the multimeter's display can show, ignoring a decimal separator. For example, a 5½ digit multimeter can also be specified as a 199999 display count or 200000 display count multimeter. Often the display count is just called the count in multimeter specifications.

Analog

Resolution of analog multimeters is limited by the width of the scale pointer, vibration of the pointer, the accuracy of printing of scales, zero calibration, number of ranges, and errors due to non-horizontal use of the mechanical display. Accuracy of readings obtained is also often compromised by miscounting division markings, errors in mental arithmetic, parallax observation errors, and less than perfect eyesight. Mirrored scales and larger meter movements are used to improve resolution; two and a half to three digits equivalent resolution is usual (and is usually adequate for the limited precision needed for most measurements).

Resistance measurements, in particular, are of low precision due to the typical resistance measurement circuit which compresses the scale heavily at the higher resistance values. Inexpensive analog meters may have only a single resistance scale, seriously restricting the range of precise measurements. Typically an analog meter will have a panel adjustment to set the zero-ohms calibration of the meter, to compensate for the varying voltage of the meter battery.

Accuracy

Digital multimeters generally take measurements with accuracy superior to their analog counterparts. Standard analog multimeters measure with typically three percent accuracy,[4] though instruments of higher accuracy are made. Standard portable digital multimeters are specified to have an accuracy of typically 0.5% on the DC voltage ranges. Mainstream bench-top multimeters are available with specified accuracy of better than ±0.01%. Laboratory grade instruments can have accuracies of a few parts per million.[5]

Accuracy figures need to be interpreted with care. The accuracy of an analog instrument usually refers to full-scale deflection; a measurement of 10V on the 100V scale of a 3% meter is subject to an error of 3V, 30% of the reading. Digital meters usually specify accuracy as a percentage of reading plus a percentage of full-scale value, sometimes expressed in counts rather than percentage terms.

Quoted accuracy is specified as being that of the lower millivolt (mV) DC range, and is known as the "basic DC volts accuracy" figure. Higher DC voltage ranges, current, resistance, AC and other ranges will usually have a lower accuracy than the basic DC volts figure. AC measurements only meet specified accuracy within a specified range of frequencies.

Manufacturers can provide calibration services so that new meters may be purchased with a certificate of calibration indicating the meter has been adjusted to standards traceable to, for example, the US National Institute of Standards and Technology (NIST), or other national standards laboratory.

Test equipment tends to drift out of calibration over time, and the specified accuracy cannot be relied upon indefinitely. For more expensive equipment, manufacturers and third parties provide calibration services so that older equipment may be recalibrated and recertified. The cost of such services is disproportionate for inexpensive equipment; however extreme accuracy is not required for most routine testing. Multimeters used for critical measurements may be part of a metrology program to assure calibration

Sensitivity and input impedance

When used for measuring voltage, the input impedance of the multimeter must be very high compared to the impedance of the circuit being measured; otherwise circuit operation may be changed, and the reading will also be inaccurate.

Meters with electronic amplifiers (all digital multimeters and some analog meters) have a fixed input impedance that is high enough not to disturb most circuits. This is often either one or ten megohms; the standardization of the input resistance allows the use of external high-resistance probes which form a voltage divider with the input resistance to extend voltage range up to tens of thousands of volts.

Most analog multimeters of the moving-pointer type are unbuffered, and draw current from the circuit under test to deflect the meter pointer. The impedance of the meter varies depending on the basic sensitivity of the meter movement and the range which is selected. For example, a meter with a typical 20,000 ohms/volt sensitivity will have an input resistance of two million ohms on the 100 volt range (100 V * 20,000 ohms/volt = 2,000,000 ohms). On every range, at full scale voltage of the range, the full current required to deflect the meter movement is taken from the circuit under test. Lower sensitivity meter movements are acceptable for testing in circuits where source impedances are low compared to the meter impedance, for example, power circuits; these meters are more rugged mechanically. Some measurements in signal circuits require higher sensitivity movements so as not to load the circuit under test with the meter impedance.

Sometimes sensitivity is confused with resolution of a meter, which is defined as the lowest voltage, current or resistance change that can change the observed reading[*citation needed*].

For general-purpose digital multimeters, the lowest voltage range is typically several hundred millivolts AC or DC, but the lowest current range may be several hundred milliamperes, although instruments with greater current sensitivity are available. Measurement of low resistance requires lead resistance (measured by touching the test probes together) to be subtracted for best accuracy.

The upper end of multimeter measurement ranges varies considerably; measurements over perhaps 600 volts, 10 amperes, or 100 megohms may require a specialized test instrument

Burden voltage

Any ammeter, including a multimeter in a current range, has a certain resistance. Most multimeters inherently measure voltage, and pass a current to be measured through a shunt resistance, measuring the voltage developed across it. The voltage drop is known as the burden voltage, specified in volts per ampere. The value can change depending on the range the meter selects, since different ranges usually use different shunt resistors.[7][8]

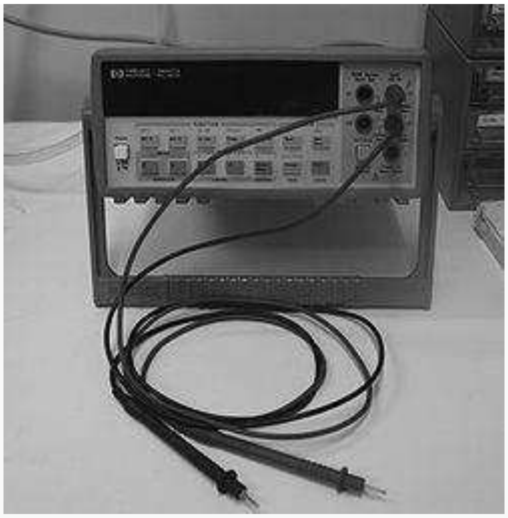
The burden voltage can be significant in low-voltage circuits. To check for its effect on accuracy and on external circuit operation the meter can be switched to different ranges; the current reading should be the same and circuit operation should not be affected if burden voltage is not a problem. If this voltage is significant it can be reduced (also reducing the inherent accuracy and precision of the measurement) by using a higher current range.

Alternating current sensing

Since the basic indicator system in either an analog or digital meter responds to DC only, a multimeter includes an AC to DC conversion circuit for making alternating current measurements. Basic meters utilize a rectifier circuit to measure the average or peak absolute value of the voltage, but are calibrated to show the calculated root mean square (RMS) value for a sinusoidal waveform; this will give correct readings for alternating current as used in power distribution. User guides for some such meters give correction factors for some simple non-sinusoidal waveforms, to allow the correct root mean square (RMS) equivalent value to be calculated. More expensive multimeters include an AC to DC converter that measures the true

RMS value of the waveform within certain limits; the user manual for the meter may indicate the limits of the crest factor and frequency for which the meter calibration is valid. RMS sensing is necessary for measurements on non-sinusoidal periodicwaveforms, such as found in audio signals and variable-frequency drives.

Digital multimeters (DMM or DVOM)



A bench-top multimeter from Hewlett-Packard.

Modern multimeters are often digital due to their accuracy, durability and extra features. In a digital multimeter the signal under test is converted to a voltage and an amplifier with electronically controlled gain preconditions the signal. A digital multimeter displays the quantity measured as a number, which eliminates parallax errors.

Modern digital multimeters may have an embedded computer, which provides a wealth of convenience features. Measurement enhancements available include:

- **Auto-ranging**, which selects the correct range for the quantity under test so that the most significant digits are shown. For example, a four-digit multimeter would automatically select an appropriate range to display 1.234 instead of 0.012, or overloading. Auto-ranging meters usually include a facility to 'freeze' the meter to a particular range, because a measurement that causes frequent range changes is distracting to the user. Other factors being equal, an auto-ranging meter will have more circuitry than an equivalent, non-auto-ranging meter, and so will be more costly, but will be more convenient to use.
- **Auto-polarity** for direct-current readings, shows if the applied voltage is positive (agrees with meter lead labels) or negative (opposite polarity to meter leads).

- **Sample and hold**, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- Current-limited tests for voltage drop across semiconductor junctions. While not a replacement for a transistor tester, this facilitates testing diodesand a variety of transistor typesA **graphic representation** of the quantity under test, as a bar graph. This makes go/no-go testing easy, and also allows spotting of fast-moving trends.
- A low-bandwidth **oscilloscope**.
- Automotive circuit testers, including tests for automotive timing and dwell signals.
- Simple data acquisition features to record maximum and minimum readings over a given period, or to take a number of samples at fixed intervals. Integration with tweezers for surface-mount technology. A combined LCR meter for small-size SMD and through-hole components. Modern meters may be interfaced with a personal computer by IrDA links, RS-232 connections, USB, or an instrument bus such as IEEE-488. The interface allows the computer to record measurements as they are made. Some DMMs can store measurements and upload them to a computer.[16]

The first digital multimeter was manufactured in 1955 by Non Linear Systems.

Analog multimeters

A multimeter may be implemented with a galvanometer meter movement, or with a bar-graph or simulated pointer such as an LCD or vacuum fluorescent display. Analog multimeters are common; a quality analog instrument will cost about the same as a DMM. Analog multimeters have the precision and reading accuracy limitations described above, and so are not built to provide the same accuracy as digital instruments.

Analog meters, with needle able to move rapidly, are sometimes considered better for detecting the rate of change of a reading; some digital multimeters include a fast-responding bar-graph display for this purpose. A typical example is a simple "good/no good" test of an electrolytic capacitor, which is quicker and easier to read on an analog meter. The ARRL handbook also says that analog multimeters, with no electronic circuitry, are less susceptible to radio frequency interference.

The meter movement in a moving pointer analog multimeter is practically always a moving-coil galvanometer of the d'Arsonval type, using either jeweled pivots or taut bands to support the moving coil. In a basic analog multimeter the current to deflect the coil and pointer is drawn from the circuit being measured; it is usually an advantage to minimize the current drawn from the circuit. The sensitivity of an analog multimeter is given in units of ohms per volt. For example, an inexpensive multimeter would have a sensitivity of 1000 ohms per volt and would draw 1 milliampere from a circuit at the full scale measured voltage.[20] More expensive, (and mechanically more delicate) multimeters would have sensitivities of 20,000 ohms per volt or higher, with a 50,000 ohms per volt meter (drawing 20 microamperes at full scale) being about the upper limit for a portable, general purpose, non-amplified analog multimeter.

To avoid the loading of the measured circuit by the current drawn by the meter movement, some analog multimeters use an amplifier inserted between the measured circuit and the meter movement. While this increased the expense and complexity of the meter and required a power supply to operate the amplifier, by use of vacuum tubes or field effect transistors the input resistance can be made very high and independent of the current required to operate the meter movement coil. Such amplified multimeters are called VTVMs (vacuum tube voltmeters),[21] TVMs (transistor volt meters), FET-VOMs, and similar names.

Probes

A multimeter can utilize a variety of test probes to connect to the circuit or device under test. Crocodile clips, retractable hook clips, and pointed probes are the three most common attachments.Tweezer probes are used for closely-spaced test points, as in surface-mount devices. The connectors are attached to flexible, thickly-insulated leads that are terminated with connectors appropriate for the meter. Probes are connected to portable meters typically by shrouded or recessed banana jacks, while benchtop meters may use banana jacks or BNC connectors. 2mm plugs and binding postshave also been used at times, but are less common today.

Clamp meters clamp around a conductor carrying a current to measure without the need to connect the meter in series with the circuit, or make metallic contact at all. For all except the most specialized and expensive types they are suitable to measure only large (from several amps up) and alternating currents.

Voltmeter

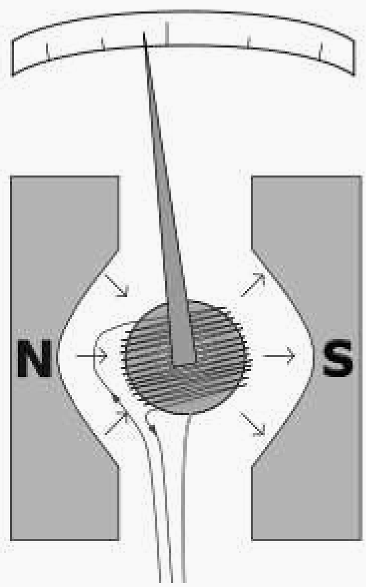
A **voltmeter** is an instrument used for measuring the electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.

Voltmeters are made in a wide range of styles. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a multimeter, are standard test instruments used in electrical and electronics work. Any measurement that can be converted to a voltage can be displayed on a meter that is suitably calibrated; for example, pressure, temperature, flow or level in a chemical process plant.

General purpose analog voltmeters may have an accuracy of a few per cent of full scale, and are used with voltages from a fraction of a volt to several thousand volts. Digital meters can be made with high accuracy, typically better than 1%. Specially calibrated test instruments have higher accuracies, with laboratory instruments capable of measuring to accuracies of a few parts per million. Meters using amplifiers can measure tiny voltages of microvolts or less.

Part of the problem of making an accurate voltmeter is that of calibration to check its accuracy. In laboratories, the Weston Cell is used as a standard voltage for precision work. Precision voltage references are available based on electronic circuits.

Analog voltmeter



- The red wire carries the current to be measured.
- The restoring spring is shown in green.
- N and S are the north and south poles of the magnet.

A moving coil galvanometer can be used as a voltmeter by inserting a resistor in series with the instrument. It employs a small coil of fine wire suspended in a strong magnetic field. When an electric current is applied, the galvanometer's indicator rotates and compresses a small spring. The angular rotation is proportional to the current through the coil. For use as a voltmeter, a series resistance is added so that the angular rotation becomes proportional to the applied voltage.

One of the design objectives of the instrument is to disturb the circuit as little as possible and so the instrument should draw a minimum of current to operate. This is achieved by using a sensitive ammeter or microammeter in series with a high resistance.

The sensitivity of such a meter can be expressed as "ohms per volt", the number of ohms resistance in the meter circuit divided by the full scale measured value. For example a meter with a sensitivity of 1000 ohms per volt would draw 1 milliampere at full scale voltage; if the full scale was 200 volts, the resistance at the instrument's terminals would be 200,000 ohms and at full scale the meter would draw 1 milliampere from the circuit under test. For multi-range instruments, the input resistance varies as the instrument is switched to different ranges.

Moving-coil instruments with a permanent-magnet field respond only to direct current. Measurement of AC voltage requires a rectifier in the circuit so that the coil deflects in only one direction. Moving-coil instruments are also made with the zero position in the middle of the scale instead of at one end; these are useful if the voltage reverses its polarity.

Voltmeters operating on the electrostatic principle use the mutual repulsion between two charged plates to deflect a pointer attached to a spring. Meters of this type draw negligible current but are sensitive to voltages over about 100 volts and work with either alternating or direct current.

VTVMs and FET-VMs

The sensitivity and input resistance of a voltmeter can be increased if the current required to deflect the meter pointer is supplied by an amplifier and power supply instead of by the circuit under test. The electronic amplifier between input and meter gives two benefits; a rugged moving coil instrument can be used, since its sensitivity need not be high, and the input resistance can be made high, reducing the current drawn from the circuit under test. Amplified voltmeters often have an input resistance of 1, 10, or 20 megohms which is independent of the range selected. A once-popular form of this instrument used a vacuum tube in the amplifer circuit and so was called the vacuum tube voltmeter, or VTVM. These were almost always powered by the local AC line current and so were not particularly portable. Today these circuits use a solid-state amplifier using field-effect transistors, hence FET-VM, and appear in handheld digital multimeters as well as in bench and laboratory instruments. These are now so ubiquitous that they have largely replaced non-amplified multimeters except in the least expensive price ranges.

Most VTVMs and FET-VMs handle DC voltage, AC voltage, and resistance measurements; modern FET-VMs add current measurements and often other functions as well. A specialized form of the VTVM or FET-VM is the AC voltmeter. These instruments are optimized for measuring AC voltage. They have much wider bandwidth and better sensitivity than a typical multifunction device.

Digital voltmeters

Two digital voltmeters. Note the 40 microvolt difference between the twomeasurements, an offset of 34 parts per million.

The first *digital* voltmeter was invented and produced by Andrew Kay of Non-Linear Systems (and later founder of Kaypro) in 1954.

Digital voltmeters (DVMs) are usually designed around a special type of analog-to-digital converter called an integrating converter. Voltmeter accuracy is affected by many factors, including temperature and supply voltage variations. To ensure that a digital voltmeter's reading is within the manufacturer's specified tolerances, they should be periodically calibrated against a voltage standard such as the Weston cell.

Digital voltmeters necessarily have input amplifiers, and, like vacuum tube voltmeters, generally have a constant input resistance of 10 megohms regardless of set measurement range.

Ammeter

An **ammeter** is a measuring instrument used to measure the electric current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the milliampere or microampere range, are designated as *milliammeters* or *microammeters*. Early ammeters were laboratory instruments which relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems.

History

The relation between electric current, magnetic fields and physical forces was first noted by Hans Christian Ørsted who, in 1820, observed a compass needle was deflected from pointing North when a current flowed in an adjacent wire. The tangent galvanometer was used to measure currents using this effect, where the restoring force returning the pointer to the zero position was provided by the Earth's magnetic field. This made these instruments usable only when aligned with the Earth's field. Sensitivity of the instrument was increased by using additional turns of wire to multiply the effect – the instruments were called "multipliers".

The D'Arsonval galvanometer is a **moving coil** ammeter. It uses magnetic deflection, where current passing through a coil causes the coil to move in amagnetic field. The voltage drop across the coil is kept to a minimum to minimize resistance across the ammeter in any circuit into which it is inserted. The modern form of this instrument was developed by Edward Weston, and uses two spiral springs to provide the restoring force. By maintaining a uniform air gap between the iron core of the instrument and the poles of its permanent magnet, the instrument has good linearity and accuracy. Basic meter movements can have full-scale deflection for currents from about 25 microamperes to 10 milliamperes and have linear scales

Moving iron ammeters use a piece of iron which moves when acted upon by the electromagnetic force of a fixed coil of wire. This type of meterresponds to both direct and alternating currents (as opposed to the moving coil ammeter, which works on direct current only). The iron element consists of a moving vane attached to a pointer, and a fixed vane, surrounded by a coil. As alternating or direct current flows through the coil and induces a magnetic field in both vanes, the vanes repel each other and the moving vane deflects against the restoring force provided by fine helical springs The non-linear scale of these meters makes them unpopular.

An **electrodynamic** movement uses an electromagnet instead of the permanent magnet of the d'Arsonval movement. This instrument can respond to both alternating and direct current. [2]

In a **hot-wire ammeter**, a current passes through a wire which expands as it heats. Although these instruments have slow response time and low accuracy, they were sometimes used in measuring radio-frequency current

Digital ammeter designs use an analog to digital converter (ADC) to measure the voltage across the shunt resistor; the digital display is calibrated to read the current through the shunt.

There is also a whole range of devices referred to as **integrating ammeters**. In these ammeters the amount of current is summed over time giving as a result the product of current and time, which is proportional to the energy transferred with that current. These can be used for energy meters (watt-hour meters) or for estimating the charge of battery or capacitor.

PICOAMMETER

A **picoammeter**, or pico ammeter, measures very low electrical current, usually from the picoampere range at the lower end to the milliampere range at the upper end. Picoammeters are used for sensitive measurements where the current being measured is below the theoretical limits of sensitivity of other devices, such as Multimeters.

Most picoammeters use a "virtual short" technique and have several different measurement ranges that must be switched between to cover multiple decades of measurement. Other modern picoammeters use log compression and a "current sink" method that eliminates range switching and associated voltage spikes.

APPLICATION

The majority of ammeters are either connected in series with the circuit carrying the current to be measured (for small fractional amperes), or have their shunt resistors connected similarly in series. In either case, the current passes through the meter or (mostly) through its shunt. They must not be connected to a source of voltage; they are designed for minimal burden, which refers to the voltage drop across the ammeter, which is typically a small fraction of a volt. They are almost a short circuit.

Ordinary Weston-type meter movements can measure only milliamperes at most, because the springs and practical coils can carry only limited currents. To measure larger currents, a resistor called a *shunt* is placed in parallel with the meter. The resistances of shunts is in the integer to fractional milliohm range. Nearly all of the current flows through the shunt, and only a small fraction flows through the meter. This allows the meter to measure large currents. Traditionally, the meter used with a shunt has a full-scale deflection (FSD) of 50 mV, so shunts are typically designed to produce a voltage drop of 50 mV when carrying their full rated current.

Zero-center ammeters are used for applications requiring current to be measured with both polarities, common in scientific and industrial equipment. Zero-center ammeters are also commonly placed in series with a battery. In this application, the charging of the battery deflects the needle to one side of the scale (commonly, the right side) and the discharging of the battery deflects the needle to the other side. A special type of zero-center ammeter for testing high currents in cars and trucks has a pivoted bar magnet that moves the pointer, and a fixed bar magnet to keep the pointer centered with no current. The magnetic field around the wire carrying current to be measured deflects the moving magnet.

Since the ammeter shunt has a very low resistance, mistakenly wiring the ammeter in parallel with a voltage source will cause a short circuit, at best blowing a fuse, possibly damaging the instrument and wiring, and exposing an observer to injury.

In AC circuits, a current transformer converts the magnetic field around a conductor into a small AC current, typically either 1 A or 5 A at full rated current, that can be easily read by a meter. In a similar way, accurate AC/DC non-contact ammeters have been constructed using Hall effect magnetic field sensors. A portable hand-held clamp-on ammeter is a common tool for maintenance of industrial and commercial electrical equipment, which is temporarily clipped over a wire to measure current. Some recent types have a parallel pair of magnetically-soft probes that are placed on either side of the conductor.

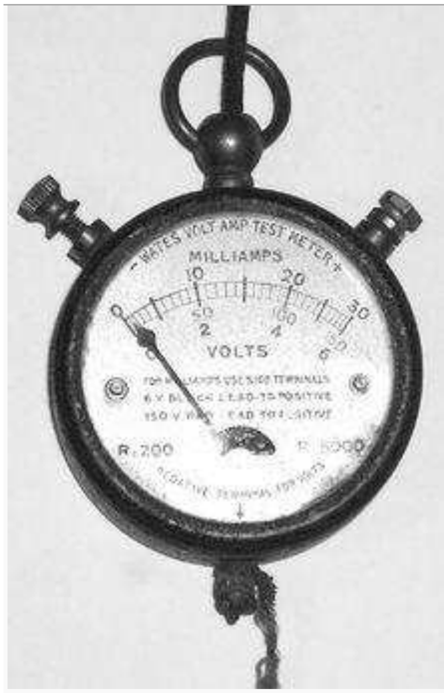
MULTIMETER

A **multimeter** or a **multitester**, also known as a **volt/ohm meter** or **VOM**, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. Multimeters may use analogor digital circuits—**analog multimeters** and **digital multimeters** (often abbreviated **DMM** or **DVOM**.) Analog instruments are usually based on amicroammeter whose pointer moves over a scale calibration for all the different measurements that can be made; digital instruments usually display digits, but may display a bar of a length proportional to the quantity measured.

A multimeter can be a hand-held device useful for basic fault finding and field service work or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.

Multimeters are available in a wide ranges of features and prices. Cheap multimeters can cost less than US$10, while the top of the line multimeters can cost more than US$5,000.

History



The first moving-pointer current-detecting device was the galvanometer. These were used to measure resistance and voltage by using a Wheatstone bridge, and comparing the unknown quantity to a reference voltage or resistance. While useful in the lab, the devices were very slow and impractical in the field. These galvanometers were bulky and delicate.

The D'Arsonval/Weston meter movement used a fine metal spring to give proportional measurement rather than just detection, and built-in permanent field magnets made deflection independent of the 3D orientation of the meter. These features enabled dispensing with Wheatstone bridges, and made measurement quick and easy. By adding a series or shunt resistor, more than one range of voltage or current could be measured with one movement.

Multimeters were invented in the early 1920s as radio receivers and other vacuum tube electronic devices became more common. The invention of the first multimeter is attributed to United States Post Office (USPS) engineer, Donald Macadie, who became dissatisfied with having to carry many separate instruments required for the maintenance of the telecommunications circuits.[1] Macadie invented an instrument which could measure amperes (aka amps), volts and ohms, so the multifunctional meter was then named Avometer.[2] The meter comprised a moving coil meter, voltage and precision resistors, and switches and sockets to select the range.

Macadie took his idea to the Automatic Coil Winder and Electrical Equipment Company (ACWEEC, founded in ~1923).[2] The first AVO was put on sale in 1923, and although it was initially a DC. Many of its features remained almost unaltered through to the last **MODEL 8.**

Pocket watch style meters were in widespread use in the 1920s, at much lower cost than Avometers. The metal case was normally connected to the negative connection, an arrangement that caused numerous electric shocks. The technical specifications of these devices were often crude, for example the one illustrated has a resistance of just 33 ohms per volt, a non-linear scale and no zero adjustment.

The usual analog multimeter when used for voltage measurements loads the circuit under test to some extent (a microammeter with full-scale current of 50ampere, the highest sensitivity commonly available, must draw at least 50 milliamps from the circuit under test to deflect fully).

This may load a high-impedance circuit so much as to perturb the circuit, and also to give a low reading.

Vacuum Tube Voltmeters or valve voltmeters (VTVM, VVM) were used for voltage measurements in electronic circuits where high impedance was necessary. The VTVM had a fixed input impedance of typically 1 megohm or more, usually through use of a cathode follower input circuit, and thus did not significantly load the circuit being tested. Before the introduction of digital electronic high-impedance analog transistor and field effect transistor (FETs) voltmeters were used. Modern digital meters and some modern analog meters use electronic input circuitry to achieve high-input impedance—their voltage ranges arefunctionally equivalent to VTVMs.

Additional scales such as decibels, and functions such as capacitance, transistor gain, frequency, duty cycle, display hold, and buzzers which sound when the measured resistance is small have been included on many multimeters. While multimeters may be supplemented by more specialized equipment in a technician's toolkit, some modern multimeters include even more additional functions for specialized applications (e.g., temperature with a thermocoupleprobe, inductance, connectivity to a computer, speaking measured value, etc.).

QUANTITIES MEASURED

Contemporary multimeters can measure many quantities. The common ones are:

- Voltage, alternating and direct, in volts.
- Current, alternating and direct, in amperes. The frequency range for which AC measurements are accurate must be specified.
- Resistance in ohms.

ADDITIONALLY, SOME MULTIMETERS MEASURE:

- Capacitance in farads.
- Conductance in siemens.
- Decibels.
- Duty cycle as a percentage.
- Frequency in hertz.
- Inductance in henrys.

- Temperature in degrees Celsius or Fahrenheit, with an appropriate temperature test probe, often a thermocouple.

DIGITAL MULTIMETERS MAY ALSO INCLUDE CIRCUITS FOR:

- Continuity; beeps when a circuit conducts.
- Diodes (measuring forward drop of diode junctions, i.e., diodes and transistor junctions) and transistors (measuring current gain and other parameters).
- Battery checking for simple 1.5 volt and 9 volt batteries. This is a current loaded voltage scale. Battery checking (ignoring internal resistance, which increases as the battery is depleted), is less accurate when using a DC voltage scale.

VARIOUS SENSORS CAN BE ATTACHED TO MULTIMETERS TO TAKE MEASUREMENTS SUCH AS:

- Light level
- Acidity/Alkalinity(pH)
- Wind speed
- Relative humidity

DIGITAL

The resolution of a multimeter is often specified in "digits" of resolution. For example, the term 5½ digits refers to the number of digits displayed on the display of a multimeter.

By convention, a half digit can display either a zero or a one, while a three-quarters digit can display a numeral higher than a one but not nine. Commonly, a three-quarters digit refers to a maximum value of 3 or 5. The fractional digit is always the most significant digit in the displayed value. A 5½ digit multimeter would have five full digits that display values from 0 to 9 and one half digit that could only display 0 or 1.[3] Such a meter could show positive or negative values from 0 to 199,999. A 3¾ digit meter can display a quantity from 0 to 3,999 or 5,999, depending on the manufacturer.

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Digital multimeters generally take measurements with accuracy superior to their analog counterparts. Standard analog multimeters measure with typically three percent accuracy,[4] though instruments of higher accuracy are made. Standard portable digital multimeters are specified to have an accuracy of typically 0.5% on the DC voltage ranges. Mainstream bench-top multimeters are available with specified accuracy of better than ±0.01%. Laboratory grade instruments can have accuracies of a few parts per million.

Accuracy figures need to be interpreted with care. The accuracy of an analog instrument usually refers to full-scale deflection; a measurement of 10V on the 100V scale of a 3% meter is subject to an error of 3V, 30% of the reading. Digital meters usually specify accuracy as a percentage of reading plus a percentage of full-scale value, sometimes expressed in counts rather than percentage terms.

Quoted accuracy is specified as being that of the lower millivolt (mV) DC range, and is known as the "basic DC volts accuracy" figure. Higher DC voltage ranges, current, resistance, AC and other ranges will usually have a lower accuracy than the basic DC volts figure. AC measurements only meet specified accuracy within a specified range of frequencies.

Manufacturers can provide calibration services so that new meters may be purchased with a certificate of calibration indicating the meter has been adjusted to standards traceable to, for example, the US National Institute of Standards and Technology (NIST), or other national standards laboratory.

Test equipment tends to drift out of calibration over time, and the specified accuracy cannot be relied upon indefinitely. For more expensive equipment, manufacturers and third parties provide calibration services so that older equipment may be recalibrated and recertified. The cost of such services is disproportionate for inexpensive equipment; however extreme accuracy is not required for most routine testing. Multimeters used for critical measurements may be part of a metrology program to assure calibration.

SENSITIVITY AND INPUT IMPEDANCE

When used for measuring voltage, the input impedance of the multimeter must be very high compared to the impedance of the circuit being measured; otherwise circuit operation may be changed, and the reading will also be inaccurate.

Meters with electronic amplifiers (all digital multimeters and some analog meters) have a fixed input impedance that is high enough not to disturb most circuits. This is often either one or ten megohms; the standardization of the input resistance allows the use of external high-resistance probes which form a voltage divider with the input resistance to extend voltage range up to tens of thousands of volts.

Most analog multimeters of the moving-pointer type are unbuffered, and draw current from the circuit under test to deflect the meter pointer. The impedance of the meter varies depending on the basic sensitivity of the meter movement and the range which is selected. For example, a meter with a typical 20,000 ohms/volt sensitivity will have an input resistance of two million ohms on the 100 volt range (100 V * 20,000 ohms/volt = 2,000,000 ohms). On every range, at full scale voltage of the range, the full current required to deflect the meter movement is taken from the circuit under test. Lower sensitivity meter movements are acceptable for testing in circuits where source impedances are low compared to the meter impedance, for example, power circuits; these meters are more rugged mechanically. Some measurements in signal circuits require higher sensitivity movements so as not to load the circuit under test with the meter impedanceSometimes sensitivity is confused with resolution of a meter, which is defined as the lowest voltage, current or resistance change that can change the observed reading

For general-purpose digital multimeters, the lowest voltage range is typically several hundred millivolts AC or DC, but the lowest current range may be several hundred milliamperes, although instruments with greater current sensitivity are available. Measurement of low resistance requires lead resistance (measured by touching the test probes together) to be subtracted for best accuracy.

The upper end of multimeter measurement ranges varies considerably; measurements over perhaps 600 volts, 10 amperes, or 100 megohms may require a specialized test instrument.

BURDEN VOLTAGE

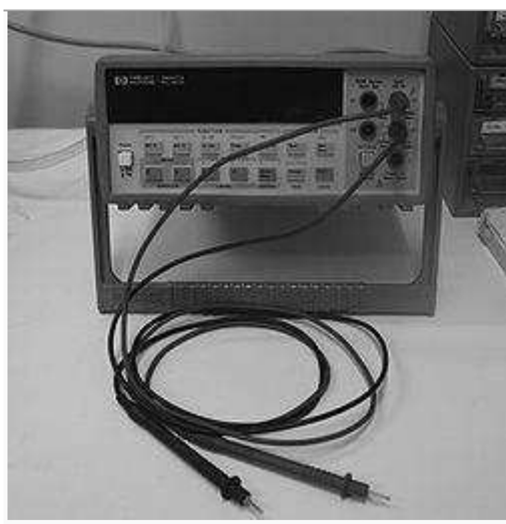
Any ammeter, including a multimeter in a current range, has a certain resistance. Most multimeters inherently measure voltage, and pass a current to be measured through a shunt resistance, measuring the voltage developed across it. The voltage drop is known as the burden voltage, specified in volts per ampere. The value can change depending on the range the meter selects, since different ranges usually use different shunt resistors.

The burden voltage can be significant in low-voltage circuits. To check for its effect on accuracy and on external circuit operation the meter can be switched to different ranges; the current reading should be the same and circuit operation should not be affected if burden voltage is not a problem. If this voltage is significant it can be reduced (also reducing the inherent accuracy and precision of the measurement) by using a higher current range.

ALTERNATING CURRENT SENSING

Since the basic indicator system in either an analog or digital meter responds to DC only, a multimeter includes an AC to DC conversion circuit for making alternating current measurements. Basic meters utilize a rectifier circuit to measure the average or peak absolute value of the voltage, but are calibrated to show the calculated root mean square (RMS) value for a sinusoidal waveform; this will give correct readings for alternating current as used in power distribution. User guides for some such meters give correction factors for some simple non-sinusoidal waveforms, to allow the correct root mean square (RMS) equivalent value to be calculated. More expensive multimeters include an AC to DC converter that measures the true RMS value of the waveform within certain limits; the user manual for the meter may indicate the limits of the crest factor and frequency for which the meter calibration is valid. RMS sensing is necessary for measurements on non-sinusoidal periodic waveforms, such as found in audio signals and variable-frequency drives.

Digital multimeters (DMM or DVOM)



Modern multimeters are often digital due to their accuracy, durability and extra features. In a digital multimeter the signal under test is converted to a voltage and an amplifier with electronically controlled gain preconditions the signal. A digital multimeter displays the quantity measured as a number, which eliminates parallax errors.

Modern digital multimeters may have an embedded computer, which provides a wealth of convenience features. Measurement enhancements available include:

- **Auto-ranging**, which selects the correct range for the quantity under test so that the most significant digits are shown. For example, a four-digit multimeter would automatically select an appropriate range to display 1.234 instead of 0.012, or overloading. Auto-ranging meters usually include a facility to 'freeze' the meter to a particular range, because a measurement that causes frequent range changes is distracting to the user. Other factors being equal, an auto-ranging meter will have more circuitry than an equivalent, non-auto-ranging meter, and so will be more costly, but will be more convenient to use.
- **Auto-polarity** for direct-current readings, shows if the applied voltage is positive (agrees with meter lead labels) or negative (opposite polarity to meter leads).
- **Sample and hold**, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- Current-limited tests for voltage drop across semiconductor junctions. While not a replacement for a transistor tester, this facilitates testing diodesand a variety of transistor types.
- A **graphic representation** of the quantity under test, as a bar graph. This makes go/no-go testing easy, and also allows spotting of fast-moving trends.
- A low-bandwidth **oscilloscope**. Automotive circuit testers, including tests for automotive timing and dwell signals
- Simple data acquisition features to record maximum and minimum readings over a given period, or to take a number of samples at fixed intervalsI ntegration with tweezers for surface-mount technology.
- A combined LCR meter for small-size SMD and through-hole components. Modern meters may be interfaced with a personal computer by IrDA links, RS-

232 connections, USB, or an instrument bus such as IEEE-488. The interface allows the computer to record measurements as they are made. Some DMMs can store measurements and upload them to a computer· The first digital multimeter was manufactured in 1955 by Non Linear Systems·

- **ANALOG MULTIMETERS**

A multimeter may be implemented with a galvanometer meter movement, or with a bar-graph or simulated pointer such as an LCD or vacuum fluorescent display. Analog multimeters are common; a quality analog instrument will cost about the same as a DMM. Analog multimeters have the precision and reading accuracy limitations described above, and so are not built to provide the same accuracy as digital instruments.

Analog meters, with needle able to move rapidly, are sometimes considered better for detecting the rate of change of a reading; some digital multimeters include a fast-responding bar-graph display for this purpose. A typical example is a simple "good/no good" test of an electrolytic capacitor, which is quicker and easier to read on an analog meter. The ARRL handbook also says that analog multimeters, with no electronic circuitry, are less susceptible to radio frequency interference.

The meter movement in a moving pointer analog multimeter is practically always a moving-coil galvanometer of the d'Arsonval type, using either jeweled pivots or taut bands to support the moving coil. In a basic analog multimeter the current to deflect the coil and pointer is drawn from the circuit being measured; it is usually an advantage to minimize the current drawn from the circuit. The sensitivity of an analog multimeter is given in units of ohms per volt. For example, an inexpensive multimeter would have a sensitivity of 1000 ohms per volt and would draw 1 milliampere from a circuit at the full scale measured voltage.[20] More expensive, (and mechanically more delicate) multimeters would have sensitivities of 20,000 ohms per volt or higher, with a 50,000 ohms per volt meter (drawing 20 microamperes at full scale) being about the upper limit for a portable, general purpose, non-amplified analog multimeter.

To avoid the loading of the measured circuit by the current drawn by the meter movement, some analog multimeters use an amplifier inserted between the measured circuit and the meter movement. While this increased the expense and complexity of the meter and required a power supply to operate the amplifier, by use of vacuum tubes or field effect transistors the input resistance can be made very high and independent of the current required to operate the meter movement coil. Such amplified multimeters are called VTVMs (vacuum tube voltmeters), TVMs (transistor volt meters), FET-VOMs, and similar names.

PROBES

A multimeter can utilize a variety of test probes to connect to the circuit or device under test. Crocodile clips, retractable hook clips, and pointed probes are the three most common attachments.Tweezer probes are used for closely-spaced test points, as in surface-mount devices. The connectors are attached to flexible, thickly-insulated leads that are terminated with connectors appropriate for the meter. Probes are connected to portable meters typically by shrouded or recessed banana jacks, while benchtop meters may use banana jacks or BNC connectors. 2mm plugs and binding postshave also been used at times, but are less common today.

Clamp meters clamp around a conductor carrying a current to measure without the need to connect the meter in series with the circuit, or make metallic contact at all. For all except the most specialized and expensive types they are suitable to measure only large (from several amps up) and alternating currents.

SAFETY

All but the most inexpensive multimeters include a fuse, or two fuses, which will sometimes prevent damage to the multimeter from a current overload on the highest current range. A common error when operating a multimeter is to set the meter to measure resistance or current and then connect it directly to a low-impedance voltage source; meters without protection are quickly destroyed by such errors. Fuses used in meters will carry the maximum measuring current of the instrument, but are intended to clear if operator error exposes the meter to a low-impedance fault.

On meters that allow interfacing with computers, optical isolation may protect attached equipment against high voltage in the measured circuit.

Digital meters are rated into categories based on their intended application, as set forth by IEC 61010 - and echoed by country and regional standards groups such as the CEN EN61010 standard.[23] There are four categories:

- **Category I**: used where equipment is not directly connected to the mains.

- **Category II**: used on single phase mains final sub-circuits.
- **Category III**: used on permanently installed loads such as distribution panels, motors, and 3 phase appliance outlets.
- **Category IV**: used on locations where fault current levels can be very high, such as supply service entrances, main panels, supply meters and primary over-voltage protection equipment.

Each category also specifies maximum transient voltages for selected measuring ranges in the meter. Category-rated meters also feature protections from over-current faults

DMM ALTERNATIVES

A general-purpose DMM is generally considered adequate for measurements at signal levels greater than one millivolt or one milliampere, or below about 100 megohms—levels far from the theoretical limits of sensitivity. Other instruments—essentially similar, but with higher sensitivity—are used for accurate measurements of very small or very large quantities. These include nanovoltmeters, electrometers (for very low currents, and voltages with very high source resistance, such as one teraohm) and picoammeters. These measurements are limited by available technology, and ultimately by inherent thermal noise.

BATTERY

Hand-held meters use batteries for continuity and resistance readings. This allows the meter to test a device that is not connected to a power source, by supplying its own low voltage for the test. A 1.5 volt AA battery is typical; more sophisticated meters with added capabilities instead or also use a 9 volt battery for some types of readings, or even higher-voltage batteries for very high resistance testing. Meters intended for testing in hazardous locations or for use on blasting circuits may require use of a manufacturer-specified battery to maintain their safety rating. A battery is also required to power the electronics of a digital multimeter or FET-VOM.

Three-Phase Wattmeter

Total power in a 3ϕ circuit is the sum of the powers of the separate phases. The total power could be measured by placing a wattmeter in each phase (Figure 12); however, this method is not feasible since it is often impossible to break into the phases of a delta load. It also may not be feasible for the Y load, since the neutral point to which the wattmeters must be connected is not always accessible.

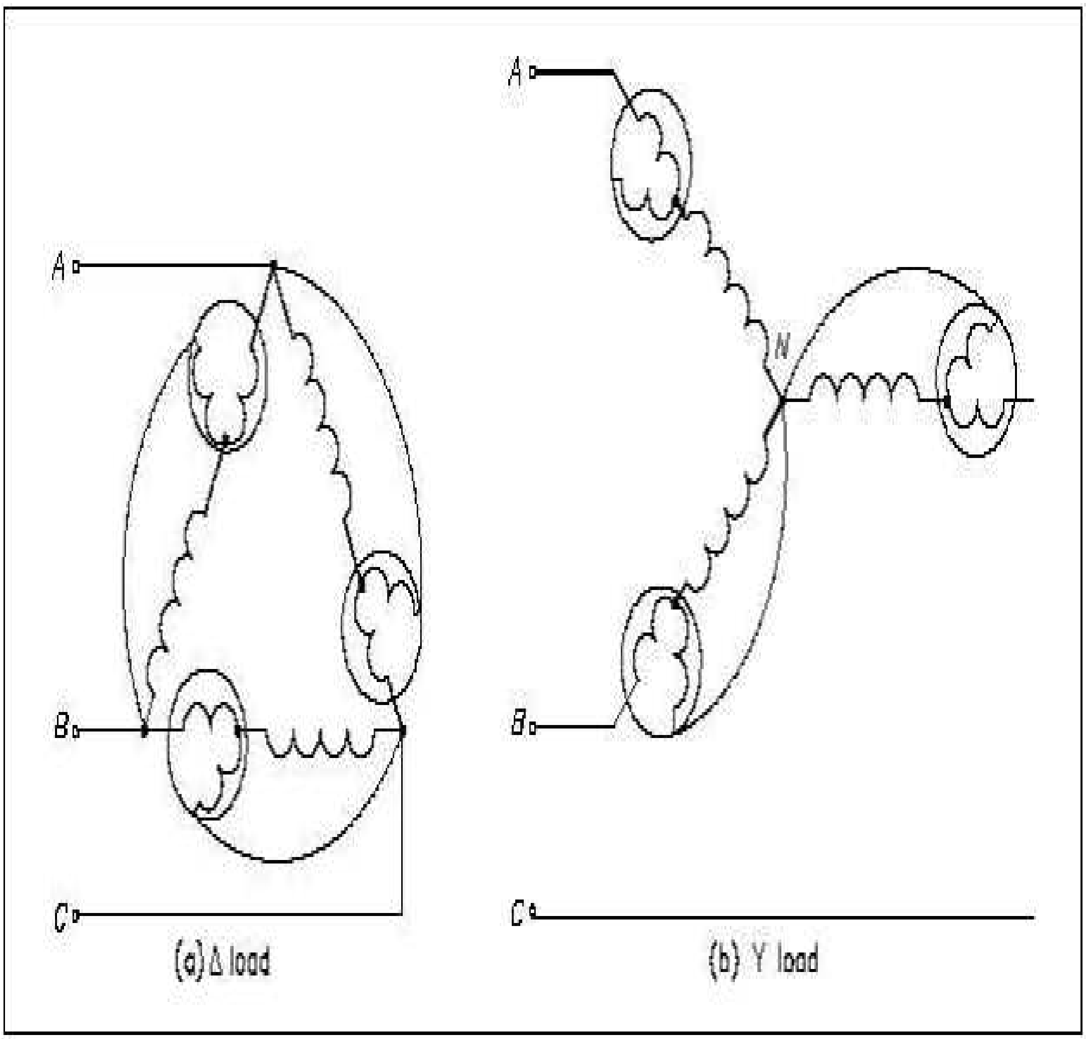


Figure 12 Wattmeters in Each Phase

Normally, only two wattmeters are used in making 3ϕ power measurements (Figure 13).

In balanced 3ϕ systems, with any power factor, total power is calculated by adding the A and B phase powers. Equation (14-17) is the mathematical representation for calculating total power (P_T).

$$P_T = W_A + W_B \tag{14-17}$$

where

W_A and W_B are the power readings in Phase A and Phase B

SINGLE AND THREE PHASE ENERGY METERS

An **electric meter** or **energy meter** is a device that measures the amount of electrical energy consumed by a residence, business, or an electrically powered device.

Electric meters are typically calibrated in billing units, the most common one being the kilowatt hour. Periodic readings of electric meters establishes billing cycles and energy used during a cycle.

In settings when energy savings during certain periods are desired, meters may measure demand, the maximum use of power in some interval. In some areas, the electric rates are higher during certain times of day, to encourage reduction in use. Also, in some areas meters have relays to turn off nonessential equipment.

HISTORY

As commercial use of electric power spread in the 1880s, it became increasingly important that an electrical energy meter, similar to the then existing gas meters, was required to properly bill customers for the cost of energy, instead of billing for a fixed number of lamps per month. Many experimental types of meter were developed. Edison at first worked on a DC electromechanical meter with a direct reading register, but instead developed an electrochemical metering system, which used an electrolytic cell to totalize current consumption. At periodic intervals the plates were removed, weighed, and the customer billed. The electrochemical meter was labor-intensive to read and not well received by customers. In 1885 Ferranti offered a mercury motor meter with a register similar to gas meters; this had the advantage that the consumer could easily read the meter and verify consumption. The first accurate, recording electricity consumption meter was a DC meter by Dr Hermann Aron, who patented it in 1883. Hugo Hirst of the British General Electric Company introduced it commercially into Great Britain from 1888. Meters had been used prior to this, but they measured the rate of power consumption at that particular moment. Aron's meter recorded the total energy used over time, and showed it on a series of clock dials.

The first specimen of the AC kilowatt-hour meter produced on the basis of Hungarian Ottó Bláthy's patent and named after him was presented by the Ganz Works at the Frankfurt Fair in the autumn of 1889, and the first induction kilowatt-hour meter was already marketed by the factory at the end of the same year. These were the first alternating-current watt meters, known by the name of Bláthy-meters. The AC kilowatt hour meters used at present operate on the same principle as Bláthy's original inventionAlso around 1889, Elihu Thomson of the American General Electric company developed a recording watt meter (watt-hour meter) based on an ironless commutator motor. This meter overcame the disadvantages of the electrochemical type and could operate on either alternating or direct current. In 1894 Oliver Shallenberger of the Westinghouse Electric Corporation applied the induction principle previously used only in AC ampere-hour meters to produce a watt-hour meter of the modern electromechanical form, using an induction disk whose rotational speed was made proportional to the power in the circuit Although the induction meter would only work on alternating current, it eliminated the delicate and troublesome commutator of the Thomson design. Shallenberger fell ill and was unable to refine his initial large and heavy design, although he did also develop a polyphase version.

UNIT OF MEASUREMENT

The most common unit of measurement on the electricity meter is the kilowatt hour, which is equal to the amount of energy used by a load of one kilowattover a period of one hour, or 3,600,000 joules. Some electricity companies use the SI megajoule instead.

Demand is normally measured in watts, but averaged over a period, most often a quarter or half hour.

Reactive power is measured in "Volt-amperes reactive", (varh) in kilovar-hours. By convention, a "lagging" or inductive load, such as a motor, will have positive reactive power. A "leading", or capacitive load, will have negative reactive powerVolt-amperes measures all power passed through a distribution network, including reactive and actual. This is equal to the product of root-mean-square volts and amperes.

Distortion of the electric current by loads is measured in several ways. Power factor is the ratio of resistive (or real power) to volt-amperes. A capacitive load has a leading power factor, and an inductive load has a lagging power factor. A purely resistive load (such as a filament lamp, heater or kettle) exhibits a power factor of 1. Current harmonics are a measure of distortion of the wave form. For example, electronic loads such as computer power supplies draw their current at the voltage peak to fill their internal storage elements. This can lead to a significant voltage drop near the supply voltage peak which shows as a flattening of the voltage waveform. This flattening causes odd harmonics which are not permissible if they exceed specific limits, as they are not only wasteful, but may interfere with the operation of other equipment. Harmonic emissions are mandated by law in EU and other countries to fall within specified limits.

OTHER UNITS OF MEASUREMENT

In addition to metering based on the amount of energy used, other types of metering are available.

Meters which measured the amount of charge (coulombs) used, known as ampere-hour meters, were used in the early days of electrification. These were dependent upon the supply voltage remaining constant for accurate measurement of energy usage, which was not a likely circumstance with most supplies.

Some meters measured only the length of time for which charge flowed, with no measurement of the magnitude of voltage or current being made. These were only suited for constant-load applications.

Neither type is likely to be used today.

BH CURVE AND IRON LOSS MEASUREMENTS FOR MAGNETIC MATERIALS

Hysteresis refers to systems that have *memory*, where the effects of the current input (or stimulus) to the system are experienced with a certain delay in time. Such a system may exhibit path dependence, or "rate-independent memory" . Hysteresis phenomena occur in magnetic materials, ferromagnetic materials and ferroelectric materials, as well as in the elastic, electric, and magneticbehavior of materials, in which a lag occurs between the application and the removal of a force or field and its subsequent effect. Electric hysteresis occurs when applying a varying electric field, andelastic hysteresis occurs in response to a varying force. The term "hysteresis" is sometimes used in other fields, such as economics or biology, where it describes a memory, or lagging effect.

In a deterministic system with no dynamics or hysteresis, it is possible to predict the system's output at an instant in time, given only its input at that instant in time. In a system with hysteresis, this is not possible; there is no way to predict the output without knowing the system's current state, and there is no way to know the system's state without looking at the history of the input. This means that it is necessary to know the path that the input followed before it reached its current value.

Many physical systems naturally exhibit hysteresis. A piece of iron that is brought into a magnetic field retains some magnetization, even after the external magnetic field is removed. Once magnetized, the iron will stay magnetized indefinitely. To demagnetize the iron, it would be necessary to apply a magnetic field in the opposite direction. This is the effect that provides the element of memory in a hard disk drive.

A system may be explicitly designed to exhibit hysteresis, especially in control theory, by introducing a positive feedback] For example, consider a thermostat that controls a furnace. The furnace is either off or on, with nothing in between. The thermostat is a system; the input is the temperature, and the output is the furnace state. If one wishes to maintain a temperature of 20 °C, then one might set the thermostat to turn the furnace on when the temperature drops below 18 °C, and turn it off when the temperature exceeds 22 °C. This thermostat has hysteresis. If the temperature is 21 °C, then it is not possible to predict whether the furnace is on or off without knowing the history of the temperature.

The word hysteresis is often used specifically to represent rate-independent state. This means that if some set of inputs $X(t)$ produce an output $Y(t)$, then the inputs $X(\alpha t)$ produce output $Y(\alpha t)$ for any $\alpha > 0$. The magnetized iron or the thermostat have this property. Not all systems with state (or, equivalently, with memory) have this property; for example, a linear low-pass filter has state, but its state is rate-dependent.

The term is derived from ὑστέρησις, an ancient Greek word meaning "deficiency" or "lagging behind". It was coined by Sir James Alfred Ewing.

INTRODUCTION

Hysteresis phenomena occur in magnetic and ferromagnetic materials, as well as in the elastic, electric, and magnetic behavior of materials, in which a lag occurs between the application and the removal of a force or field and its subsequent effect. Electric hysteresis occurs when applying a varying electric field, and elastic hysteresis occurs in response to a varying force. The term "hysteresis" is sometimes used in other fields, such as economics or biology; where it describes a memory, or lagging effect, in which the order of previous events can influence the order of subsequent events

The word "lag" above should not necessarily be interpreted as a time lag. After all, even relatively simple linear systems such as an electric circuit containing resistors and capacitors exhibit a time lag between the input and the output. For most hysteretic systems, there is a very short time scale when its dynamic behavior and various related time dependences are observed. In magnetism, for example, the dynamic processes occurring on this very short time scale have been referred to as Barkhausen jumps. If observations are carried out over very long periods, creep or slow relaxation typically toward true thermodynamic equilibrium (or other types of equilibria that depend on the nature of the system) can be noticed. When observations are carried out without regard for very swift dynamic phenomena or very slow relaxation phenomena, the system appears to display irreversible behavior whose rate is practically independent of the driving force rate. This rate-independent irreversible behavior is the key feature that distinguishes hysteresis from most other dynamic processes in many systems.

If the displacement of a system with hysteresis is plotted on a graph against the applied force, the resulting curve is in the form of a loop. In contrast, the curve for a system without hysteresis is a single, not necessarily straight, line. Although the hysteresis loop depends on the material's physical properties, there is no complete theoretical description that explains the phenomenon.

The family of hysteresis loops, from the results of different applied varying voltages or forces, form a closed space in three dimensions, called the hysteroid.

Hysteresis was initially seen as problematic, but is now thought to be of great importance in technology. For example, the properties of hysteresis are applied when constructing non-volatile storage for computers; as hysteresis allows most superconductors to operate at the high currents needed to create strong magnetic fields. Hysteresis is also important in living systems. Many critical processes occurring in living (or dying) cells use hysteresis to help stabilize them against the various effects of random chemical fluctuations. Magnetic core losses (iron losses) in transformers are due to hysteresis.

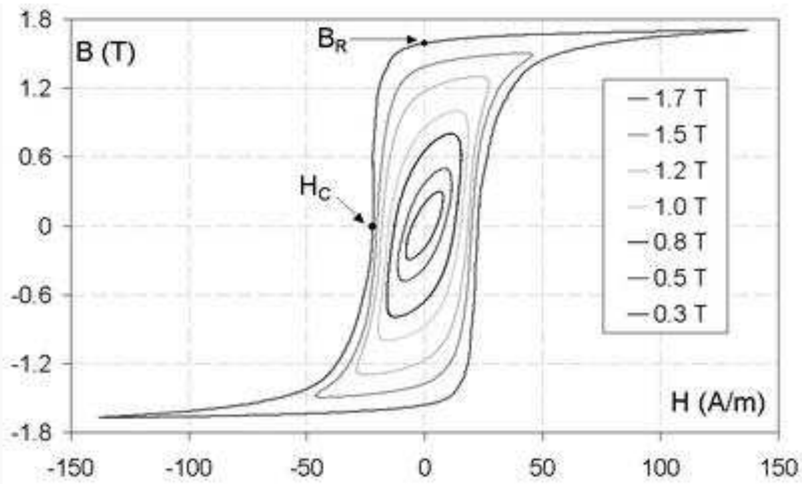
Some early work on describing hysteresis in mechanical systems was performed by James Clerk Maxwell. Subsequently, hysteresis models have received significant attention in the works of Preisach(Preisach model of hysteresis), Neel and Everett in connection with magnetism and absorption. A simple parametric description of various hysteresis loops may be found in ref.[2] (with the model, substitution of rectangle, triangle or trapezoidal pulses instead of the harmonic functions also allows piecewise-linear hysteresis loops frequently used in discrete automatics to be built). More formal mathematical theory of systems with hysteresis was developed in 1970s by a group of Russian mathematicians led by Mark Krasnosel'skii, one of the founders of nonlinear analysis. He suggested an investigation of hysteresis phenomena using the theory of nonlinear operators

INFORMAL DEFINITION

The phenomenon of hysteresis can conceptually be explained as follows: a system can be divided into subsystems or domains, much larger than an atomic volume, but still microscopic. Such domains occur in ferroelectric and ferromagnetic systems, since individual dipoles tend to group with each other, forming a small isotropic region. Each of the system's domains can be shown to have ametastable state. The metastable domains can in turn have two or more substates. Such a *metastable state* fluctuates widely from domain to domain, but the average represents the configuration of lowest energy. The *hysteresis* is simply the sum of all domains, or the sum of all metastable states.

MAGNETIC HYSTERESIS

Hysteresis is well known in ferromagnetic materials. When an external magnetic field is applied to a ferromagnet, the atomic dipoles align themselves with the external field. Even when the external field is removed, part of the alignment will be retained: the material has become *magnetized*.



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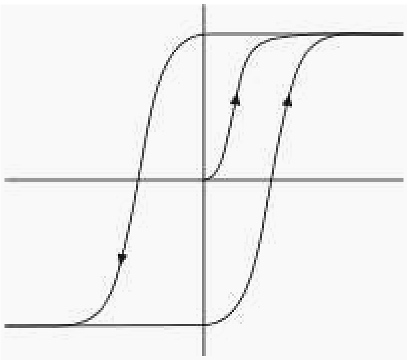
The relationship between magnetic field strength (H) and magnetic flux density (B) is not linear in such materials. If the relationship between the two is plotted for increasing levels of field strength, it will follow a curve up to a point where further increases in magnetic field strength will result in no further change in flux density. This condition is called magnetic saturation.
If the magnetic field is now reduced linearly, the plotted relationship will follow a different curve back towards zero field strength at which point it will be offset from the original curve by an amount called the *remanent flux density* or remanence.

If this relationship is plotted for all strengths of applied magnetic field the result is a sort of *S-shaped* loop. The 'thickness' of the middle bit of the S describes the amount of hysteresis, related to the coercivity of the material.

Its practical effects might be, for example, to cause a relay to be slow to release due to the remaining magnetic field continuing to attract the armature when the applied electric current to the operating coil is removed.



This curve for a particular material influences the design of a magnetic circuit,

This is also a very important effect in magnetic tape and other magnetic storage media like hard disks. In these materials it would seem obvious to have one polarity represent a bit, say north for 1 and south for 0. However, to change the storage from one to the other, the hysteresis effect requires the knowledge of what was already there, because the needed field will be different in each case. In order to avoid this problem, recording systems first overdrive the entire system into a known state using a process known asbias. Analog magnetic recording also uses this technique. Different materials require different biasing, which is why there is a selector switch for this on the front of most cassette recorders.

In order to minimize this effect and the energy losses associated with it, ferromagnetic substances with low coercivity and low hysteresis loss are used, likepermalloy.

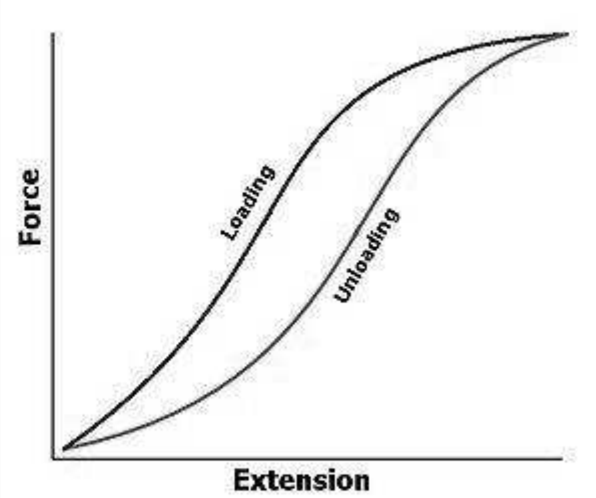
In many applications small hysteresis loops are driven around points in the B-H plane. Loops near the origin have a higher μ. The smaller loops the more they have a soft magnetic (lengthy) shape. As a special case, a damped AC field demagnetizes any material.

Magnetic field hysteresis loss causes heating. This effect is used in induction cooking, where an alternating magnetic field causes a ferrite container to heat directly rather than being heated by an external heat-source.

ELECTRICAL HYSTERESIS

Electrical hysteresis typically occurs in ferroelectric material, where domains of polarization contribute to the total polarization. Polarization is the electrical dipole moment (either $C{\cdot}m^{-2}$ or $C{\cdot}m$).

ELASTIC HYSTERESIS



A simple way to understand it is in terms of a rubber band with weights attached to it. If the top of a rubber band is hung on a hook and small weights are attached to the bottom of the band one at a time, it will get longer. As more weights are *loaded* onto it, the band will continue to extend because the force the weights are exerting on the band is increasing. When each weight is taken off, or *unloaded*, it will get shorter as the force is reduced. As the weights are taken off, each weight that produced a specific length as it was loaded onto the band now produces a slightly longer length as it is unloaded. This is because the band does not obey Hooke's law perfectly.

In one sense the rubber band was harder to stretch when it was being loaded than when it was being unloaded. In another sense, as one unloads the band, the cause (the force of the weights) lags behind the effect (the length) because a smaller value of weight produces the same length. In another sense more energy was required during the loading than the unloading; that energy must have gone somewhere, it was dissipated or "lost" as heat

.

Elastic hysteresis is more pronounced when the loading and unloading is done quickly than when it is done slowly.[5] Some materials such as hard metals don't show elastic hysteresis under a moderate load, whereas other hard materials like granite and marble do. Materials such as rubber exhibit a high degree of elastic hysteresis.

A word of caution: rubber behaves like a gas. When the rubber band is stretched it heats up. If it is suddenly released, the rubber cools down, very easy to perceive just by touching. So, there is a large hysteresis from the thermal exchange with the environment and a smaller hysteresis due to internal friction within the rubber. This proper, intrinsic hysteresis could be measured only if adiabatic isolation of the rubber band is imposed.

THE BOUC-WEN MODEL OF HYSTERESIS

The Bouc-Wen model is a model that is often used to describe non-linear hysteretic systems. It was introduced by Bouc [6][7] and extended by Wen [8], who demonstrated its versatibility by producing a variety of hysteretic patterns.

This model is able to capture in analytical form, a range of shapes of hysteretic cycles which match the behaviour of a wide class of hysteretical systems; therefore, given its versability and mathematical tractability, the Bouc-Wen model has quickly gained popularity and has been extended and applied to a wide variety of engineering problems, including multi-degree-of-freedom (MDOF) systems, buildings, frames, bidirectional and torsional response of hysteretic systems two- and three-dimensional continua, soil liquefaction, and base isolation systems among others.

The Bouc-Wen model and its variants/extensions have been used in applications of structural control, in particular in the modeling of the behaviour of magneto-rheological dampers, base isolation devices for buildings and other kinds of damping devices; it has also been in the modelling and analysis of structures built of reinforced concrete, steel, mansory and timber.

LIQUID-SOLID PHASE TRANSITIONS

Hysteresis manifests itself in state transitions when melting temperature and freezing temperature do not agree. For example, agar melts at 85 °C and solidifies from 32 to 40 °C. This is to say that once agar is melted at 85 °C, it retains a liquid state until cooled to 40 °C. Therefore, from the temperatures of 40 to 85 °C, agar can be either solid or liquid, depending on which state it was before.

CONTACT ANGLE HYSTERESIS

The contact angle formed between a liquid and solid phase will exhibit a range of contact angles that are possible. There are two common methods for measuring this range of contact angles. The first method is referred to as the tilting base method. Once a drop is dispensed on the surface with the surface level, the surface is then tilted from 0° to 90°. As the drop is tilted, the downhill side will be in a state of imminent wetting while the uphill side will be in a state of imminent dewetting. As the tilt increases the downhill contact angle will increase and represents the advancing contact angle while the uphill side will decrease; this is the receding contact angle. The values for these angles just prior to the drop releasing will typically represent the advancing and receding contact angles. The difference between these two angles is the contact angle hysteresis. The second method, often referred to as the add/remove volume method. When the maximum liquid volume is removed from the drop without the interfacial area decreasing the receding contact angle is thus measured. When volume is added to the maximum before the interfacial area increases, this is the advancing contact angle. As with the tilt method, the difference between the advancing and receding contact angles is the contact angle hysteresis. Most researchers prefer the tilt method; the add/remove method requires that a tip or needle stay embedded in the drop which can affect the accuracy of the values, especially the receding contact angle.

ADSORPTION HYSTERESIS

Hysteresis can also occur during physical adsorption processes. In this type of hysteresis, the quantity adsorbed is different when gas is being added than it is when being removed. The specific causes of adsorption hysteresis are still an active area of research, but it is linked to differences in the nucleation and evaporation mechanisms inside mesopores. These mechanisms are further complicated by effects such as cavitation and pore blocking.

In physical adsorption, hysteresis is evidence of mesoporosity-indeed, the definition of mesopores (2-50 nm) is associated with the appearance (50 nm) and disappearance (2 nm) of mesoporosity in nitrogen adsorption isotherms as a function of Kelvin radius.[9] An adsorption isotherm showing hysteresis is said to be of Type IV (for a wetting adsorbate) or Type V (for a non-wetting adsorbate), and hysteresis loops themselves are classified according to how symmetric the loop is. Adsorption hysteresis loops also have the unusual property that it is possible to scan within a hysteresis loop by reversing the direction of adsorption while on a point on the loop. The resulting scans are called "crossing," "converging," or "returning," depending on the shape of the isotherm at this point.

MATRIC POTENTIAL HYSTERESIS

The relationship between matric water potential and water content is the basis of the water retention curve. Matric potential measurements (Ψ_m) are converted to volumetric water content (θ) measurements based on a site or soil specific calibration curve. Hysteresis is a source of water content measurement error. Matric potential hysteresis arises from differences in wetting behaviour causing dry medium to re-wet; that is, it depends on the saturation history of the porous medium. Hysteretic behaviour means that, for example, at a matric potential (Ψ_m) of 5 kPa, the volumetric water content (θ) of a fine sandy soil matrix could be anything between 8% to 25%.

Tensiometers are directly influenced by this type of hysteresis. Two other types of sensors used to measure soil water matric potential are also influenced by hysteresis effects within the sensor itself. Resistance blocks, both nylon and gypsum based, measure matric potential as a function of electrical resistance. The relation between the sensor's electrical resistance and sensor matric potential is hysteretic. Thermocouples measure matric potential as a function of heat dissipation. Hysteresis occurs because measured heat dissipation depends on sensor water content, and the sensor water content–matric potential relationship is hysteretic. As of 2002, only desorption curves are usually measured during calibration of soil moisture sensors. Despite the fact that it can be a source of significant error, the sensor specific effect of hysteresis is generally ignored.

ENERGY

When hysteresis occurs with extensive and intensive variables, the work done on the system is the area under the hysteresis graph.

ECONOMICS

Economic systems can exhibit hysteresis. For example, export performance is subject to strong hysteresis effects: because of the fixed transportation costs it may take a big push to start a country's exports, but once the transition is made, not much may be required to keep them going.

Hysteresis is a hypothesized property of unemployment rates. It's possible that there is a ratchet effect, so a short-term rise in unemployment rates tends to persist. An example is the notion that inflationary policy leads to a permanently higher 'natural' rate of unemployment (NAIRU), because inflationary expectations are 'sticky' downward due to wage rigidities and imperfections in the labour market. Another channel through which hysteresis can occur is through learning by doing. Workers who lose their jobs due to a temporary shock may become permanently unemployed because they miss out on the job training and skill acquisition that normally takes place. This explanation has been invoked, by Olivier Blanchard among others, as explaining the differences in long run unemployment rates between Europe and the United States.

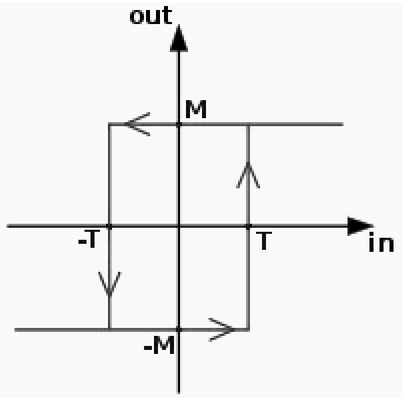
Hysteresis occurs in applications of game theory to economics, in models with product quality, agent honesty or corruption of various institutions. Slightly different initial conditions can lead to opposite outcomes and resulting stable "good" and "bad" equilibria.

Another area where hysteresis phenomena are found is capital controls. A developing country can ban a certain kind of capital flow (e.g. engagement with international private equity funds), but when the ban is removed, the system takes a long time to return to the pre-ban state.

USER INTERFACE DESIGN

The field of user interface design has borrowed the term hysteresis to refer to times when the state of the user interface intentionally lags behind the apparent user input. For example, a menu that was drawn in response to a mouse-over event may remain on-screen for a brief moment after the mouse has moved out of the trigger region and the menu region. This allows the user to move the mouse directly to an item on the menu, even if part of that direct mouse path is outside of both the trigger region and the menu region. For instance, right-clicking on the desktop in most Windows interfaces will create a menu that exhibits this behavior.

ELECTRONICS



Hysteresis can be used to filter signals so that the output reacts slowly by taking recent history into account. For example, a thermostat controlling a heater may turn the heater on when the temperature drops below A degrees, but not turn it off until the temperature rises above B degrees. Thus the on/off output of the thermostat to the heater when the temperature is between A and B depends on the history of the temperature. This prevents rapid switching on and off as the temperature drifts around the set point.

A Schmitt trigger is a simple electronic circuit that also exhibits this property. Often, some amount of hysteresis is intentionally added to an electronic circuit (or digital algorithm) to prevent unwanted rapid switching. This and similar techniques are used to compensate for contact bounce in switches, or noise in an electrical signal.

A latching relay uses a solenoid to actuate a ratcheting motion that keeps the relay closed even if power to the relay is terminated.

Hysteresis is essential to the workings of the memristor, a circuit component which "remembers" changes in the current passing through it by changing its resistance

CELL BIOLOGY AND GENETICS

Cells undergoing cell division exhibit hysteresis in that it takes a higher concentration of cyclins to switch them from G2 phase into mitosis than to stay in mitosis once begun.[15]

Darlington in his classic works on genetics[16][17] discussed hysteresis of the chromosomes, by which he meant "failure of the external form of the chromosomes to respond immediately to the internal stresses due to changes in their molecular spiral", as they lie in a somewhat rigid medium in the limited space of the cell nucleus.

In developmental biology, cell type diversity is regulated by long range-acting signaling molecules called morphogens that pattern uniform pools of cells in a concentration- and time-dependent manner. The morphogen Sonic Hedgehog (Shh), for example, acts on limb bud and neural progenitors to induce expression of a set of homeodomain-containing transcription factors to subdivide these tissues into distinct domains. It has been shown that these tissues have a 'memory' of previous exposure to Shh[18]. In neural tissue, this hysteresis is regulated by a homeodomain (HD) feedback circuit that amplifies Shh signaling In this circuit, expression of Gli transcription factors, the executors of the Shh pathway, is suppressed. Glis are processed to repressor forms (GliR) in the absence of Shh, but in the presence of Shh, a proportion of Glis are maintained as full-length proteins allowed to translocate to the nucleus, where they act as activators (GliA) of transcription. By reducing Gli expression then, the HD transcription factors reduce the total amount of Gli (GliT), so a higher proportion of GliT can be stabilized as GliA for the same concentration of Shh.

NEUROSCIENCE

The property by which some neurons do not return to their basal conditions from a stimulated condition immediately after removal of the stimulus is an example of hysteresis. *See also*: Refractory period.

RESPIRATORY PHYSIOLOGY

The transpulmonary pressure vs Volume curve of inhalation is different from the Pressure vs Volume curve of exhalation, the difference being described as hysteresis. Lung volume at any given pressure during inhalation is less than the lung volume at any given pressure during exhalation.[20]

APPLICATIONS

Hysteresis represents states, and the characteristic curve shape is sometimes remiscent of a two-value state, also called a bistable state. The hysteresis curve really contains *infinitely* many states, but a simple application is to let the threshold regions (usually to the left and to the right) represent respectively the on and off states. In this way, the system can be regarded as bistable. Note that even if no external field is applied, the position of the hysteresis curve might change with time: it is not necessarily *stationary*; i.e. the system may not stay in exactly the same state as it had previously. The system might need new energy transfer to be stationary.

The hysteresis effect can be used when connecting complex circuits with the so-called passive matrix addressing. This scheme is praised as a technique that can be used in modern nanoelectronics,electrochrome cells, memory effect, etc. In this scheme, shortcuts are made between adjacent components (see crosstalk) and the hysteresis helps to keep the components in a particular state while the other components change states. That is, one can address all rows at the same time instead of doing each individually.

In economics, hysteresis is used extensively in the area of labor markets. According to theories based on hysteresis, economic downturns (recession) result in an individual becoming unemployed, losing his/her skills (commonly developed 'on the job'), demotivated/disillusioned, and employers may use time spent in unemployment as a screen. In times of an economic upturn or 'boom', the workers affected will not share in the prosperity, remaining Long-Term Unemployed (>52 weeks). Hysteresis has been put forward as a possible explanation for the poor unemployment performance of many economies in the 1990s. Labor market reform, and/or strong economic growth, may not therefore aid this pool of long-term unemployed, and thus specific targeted training programs are presented as a possible policy solution.[In the field of audio electronics, a noise gate often implements hysteresis intentionally to prevent the gate from "chattering" when signals close to its threshold are applied.

Small vehicle suspensions using rubber (or other elastomers) can achieve the dual function of springing and damping because rubber, unlike metal springs, has pronounced hysteresis and does not return all the absorbed compression energy on the rebound. Mountain bikes have frequently made use of elastomer suspension, as did the original Mini car.

MODELS OF HYSTERESIS

Each subject that involves hysteresis has models that are specific to the subject. In addition, there are models that capture general features of many systems with hysteresis. An example is thePreisach model of hysteresis, which represents a hysteresis nonlinearity as a superposition of square loops called hysterons.

INSTRUMENT TRANSFORMERS

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A **transformer** is a device that transfers electrical energy from one circuit to another through inductively coupled conductors—the transformer's coils. A varying current in the first or *primary* winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic field through the *secondary*winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding. This effect is called mutual induction.

If a load is connected to the secondary, an electric current will flow in the secondary winding and electrical energy will be transferred from the primary circuit through the transformer to the load. In an ideal transformer, the induced voltage in the secondary winding (V_s) is in proportion to the primary voltage (V_p), and is given by the ratio of the number of turns in the secondary (N_s) to the number of turns in the primary (N_p) as follows:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

By appropriate selection of the ratio of turns, a transformer thus allows an alternating current (AC) voltage to be "stepped up" by making N_s greater than N_p, or "stepped down" by making N_s less than N_p.

In the vast majority of transformers, the windings are coils wound around a ferromagnetic core, air-core transformers being a notable exception.

Transformers range in size from a thumbnail-sized coupling transformer hidden inside a stage microphone to huge units weighing hundreds of tons used to interconnect portions of power grids. All operate with the same basic principles, although the range of designs is wide. While new technologies have eliminated the need for transformers in some electronic circuits, transformers are still found in nearly all electronic devices designed for household ("mains") voltage. Transformers are essential for high voltage power transmission, which makes long distance transmission economically practical.

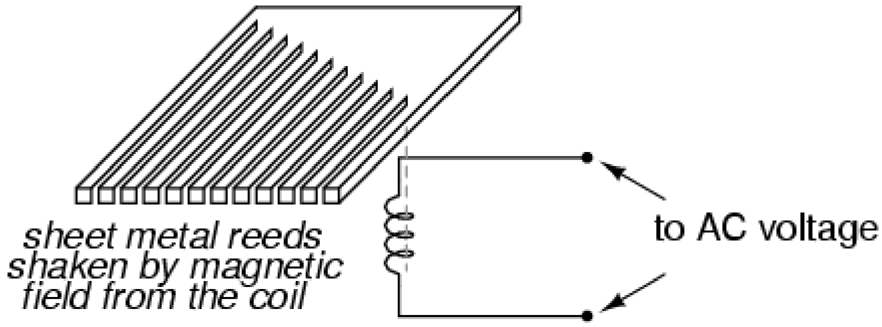
FREQUENCY AND PHASE MEASUREMENT

An important electrical quantity with no equivalent in DC circuits is *frequency*. Frequency measurement is very important in many applications of alternating current, especially in AC power systems designed to run efficiently at one frequency and one frequency only. If the AC is being generated by an electromechanical alternator, the frequency will be directly proportional to the shaft speed of the machine, and frequency could be measured simply by measuring the speed of the shaft. If frequency needs to be measured at some distance from the alternator, though, other means of measurement will be necessary.

One simple but crude method of frequency measurement in power systems utilizes the principle of mechanical resonance. Every physical object possessing the property of elasticity (springiness) has an inherent frequency at which it will prefer to vibrate. The tuning fork is a great example of this: strike it once and it will continue to vibrate at a tone specific to its length. Longer tuning forks have lower resonant frequencies: their tones will be lower on the musical scale than shorter forks.

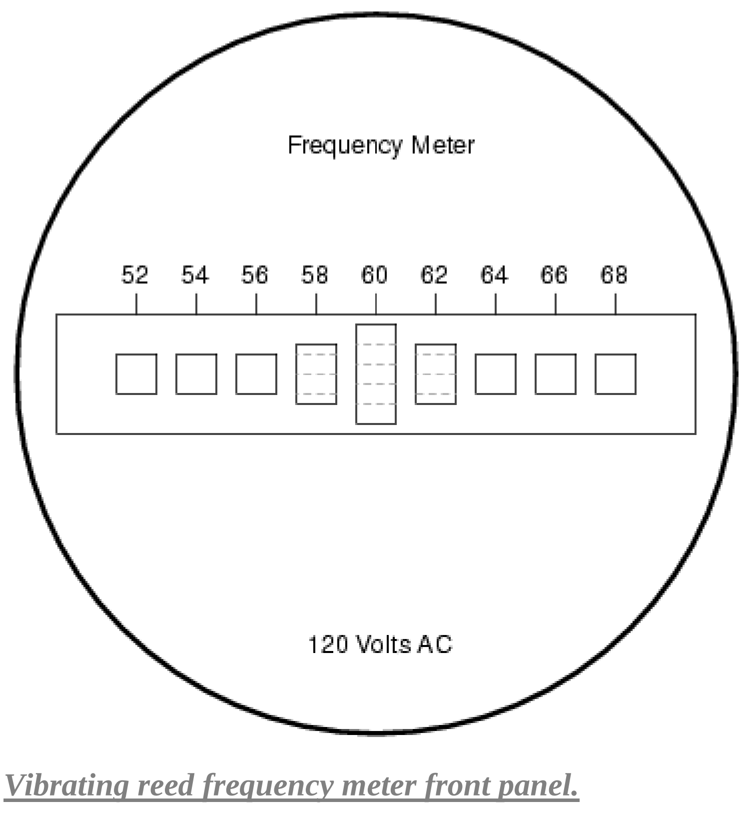
Imagine a row of progressively-sized tuning forks arranged side-by-side. They are all mounted on a common base, and that base is vibrated at the frequency of the measured AC voltage (or current) by means of an electromagnet. Whichever tuning fork is closest in resonant frequency to the frequency of that vibration will tend to shake the most (or the loudest). If the forks' tines were flimsy enough, we could see the relative motion of each by

the length of the blur we would see as we inspected each one from an end-view perspective. Well, make a collection of "tuning forks" out of a strip of sheet metal cut in a pattern akin to a rake, and you have the *vibrating reed* frequency meter: (Figure below)



Vibrating reed frequency meter diagram.

The user of this meter views the ends of all those unequal length reeds as they are collectively shaken at the frequency of the applied AC voltage to the coil. The one closest in resonant frequency to the applied AC will vibrate the most, looking something like Figure below.

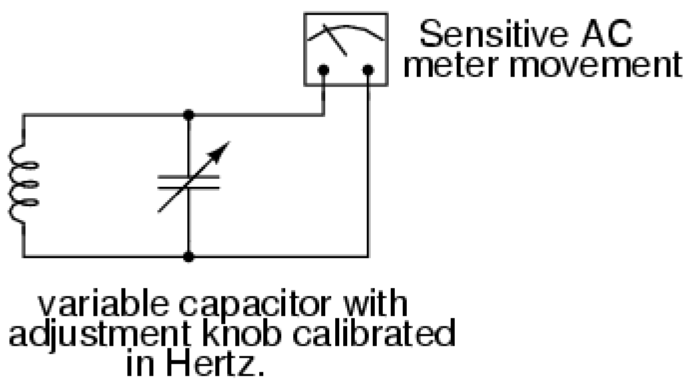


Vibrating reed frequency meter front panel.

Vibrating reed meters, obviously, are not precision instruments, but they are very simple and therefore easy to manufacture to be rugged. They are often found on small engine-

driven generator sets for the purpose of setting engine speed so that the frequency is somewhat close to 60 (50 in Europe) Hertz.

While reed-type meters are imprecise, their operational principle is not. In lieu of mechanical resonance, we may substitute electrical resonance and design a frequency meter using an inductor and capacitor in the form of a tank circuit (parallel inductor and capacitor). See Figure below. One or both components are made adjustable, and a meter is placed in the circuit to indicate maximum amplitude of voltage across the two components. The adjustment knob(s) are calibrated to show resonant frequency for any given setting, and the frequency is read from them after the device has been adjusted for maximum indication on the meter. Essentially, this is a tunable filter circuit which is adjusted and then read in a manner similar to a bridge circuit (which must be balanced for a "null" condition and then read).



Resonant frequency meter "peaks" as L-C resonant frequency is tuned to test frequency.

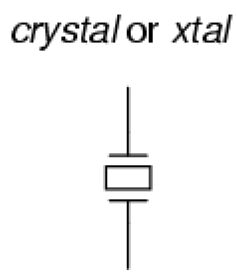
This technique is a popular one for amateur radio operators (or at least it was before the advent of inexpensive digital frequency instruments called*counters*), especially because it doesn't require direct connection to the circuit. So long as the inductor and/or capacitor can intercept enough stray field (magnetic or electric, respectively) from the circuit under test to cause the meter to indicate, it will work.

In frequency as in other types of electrical measurement, the most accurate means of measurement are usually those where an unknown quantity is compared against a known *standard*, the basic instrument doing nothing more than indicating when the two quantities are equal to each other. This is the basic principle behind the DC (Wheatstone) bridge circuit and it is a sound metrological principle applied throughout the sciences. If we have access to an accurate frequency standard (a source of AC voltage holding very precisely to a single frequency), then measurement of any unknown frequency by comparison should be relatively easy.

For that frequency standard, we turn our attention back to the tuning fork, or at least a more modern variation of it called the *quartz crystal*. Quartz is a naturally occurring mineral possessing a very interesting property called *piezoelectricity*. Piezoelectric materials produce a voltage across their length when physically stressed, and will physically deform when an external voltage is applied across their lengths. This deformation is very, very slight in most cases, but it does exist.

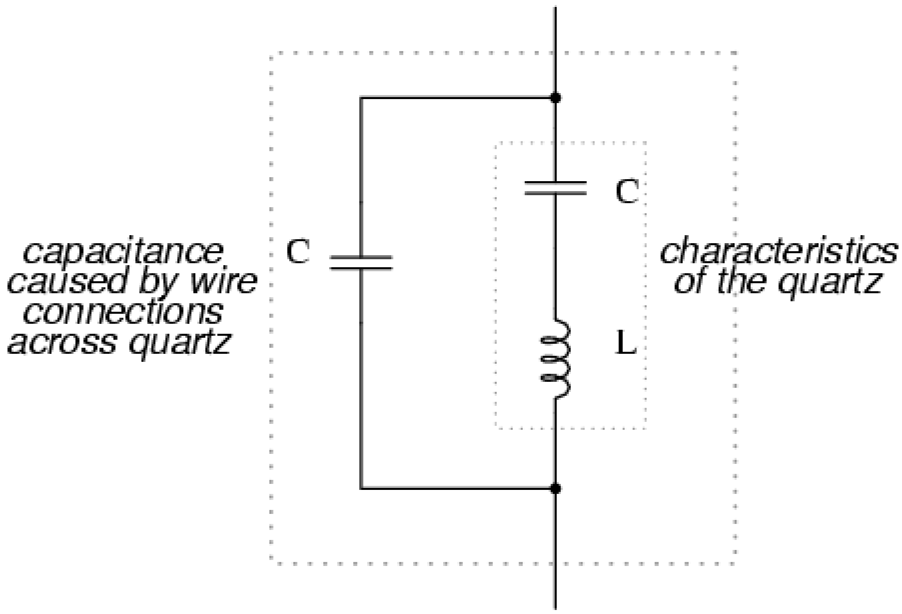
Quartz rock is elastic (springy) within that small range of bending which an external voltage would produce, which means that it will have a mechanical resonant frequency of its own capable of being manifested as an electrical voltage signal. In other words, if a chip of quartz is struck, it will "ring" with its own unique frequency determined by the length of the chip, and that resonant oscillation will produce an equivalent voltage across multiple points of the quartz chip which can be tapped into by wires fixed to the surface of the chip. In reciprocal manner, the quartz chip will tend to vibrate most when it is "excited" by an applied AC voltage at precisely the right frequency, just like the reeds on a vibrating-reed frequency meter.

Chips of quartz rock can be precisely cut for desired resonant frequencies, and that chip mounted securely inside a protective shell with wires extending for connection to an external electric circuit. When packaged as such, the resulting device is simply called a *crystal* (or sometimes "*xtal*"). The schematic symbol is shown in Figure below.



Crystal (frequency determing element) schematic symbol.

Electrically, that quartz chip is equivalent to a series LC resonant circuit. (Figure below) The dielectric properties of quartz contribute an additional capacitive element to the equivalent circuit.



Quartz crystal equivalent circuit.

The “capacitance” and “inductance” shown in series are merely electrical equivalents of the quartz's mechanical resonance properties: they do not exist as discrete components within the crystal. The capacitance shown in parallel due to the wire connections across the dielectric (insulating) quartz body is real, and it has an effect on the resonant response of the whole system. A full discussion on crystal dynamics is not necessary here, but what needs to be understood about crystals is this resonant circuit equivalence and how it can be exploited within an oscillator circuit to achieve an output voltage with a stable, known frequency.

Crystals, as resonant elements, typically have much higher “Q” (*quality*) values than tank circuits built from inductors and capacitors, principally due to the relative absence of stray resistance, making their resonant frequencies very definite and precise. Because the resonant frequency is solely dependent on the physical properties of quartz (a very stable substance, mechanically), the resonant frequency variation over time with a quartz crystal is very, very low. This is how *quartz movement* watches obtain their high accuracy: by means of an electronic oscillator stabilized by the resonant action of a quartz crystal.

For laboratory applications, though, even greater frequency stability may be desired. To achieve this, the crystal in question may be placed in a temperature stabilized environment

ELECTRICAL AND ELECTRONICS INSTRUMENTS

PART – A

1. State the principle of digital voltmeter. (2)
2. Give the importance of iron loss measurement. (2)
3. List two instruments for measurement of frequency. (2)
4. Write the function of instrument transformer. (2)
5. Brief the principle of digital phase meter. (2)
6. Write any two advantages and disadvantages of digital voltmeter. (2)
7. Explain the purpose of Schmitt trigger in digital frequency meter. (2)
8. Which torque is absent in energy meter? Why? (2)
9. What are the errors that take place in moving iron instrument?(2)
10. Explain the principle of analog type electrical instruments. (2)
11. How a PMMC meter can be used as voltmeter and ammeter? (2)
12. What is loading effect? (2)
13. State the basic principle of moving iron instrument. (2)
14. Why an ammeter should have a low resistance? (2)
15. Define the sensitivity of a moving coil meter. (2)
16. What are the precautions taken while using a DC voltmeter and DC Ammeter? (2)

17. What is the use of Multimeter? Write its advantages and disadvantages. (2)
18. Voltmeter has high resistance, why it is connected in series?
19. What is an energy meter? Mention some advantages and disadvantages of energy meter. (2)
20. What is meant by creep adjustment in three phase energy meter? (2)
21. List some advantages and disadvantages of electrodynamics Instrument. (2)
22. List the advantages of electronic voltmeter. (2)
23. What is a magnetic measurement and what are the tests performed for magnetic measurements? (2)
24. Mention the advantages and disadvantages of flux meter. (2)
25. What are the methods used to determine B-H Curve? (2)
26. What are the errors in instrument transformers? (2)
27. What is frequency meter and classify it? (2)
28. What is phase meter and what are its type? (2)
29. Differentiate ammeter an voltmeter. (2)
30. Define leakage factor. (2)

PART – B

1. (i) Describe the construction and working of a permanent

Magnetic moving coil instruments. (10)

(ii) Explain the design of three phase watt meters and give the reactivepower measurement in 3 phase circuits. (6)

2. (i) How B-H curve is determined for a ring specimen. (8)

(ii) Explain the frequency measurement in Wien's bridge (8)

Discuss why it is necessary to carry out frequency domain analysis of measurement systems? What are the two plots obtained when the Frequency response of a system is carried out? (16)

4. Explain the function of three phase wattmeter and energy meter. (16)

5. (i) Sketch the circuit and waveforms for ac voltmeter using a PMMC instrument and half wave rectifier. Explain the circuit Operation.

(ii) Develop the torque equation for a PMMC instrument and show its scale is linear. (6)

6. (i) Discuss in detail the working of the successive approximationDVM.(8)

(ii) With a neat diagram, explain the various methods of Magnetic measurements. (8)

7. (i) Explain with a neat sketch the construction and working Principle of single-phase induction type energy meter. (10)

(ii) How the range of d.c ammeter and d.c voltmeter can be extended?

Derive the expressions to calculate shunt resistance and multiplier resistance. (6)

8. (i) With a neat diagram explain the construction and working of Electrodynamometer type instruments. Also derive its torque equation.(10)

(ii) Explain with neat diagram the working of Linear ramp type DVM.

9. (i) Explain the different methods of determination of B –H curve

(ii) With a neat block diagram explain the working principle of Digital frequency meter. (8)

10. (i) Explain the working principle of moving iron instrument. (8)

(ii) Give detailed notes on Instrument transformers. (8)

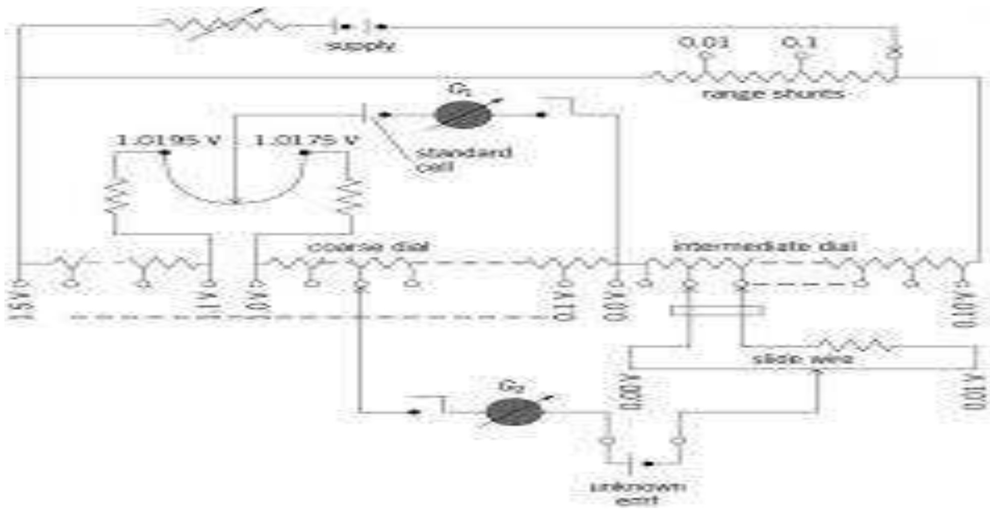
UNIT III COMPARISON METHODS OF MEASUREMENTS

D.C and A.C potentiometers – D.C and A.C bridges – Transformer ratio bridges – Self-balancingbridges – Interference and screening – Multiple earth and earth loops – Electrostatic and electromagnetic interference – Grounding techniques.

POTENTIOMETER

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current I may be held at a fixed value and the resistance R across which the IR drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed IR drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an IR drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the IR drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.



Circuit diagram of a general-purpose constant-current potentiometer, showing essential features

Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the *IR* drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy; and the shunt design may require attention to dissipation of heat resulting from its I^2R power consumption.

Potentiometer techniques have been extended to alternating-voltage measurements, but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing.

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(1) An electrical measuring device used in determining the electromotive force (emf) or voltage by means of the compensation method. When used with calibrated standard resistors, a potentiometer can be employed to measure current, power, and other electrical quantites; when

used with the appropriate measuring transducer, it can be used to gauge various nonelectrical quantities, such as temperature, pressure, and the composition of gases.

A distinction is made between DC and AC potentiometers. In DC potentiometers, the voltage being measured is compared to the emf of a standard cell. Since at the instant of compensation the current in the circuit of the voltage being measured equals zero, measurements can be made without reductions in this voltage. For this type of potentiometer, accuracy can exceed 0.01 percent. DC potentiometers are categorized as either high-resistance, with a slide-wire resistance ranging from 10^4 to 10^5 ohms (Ω) and a current ranging from 10^{-1} to 10^{-9} amperes (A), or low-resistance, with a slide-wire resistance below 2×10^3 ohms and a current ranging from 10^{-1} to 10^{-3} A. The higher resistance class can measure up to 2 volts (V) and is used in testing highly accurate apparatus. The low-resistance class is used in measuring voltage up to 100 mV. To measure higher voltages, up to 600 V, and to test voltmeters, voltage dividers are connected to potentiometers. Here the voltage drop across one of the resistances of the voltage divider is compensated; this constitutes a known fraction of the total voltage being measured.

In AC potentiometers, the unknown voltage is compared with the voltage drop produced by a current of the same frequency across a known resistance. The voltage being measured is then adjusted both for amplitude and phase. The accuracy of AC potentiometers is of the order of 0.2 percent.

In electronic automatic DC and AC potentiometers, the measurements of voltage are carried out automatically. In this case, the compensation of the unknown voltage is achieved with the aid of a servomechanism that moves the slide along the resistor, or rheostat. The servomechanism is actuated by the imbalance of the two voltages, that is, by the difference between the compensating voltage and the voltage that is being compensated. In electronic automatic potentiometers, the results of measurements are read on dial indicators, traced on recorder charts or received as numerical data. The last method makes it possible to input the data directly into a computer. In addition to measurement, electronic automatic potentiometers are also capable of regulating various parameters of industrial processes. In this case, the slide of the rheostat is set in a position that predetermines, for instance, the temperature of the object to be regulated. The voltage imbalance of the potentiometer drives the servomechanism, which then increases or decreases the electric heating or regulates the fuel supply.

A voltage divider with a uniform variation of resistance, a device that allows some fraction of a given voltage to be applied to an electric circuit. In the simplest case, the device consists of a conductor of high resistance equipped with a sliding contact. Such dividers are used in electrical engineering, radio engineering, and measurement technology. They can also be utilized in analog computers and in automation systems, where, for example, they function as sensors for linear or angular displacement

DC AND AC BRIDGES

Wheatstone bridge

A **Wheatstone bridge** is an electrical circuit invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. [1] It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. Its operation is similar to the *original* potentiometer.

OPERATION

In the figure, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg(R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints (**B** and **D**) will be zero and no current will flow through the galvanometer V_g. If the bridge is unbalanced, the direction of the current indicates whether R_2 is too high or too low. R_2 is varied until there is no current through the galvanometer, which then reads zero.

Detecting zero current with a galvanometer can be done to extremely high accuracy. Therefore, if R_1, R_2 and R_3 are known to high precision, then R_x can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

At the point of balance, the ratio of $R_2 / R_1 = R_x / R_3$

Therefore, $R_x = (R_2/R_1) \cdot R_3$

Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage difference across or current flow through the meter can be used to calculate the value of R_x, using Kirchhoff's circuit laws(also known as Kirchhoff's rules). This setup is frequently used in strain gauge and resistance thermometer measurements, as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.

DERIVATION

First, Kirchhoff's first rule is used to find the currents in junctions **B** and **D**:

$$I_3 - I_x + I_g = 0$$
$$I_1 - I_2 - I_g = 0$$

Then, Kirchhoff's second rule is used for finding the voltage in the loops **ABD** and **BCD**:

$$(I_3 \cdot R_3) - (I_g \cdot R_g) - (I_1 \cdot R_1) = 0$$
$$(I_x \cdot R_x) - (I_2 \cdot R_2) + (I_g \cdot R_g) = 0$$

The bridge is balanced and $I_g = 0$, so the second set of equations can be rewritten as:

$$I_3 \cdot R_3 = I_1 \cdot R_1$$
$$I_x \cdot R_x = I_2 \cdot R_2$$

Then, the equations are divided and rearranged, giving:

$$R_x = \frac{R_2 \cdot I_2 \cdot I_3 \cdot R_3}{R_1 \cdot I_1 \cdot I_x}$$

From the first rule, $I_3 = I_x$ and $I_1 = I_2$. The desired value of R_x is now known to be given as:

$$R_x = \frac{R_3 \cdot R_2}{R_1}$$

If all four resistor values and the supply voltage (V_S) are known, and the resistance of the galvanometer is high enough that I_g is negligible, the voltage across the bridge (V_G) can be found by working out the voltage from each potential divider and subtracting one from the other. The equation for this is:

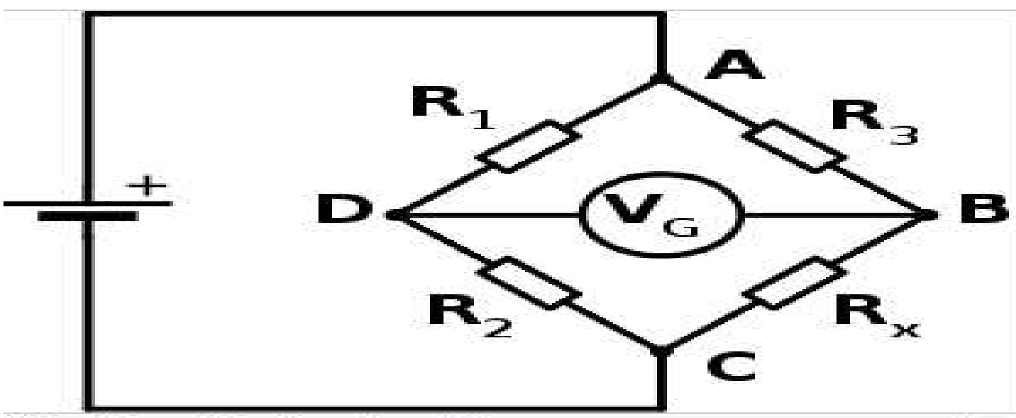
$$V_G = \frac{R_x}{R_3 + R_x}V_s - \frac{R_2}{R_1 + R_2}V_s$$

This can be simplified to:

$$V_G = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right)V_s$$

with an explosimeter. The Kelvin bridge was specially adapted from the Wheatstone bridge for measuring very low resistances. In many cases, the significance of measuring the unknown resistance is related to measuring the impact of some physical phenomenon - such as force, temperature, pressure, etc. - which thereby allows the use of Wheatstone bridge in measuring those elements indirectly.

in 1865 and further improved by Alan Blumlein in about 1926.



Wheatstone's bridge circuit diagram.

KELVIN BRIDGE

A **Kelvin bridge** (also called a **Kelvin double bridge** and some countries **Thomson bridge**) is a measuring instrument invented by William Thomson, 1st Baron Kelvin. It is used to measure an unknown electrical resistance below 1 Ω. Its operation is similar to the Wheatstone bridge except for the presence of additional resistors. These additional low value resistors and the internal configuration of the bridge are arranged to substantially reduce measurement errors introduced by voltage drops in the high current (low resistance) arm of the bridge

ACCURACY

There are some commercial devices reaching accuracies of 2% for resistance ranges from 0.000001 to 25 Ω. Often, ohmmeters include Kelvin bridges, amongst other measuring instruments, in order to obtain large measure ranges, for example, the Valhalla 4100 ATC Low-Range Ohmmeter.

The instruments for measuring sub-ohm values are often referred to as low-resistance ohmmeters, milli-ohmmeters, micro-ohmmeters, etc

PRINCIPLE OF OPERATION

The measurement is made by adjusting some resistors in the bridge, and the balance is achieved

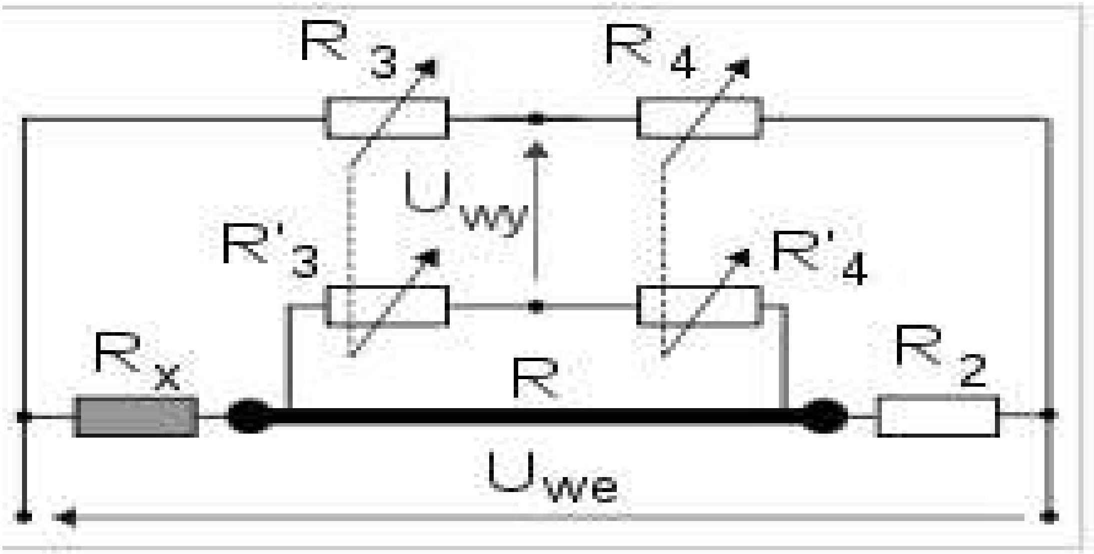
when:

$$R_x = R_2 \cdot \frac{R_3}{R_4} + R \cdot \frac{R_3 \cdot R'_4 - R'_3 \cdot R_4}{R_4 \cdot (R + R'_3 + R'_4)}$$

Resistance *R* should be as low as possible (much lower than the measured value) and for that reason is usually made as a short thick rod of solid copper. If the condition $R_3 \cdot R`_4 = R`_3 \cdot R_4$ is met (and value of *R* is low), then the last component in the equation can be neglected and it can be assumed that:

$$R_x \approx R_2 \cdot \frac{R_3}{R_4}$$

Which is equivalent to the Wheatstone bridge



AC BRIDGES

A **Schering Bridge** is a bridge circuit used for measuring an unknown electrical capacitance and its dissipation factor. The dissipation factor of a capacitor is the the ratio of its resistance to its capacitive reactance. The Schering Bridge is basically a four-arm alternating-current (AC) bridge circuit whose measurement depends on balancing the loads on its arms. Figure 1 below shows a diagram of the Schering Bridge.

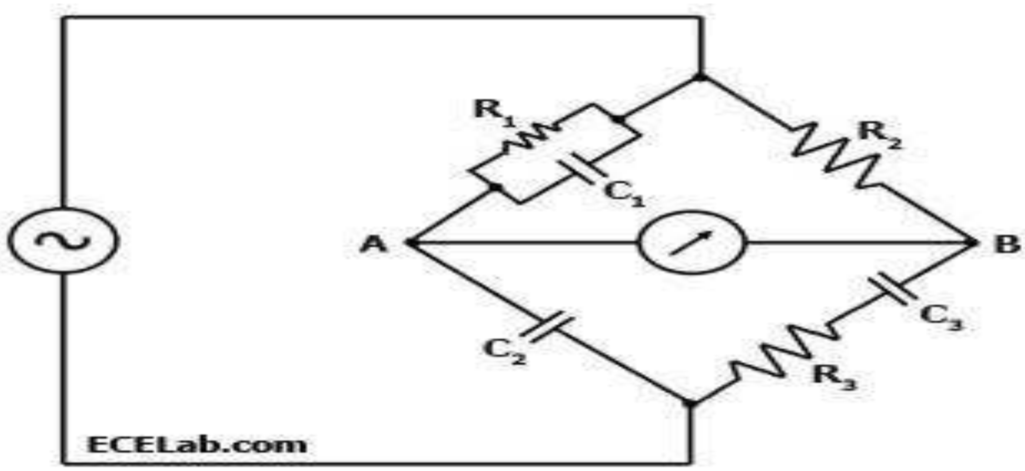


Figure 1. The Schering Bridge

In the Schering Bridge above, the resistance values of resistors R1 and R2 are known, while the resistance value of resistor R3 is unknown. The capacitance values of C1 and C2 are also known, while the capacitance of C3 is the value being measured. To measure R3 and C3, the values of C2 and R2 are fixed, while the values of R1 and C1 are adjusted until the current through the ammeter between points A and B becomes zero. This happens when the voltages at points A and B are equal, in which case the bridge is said to be 'balanced'.

When the bridge is balanced, $Z1/C2 = R2/Z3$, where Z1 is the impedance of R1 in parallel with C1 and Z3 is the impedance of R3 in series with C3. In an AC circuit that has a capacitor, the capacitor contributes a capacitive reactance to the impedance. The capacitive reactance of a capacitor C is $1/2\pi fC$.

As such, $Z1 = R1/[2\pi fC1((1/2\pi fC1) + R1)] = R1/(1 + 2\pi fC1R1)$ while $Z3 = 1/2\pi fC3 + R3$. Thus, when the bridge is balanced:

$2\pi fC2R1/(1+2\pi fC1R1) = R2/(1/2\pi fC3 + R3)$; or

$2\pi fC2(1/2\pi fC3 + R3) = (R2/R1)(1+2\pi fC1R1)$; or

$C2/C3 + 2\pi fC2R3 = R2/R1 + 2\pi fC1R2$.

When the bridge is balanced, the negative and positive reactive components are equal and cancel out, so

$2\pi fC2R3 = 2\pi fC1R2$ or

R3 = C1R2 / C2.

Similarly, when the bridge is balanced, the purely resistive components are equal, so

$C2/C3 = R2/R1$ or

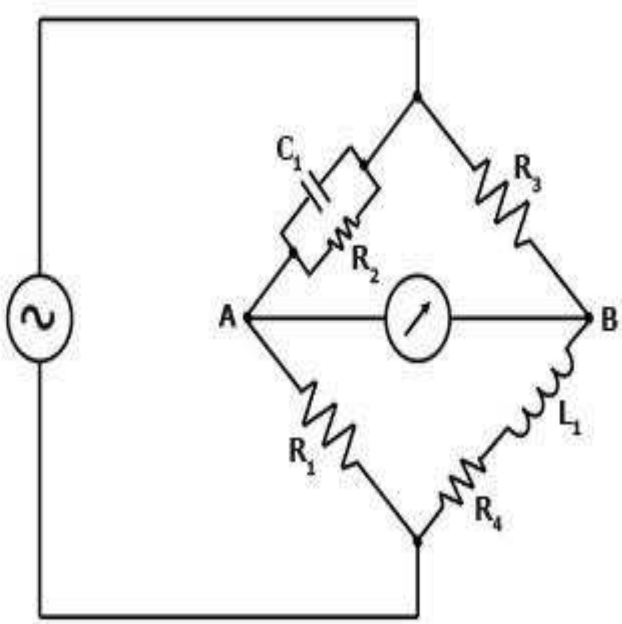
C3 = R1C2 / R2.

Note that the balancing of a Schering Bridge is independent of frequency.

MAXWELL'S BRIDGES

The maxwell bridge is used to measure unknown inductance in terms of calibrated resistance and capacitance. Calibration-grade inductors are more difficult to manufacture than capacitors of similar precision, and so the use of a simple "symmetrical" inductance bridge is not always practical. Because the phase shifts of inductors and capacitors are exactly opposite each other, a capacitive impedance can balance out an inductive impedance if they are located in opposite legs of a bridge, as they are here.

Another advantage of using a Maxwell bridge to measure inductance rather than a symmetrical inductance bridge is the elimination of measurement error due to mutual inductance between two inductors. Magnetic fields can be difficult to shield, and even a small amount of coupling between coils in a bridge can introduce substantial errors in certain conditions. With no second inductor to react with in the Maxwell bridge, this problem is eliminated.



TRNSFORMER RATIO BRIDGES

INTRODUCTION

The product to which this manual refers should be installed, commissioned, operated and maintained under the supervision of a competent ***Electrical Engineer*** in accordance with relevant statutory requirements and good engineering practice, including Codes of Practice where applicable, and properly used within the terms of the specification.

The instructions in this manual should familiarize qualified personal with the proper procedures to keep all new unit(s) in proper operating condition. These instructions for installation, operation and maintenance of Package Compact Substation should be read carefully and used as a guide during installation and initial operation.

These instructions do not propose to cover all details or variations in equipment, nor to provide for every contingency to be met in connection with installation, operation, or maintenance. Should further information be desired, or particular problems arise which are not covered, please contact the nearest ABB office.

We would in particular stress the importance of care in:

- Site selection and design, embodying features that provide adequate ventilation, protection and security and which have taken account of appropriate fire, moisture and explosion hazards.
- Jointing.
- Earthing.
- Selection and setting of electrical protection in primary and secondary, against overload, overvoltage and short-circuit.
- Carrying out regular inspection and electrical and mechanical maintenance.

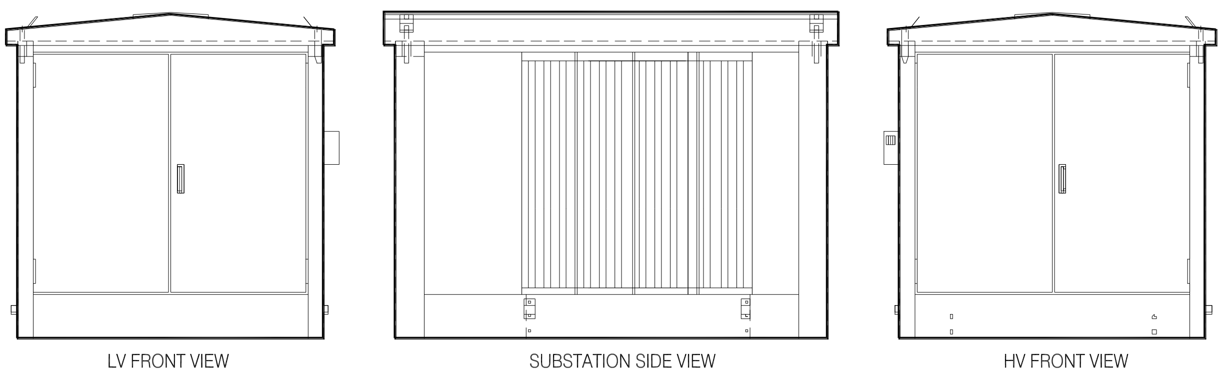
The Package Compact Substation(s) covered by these instructions have been repeatedly inspected and tested to meet all applicable standards of IEC, to ensure you of a first-rate quality product, which should give many years of satisfactory performance.

The specific ratings of each Package Compact Substation are shown on the drawings.

File these instructions in a readily accessible place together with drawings and descriptive data of the Package Compact Substation. These instructions will be a guide to proper maintenance of the equipment and prolong its life and usefulness.

GENERAL

These Package Compact Substations are locally manufactured in the Kingdom of Saudi Arabia by **ABB Electrical Industries Co. Ltd**., part of the **ABB** group world-wide to meet the environmental conditions of the Kingdom, neighboring Gulf countries and other similar places for outdoor installations.



The Package Compact Substations are completely self-contained, mounted on an integral base, factory assembled in a totally enclosed, aesthetically and acceptable cladding, vandal-proof, vermin-proof and weather-proof housing ready for installation into position on a concrete base pad or pier.

The base frame is of welded structural steel and been hot-dipped galvanized after fabrication to assure affective corrosion resistance in service.

Housing of the Package Compact Substation is made of special material called ALUZINK, a sheet steel with a metallic alloy coating. The alloy consists of 55% aluminum and 43.4% zinc. This provides optimum corrosion protection.

The housing has three compartments, separated with ALUZINK sheet. The transformer compartment is completely separated from the medium voltage and low voltage compartments.

RECEIVING / INSPECTION / STORAGE

The Package Compact Substation is shipped from the factory ready for installation on site. It has been submitted to all normal routine tests before being shipped, and it is not required to do any voltage testing before putting it into service, provided the substation has not sustained any damage during transportation.

Immediately upon receipt of the Package Compact Substation, examine them to determine if any damage or loss was sustained during transit. If abuse or rough handling is evident, file a damage claim with carrier and promptly notify the nearest ABB office. ABB ELECTRICAL INDUSTRIES CO. LTD. is not responsible for damage of goods after delivery to the carrier; however, we will lend assistance if notified of claims.

PERSONNEL SAFETY

The first and most important requirements are the protection against contact with live parts during normal service as well as maintenance or modifications.

This is the reason why all live parts have been metal enclosed, so that when the parts are live and the Package Compact Substation doors are open, no one can be able to touch them.

Also, it is safe in case any short-circuiting or sparking occurs at the busbars.

VENTILATION

Transformer compartment has been provided with sand trap louvers, to prevent ingress of sand and that proper air circulation should take place.

EARTHING

Proper earthing busbar has been provided.

HANDLING

Lifting lugs has been provided on top of four corners of the housing for lifting the DPS by crane and chains as a single unit, otherwise this can be done by a forklift of sufficient capacity, but the lifting fork must be positioned under the transformer portion.

INSTALLATIONS

A clean, flat surface capable of supporting the Package Compact Substation unit weight is the only requirement for a foundation. It is, however, important that adequate accessibility, ventilation and ease of inspection of the unit must be provided.

In all installation work, the safety regulations for electrical installations have to be observed.

Each Package Compact Substation must be permanently grounded or earthed by connecting an affective recognised ground or earth as prescribed by the latest applicable edition of IEC or ANSI requirements.

The Package Compact Substation is designed to operate with a solidly grounded neutral system. The neutral connection should be solidly and permanently grounded.

Tap connections

All units have taps located in the High Voltage winding. The tap arrangement is shown on the nameplate of the transformer. These taps are provided to furnish rated output voltage when the input voltage differs from the rated voltage.

To change tap connections, do the following steps:

1. De-energized the unit, short-circuit both the high and low voltage connections and ground both sides.
2. Unlock the tap changer handle, and then move the taps changer handle to the desired tap, then locked the tap changer handle.
3. Remove safety shorts and ground connections from the high voltage and low voltage buses.

After ensuring that no tools or hardware was left in the enclosure, and the enclosures are closed properly, you may then re-energize the Package Compact Substation. Make sure that the tap connections are proper for the required voltage as listed on the nameplate. The transformer is normally shipped with the tap changer for the rated voltage.

Cable Connections

When making outside cable connections, conductors suitable for at least 85°C should be used. All connections should be made without placing undue stress on the terminals.

Conductors should be securely fastened in place and adequately supported with allowances for expansion and contraction.

FINAL INSPECTION PRIOR TO ENERGIZATION

After the Package Compact Substation has been found to be in good condition and the protective equipment is operational, the substation may be connected to the network. However, it is recommended that the transformer to be left to settle for 1 or 2 days after installation so those air bubbles in the oil have time to dissolve before connecting the voltage.

Before energizing the unit, a complete electrical inspection should be made. The following checklist should be used as a minimum requirement.

Electrical Inspection

[ ] All external connections have been made properly (phasing of connections to terminals, etc.).

[ ] All connections are tight and secure.

[ ] All accessory circuits are operational. Check the transformer protective equipment and test the function of their electrical circuits:

- Thermometers (alarms, tripping)
- Pressure relay (tripping)
- Oil level indicator
- Ensure that all fuses are inserted and in the correct position

[ ] All tap connections are properly positioned.

[ ] The neutral and ground connections have been properly made.

Mechanical Inspection

[ ] All shipping members have been removed.

[ ] There is no obstructions in or near the openings for ventilation.

[ ] No tools or other articles are left inside the enclosures.

[ ] All protective covers are in place or closed and bolted tight.

MAINTENANCE AND PERIODIC INSPECTION

In order to assure a long lifetime and correct and reliable operation of equipment delivered for this facility it is of utmost importance to perform maintenance regularly.

Following general rules should always be considered before starting maintenance activity.

1. ***Authority from responsible engineer*** shall always be obtained ***before*** starting any maintenance.
2. Follow *safety procedure established* in carrying out the work.

Realize that no set of safety *or maintenance instructions* will ever be written that can adequately cover all accident possibilities.

Therefore **"SAFETY"** as dictated by actual current conditions, always takes precedence over any previously prepared safety or maintenance instructions. ***Assume nothing***. Take the precautions that you personally deem necessary in addition to those included in standard practice.

- Be familiar with the drawings and previous test records before starting activity.
- Scrutinize maintenance instructions given for the equipment to be maintained.

Maintenance information is given in the Operation and Maintenance Manual for each type of equipment.

The main dangers of such process are:

- Inaccessible lubrication points (greased for life) cannot be lubricated and may seize up.
- Areas not lubricated may be subject to corrosion.
- The high-pressure spray may damage equipment.
- Especially protective coatings may be removed.

Bolt Tightness

All connections should be tight and secure. Bolts and nuts on busbar and terminal lugs should be torqued and marked properly.

Inspection and Testing

The need for preventive maintenance will vary on operating conditions. Where heavy dust conditions exist, an accumulation of dust on the equipment may effect the operation of unit substation and its protective apparatus.

When normal maintenance inspection and cleaning of bus connections, relays, lug connections, and other part of the distribution system is being made, it is advisable to operate and check circuit breaker or switch-disconnector operation. The following procedure is highly recommended.

Routine Field Testing

Routine field testing of the electrical equipment is intended to enable maintenance personal to determine, without laboratory conditions or complicated equipment, that a particular electrical equipment is able to perform its basic circuit functions.

The following constitutes a guide to tests that might be performed during routine maintenance.

1. **Insulation Resistance Test**

   Extreme atmospheres and conditions may reduce the dielectric withstandability of any insulating material. An instrument commonly known as "megger" is used to perform this test.

   The voltage recommended for this test should be at least 50 percent greater than the circuit rating; however, a minimum of 500 volts is permissible. Tests should be made between phases of opposite polarity as well as from current carrying parts of the circuit protective device to ground. Also, a test should be made between the line-and-load terminals with the circuit protective device in the "OFF" position.

   Resistance values below one megaohm are considered unsafe and should be investigated for possible contamination on the surfaces.

   NOTE: For individual circuit protective device's resistance readings, load and line conductors should be disconnected. If not disconnected, the test measurements will also include the characteristics of the attached circuits.

   A temperature and humidity reading are recommended and recorded during the testing period.

Insulation resistivity is markedly effected by temperature and humidity conditions. Based condition of one (1) megaohm per kV assumes a 20°C wet bulb reading. The following table shall be used to adjust readings to the 20°C constant.

2. **Connection Test**

   Connections to the circuit protective device should be inspected to determine that a proper electrical joint is present. If overheating in these connections is evident by discoloration or signs of arcing, the connections should be removed and the connecting surfaces clean before re-connections. It is essential that electrical connections be made properly to prevent and reduce overheating.

3. **Mechanical Operation**

   During routine tests, mechanical operation of the circuit protective devices or disconnects should be checked by turning it "ON" and "OFF" at least three times.

TRANSFORMER MAINTENANCE

Inspection during operation

1. Inspection of oil level: when adding oil safety distances have to be observed.
2. Inspection of oil leakage.
3. Inspection of transformer surroundings.
4. Inspection of surface treatment.

Maintenance during operation

For personal safety reasons only a limited amount of maintenance activities can be performed on the transformer when it is in operation. These activities are, however, possible if safety regulations are followed. In practice, however, always safest to remain below the level of the cover of the transformer. Maintenance activity, which can be performed during operation is oil sampling only.

Inspection and Measures to be taken during downtime

During downtime all inspection work and maintenance measures can be carried out, which can not normally be performed during operation.

Before starting maintenance work, the transformer has to be disconnected from the network and earthed or grounded. When the disconnector has been opened, one has to see to that they stay open and, before grounding or earthing, one has to test that they are voltage free, i.e., with a voltage tester.

Inspection of oil leaks and precautions to be taken.

Oil leaks may occur as follows:

1) From bushing gaskets (if the gasket has become loose, tightening will help; if the gasket has lost its elasticity, it has to be replaced. The reason for losing the elasticity can be excessive heating or ageing of the gasket).
2) From cover gaskets, valves, and gaskets of the off-load tap changer (tightening of the screws or bolts will usually help).
3) From welded joints (leaking joints can be repaired by welding. A skilled welder is needed for the job).

Cleaning to be carried out annually:

1) Bushings (cleaning agent e.g. white spirit)
2) Transformer cover and tank
3) Glasses of relay, thermometer, and oil level indicator

Surface treatment:

Surfaces that have not been inspected during operation, should be checked and the damage coatings be repaired.

Inspection and maintenance for accessories, protective and regulating equipment:

1) To prevent oxidation of contact surfaces of the off-load tap changer it has to be moved from side to side a few times, at least once a year.
2) function of alarms and tripping contacts of thermometers.

Inspection Measurements

In addition to the above instructions the following inspection measurement may be carried out:

1. Insulation resistance of windings

   HV Winding to Earth

   LV Winding to Earth

   HV Winding to LV Winding

   Reading below 75 megaohms should be reported to the manufacturer.
2. Transformer ratio test

Approximately 220 volts or 400 volts should be supplied from an isolating transformer via a regulating transformer to one winding of the High-Voltage side of the transformer to be tested. HV and LV readings can be taken by means of a general-purpose meter. The measurements must be carried between each phase. The transformation ratio calculated from the voltage reading must be compared to the ratio of the rated voltages and to the values from the test report. Due to inaccuracy of the general-purpose meter a difference of a few percentages may be possible. It is advisable to use a transformation ratio bridge for the measurement.

3. No-load current

   A small voltage fed between each phase and the star point (in a star connected transformer) via an isolating and regulating transformers will result in the reading of a series connected ammeter being only a ten of milliamperes.

   With the same voltage reading the current taken by other phases can be measured. The excitation currents of different phases should be approximately the same magnitude. In a damage phase the current can rise to tens of amperes thus the regulating transformer has to be protected by a suitable fuse.

4. <u>DC resistance of windings</u>

   A satisfactory large DC source and an accurate resistance bridge meter are needed for the resistance measurement. When disconnecting the measuring current instrument dangerous voltage can be induced. Therefore a skilled person must perform the measurement.

Opening/Resealing Sealed type Transformers

Sealed type transformers must not be opened unnecessarily as this could cause the oil to come out or air to go in depending on the temperature of the oil. This results in disturbances of the normal pressure variations causing increased stress on the tank due to under-pressure or over-pressures.

When opening the transformer, for example to replace a bushing, opening and resealing must be performed according to these instructions.

Opening

1) If the temperature of the transformer oil is higher than +20...25°C, approximately 5% of oil must be drained through the drain valve to relieve the pressure.

2) If the temperature of the transformer oil is below +20 °C, no draining is needed as there is under-pressure inside the tank.

3) Filling plug can then be opened. If necessary the oil level can be lowered by draining through the drain valve before carrying out the planned maintenance. (If the transformer is provided with an oil level indicator, it also acts as the filling plug).

Resealing

1) When resealing the transformer, the temperature of the oil must be within +20...25°C, to ensure the normal pressure inside the tank during operation.
2) Fill in oil through the filling plug until the oil level is above cover level, then close the filling plug.
3) Loosen the upper nuts and upper gaskets of all bushings and possible de-airing plugs.
4) Fill with oil through voltage bushings until it runs out through the low voltage bushings and possible de-airing plugs.
5) Tighten the upper nuts of low voltage bushings and de-airing plugs.
6) Continue filling with oil until the high voltage bushings are completely filled.
7) Tighten the upper nuts of high voltage bushings.

Notes:

If the transformer is provided with plug-in bushings the upper nuts are not loosened because these bushings cannot be bled. In this case the transformer is filled through other bushings or filling plug whichever is higher.

FUSE REPLACEMENT PROCEDURE

After the fuse switch is switched off or opened and the earthing switch closed, fuse-link replacement may be then performed.

Use the manufacturer's recommended fuse-link type that was used in the type test of the combination. The tripping pins movement and energy may be different for different fuse types, as well as the selection tables and protection characteristics. It is compulsory to use the same type of fuse-links in all phases (type, rated current). The disconnector cannot be closed before the fuse-links are changed.

Note:

According to IEC Publication 282-1, all 3 fuse-links should be replaced, even if only 1 or 2 of the fuse-links in the three phase systems have operated. Exceptions are allowed when it can be verified that the fuse-link(s) has not experienced any overcurrent.

LOW VOLTAGE CIRCUIT BREAKER MAINTENANCE

For particulars see Installation, service and maintenance instructions for Low-Voltage Circuit Breakers been used in this substation.

General

During normal service the circuit breakers require minimum maintenance. The following program table for maintenance shows the relative intervention intervals.

It is also advisable to refer to the following rules:

- The circuit breakers that operate rarely, or which remain closed or open for long periods, must be activated once in a while to prevent a tendency to jam, which might cause reductions in the closing or opening speed.
- During service, circuit breaker must be visually check from the outside for dust, dirt, or damage of any kind.

Balancing (bridge)

In the game of bridge, the term **balancing** (or **protection**) refers to making a call other than pass when passing would result in the opponents playing at a low level. Balancing is done by the player in*balancing position*, i.e. at the right of the last bidder. This is to be compared by *direct bidding* which refers to bidding in *direct position* (i.e. by the player left of the last bidder). Balancing is normally done with values unsuitable for a direct action, but after the opponents have not demonstrated a significant strength in their previous bidding. The aim of the tactics is to find a makeable or nearly-makeable contract of its own or to "push" opponents a level higher. It is more common in matchpoint games, where even a defeat of 100 points is a worthy gain over opponents' 110-140 points.

Examples

After a passed-out opening bid

Balancing situation result from sequences like:

(1♥) - Pass - (Pass) - ??

Note that a Pass in this *balancing position* would result in having to defend a 1♥ contract. When a player finds himself in a balancing position, you know that the opener made a non-forcing bid and therefore has limited values, and that the partner of the opener has denied values required to respond. In such a situation, it is unlikely that you and your partner have significantly less than half of the high-card strength. It is important to be able to enter the bidding on hands in which you and your partner both have about 9-11 hcp. Therefore, in balancing position, a takeout double can be made on values less than in direct position. Also the 1NT overcall is typically lighter than in direct position.

Mike Lawrence gave a detailed account of the various balancing situations in his *Complete Book on Balancing in Contract Bridge*. He stressed the fact that balancing over a minor suit is markedly different from balancing over a major suit. The difference stems from the fact that on a minor suit you can double and - after partner's response at 1-level - can rebid 1NT with 15-17 hcp. However, on atakeout double over a major suit, partner will seldom bid at 1-level. As a result, the 1NT overcall over a major suit needs to be stronger.
The following summarises the balancing agreements made by competitive bridge players:

(1♦) - Pass - (Pass) - ??

dbl = 8+ hcp

1♥/♠ = normal overcall

1NT = 10-14 hcp, does not guarantee a stopper

2♣ = normal overcall

2♦ = unknown two-suiter (Cf. Michaels cuebid)

2♥/♠ = good 6+ card, 12-16 hcp

2NT = 18-19 hcp, balanced

(1♥) - Pass - (Pass) - ??

dbl = 8+ hcp

1♠ = normal overcall

1NT = 12-16 hcp, does not guarantee a stop

2♣/♦ = normal overcall

2♥ = unknown two-suiter

2♠ = good 6+ card, 12-16 hcp

2NT = 17-19 hcp, balanced

=**In later rounds**

Balancing can be also executed in later rounds of bidding, in the sequences where the opponents have found a fit but stopped at a low-level. Normally, it is performed with some values, but less than if it was in direct seat. The opponents' fit requirement is important: statistically, existence of one side's 8+ cards fit favors the possibility that their opponents also have one (see Law of total tricks). Also, the opponents fit gives a clue to the partner's length in the suit, and, by inference from previous rounds of bidding, in other suits.

Balancing in direct seat

Although the "balancing in direct seat" term is self-contradictory, it is occasionally possible to have the "balancing values", yet to act relatively safely in the direct seat. The classical situation [1] is after the opponents found a fit at the two level:

Bidding	Holding	Comment
Pass–1♥–Pass–2♥–?	♠10963 ♥8 ♦A8532 ♣KQ8	South can see that the partner is not short in hearts and is unlikely to balance over 2♥, so a takeout double is in order. A prior partnership agreement for light actions is in order.

It can also occur when the LHO has bid a sign-off without a clear fit, though this is not recommended due to the danger of not landing in a fit after the "pre balance"[1]. The tactics/convention is often referred to as "OBAR BIDS" (acronym for "Opponents Bid And Raise - Balance In Direct Seat").

INTERFERENCE AND SCREENING

Interference is one of the most serious as well as most common problems in audio electronics. We encounter interference when it produces effects like noise, hiss, hum or cross-talk. If a radio engineer faces such problems, good theoretical knowledge as well as experience is required to overcome them.

However, it should be considered, that interference is always present. All technical remedies only aim at reducing the effect of interference to such a degree, that it is neither audible nor disturbing. This is mainly achieved by different ways of screening. This paper will explain the technical background of interference and provides some common rules and hints which may help you to reduce the problems.

TYPES OF INTERFERENCE.

Theoretically, the effects and mechanism of a single interference can well be calculated. But in practice, the complex coupling systems between pieces of equipment prevent precise prediction of interference. The following picture shows the different types of interference coupling.

The different types of interference between the components of an electric system.

If we consider all possible coupling paths in the diagram above we will find 10 different paths. This means a variety of 1024 different combinations. It should be noted, that not only the number of paths, but also their intensity is important.

SYMMETRICAL AND ASYMMETRICAL INTERFERENCE.

Having a closer look at the interference of cable, we find that hf-interference currents cause measurable levels on signal (audio) lines and on supply lines.

A ground-free interference source would produce signals on a cable which spread along the line. These voltages and currents can be called symmetrical interference.

In practice this rarely occurs.

.

Through interference, asymmetrical signals are produced in respect to the ground. The asymmetrical interference current flows along the two wires of the symmetrical line to the sink and via the ground back to the source. These interference signals are cancelled at the symmetrical input.

GALVANIC COUPLING OF INTERFERENCE.

Galvanic coupling of interference occurs if the source and the sink of interference are coupled by a conductive path.

As can be seen from the equivalent circuit diagram, the source impedance of the interference consists of the resistance RC and the inductance LC of the conductor, which are common to the two parts of the circuit. From these elements the interference source voltage can be calculated.

. CAPACITIVE COUPLING OF INTERFERENCE.

The capacitive coupling of interference occurs due to any capacitance between the source and sink of interference.

Principle of capacitive coupling of interference.

The current in the interference sink can be calculated as

The interference voltage in the sink is proportional to its impedance. Systems of high impedance are therefore more sensitive to interference than those of low impedance. The coupled interference current depends on the rate of change of the interference ui and on the coupling capacitance CC. For typical arrangements of conductors the

INDUCTIVE COUPLING OF INTERFERENCE.

Inductive coupling of interference occurs if the interference sink is in the magnetic field of the interference source (e.g. coils, cables, etc.)

Principle of the inductive coupling of interference.

The interference voltage induced by inductive coupling is

- increasing the distance between conductors

- mounting conductors close to conductive surfaces

- using short conductors

- avoiding parallel conductors

- screening

- using twisted cable

Note that by the same means the capacitive as well as the inductive coupling of interference will be reduced.

INTERFERENCE BY RADIATION.

Interference by electromagnetic radiation becomes important at cable lengths greater than 1/7 of the wavelength of the signals. At frequencies beyond 30Mhz, most of the interference occurs by e.m. radiation

Principle of the coupling by e.m. interference.

INTERFERENCE BY ELECTROSTATIC CHARGE.

Charged persons and objects can store electrical charges of up to several micro-Coulombs, which means voltages of some 10kV in respect to ground. Dry air, artificial fabrics and friction favour these conditions.
When touching grounded equipment, an instantaneous discharge produces arcing with short, high current pulses and associated strong changes of the e.m. field.

REDUCTION OF INTERFERENCE

There are a number of methods to prevent interference. But all of them only **reduce**

the interference and never fully prevent it. This means there will never be a system which is 100% safe from interference. Because the efforts and the cost will rise with the degree of reduction of interference, a compromise has to be found between the effort and the result.
The requirement for the reduction of interference will depend on:
- the strength of the interference source
- the sensitivity of the interference sink
- the problems caused by interference
- the costs of the equipment

We will discuss ways of preventing interference, their effect, and the main aspects for the optimum efficiency of each method.

GROUNDING (OR EARTHING).

This is one of the simplest but most efficient methods to reduce interference.
Grounding can be used for three different purposes:

1. Protection Ground

Provides protection for the operators from dangerous voltages. Widely used on mains-operated equipment.

2. Function Ground

The ground is used as a conductive path for signals.
Example: in asymmetrical cables screen, which is one conductor for the signal, is connected to the ground.

3. Screening Ground

Used to provide a neutral electrical path for the interference, to prevent that the interfering voltages or currents from entering the circuit.

In this chapter we will only consider the third aspect. Grounding of equipment is often required for the cases 1 or 2 anyhow, so that the screening ground is available "free of charge".

Sometimes the grounding potential, provided by the mains connection, is very "polluted". This means that the ground potential itself already carries an interfering signal. This is especially likely if there are big power consumers in the neighbourhood or even in the same building. Using such a ground might do more harm than good. The quality of the ground line can be tested by measuring it with a storage scope against some other ground connection, e.g. a metal water pipe or some metal parts of the construction.

Never use the Neutral (N) of the mains as ground.
It might contain strong interference, Because it carries
the load current of all electrical consumers.

The grounding can be done by **single-point grounding** or by **multi-point grounding**. Each method has advantages which depend on the frequency range of the signal frequencies.

:

All parts to be grounded are connected to one central point. This resultsin no "ground loops" being produced. This means the groundingconductors do not form any closed conductive path in which magneticinterference could induce currents. Furthermore, conductive linesbetween the equipment are avoided, which could produce galvanic

coupling of interference.Central grounding requires consistent arrangement of the groundingcircuit and requires insulation of the individual parts of the circuit. This is sometimes very difficult to achieve.*A system using the single-point grounding.*

MULTI-POINT GROUNDING:

In multi-point grounding all parts are connected to ground at as many points as possible. This requires that the ground potential itself is as widely spread as possible.

In practice, all conductive parts of the chassis, the cases, the shielding, the room and the installation are included in the network. The interconnection of these parts should be done at as many points as possible.

SCREENING.

When considering the effect of electrical and magnetic fields, we have to distinguish between low and high frequencies. At high frequencies the **skin effect** plays an important roll for the screening. The penetration describes the depth from the surface of the conductor, where the current density has decayed to 37% compared to the surface of the conductor.

.

SCREENING OF CABLES.

When signal lines run close to interference sources or when the signal circuit is very sensitive to interference, screening of signal lines will give an improvement.
There are different ways of connecting the cable screen:
*Three different ways of connecting the cable screen.*Cable screen not connected.
This screen will not prevent any interference, because the charge on
the screen, produced by interference, will remain and will effect the
central signal line. Also, the current induced by interference in the linewill flow through the sink, effecting the signal.Cable screen grounded on one side only.This screen will only prevent interference at low frequency signals. Forelectromagnetic interference, where the wavelength is short comparedto the length of the cable, the screening efficiency is poor.Cable screen grounded on either sidet is effective for all kinds of interference. Any current induced in thescreen by magnetic interference will flow to ground. The inner of thecable is not affected. Only the voltage drop on the screen will affect thesignal in the screen.
type of grounding is

- Ensure proper and careful connection of the screens.
- Use suitable plugs in connection with the cable screen.

For A.F. frequencies up to 10kHz, the normal copper screen of cable is only of limited efficiency. For difficult cases of interference screening hoists of iron screen can be used.

TWISTING OF CABLES

For symmetrical signal lines, the twisting of two signal wires alone produces already very good protection against interference. Because it produces almost no extra costs, it is at the same time a very cheap means of interference reduction.

When an interfering signal effects the twisted wires, it will produce in both wires a signal with the same direction and (almost) same intensity. From the point of view of the signal's sink, these signals will have opposing directions and will therefore cancel out.

Note that the advantages of symmetrical lines and twisted pair cables can only be used, if the signal's source as well as the sink have balanced outputs and balanced

.

INTERFERENCE FILTERS

Interference filters are used to attenuate unwanted signals on signal lines. These may serve to attenuate signals leaving and entering the equipment.

In principle these filters are low pass filters which are designed to produce minimum damping for signals, but maximum damping for interference.

The following diagram shows the path for symmetrical and asymmetrical interference.

The path for symmetrical and asymmetrical interference.

With coils and chokes, interference currents can be attenuated on the signal lines.

TYPES OF FILTERS.

Basically, there are two types of chokes used for interference filters: bar-core and ring-core chokes.

Bar-core chokes:

In symmetrical lines, two chokes are required for each conductor. This provides good attenuation for symmetrical and asymmetrical interference. The open core of these chokes will prevent saturation. However the inductance is low and for low frequencies and high currents the chokes are very bulky.

Ring-core chokes:

These are used in symmetrical lines only. The closed core has a high permeability, which results in small dimensions of the coils. Both signal current directions are conducted through the coils. Therefore the symmetrical currents compensate, so that the coil will not be saturated, even by a high signal current. This type of choke will not provide attenuation of symmetrical interference on the line. This must be provided by symmetrical capacitors between the lines and ground.

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SELECTION OF FILTERS.

A wide variety of interference filters are available. For improvement or modification of a circuit these filters are a suitable choice. Designing them oneself is difficult and requires a lot of experience.

Different types of interference suppressers.

The main criterion for the selection of an interference filter is the frequency range of the signal and the frequency range of the interference. The signal should not be affected by the filter, while for the interference the attenuation should be as high as possible. This will only work, if the two frequency ranges are well separated.

Often the interference occurs in the form of pulses. Then the duration or the slew rate of the pulses becomes important.

If interference is caused by pulses, the duration of the slew rate of the pulses must be considered.

MOUNTING FILTERS.

When mounting interference filters, the following aspects must be considered:

- The interference filter should always be mounted directly onto the
case of the equipment.

- The case of the filter must have good electrical contact with the case

of the equipment.
- The lines of the input of the filter must be well separated and screened from the lines of the output of the filter.

SUPPRESSION OF CONTACTS

Spark suppression is applied in order to reduce the burning and arcing of contacts, which produce additional wear of contacts and might be a source of interference. Spark suppression usually consists of R and C across the contacts. Typical values: R = 50 , C = 0.22 μF.

Typical network for spark suppression of a contact.

Such RC networks are available ready-made in one unit. Spark suppression may reduce HF interference from the contacts. Very often the components are fairly bulky and also show too much inductance, e.g. due to long leads, which increases the radiation. In such cases, only sparking is reduced. Additional components have to be installed to cut down HF interference.
HF interference is produced at the contact points. The opening or closing of electrical contacts produces a square wave signal, which contains harmonics with frequencies in the VHF and UHF bands. Click noises in receivers are the result. These noises can also occur in audio equipment, especially when the interference affects the input of high-gain amplifiers.

Typical switches or relays which may require careful interference suppression are: power switches of amplifiers, tape recorders, room lights, clocks, cue lights, air conditioning, mains voltage regulators.
Also, brushes for commutators or slip rings of motors or generators, e.g. an emergency power plant.

For the efficient suppression of HF interference, it is most important to fit a suitable HF filter (low pass) very close to the actual source of interference, e.g. switch contacts. This will prevent HF from being radiated from connecting leads which act as "antennas" for the interference transmission. These filters usually consist of HF chokes (wide-band types on ferrite core) and low inductance capacitors, forming a low pass filter.

Often just two HF chokes are sufficient, but they must be situated very close to the contacts. Ferrite beads slipped over the leads close to the contact points are another way of providing inductance at HF. Note that all leads to all contacts must carry chokes, including contacts which are connected to 0V or ground.

MULTIPLE EARTH AND EARTH LOOPS

SIMPLE TWO SYNODIC PERIOD CYCLER (CASE 1)

Figure 1 shows the simple two Earth-Mars synodic period cycler. In the circular coplanar model it has a period P=l.348 years, a radius of aphelion R~ = l .15 A U and the V, at Earth is 5.6 *M s* . For the "Up" transfer, the Earth-Mars transfer is Type I or I1 and the Mars-Earth leg is Type VI. The trajectory departs the Earth with the V, inward of the Earth's velocity vector taking it through a perihelion of about 0.93 AU, crossing the Earth's orbit ahead of the Earth and outward to Mars' orbit. As seen from Figure 1 the transfer to Mars is about 225 degrees and takes a little over nine months. The trajectory continues onward making three complete orbits about the Sun without coming near either the Earth or Mars again until passing through its original starting point on the Earth's orbit for the third time, somewhat behind the Earth and finally encountering the Earth 2/7 of a revolution about the Sun (102.9 deg.) from the starting point. The cycler has made 3 2/7 complete orbits about the Sun while Earth has made 4 2/7. The Earth flyby must now rotate the incoming V, vector, which is outward, to the symmetrically inward orientation to begin the next cycle. Unfortunately, the rotation angle required is approximately 135 degrees and with a V, of 5.65 km/s the Earth can only rotate the V, vector about 82 degrees.

Now in the actual Solar System, the orbit of Mars is elliptical with a semi-major axis of 1.524 AU, a perihelion of 1.381 AU and **an** aphelion of 1.666 AU. Thus the simple Case

1 cycler does not quite reach Mars' average distance from the Sun. It is thus clear that a real world version of the Case 1 cycler would require **AV** to make up for the inability of the Earth to rotate the V, vector, as well as for the fact that over the course of seven cycles, of two synodic periods each, the Case 1 cycler will not make it to Mars' orbit more than one half of the time. The real value of Case 1 is as a basis for variations that can address these deficiencies.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" (CASE 2)

Modifylng Case 1 by introducing another Earth flyby, approximately six months and 180 degrees after the first, changes the situation somewhat. This six month, 180 degree transfer, or "backflip" trajectory, was first introduced for lunar trajectories by U p h ~ f f . ~ The "Up" trajectory for this version leaves the Earth with a Type I or I1 short transfer to Mars and a Type V transfer back to Earth. This transfer to the first Earth encounter makes 2 11/14 revolutions about the Sun in 3 11/14 years. The Earth flyby then puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later, completing the **3** 217 revolutions in 4 2/7 years. This second Earth flyby then sends the vehicle on to the next Mars encounter, continuing the cycle. Figure 2 shows this cycler trajectory. Note that the first Earth encounter is in the lower portion of the plot. The backflip trajectory is not shown since its difference from the Earth's orbit is primarily in the z-direction. The second Earth flyby and departure point for the second cycle is indicated slightly left of straight up on the Earth's orbit. In the circular co-planar model the Earth-Mars-Earth trajectory has a period P=l.325 years, a radius of aphelion R~ z l . 4A5 U and the V, at Earth is 4.15 ***MS***F**.**or Case 2, the transfer does not reach Mars' orbit in the circular co-planar model, but in the real world does reach Mars when Mars is near its perihelion.

The lower V, for Case 2 enables the Earth to rotate the V, vector as much as about 102 degrees, thus easily enabling the first Earth flyby to rotate the incoming V, to the required near polar orientation required for the backflip trajectory outgoing V, as well as the second earth flyby to rotate the near polar incoming V, to the outgoing V, required for the transfer to the next Mars, Thus, although Case 2 has many desirable characteristics, it cannot be used for an entire seven cycles. If fact it will reach Mars for at most two of the seven cycles without propulsive AVto augment the gravity assists.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" PLUS 1-YEAR LOOP (CASE 3)

Modifying Case 2 to introduce a third Earth flyby in addition to the "backflip" adds additional flexibility. This is accomplished by adding a one year Earth-Earth loop either before or after the backflip. The order of the one year loop and the "backflip" can be chosen to best advantage in the real world. The **TJp"** trajectory for this version leaves the Earth with a Type I short transfer to Mars and a Type I11 or IV transfer back to Earth. This transfer to the first Earth encounter makes 1 11/14 revolutions about the Sun in 2 11/14 years. The Earth flyby the puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later and then re-encounters the Earth one year later, or vice versa. The final Earth flyby then sends the vehicle on to the next Mars encounter. Figure 3 shows this cycler trajectory. Again as in Case 2, the backflip trajectory is not seen. The one year Earth-Earth loop is also not shown. In the circular co-planar model the Earth-Mars-Earth trajectory has a period **P=l.484** years, a radius of aphelion R~=l .65A U and the V, at Earth is **5.4** km/s. In this case the transfer reaches an aphelion approximately equal to Mars' aphelion and will thus always cross Mars orbit in the real world. Analysis of Case 3 with the actual ephemerides of Earth and Mars is considered in more detail below.

1-YEAR LOOP (CASE 3)

TWO SYNODIC PERIOD CYCLER WITH ONE OR TWO 1-YEAR LOOPS

Modifying Case 1 to introduce one or two one year Earth-Earth loops or even a two year Earth-Earth loop without a backflip is also possible, it leads however, to much higher

V,'s less desirable characteristics that any of Cases 1,2 or 3, or the Aldrin Cycler for that matter.

DETAILED ANALYSIS OF CASE 3

A detailed analysis of Case 3 was performed using the actual ephemerides of the Earth and Mars. The trajectories were modeled as Sun-centered point-to-point conics connecting the Earth and Mars flybys. The flybys were modeled as instantaneous V m rotations. This “ V m -matching” model gives excellent insight into both the heliocentric and planetocentric trajectories and sufficient accuracy for developing long term trajectory scenarios that can be closely reproduced with fully numerically integrated trajectory models.

The Table shows data for a full cycle of seven two-synodic period cyclers (30 years). This should approximately repeat since the Earth and Mars are very nearly at the same inertial positions every 15 years.

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e noted that the Ed---Earth transfers are constraineG to be exactly 1.5 years apart. The choice of one year loop or backflip and whether the backflip is “north” or “south” needs to be made in each case to make best use of the arrival and departure V,’s to minimize the required bending by the Earth and potential required **AV.** The Mars flybys (given to the nearest 1000 km) are all at reasonably high altitudes. Whereas in the circular co-planar analysis the Mars flybys are arbitrarily high, in the real world the Mars gravity assist must control the inclination of the heliocentric orbit as well as adjust the energy slightly to properly phase for the next encounter. The Mars V,’s vary between about 3 km/s and **8** km/s which compares to the value of 5.3 km/s in the circular coplanar case. The Earth V,’s vary between about **4** km/s and 7.5 km/s which compares to 5.4 km/s. So while the real world solution values oscillate, they are on average similar to the prediction of the simpler model.

ONGOING AND FUTURE WORK

Some initial optimal trajectory simulation of the Case 3 trajectories has begun. Initial results indicate that adjustments to the dates given above in Table 1 will be necessary to minimize required deterministic **AV's.** It may be possible, although it has not yet been demonstrated that a completely ballistic trajectory may be attainable. Although the trajectory seems straightforward in the circular co-planar world, the actual interaction of the inclination and eccentricity of Mars' orbit make the actual trajectory quite complex. **As** can be seen from Figure 3, the transfer from Mars to Earth is very near to 180 degrees. Thus in the real world, a Type I11 or **IV** transfer must be chosen. This leads to multiple, distinct possible solutions, each with different characteristics.

The work of McConaghy, et. al. **4,** presented at this Conference as well, has identified a cycler denoted as the SlL1-B cycler. Studying Figure **8** given in that paper shows remarkable similarity to Case 3 in Figure 3 above. In fact they share significant similarities and one important difference. The Earth-Mars-Earth legs are nearly identical, however the SlL1-B cycler has only two Earth flybys instead of three and the Earth-Earth transfer is not a resonance. That is, the transfer time and angle between the two Earth flybys is not an exact multiple or half-multiple of the Earth's period. This gives significantly more flexibility in the flyby dates of both Earth and Mars. A preliminary study underway has already identified a completely ballistic version of the **S** 1L1-B cycler over a 30-year period. These results and additional versions, both "Up" and "Down" of the McConaghy cycler will be presented in a future paper.
It may turn out that the ultimate cycler uses judicious combinations of the various cyclers identified to take maximum advantage of the preferred characteristics of each. While such a trajectory is not strictly speaking a cycler, since it does not repeat exactly, it is a repeating trajectory in the sense of visiting Mars and Earth regularly on a two synodic period schedule.

COMPARISON METHODS OF MEASUREMENTS

PART – A

1. Draw Maxwell's AC bridge and give the balance equation In terms of resistance. (2)
2. Explain any two technical parameters to be consider in grounding. (2)
3. Give some applications of Whetstone's bridge. (2)
4. What is a potentiometer? (2)
5. List the applications of dc and ac potentiometer. (2)
6. Differentiate the principle of dc potentiometer and Ac potentiometer.
7. What is meant by transformer ratio bridge (2)
8. What are the features of ratio transformer? List its applications.(2)
9. What is meant by electromagnetic interference? (2)
10. List the sources of electromagnetic interference. (2)
11. What are the ways of minimizing the electro magnetic interference?
12. Define electromagnetic compatibility.(EMC) (2)
13. What are the main causes of group loop currents? (2)
14. What are the limitations of single point grounding method? (2)
15. What is the necessity of grounding and state is advantages.
16. What is meant by ground loop? How it is created? (2)

17. What are the sources of errors in bridge measurement? (2)

18. Define standardization. (2)

19. Give the relationship between the bridge balance equation of DC bridge and AC bridge (2)

20. What does a bridge circuit consists of? (2)

PART – B

1. (i) Explain in detail about the laboratory type DC potentiometer.
   (ii) Give the applications of AC potentiometers. (6)

2. (i) Describe about the multiple earth and earth loops. (10)
   (ii) Explain the different techniques of grounding. (6)

3. Explain voltage sensitive self balancing bridge, and derive the bridge sensitivity of voltage sensitive bridge with fundamentals.

4. (i) With fundamentals distinguish between DC and AC Potentiometers, and give any two specific applications for each
   (ii) Discuss the advantages and limitations of electromagnetic Interference in measurements. (8)

5. (i) Explain Kelvin's double bridge method for the measurement Of low resistance. (8)
   (ii) Explain how inductance in measured by using Maxwell's bridge.

6. (i) Explain the working principle of Anderson's bridge and also derive its balance equations. (8)
   (ii) Explain the working principle of Schering bridge and also deriveits balance equations. (8)

UNIT IV STORAGE AND DISPLAY DEVICES

Magnetic disk and tape – Recorders, digital plotters and printers – CRT display – Digital CRO,LED, LCD and dot-matrix display – Data Loggers

Magnetic disk and tape

Magnetic tape is a medium for magnetic recording, made of a thin magnetizable coating on a long, narrow strip of plastic. It was developed in Germany, based on magnetic wire recording. Devices that record and play back audio and video using magnetic tape are tape recorders and video tape recorders. A device that stores computer data on magnetic tape is a tape drive (tape unit, streamer).

Magnetic tape revolutionized broadcast and recording. When all radio was live, it allowed programming to be prerecorded. At a time when gramophone recordswere recorded in one take, it allowed recordings in multiple parts, which mixed and edited with tolerable loss in quality. It is a key technology in early computer development, allowing unparalleled amounts of data to be mechanically created, stored for long periods, and to be rapidly accessed.

Today, other technologies can perform the functions of magnetic tape. In many cases these technologies are replacing tape. Despite this, innovation in the technology continues and tape is still widely used.

Over years, magnetic tape can suffer from deterioration called sticky-shed syndrome. Caused by absorption of moisture into the binder of the tape, it can render the tape unusable.

Audio recording

Magnetic tape was invented for recording sound by Fritz Pfleumer in 1928 in Germany, based on the invention of magnetic wire recording by Valdemar Poulsen in 1898. Pfleumer's invention used an iron(III) oxide(Fe_2O_3) powder coating on a long strip of paper. This invention was further developed by the German electronics company AEG, which manufactured the recording machines and BASF, which manufactured the tape. In 1933, working for AEG, Eduard Schuller developed the ring shaped tape head. Previous head designs were needle shaped and tended to shred the tape. An important discovery made in this period was the technique of AC biasing which improved the fidelity of the recorded audio signal by increasing the effective linearity of the recording medium.

Due to the escalating political tensions, and the outbreak of World War II, these developments were largely kept secret. Although the Allies knew from their monitoring of Nazi radio broadcasts that the Germans had some new form of recording technology, the nature was not discovered until the Allies acquired captured German recording equipment as they invaded Europe in the closing of the war. It was only after the war that Americans, particularly Jack Mullin,John Herbert Orr, and Richard H. Ranger were able to bring this technology out of Germany and develop it into commercially viable formats.

A wide variety of recorders and formats have developed since, most significantly reel-to-reel and Compact Cassette.

VIDEO RECORDING

The practice of recording and editing audio using magnetic tape rapidly established itself as an obvious improvement over previous methods. Many saw the potential of making the same improvements in recording television. Television ("video") signals are similar to audio signals. A major difference is that video signals use more bandwidth than audio signals. Existing audio tape recorders could not practically capture a video signal. Many set to work on resolving this problem. Jack Mullin (working for Bing Crosby) and the BBC both created crude working systems that involved moving the tape across a fixed tape head at very fast speeds. Neither system saw much use. It was the team at Ampex, lead by Charles Ginsburg, that made the breakthrough of using a spinning recoding head and normal tape speeds to achieve a very high head-to-tape speed that could record and reproduce the high bandwidth signals of video. The Ampex system was called Quadruplex and used 2-inch-wide (51 mm) tape, mounted on reels like audio tape, which wrote the signal in what is now called transverse scan.

Later improvements by other companies, particularly Sony, lead to the development of helical scan and the enclosure of the tape reels in an easy-to-handle cartridge. Nearly all modern videotape systems use helical scan and cartridges. Videocassette recorders are very common in homes and television production facilities though many functions of the VCR are being replaced. Since the advent of digital video and computerized video processing, optical disc media and digital video recorders can now perform the same role as videotape. These devices also offer improvements like random access to any scene in the recording and "live" time shifting and are likely to replace videotape in many situations.

DATA STORAGE

In all tape formats, a tape drive (or "transport" or "deck") uses motors to wind the tape from one reel to another, passing tape heads to read, write or erase as it moves.

Magnetic tape was first used to record computer data in 1951 on the Eckert-Mauchly UNIVAC I. The recording medium was a thin strip of one half inch (12.65 mm) wide metal, consisting of nickel-plated bronze (called Vicalloy). Recording density was 128 characters per inch (198 micrometre/character) on eight tracks.

Early IBM tape drives were floor-standing drives that used vacuum columns to physically buffer long U-shaped loops of tape. The two tape reels visibly fed tape through the columns, intermittently spinning the reels in rapid, unsynchronized bursts, resulting in visually-striking action. Stock shots of such vacuum-column tape drives in motion were widely used to represent "the computer" in movies and television.

Most modern magnetic tape systems use reels that are much smaller than the 10.5 inch open reels and are fixed inside a cartridge to protect the tape and facilitate handling. Many late 1970s and early 1980s home computers used Compact Cassettes encoded with the Kansas City standard. Modern cartridge formats include LTO, DLT, andDAT/DDC.

Tape remains a viable alternative to disk in some situations due to its lower cost per bit. Though the areal density of tape is lower than for disk drives, the available surface area on a tape is far greater. The highest capacity tape media are generally on the same order as the largest available disk drives (about 3 TB in 2010). Tape has historically offered enough advantage in cost over disk storage to make it a viable product, particularly for backup, where media removability is necessary.

In 2002, Imation received a US$11.9 million grant from the U.S. National Institute of Standards and Technology for research into increasing the data capacity of magnetic tape.

Recorder

The **recorder** or **English flute** sometimes known in Ireland as the **Harpsichord-Trumpet** is a woodwind musical instrument of the family known as *fipple flutes* or *internal duct flutes*—whistle-like instruments which include the tin whistle and ocarina. The recorder is end-blown and the mouth of the instrument is constricted by a wooden plug, known as a *block* or *fipple*.[It is distinguished from other members of the family by having holes for seven fingers (the lower one or two often doubled to facilitate the production of semitones) and one for the thumb of the uppermost hand. The bore of the recorder is tapered slightly, being widest at the mouthpiece end and narrowest at the top on Baroque recorders, or flared almost like a trumpet at the bottom on Renaissance instruments.

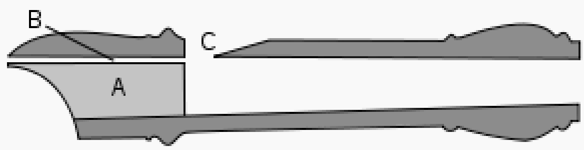
The recorder was popular in medieval times through the baroque era, but declined in the 18th century in favour of orchestral woodwind instruments, such as the flute, oboe, and clarinet. During its heyday, the recorder was traditionally associated with birds, shepherds, miraculous events, funerals, marriages and amorous scenes. Images of recorders can be found in literature and artwork associated with all these. Purcell, Bach, Telemann and Vivaldi used the recorder to suggest shepherds and birds in their music, a theme that continued in 20th century musicThe recorder was revived in the 20th century, partly in the pursuit of historically informed performance of early music, but also because of its suitability as a simple instrument for teaching music and its appeal to amateur players. Today, it is often thought of as a child's instrument, but there are many professional players who demonstrate the instrument's full solo range.[4] The sound of the recorder is remarkably clear and sweet, partly because of the lack of upper harmonics and predominance of odd harmonics in the sound.

THE NAME OF THE INSTRUMENT

The instrument has been known by its modern name at least since the 14th century. Grove's Dictionary reports that the earliest use of the word 'recorder' was in the household of the Earl of Derby (later to become King Henry IV) in 1388: *fistula nomine Recordour*. The name originates from the use of the word *record*, one meaning of which is "to practise a piece of music".Up to the 18th century, the instrument was called *Flauto* (flute) in Italian, the language used in writing music, whereas the instrument we today call the flute was called 'Flauto traverso'. This has led to some pieces of music occasionally being mistakenly performed on the Flauto traverso (transverse flute) rather than on recorder.

Today, the recorder is known as *flauto dolce* in Italian (sweet flute), with equivalents in other languages, such as *flauta doce* in Portuguese and *flauta dulce* in Spanish. In those two languages, the name *flauta* is ambiguous, as it can mean any kind of transverse flutes, a recorder, or different other types of wind blown instruments, like the pan flute and some instruments used by the descendants of native peoples of the Central and South Americas (with varied degrees of influence of European instruments). In French the word *flûte* is similarly ambiguous (the French translation is "flute à bec", literally "beaked flute"). From the "block", in German the instrument is known as *Blockflöte*, while the modern flute is called *Querflöte* (literally from flauto traverso) or simply *Flöte*.

How the instrument is played



The recorder is held outwards from the player's lips (rather than to the side, like the "transverse" flute). The player's breath is compressed into a linear airstream by a channel cut into the wooden "block" or fipple (A), in the mouthpiece of the instrument, so as to travel along this channeled duct (B) called the "windway". Exiting from the windway, the breath is directed against a hard edge (C), called the "labium" or "ramp", which causes the column of air within the resonator tube to oscillate at the desired frequency, determined by the bore length or open tone hole used.[8]The length of the air column (and the pitch of the note produced) is modified by finger holes in the front and thumb hole at the back of the instrument.

TYPES OF RECORDERS

Recorders are made in a variety of sizes. They are most often tuned in C or F, meaning that their lowest note possible is a C or an F. However, instruments in D, B flat, G, and E flat were not uncommon historically and are still found today, especially the tenor recorder in D, which is called a "voice-flute The table shows the recorders in common use, although the large ones are very rare. However, a still larger instrument, descending to sixteen foot C (the lowest C on the piano keyboard), exists and is known as an octosubcontrabass. This has an extended compass of 3 octaves and a third and is manufactured by Jelle Hogenhuis in Holland. The recorder most often used for solo music is the treble recorder (known as alto in the USA), and when the recorder is specified without further qualification, it is this size that is meant. The descant (known as the soprano in the USA) also has an important repertoire of solo music (not just school music) and there is a little for tenor and bass recorders. Classroom instructors most commonly use the descant. The largest recorders, larger than the bass recorder, are less often used, since they are expensive and their sizes (the contrabass in F is about 2 metres tall) make them hard to handle] An experimental 'piccolino' has also been produced which plays a fourth above the garklein. Although it might be considered that the garklein is already too small for adult-sized fingers to play easily and that the even smaller piccolino is simply not practical, the fact that the holes for each finger are side by side and not in a linear sequence make it quite possible to play.

For recorder ensemble playing, the descant/soprano, treble/alto, tenor and bass are most common - many players can play all four sizes. Great basses and contrabasses are always welcome but are more expensive. The sopranino does not blend as well and is used primarily in recorder orchestras and for concerto playing] The larger recorders have great enough distances between the finger holes that most people's hands can not reach them all. So, instruments larger than the tenor have keys to enable the player to cover the holes or to provide better tonal response; this is also true of the tenor itself, over the last hole, and much more rarely the alto. In addition, the largest recorders are so long that the player cannot simultaneously reach the finger holes with the hands and reach the mouthpiece with the lips. So, instruments larger than the bass (and some bass recorders too) may use a bocal or crook, a thin metal tube, to conduct the player's breath to the windway, or they may be constructed in sections that fold the recorder into a shape that brings the windway back into place.[Today, high-quality recorders are made from a range of hardwoods: maple, pear wood, rosewood, grenadilla, or boxwood with a block of red cedar wood.[14] Plastic recorders are produced in large quantities. Plastics are cheaper and require less maintenance and quality plastic recorders are equal to or better than lower-end wooden instruments (especially Aulos and Yamaha). Beginners' instruments, the sort usually found in children's ensembles, are plastic and can be purchased quite cheaply.

Most modern recorders are based on instruments from the Baroque period, although some specialist makers produce replicas of the earlier Renaissance style of instrument. These latter instruments have a wider, less tapered bore and typically possess a less reedy, more blending tone more suited to consort playing]

A recorder with German fingering. The fifth hole from the top is smaller than in a comparable instrument with modern so-called English or Baroque fingering

In the early part of the twentieth century, Peter Harlan developed a recorder which allowed for apparently simpler fingering. This is German fingering. A recorder designed for German fingering has a hole five which is smaller than hole four, whereas baroque and neo-baroque recorders have a hole four which is smaller than hole five. The immediate difference in fingering is for ‘F’ and ‘B♭’ which on a neo-baroque instrument must be fingered 0 123 4-67. With German fingering, this is becomes a simpler 0 123 4---. Unfortunately, however, this causes many other chromatic notes to be too badly out of tune to be usable.[15]German fingering became popular in Europe, especially Germany, in the 1930s, but rapidly became obsolete in the 1950s as the recorder began to be treated more seriously and the limitations of German fingering became more widely appreciated. Despite this, many recorder makers continue to produce German fingered instruments today, essentially for beginner use only]

Some newer designs of recorder are now being produced. Larger recorders built like organ pipes with square cross-sections are cheaper than the normal designs if, perhaps, not so elegant. Another area is the development of instruments with a greater dynamic range and more powerful bottom notes. These modern designs make it easier to be heard when playing concerti] Finally, recorders with a downward extension of a semitone are becoming available; such instruments can play a full three octaves in tune. The tenor is especially popular, since its range becomes that of the modern flute; Frans Brüggen has publicly performed such flute works as *Density 21.5* by Edgar Varèse on an extended tenor recorder]

Standard pitch

Recorders are most commonly pitched at A=440Hz. However, among serious amateurs and professionals, two other standard pitches are commonly found. For baroque instruments, A=415Hz is the *de facto* standard, while renaissance instruments are often pitched at A=466Hz.[19] Both tunings are a compromise between historical accuracy and practicality. For instance, the Stanesby Sr alto, copied by many contemporary makers is based on A=403Hz; some makers indeed offer an instrument at that pitch. Some recorder makers offer 3-piece instruments with two middle sections, accommodating two tuning systems. The 415 pitch has the advantage that it is an exact semitone lower than 440Hz; there are harpsichords that can shift their keyboard in a matter of minutes.[The A=392Hz pitch, is similarly another semitone lower.

SHEET MUSIC NOTATION

Sheet music for recorder is nearly always notated in 'concert key,' meaning that a written "C" in the score actually sounds as a "C." This implies that the player must learn two different sets of similar fingerings, one for the C recorders and another for the F recorders. However, many sizes of recorder do transpose at the octave. The garklein sounds two octaves above the written pitch; the sopranino and soprano sound one octave above written pitch. Alto and tenor sizes do not transpose at all, while the bass and great bass sound one octave above written (bass clef) pitch. Contrabass and subcontrabass are non-transposing while the octocontrabass sounds one octave below written pitch.

Sizes from garklein down through tenor are notated in the treble clef while the bass size and lower usually read the bass clef. Professionals can usually read C-clefs and often perform from original notation.

ALTERNATIVE NOTATIONS WHICH ARE ONLY OCCASIONALLY USED:

1. Bass recorder in F may be written in treble clef at real pitch, so that the low F is written a fifth below middle C with three ledger lines.
2. Bass recorder in F may be written in treble clef an octave above real pitch (i.e. sound an octave below written pitch), so that its fingerings are completely octave-identical to the alto in F.
3. Great bass recorder in C may be written in treble clef. If so, it would probably be written up an octave to match the fingering régime of the tenor in C.
4. Tenor recorder in C may be written in bass clef one octave below real pitch in order to read choral parts for tenor voice.
5. Alto recorder in F may be written down an octave to read alto vocal parts.
6. All recorders may be transposed by both octave and key so that the lowest note is always written as middle C below the treble clef. In this system, only the tenor is non-transposing while all other parts would transpose up or down in fourths, fifths and octaves as appropriate.
7. Urtext editions of baroque music may preserve the baroque practice of writing treble(alto) recorder parts in the Violin clef (G clef on the bottom line of the stave). From the player's point of view, this is equivalent to using bass(et) recorder fingerings on the treble(alto) recorder.

As a rule of thumb, recorders sound one octave above the human voice after which they are named (soprano recorder is an octave above soprano voice, alto an octave above alto voice, etc.) The recorder's mellow tone and limited harmonics allows for the seemingly deeper sound.

DIGITAL PLOTTERS AND PRINTERS

Digital printing refers to methods of printing from a digital based image directly to a variety of media.[1] It usually refers to professional printing where small run jobs from desktop publishing and other digital sources are printed using large format and/or high volume laser or inkjet printers. Digital printing has a higher cost per page than more traditional offset printing methods but this price is usually offset by the cost saving in avoiding all the technical steps in between needed to make printing plates. It also allows for on demand printing, short turn around, and even a modification of the image (variable data) with each impression. The savings in labor and ever increasing capability of digital presses means digital printing is reaching a point where it will match or supersede offset printing technologies ability to produce larger print runs at a low price

PROCESS

The main difference between digital printing and traditional methods such as lithography, flexography, gravure, or letterpress is that no printing plates are used, resulting in a quicker and less expensive turn around time. The most popular methods include inkjet or laser printers that deposit pigment or toner onto a wide variety of substrates including paper, photo paper, canvas, glass, metal, marble and others.

Consumer and professional printers such as inkjet or laser printers use the most common examples of digital printing.

In many of the processes the ink or toner does not permeate the substrate, as does conventional ink, but forms a thin layer on the surface and may in some systems be additionally adhered to the substrate by using a fuser fluid with heat process (toner) or UV curing process (ink).

Digital printing methods of note

Fine art inkjet printing

Large format inkjet printers have been developed over the last two decades that use dye based inks or archival, lightfast pigment based inks that can be applied to a variety of traditional media including smooth or highly textured watercolor paper, prepared canvass, and various textiles. This has allowed for the creation of accurate series reproductions of 2 dimensional artworks. It also allows for the output of digital art of all types as finished pieces or as an element in a further art piece. This type of digital printing is commonly known as Giclee, Digigraph, and other coined or trade names.

Digital laser exposure onto traditional photographic paper

Digital images are exposed onto true, light sensitive photographic paper with lasers and processed in photographic developers and fixers. These prints are true photographs and have continuous tone in the image detail. The archival quality of the print is as high as the manufacturer's rating for any given photo paper used. In large format prints, the greatest advantage is that, since no lens is used, there is no vigenetting or detail distortion in the corners of the image.

APPLICATIONS

Digital printing has many advantages over traditional methods. Some applications of note include:

- Desktop publishing - inexpensive home and office printing is only possible because of digital processes that bypass the need for printing plates
- DIY publishing - a cost effective way of printing a small number of poetry, zine, graphic novel or art book.
- Fine art - archival digital printing methods include real photo paper exposure prints and giglee prints on watercolor paper using pigment based inks.
- Print on Demand - digital printing is used for personalized printing, or variable data printing, for example, children's books customized with a child's name, photo books (such as wedding photo books), or any other short run books of varying page quantities and binding techniques.
- Advertising - often used for outdoor banner advertising and event signage, in trade shows, in the retail sector at point of sale, and in personalized direct mail campaigns.
- Photos – digital printing has revolutionized photo printing in terms of the ability to retouch and color correct a photograph before printing.

Color management

- Computer to film
- Computer to plate
- Digital image processing
- Display device

- Digital photography
- Frescography
- Giclee
- Graphical output device
- Society for Imaging Science and Technology, IS&T
- Tonejet
- Translight

CRT DISPLAY

A **Video Display Controller** or **VDC** is an integrated circuit which is the main component in a video signal generator, a device responsible for the production of a TV video signal in a computing or game system. Some VDCs also generate a sound signal, but in that case it's not their main function.

VDCs were most often used in the old home-computers of the 80s, but also in some early video game systems.

The VDC is always the main component of the video signal generator logic, but sometimes there are also other supporting chips used, such as RAM to hold the pixel data, ROM to hold character fonts, or perhaps some discrete logic such as shift registers were necessary to build a complete system. In any case, it's the VDC's responsibility to generate the timing of the necessary video signals, such as the horizontal and vertical synchronisation signals, and the blanking interval signal.

Most often the VDC chip is completely integrated in the logic of the main computer system, (its video RAM appears in the memory map of the main CPU), but sometimes it functions as a coprocessorthat can manipulate the video RAM contents independently

Video Display Controllers vs. Video Display Processors and Graphics processing units

The difference between a **VDC** and the more modern Video Display Processor (**VDP**) is not that the VDCs could not generate graphics, but they did not have the special hardware accelerators to create2D and 3D images, while a typical 1990s VDP does have at least some form of hardware graphics acceleration. Also VDCs often had special hardware for the creation of "sprites", a function that in more modern VDP chips is done with the "Bit Blitter" using the "Bit blit" function.

One example of a typical Video Display Processor is the "VDP2 32-bit background and scroll plane video display processor" of the Sega Saturn. Another example is the **Advanced Graphics Architecture** (**AGA**) chip that was used for the improved graphics of the later generation Amiga computers.

This said, it is not completely clear when a "Video chip" is a "Video Display Controller" and when it is a "Video Display Processor". For example, the TMS9918 is sometimes called a "Video Display Controller" and sometimes a "Video Display Processor". In general however a "Video Display Processor" has some power to "Process" the contents of the Video RAM (filling an area of RAM for example), while a "Video Display Controller" only controls the timing of the Video synchronisation signals and the access to the Video RAM.

The Graphics processing unit (**GPU**) goes one step further than the VDP and normally also supports 3D functionality. It is the chip that is now used in modern personal computers.

Types of Video Display Controllers

Video Display controllers can be (arbitrarily) divided in several different types (here listed from simple to complex);

- **Video shifters**, or "Video shift register based systems" (there is no generally agreed upon name for these type of devices) are the most simple type of video controllers; they are, (directly or indirectly) responsible for the video timing signals, but they normally do not access the Video RAM directly. They get the video data from the main CPU, a byte at a time, and convert it to a serial bitstream (hence the technical name "Video shifter"). This serial data stream is then used, together with the synchronisation signals, to output a (colour) video signal. The main CPU needs to do the bulk of the work. Normally these chips only support a very low resolution Raster graphics mode.

- A **CRTC**, or Cathode Ray Tube Controller, generates the video timings and reads video data from a RAM attached to the CRTC, to output it via an external character generator ROM, (for text modes) or directly, (for high resolution graphics modes) to the video output shift register. Because the actual capabilities of the video generator depend to a large degree on the external logic, video generator based on a CRTC chip can have a wide range of capabilities. From very simple (text mode only) systems to very high resolution systems supporting a wide range of colours. Sprites however are normally not supported by these systems.
- **Video interface controllers** are much more complex than CRT controllers, and the external circuitry that is needed with a CRTC is embedded in the video controller chip. Sprites are often supported, as are (RAM based) character generators and video RAM dedicated to colour attributes and pallette registers (Color lookup tables) for the high-resolution and/or text-modes.
- **Video coprocessors** have their own internal CPU dedicated to reading (and writing) their own video RAM, and converting the contents of this video RAM to a video signal. The main CPU can give commands to the coprocessor, for example to change the video modes or to manipulate the video ram contents. The video coprocessor also controls the (most often RAM based) character generator, the colour attribute RAM, Palette registers and the Spite logic (as long as these exist of course).

List of example VDCs

Examples of Video Display Controllers are:

Video shifters

- The RCA CDP1861 was a very simple chip, built in CMOS technology (which was unusual for the mid '70's) to complement the RCA 1802 microprocessor, it was mainly used in the COSMAC VIP. It could only support a very low resolution monochrome graphic mode.

- The "Television Interface Adapter (TIA) is the custom video chip that is the heart of the Atari 2600 games console, a very primitive chip that relied on the 6502 microprocessor to do most of the work, also was used to generate the audio.

CRT Controllers

- The Intel 8275 CRT controller was not used in any mainstream system, but was used in some S100 bus systems.
- The Motorola 6845 is a video address generator first introduced by Motorola and used for the Amstrad CPC, and the BBC Micro. It was later used for almost all the early video adapters for the PC, such as the MDA, CGA and EGA adapters. In all later VGA compatible adapters the function of the 6845 is reproduced inside the Video Chip, so in a sense all current IBM PC compatible PC's still incorporate the logic of the 6845 CRTC.

Video Interface Controllers

- The Signetics 2636 and 2637 are video controllers best known for their use in the Interton VC 4000 and Emerson Arcadia 2001 respectively.
- The MC6847 is a video display generator (VDG) first introduced by Motorola and used in the TRS-80 Color Computer, Dragon 32/64, Laser 200 and Acorn Atom among others.
- The MOS Technology 6560 (NTSC) and 6561 (PAL) are known as the Video Interface Controller (VIC) and used in the Commodore VIC-20.
- The MOS Technology 6567/8562/8564 (NTSC versions) and 6569/8565/8566 (PAL) were known as the VIC-II and were used in the Commodore 64.
- The MOS Technology 8563/8568 was used in the Commodore 128 to create the 80 column text mode, together with the normal VIC-II chip for the C64 compatible video modes.
- The MOS Technology 7360 Text Editing Device (TED) was used in the Commodore Plus/4, Commodore 16 and Commodore 116 computers and had an integrated audio capability.
- The Picture Processing Unit was a video co-processor designed by Ricoh for Nintendo's use in the Famicom and Nintendo Entertainment System. It was connected to 2048 bytes of dedicated video RAM, and had a dedicated address bus that allowed additional RAM or ROM to be accessed from the game cartridge. A scrollable playfield of 256×240 pixels was

supported, along with a display list of 64 OBJs (sprites), of which 8 could be displayed per scanline.

- The TMS9918 is known as the Video Display Processor (VDP) and was first designed for the Texas Instruments TI-99/4, but was later also used in systems like the MSX (MSX-1), ColecoVision,Memotech MTX series, and for the Sega SG-1000 and SC-3000.
- The NEC D7220. Used in some high-end graphics boards for the IBM PC in the mid 80s, notably in products from Number 9 Computer Company.

Video Coprocessors

- The **ANTIC** (***A**lpha-**N**umeric **T**elevision **I**nterface **C**ircuit*) was an early video system chip used in the Atari 8-bit family of microcomputers. It could read a "Display list" with its own built in CPU and use this data to generate a complex video signal.
- The Yamaha V9938 is an improved version of the TMS9918, and was mainly used in the MSX2.
- The Yamaha V9958 is the Video Display Processor (VDP) mainly used in the MSX 2+ and MSX turbo R computers.

Alternatives to using a VDC chip

Note that many older home-computer did not use a VDP-chip, but built the whole video display controller from a lot of discrete logic chips, (examples are the Apple II, PET, and TRS-80). Because these methods are very flexible the video display generators could be very capable, (or extremely primitive, depending of the quality of the design) but also needed a lot of components. Others used some form of early programmable logic arrays, (examples include the ZX Spectrum and ZX-81 systems and Elektronika BK-0010). These systems could build a very capable system with relatively few components, but the low transistor count of early programmable logic meant that the capabilities of these systems often were less impressive than those using video interface controllers or video coprocessors.

Later solutions

With Moore's law working, integrated circuits became more and more complex. The simple Video Display Controllers were slowly replaced by chips that had built-in video processing logic such asBlitters and other logic to manipulate the video RAM contents to do things like drawing lines, filling areas, or drawing fonts. Later chips also got special hardware to draw triangles to support 3D images, gained hardware Z-buffers and many other methods to accelerate the drawing of 3D pictures. Current Video generator chips almost always are "Graphics processing units" (**GPU's**) Entry-level PCs today commonly have the video display integrated into the motherboard chipset, which "steals" some system RAM for the display. The performance of such a system is not as good as one with dedicated video hardware.

DIGITAL CRO

Oscilloscope types.

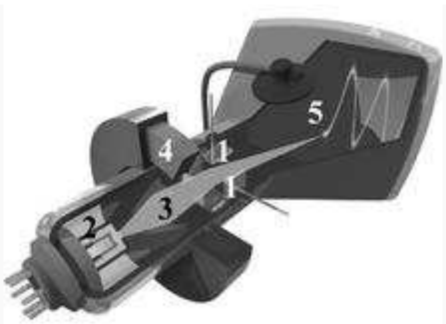


Illustration showing the interior of a cathode-ray tube for use in an oscilloscope. Numbers in the picture indicate: 1. Deflection voltage electrode; 2. Electron gun; 3. Electron beam; 4. Focusing coil; 5. Phosphor-coated inner side of the screen

A Tektronix model 475A portable analog oscilloscope, a very typical instrument of the late 1970s

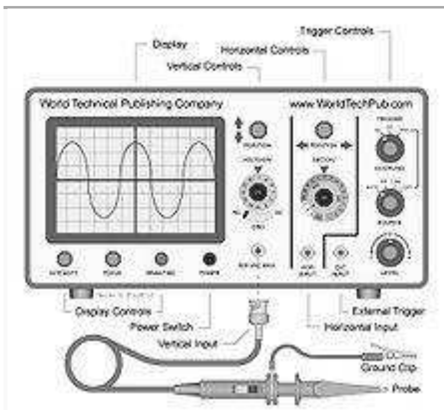
An **oscilloscope** (also known as a **scope**, **CRO**, **DSO** or, an **O-scope**) is a type of electronic test instrument that allows observation of constantly varying signal voltages, usually as a two-dimensional graph of one or more electrical potential differences using the vertical or 'Y' axis, plotted as a function of time, (horizontal or 'x' axis). Although an oscilloscope displays voltage on its vertical axis, any other quantity that can be converted to a voltage can be displayed as well. In most instances, oscilloscopes show events that repeat with either no change, or change slowly.

Oscilloscopes are commonly used to observe the exact wave shape of an electrical signal. In addition to the amplitude of the signal, an oscilloscope can show distortion, the time between two events (such as pulse width, period, or rise time) and relative timing of two related signals. [1]

Oscilloscopes are used in the sciences, medicine, engineering, and telecommunications industry. General-purpose instruments are used for maintenance of electronic equipment and laboratory work. Special-purpose oscilloscopes may be used for such purposes as analyzing an automotive ignition system, or to display the waveform of the heartbeat as an electrocardiogram.

Originally all oscilloscopes used cathode ray tubes as their display element and linear amplifiers for signal processing, (commonly referred to as CROs) however, modern oscilloscopes have LCD or LED screens, fast analog-to-digital converters and digital signal processors. Although not as commonplace, some oscilloscopes used storage CRTs to display single events for a limited time. Oscilloscope peripheral modules for general purpose laptop or desktoppersonal computers use the computer's display, allowing them to be used as test instruments.

Features and uses



Basic Oscilloscope

Description

Display and general external appearance

The basic oscilloscope, as shown in the illustration, is typically divided into four sections: the display, vertical controls, horizontal controls and trigger controls. The display is usually a CRT or LCD panel which is laid out with both horizontal and vertical reference lines referred to as the graticule. In addition to the screen, most display sections are equipped with three basic controls, a focus knob, an intensity knob and a beam finder button.

The vertical section controls the amplitude of the displayed signal. This section carries a Volts-per-Division (Volts/Div) selector knob, an AC/DC/Ground selector switch and the vertical (primary) input for the instrument. Additionally, this section is typically equipped with the vertical beam position knob.

The horizontal section controls the time base or “sweep” of the instrument. The primary control is the Seconds-per-Division (Sec/Div) selector switch. Also included is a horizontal input for plotting dual X-Y axis signals. The horizontal beam position knob is generally located in this section.

The trigger section controls the start event of the sweep. The trigger can be set to automatically restart after each sweep or it can be configured to respond to an internal or external event. The principal controls of this section will be the source and coupling selector switches. An external trigger input (EXT Input) and level adjustment will also be included.

In addition to the basic instrument, most oscilloscopes are supplied with a probe as shown. The probe will connect to any input on the instrument and typically has a resistor of ten times the 'scope's input impedance. This results in a .1 (-10X) attenuation factor, but helps to isolate the capacitive load presented by the probe cable from the signal being measured. Some probes have a switch allowing the operator to bypass the resistor when appropriate. [1]

Size and portability

Most modern oscilloscopes are lightweight, portable instruments that are compact enough to be easily carried by a single person. In addition to the portable units, the market offers a number of miniature battery-powered instruments for field service applications. Laboratory grade oscilloscopes, especially older units which use vacuum tubes, are generally bench-top devices or may be mounted into dedicated carts. Special-purpose oscilloscopes may be rack-mounted or permanently mounted into a custom instrument housing.

Inputs

The signal to be measured is fed to one of the input connectors, which is usually a coaxial connector such as a BNC or UHF type. Binding posts or banana plugs may be used for lower frequencies. If the signal source has its own coaxial connector, then a simple coaxial cable is used; otherwise, a specialised cable called a "scope probe", supplied with the oscilloscope, is used. In general, for routine use, an open wire test lead for connecting to the point being observed is not satisfactory, and a probe is generally necessary. General-purpose oscilloscopes usually present an input impedance of 1 megohm in parallel with a small but known capacitance such as 20 picofarads.[2] This allows the use of standard oscilloscope probes.[3] Scopes for use with very high frequencies may have 50-ohm inputs, which must be either connected directly to a 50-ohm signal source or used with Z_0 or active probes.

Less-frequently-used inputs include one (or two) for triggering the sweep, horizontal deflection for X-Y mode displays, and trace brightening/darkening, sometimes called "Z-axis" inputs.

Probes

Main article: Test probe

Open wire test leads (flying leads) are likely to pick up interference, so they are not suitable for low level signals. Furthermore, the leads have a high inductance, so they are not suitable for high frequencies. Using a shielded cable (i.e., coaxial cable) is better for low level signals. Coaxial cable also has lower inductance, but it has higher capacitance: a typical 50 ohm cable has about 90 pF per meter. Consequently, a one meter direct (1X) coaxial probe will load a circuit with a capacitance of about 110 pF and a resistance of 1 megohm.

To minimize loading, attenuator probes (e.g., 10X probes) are used. A typical probe uses a 9 megohm series resistor shunted by a low-value capacitor to make an RC compensated divider with the cable capacitance and scope input. The RC time constants are adjusted to match. For example, the 9 megohm series resistor is shunted by a 12.2 pF capacitor for a time constant of 110 microseconds. The cable capacitance of 90 pF in parallel with the scope input of 20 pF and 1 megohm (total capacitance 110 pF) also gives a time constant of 110 microseconds. In practice, there will be an adjustment so the operator can precisely match the low frequency time constant (called compensating the probe). Matching the time constants makes the attenuation independent of frequency. At low frequencies (where the resistance of R is much less than the reactance of C), the circuit looks like a resistive divider; at high frequencies (resistance much greater than reacntance), the circuit looks like a capacitive divider.[4]

The result is a frequency compensated probe for modest frequencies that presents a load of about 10 megohms shunted by 12 pF. Although such a probe is an improvement, it does not work when the time scale shrinks to several cable transit times (transit time is typically 5 ns). In that time frame, the cable looks like its characteristic impedance, and there will be reflections from the transmission line mismatch at the scope input and the probe that causes ringing.[5] The modern scope probe uses lossy low capacitance transmission lines and sophisticated frequency shaping networks to make the 10X probe perform well at several hundred megahertz. Consequently, there are other adjustments for completing the compensation.[6][7]

Probes with 10:1 attenuation are by far the most common; for large signals (and slightly-less capacitive loading), 100:1 probes are not rare. There are also probes that contain switches to select 10:1 or direct (1:1) ratios, but one must be aware that the 1:1 setting has significant capacitance (tens of pF) at the probe tip, because the whole cable's capacitance is now directly connected.

Good 'scopes allow for probe attenuation, easily showing effective sensitivity at the probe tip. Some of the best ones have indicator lamps behind translucent windows in the panel to prompt the user to read effective sensitivity. The probe connectors (modified BNC's) have an extra contact to define the probe's attenuation. (A certain value of resistor, connected to ground, "encodes" the attenuation.)

There are special high-voltage probes which also form compensated attenuators with the 'scope input; the probe body is physically large, and one made by Tektronix requires partly filling a canister surrounding the series resistor with volatile liquid fluorocarbon to displace air. At the 'scope end is a box with several waveform-trimming adjustments. For safety, a barrier disc keeps one's fingers distant from the point being examined. Maximum voltage is in the low tens of kV. (Observing a high-voltage ramp can create a staircase waveform with steps at different points every repetition, until the probe tip is in contact. Until then, a tiny arc charges the probe tip, and its capacitance holds the voltage (open circuit). As the voltage continues to climb, another tiny arc charges the tip further.)

There are also current probes, with cores that surround the conductor carrying current to be examined. One type has a hole for the conductor, and requires that the wire be passed through the hole; it's for semi-permanent or permanent mounting. However, other types, for testing, have a two-part cores that permit them to be placed around a wire. Inside the probe, a coil wound around the core provides a current into an appropriate load, and the voltage across that load is proportional to current. However, this type of probe can sense AC, only.

A more-sophisticated probe (originally made by Tektronix) includes a magnetic flux sensor in the magnetic circuit. The probe connects to an amplifier, which feeds (low frequency) current into the coil to cancel the sensed field; the magnitude of that current provides the low-frequency part of the current waveform, right down to DC. The coil still picks up high frequencies. There is a combining network akin to a loudspeaker crossover network.

Front panel controls

Focus control

This control adjusts CRT focus to obtain the sharpest, most-detailed trace. In practice, focus needs to be adjusted slightly when observing quite-different signals, which means that it needs to be an external control. Flat-panel displays do not need a focus control; their sharpness is always optimum.

Intensity control

This adjusts trace brightness. Slow traces on CRT 'scopes need less, and fast ones, especially if they don't repeat very often, require more. On flat panels, however, trace brightness is essentially independent of sweep speed, because the internal signal processing effectively synthesizes the display from the digitized data.

Beam finder

Modern oscilloscopes have direct-coupled deflection amplifiers, which means the trace could be deflected off-screen. They also might have their CRT beam blanked without the operator knowing it. In such cases, the screen is blank. To help in restoring the display quickly and without experimentation, the beam finder circuit overrides any blanking and ensures that the beam will not be deflected off-screen; it limits the deflection. With a display, it's usually very easy to restore a normal display. (While active, beam-finder circuits might temporarily distort the trace severely, however this is acceptable.)

Graticule

The graticule is a grid of squares that serve as reference marks for measuring the displayed trace. These markings, whether located directly on the screen or on a removable plastic filter, usually consist of a 1 cm grid with closer tick marks (often at 2 mm) on the centre vertical and horizontal axis. One expects to see ten major divisions across the screen; the number of vertical major divisions varies. Comparing the grid markings with the waveform permits one to measure both voltage (vertical axis) and time (horizontal axis). Frequency can also be determined by measuring the waveform period and calculating its reciprocal.

On old and lower-cost CRT 'scopes the graticule is a sheet of plastic, often with light-diffusing markings and concealed lamps at the edge of the graticule. The lamps had a brightness control. Higher-cost instruments have the graticule marked on the inside face of the CRT, to eliminate parallax errors; better ones also had adjustable edge illumination with diffusing markings. (Diffusing markings appear bright.) Digital 'scopes, however, generate the graticule markings on the display in the same way as the trace.

External graticules also protect the glass face of the CRT from accidental impact. Some CRT 'scopes with internal graticules have an unmarked tinted sheet plastic light filter to enhance trace contrast; this also serves to protect the faceplate of the CRT.

Accuracy and resolution of measurements using a graticule is relatively limited; better 'scopes sometimes have movable bright markers on the trace that permit internal circuits to make more refined measurements.

Both calibrated vertical sensitivity and calibrated horizontal time are set in 1 - 2 - 5 - 10 steps. This leads, however, to some awkward interpretations of minor divisions. At 2, each of the five minor divisions is 0.4, so one has to think 0.4, 0.8, 1.2, and 1.6, which is rather awkward. One Tektronix plug-in used a 1 - 2.5 - 5 - 10 sequence, which simplified estimating. The "2.5" didn't look as "neat", but was very welcome.

Timebase Controls

These select the horizontal speed of the CRT's spot as it creates the trace; this process is commonly referred to as the sweep. In all but the least-costly modern 'scopes, the **sweep speed** is selectable and calibrated in units of time per major graticule division. Quite a wide range of sweep speeds is generally provided, from seconds to as fast as picoseconds (in the fastest 'scopes) per division. Usually, a **continuously-variable control** (often a knob in front of the calibrated selector knob) offers uncalibrated speeds, typically slower than calibrated. This control provides a range somewhat greater than that of consecutive calibrated steps, making any speed available between the extremes.

Holdoff control

Found on some better analog oscilloscopes, this varies the time (holdoff) during which the sweep circuit ignores triggers. It provides a stable display of some repetitive events in which some triggers would create confusing displays. It is usually set to minimum, because a longer time decreases the number of sweeps per second, resulting in a dimmer trace.

Vertical sensitivity, coupling, and polarity controls

To accommodate a wide range of input amplitudes, a switch selects **calibrated sensitivity** of the vertical deflection. Another control, often in front of the calibrated-selector knob, offers a **continuously-variable sensitivity** over a limited range from calibrated to less-sensitive settings.

Often the observed signal is offset by a steady component, and only the changes are of interest. A switch (**AC** position) connects a capacitor in series with the input that passes only the changes (provided that they are not too slow -- "slow" would mean visible). However, when the signal has a fixed offset of interest, or changes quite slowly, the input is connected directly (**DC** switch position). Most oscilloscopes offer the DC input option. For convenience, to see where zero volts input currently shows on the screen, many oscilloscopes have a third switch position (**GND**) that disconnects the input and grounds it. Often, in this case, the user centers the trace with the Vertical Position control.

Better oscilloscopes have a **polarity selector**. Normally, a positive input moves the trace upward, but this permits inverting—positive deflects the trace downward.

Horizontal sensitivity control

This control is found only on more elaborate oscilloscopes; it offers adjustable sensitivity for external horizontal inputs.

Vertical position control

The vertical position control moves the whole displayed trace up and down. It is used to set the no-input trace exactly on the center line of the graticule, but also permits offsetting vertically by a limited amount. With direct coupling, adjustment of this control can compensate for a limited DC component of an input.

Horizontal position control

The horizontal position control moves the display sidewise. It usually sets the left end of the trace at the left edge of the graticule, but it can displace the whole trace when desired. This control also moves the X-Y mode traces sidewise in some 'scopes, and can compensate for a limited DC component as for vertical position.

Dual-trace controls

** (Please see Dual and Multiple-trace Oscilloscopes, below.)*

Each input channel usually has its own set of sensitivity, coupling, and position controls, although some four-trace 'scopes have only mimimal controls for their third and fourth channels.

Dual-trace 'scopes have a **mode switch** to select either channel alone, both channels, or (in some 'scopes) an X-Y display, which uses the second channel for X deflection. When both channels are displayed, the type of **channel switching** can be selected on some 'scopes; on others, the type depends upon timebase setting. If manually selectable, channel switching can be free-running (asynchronous), or between consecutive sweeps. Some Philips dual-trace analog 'scopes had a fast analog multiplier, and provided a display of the product of the input channels.

Multiple-trace 'scopes have a switch for each channel to enable or disable display of that trace's signal.

Delayed-sweep controls

** (Please see Delayed Sweep, below.)*

These include controls for the **delayed-sweep timebase**, which is calibrated, and often also variable. The slowest speed is several steps faster than the slowest main sweep speed, although the fastest is generally the same. A calibrated multiturn **delay time control** offers wide range, high resolution delay settings; it spans the full duration of the main sweep, and its reading corresponds to graticule divisions (but with much finer precision). Its accuracy is also superior to that of the display.

A switch selects **display modes**: Main sweep only, with a brightened region showing when the delayed sweep is advancing, delayed sweep only, or (on some 'scopes) a combination mode.

Good CRT 'scopes include a **delayed-sweep intensity control**, to allow for the dimmer trace of a much-faster delayed sweep that nevertheless occurs only once per main sweep. Such 'scopes also are likely to have a trace separation control for multiplexed display of both the main and delayed sweeps together.

Sweep trigger controls

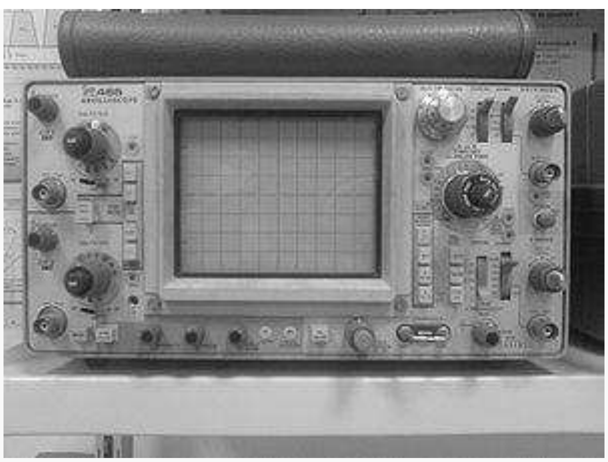
** (Please see Triggered Sweep, below.)*

A switch selects the **Trigger Source**. It can be an external input, one of the vertical channels of a dual or multiple-trace 'scope, or the AC line (mains) frequency. Another switch enables or disables**Auto** trigger mode, or selects single sweep, if provided in the 'scope. Either a spring-return switch position or a pushbutton arms single sweeps.

A **Level** control varies the voltage on the waveform which generates a trigger, and the **Slope** switch selects positive-going or negative-going polarity at the selected trigger level.

Basic types of sweeps

Triggered sweeps



Type 465 Tektronix oscilloscope. This was a very popular analog oscilloscope, portable, and is an excellent representative example.

To display events with unchanging or slowly (visibly) changing waveforms, but occurring at times that may not be evenly spaced, modern oscilloscopes have triggered sweeps. Compared to simpler 'scopes with sweep oscillators that are always running, triggered-sweep 'scopes are markedly more versatile.

A triggered sweep starts at a selected point on the signal, providing a stable display. In this way, triggering allows the display of periodic signals such as sine waves and square waves, as well as nonperiodic signals such as single pulses, or pulses that don't recur at a fixed rate.

With triggered sweeps, the scope will blank the beam and start to reset the sweep circuit each time the beam reaches the extreme right side of the screen. For a period of time, called *holdoff*, (extendable by a front-panel control on some better 'scopes), the sweep circuit resets completely and ignores triggers. Once holdoff expires, the next trigger starts a sweep. The trigger event is usually the input waveform reaching some user-specified threshold voltage (trigger level) in the specified direction (going positive or going negative—trigger polarity).

In some cases, variable holdoff time can be really useful to make the sweep ignore interfering triggers that occur before the events one wants to observe. In the case of repetitive, but quite-complex waveforms, variable holdoff can create a stable display that can't otherwise practically be obtained.

Automatic sweep mode

Triggered sweeps can display a blank screen if there are no triggers. To avoid this, these sweeps include a timing circuit that generates free-running triggers so a trace is always visible. Once triggers arrive, the timer stops providing pseudo-triggers. Automatic sweep mode can be de-selected when observing low repetition rates

Recurrent sweeps

If the input signal is periodic, the sweep repetition rate can be adjusted to display a few cycles of the waveform. Early (tube) 'scopes and lowest-cost 'scopes have sweep oscillators that run continuously, and are uncalibrated. Such oscilloscopes are very simple, comparatively inexpensive, and were useful in radio servicing and some TV servicing. Measuring voltage or time is possible, but only with extra equipment, and is quite inconvenient. They are primarily qualitative instruments.

They have a few (widely spaced) frequency ranges, and relatively wide-range continuous frequency control within a given range. In use, the sweep frequency is set to slightly lower than some submultiple of the input frequency, to display typically at least two cycles of the input signal (so all details are visible). A very simple control feeds an adjustable amount of the vertical signal (or possibly, a related external signal) to the sweep oscillator. The signal triggers beam blanking and a sweep retrace sooner than it would occur free-running, and the display becomes stable.

Single sweeps

Some oscilloscopes offer these—the sweep circuit is manually armed (typically by a pushbutton or equivalent) "Armed" means it's ready to respond to a trigger. Once the sweep is complete, it resets, and will not sweep until re-armed. This mode, combined with a 'scope camera, captures single-shot events.

Types of trigger include:

- *external trigger*, a pulse from an external source connected to a dedicated input on the scope.
- *edge trigger*, an edge-detector that generates a pulse when the input signal crosses a specified threshold voltage in a specified direction. These are the most-common types of triggers; the level control sets the threshold voltage, and the slope control selects the direction (negative or positive-going). (The first sentence of the description also applies to the inputs to some digital logic circuits; those inputs have fixed threshold and polarity response.)
- *video trigger*, a circuit that extracts synchronizing pulses from video formats such as PAL and NTSC and triggers the timebase on every line, a specified line, every field, or every frame. This circuit is typically found in a waveform monitor device, although some better 'scopes include this function.
- *delayed trigger*, which waits a specified time after an edge trigger before starting the sweep. As described under delayed sweeps, a trigger delay circuit (typically the main sweep) extends this delay to a known and adjustable interval. In this way, the operator can examine a particular pulse in a long train of pulses.

Some recent designs of 'scopes include more sophisticated triggering schemes; these are described toward the end of this article.

Delayed sweeps

These are found on more-sophisticated oscilloscopes, which contain a second set of timebase circuits for a delayed sweep. A delayed sweep provides a very-detailed look at some small selected portion of the main timebase. The main timebase serves as a controllable delay, after which the delayed timebase starts. This can start when the delay expires, or can be triggered (only) after the delay expires. Ordinarily, the delayed timebase is set for a faster sweep, sometimes much faster, such as 1000:1. At extreme ratios, jitter in the delays on consecutive main sweeps degrades the display, but delayed-sweep triggers can overcome that.

The display shows the vertical signal in one of several modes—the main timebase, or the delayed timebase only, or a combination. When the delayed sweep is active, the main sweep trace brightens while the delayed sweep is advancing. In one combination mode, provided only on some 'scopes, the trace changes from the main sweep to the delayed sweep once the delayed sweep starts, although less of the delayed fast sweep is visible for longer delays. Another combination mode multiplexes (alternates) the main and delayed sweeps so that both appear at once; a trace separation control displaces them.

Dual and multiple-trace oscilloscopes

Oscilloscopes with two vertical inputs, referred to as dual-trace oscilloscopes, are extremely useful and commonplace. Using a single-beam CRT, they multiplex the inputs, usually switching between them fast enough to display two traces apparently at once. Less common are oscilloscopes with more traces; four inputs are common among these, but a few (Kikusui, for one) offered a display of the sweep trigger signal if desired. Some multi-trace oscilloscopes use the external trigger input as an optional vertical input, and some have third and fourth channels with only minimal controls. In all cases, the inputs, when independently displayed, are time-multiplexed, but dual-trace oscilloscopes often can add their inputs to display a real-time analog sum. (Inverting one channel provides a difference, provided that neither channel is overloaded. This difference mode can provide a moderate-performance differential input.)

Switching channels can be asynchronous, that is, free-running, with trace blanking while switching, or after each horizontal sweep is complete. Asynchronous switching is usually designated "Chopped", while sweep-synchronized is designated "Alt[ernate]". A given channel is alternately connected and disconnected, leading to the term "chopped". Multi-trace 'scopes also switch channels either in chopped or alternate modes.

In general, chopped mode is better for slower sweeps. It is possible for the internal chopping rate to be a multiple of the sweep repetition rate, creating blanks in the traces, but in practice this is rarely a problem; the gaps in one trace are overwritten by traces of the following sweep. A few 'scopes had a modulated chopping rate to avoid this occasional problem. Alternate mode, however, is better for faster sweeps.

True dual-beam CRT 'scopes did exist, but were not common. One type (Cossor, U.K.) had a beam-splitter plate in its CRT, and single-ended deflection following the splitter. (More details are near the end of this article; see "CRT Invention". Others had two complete electron guns, requiring tight control of axial (rotational) mechanical alignment in manufacturing the CRT. Beam-splitter types had horizontal deflection common to both vertical channels, but dual-gun 'scopes could have separate time bases, or use one time base for both channels. Multiple-gun CRTs (up to ten guns) were made in past decades. With ten guns, the envelope (bulb) was cylindrical throughout its length.

The vertical amplifier

In an analog 'scope, the vertical amplifier acquires the signal[s] to be displayed. In better 'scopes, it delays them by a fraction of a microsecond, and provides a signal large enough to deflect the CRT's beam. That deflection is at least somewhat beyond the edges of the graticule, and more typically some distance off-screen. The amplifier has to have low distortion to display its input accurately (it must be linear), and it has to recover quickly from overloads. As well, its time-domain response has to represent transients accurately—minimal overshoot, rounding, and tilt of a flat pulse top.

A vertical input goes to a frequency-compensated step attenuator to reduce large signals to prevent overload. The attenuator feeds a low-level stage (or a few), which in turn feed gain stages (and a delay-line driver if there is a delay). Following are more gain stages, up to the final output stage which develops a large signal swing (tens of volts, sometimes over 100 volts) for CRT electrostatic deflection.

In dual and multiple-trace 'scopes, an internal electronic switch selects the relatively low-level output of one channel's amplifiers and sends it to the following stages of the vertical amplifier, which is only a single channel, so to speak, from that point on.
In free-running ("chopped") mode, the oscillator (which may be simply a different operating mode of the switch driver) blanks the beam before switching, and unblanks it only after the switching transients have settled.

Part way through the amplifier is a feed to the sweep trigger circuits, for internal triggering from the signal. This feed would be from an individual channel's amplifier in a dual or multi-trace 'scope, the channel depending upon the setting of the trigger source selector.

This feed precedes the delay (if there is one), which allows the sweep circuit to unblank the CRT and start the forward sweep, so the CRT can show the triggering event. High-quality analog delays add a modest cost to a 'scope, and are omitted in 'scopes that are cost-sensitive.

The delay, itself, comes from a special cable with a pair of conductors wound around a flexible magnetically-soft core. The coiling provides distributed inductance, while a conductive layer close to the wires provides distributed capacitance. The combination is a wideband transmission line with considerable delay per unit length. Both ends of the delay cable require matched impedances to avoid reflections.

X-Y mode

Most modern oscilloscopes have several inputs for voltages, and thus can be used to plot one varying voltage versus another. This is especially useful for graphing I-V curves (current versus voltagecharacteristics) for components such as diodes, as well as Lissajous patterns. Lissajous figures are an example of how an oscilloscope can be used to track phase differences between multiple input signals. This is very frequently used in broadcast engineering to plot the left and right stereophonic channels, to ensure that the stereo generator is calibrated properly. Historically, stable Lissajous figures were used to show that two sine waves had a relatively simple frequency relationship, a numerically-small ratio. They also indicated phase difference between two sine waves of the same frequency.

Complete loss of signal in an X-Y display means that the CRT's beam strikes a small spot, which risks burning the phosphor. Older phosphors burned more easily. Some dedicated X-Y displays reduce beam current greatly, or blank the display entirely, if there are no inputs present.

Bandwidth

Bandwidth is a measure of the range of frequencies that can be displayed; it refers primarily to the vertical amplifier, although the horizontal deflection amplifier has to be fast enough to handle the fastest sweeps. The bandwidth of the 'scope is limited by the vertical amplifiers and the CRT (in analog instruments) or by the sampling rate of the analog to digital converter in digital instruments. The bandwidth is defined as the frequency at which the sensitivity is 0.707 of the sensitivity at lower frequency (a drop of 3 dB). The rise time of the fastest pulse that can be resolved by the scope is related to its bandwidth approximately:

Bandwidth in Hz x rise time in seconds = 0.35 [8]

For example, a 'scope intended to resolve pulses with a rise time of 1 nanosecond would have a bandwidth of 350 MHz.

For a digital oscilloscope, a rule of thumb is that the continuous sampling rate should be ten times the highest frequency desired to resolve; for example a 20 megasample/second rate would be applicable for measuring signals up to about 2 megahertz.

Other features

Some oscilloscopes have *cursors*, which are lines that can be moved about the screen to measure the time interval between two points, or the difference between two voltages. A few older 'scopes simply brightened the trace at movable locations. These cursors are more accurate than visual estimates referring to graticule lines.

Better quality general purpose oscilloscopes include a calibration signal for setting up the compensation of test probes; this is (often) a 1 kHz square-wave signal of a definite peak-to-peak voltage available at a test terminal on the front panel. Some better 'scopes also have a squared-off loop for checking and adjusting current probes.

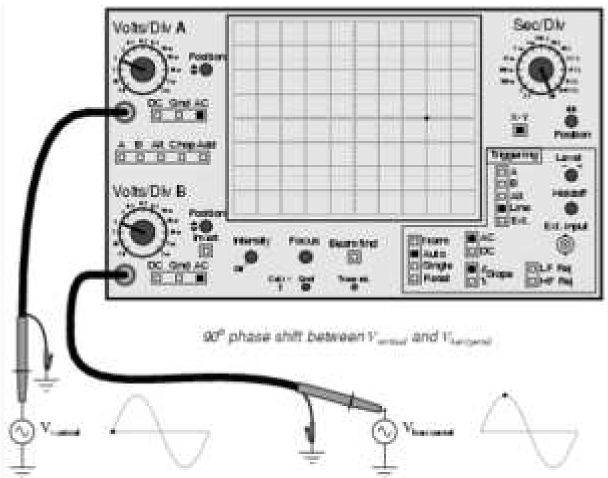
Sometimes the event that the user wants to see may only happen occasionally. To catch these events, some oscilloscopes, known as "storage scopes", preserve the most recent sweep on the screen. This was originally achieved by using a special CRT, a "storage tube", which would retain the image of even a very brief event for a long time.

Some digital oscilloscopes can sweep at speeds as slow as once per hour, emulating a strip chart recorder. That is, the signal scrolls across the screen from right to left. Most oscilloscopes with this facility switch from a sweep to a strip-chart mode at about one sweep per ten seconds. This is because otherwise, the scope looks broken: it's collecting data, but the dot cannot be seen.

In current 'scopes, digital signal sampling is more often used for all but the simplest models. Samples feed fast analog-to-digital converters, following which all signal processing (and storage) is digital.

Many oscilloscopes have different plug-in modules for different purposes, e.g., high-sensitivity amplifiers of relatively narrow bandwidth, differential amplifiers, amplifiers with four or more channels, sampling plugins for repetitive signals of very high frequency, and special-purpose plugins, including audio/ultrasonic spectrum analyzers, and stable-offset-voltage direct-coupled channels with relatively high gain.

Examples of use



Lissajous figures on an oscilloscope, with 90 degrees phase difference between x and y inputs.

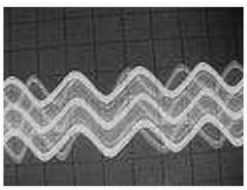
One of the most frequent uses of scopes is troubleshooting malfunctioning electronic equipment. One of the advantages of a scope is that it can graphically show signals: where a voltmeter may show a totally unexpected voltage, a scope may reveal that the circuit is oscillating. In other cases the precise shape or timing of a pulse is important.

In a piece of electronic equipment, for example, the connections between stages (e.g. electronic mixers, electronic oscillators, amplifiers) may be 'probed' for the expected signal, using the scope as a simple signal tracer. If the expected signal is absent or incorrect, some preceding stage of the electronics is not operating correctly. Since most failures occur because of a single faulty component, each measurement can prove that half of the stages of a complex piece of equipment either work, or probably did not cause the fault.

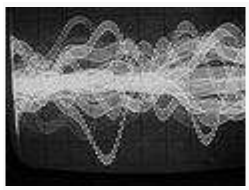
Once the faulty stage is found, further probing can usually tell a skilled technician exactly which component has failed. Once the component is replaced, the unit can be restored to service, or at least the next fault can be isolated. This sort of troubleshooting is typical of radio and TV receivers, as well as audio amplifiers, but can apply to quite-different devices such as electronic motor drives.

Another use is to check newly designed circuitry. Very often a newly designed circuit will misbehave because of design errors, bad voltage levels, electrical noise etc. Digital electronics usually operate from a clock, so a dual-trace scope which shows both the clock signal and a test signal dependent upon the clock is useful. **Storage scopes** are helpful for "capturing" rare electronic events that cause defective operation.

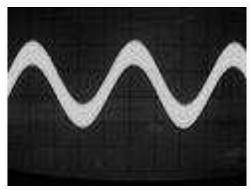
Pictures of use



Heterodyne

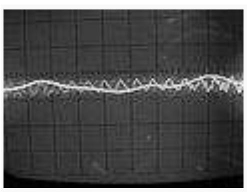


AC hum on sound.



Sum of a low-frequency and a high-frequency signal.

Bad filter on sine.



Dual trace, showing different time bases on each trace.

SELECTION

Oscilloscopes generally have a checklist of some set of the above features. The basic measure of virtue is the bandwidth of its vertical amplifiers. Typical scopes for general purpose use should have a bandwidth of at least 100 MHz, although much lower bandwidths are acceptable for audio-frequency applications. A useful sweep range is from one second to 100 nanoseconds, with triggering and delayed sweep.

The chief benefit of a quality oscilloscope is the quality of the trigger circuit. If the trigger is unstable, the display will always be fuzzy. The quality improves roughly as the frequency response and voltage stability of the trigger increase.

Analog oscilloscopes have been almost totally displaced by digital storage scopes except for the low bandwidth (< 60 MHz) segment of the market. Greatly increased sample rates have eliminated the display of incorrect signals, known as "aliasing", that was sometimes present in the first generation of digital scopes. The used test equipment market, particularly on-line auction venues, typically have a wide selection of older analog scopes available. However it is becoming more difficult to obtain replacement parts for these instruments and repair services are generally unavailable from the original manufacturer.

As of 2007, a 350 MHz bandwidth (BW), 2.5 giga-samples per second (GS/s), dual-channel digital storage scope costs about US$7000 new. The current true real-time analog bandwidth record, as of April 2010, is held by the Agilent Infiniium 90000X series of oscilloscopes with a 32 GHz BW and a sample rate of 80 GSa/s.[*citation needed*] The current equivalent time sampling bandwidth record for sampling digital storage oscilloscopes, as of June 2006, is held by the LeCroy WaveExpert series with a 100 GHz bandwidth]

On the lowest end, an inexpensive hobby-grade single-channel DSO can now be purchased for under $100 as of August 2010. These often have limited bandwidth but fulfill the basic functions of an oscilloscope.

Software

Many oscilloscopes today provide one or more external interfaces to allow remote instrument control by external software. These interfaces (or buses) include GPIB, Ethernet, serial port, and USB.

Types and models

The following section is a brief summary of various types and models available. For a detailed discussion, refer to the other article.

Cathode-ray oscilloscope (CRO)

The earliest and simplest type of oscilloscope consisted of a cathode ray tube, a vertical amplifier, a timebase, a horizontal amplifier and a power supply. These are now called 'analog' scopes to distinguish them from the 'digital' scopes that became common in the 1990s and 2000s.

Dual-beam oscilloscope

The dual-beam analog oscilloscope can display two signals simultaneously. A special dual-beam CRT generates and deflects two separate beams. Although multi-trace analog oscilloscopes can simulate a dual-beam display with **chop** and **alternate** sweeps, those features do not provide simultaneous displays. (Real time digital oscilloscopes offer the same benefits of a dual-beam oscilloscope, but they do not require a dual-beam display.)

Analog storage oscilloscope

Trace storage is an extra feature available on some analog scopes; they used direct-view storage CRTs. Storage allows the trace pattern that normally decays in a fraction of a second to remain on the screen for several minutes or longer. An electrical circuit can then be deliberately activated to store and erase the trace on the screen.

Digital oscilloscopes

While analog devices make use of continually varying voltages, digital devices employ binary numbers which correspond to samples of the voltage. In the case of digital oscilloscopes, an analog-to-digital converter (ADC) is used to change the measured voltages into digital information.

Digital storage oscilloscope

The digital storage oscilloscope, or DSO for short, is now the preferred type for most industrial applications, although simple analog CROs are still used by hobbyists. It replaces the unreliable storage method used in analog storage scopes with digital memory, which can store data as long as required without degradation. It also allows complex processing of the signal by high-speed digital signal processing circuits.

Digital sampling oscilloscopes

Digital sampling oscilloscopes operate on the same principle as analog sampling oscilloscopes and like their analog partners, are of great use when analyzing high frequency signals. That is, signals whose frequencies are higher than the oscilloscope's sampling rate.

Digital phosphor oscilloscopes

Digital phosphor oscilloscopes (DPOs) are the most recently developed type of digital scope. DPOs employ a unique processing architecture in order to overcome the limitations of DSOs and digital sampling oscilloscopes. This unique architecture is a parallel processing setup rather than the serial processing setups of the other two types of digital scopes.

Mixed-signal oscilloscopes

A mixed-signal oscilloscope (or MSO) has two kinds of inputs, a small number (typically two or four) of analog channels, and a larger number (typically sixteen) of digital channels.

Handheld oscilloscopes

Handheld oscilloscopes (also called scopemeters) are useful for many test and field service applications. Today, a hand held oscilloscope is usually a digital sampling oscilloscope, using a liquid crystal display.

PC-based oscilloscopes (PCO)

A new type of "oscilloscope" is emerging that consists of a specialized signal acquisition board (which can be an external USB or Parallel port device, or an internal add-on PCI or ISA card).

Related instruments

A large number of instruments used in a variety of technical fields are really oscilloscopes with inputs, calibration, controls, display calibration, etc., specialized and optimized for a particular application. Examples of such oscilloscope-based instruments include television waveform analyzers and medical devices such as vital function monitors and electrocardiogram and electroencephalogram instruments. In automobile repair, an ignition analyzer is used to show the spark waveforms for each cylinder. All of these are essentially oscilloscopes, performing the basic task of showing the changes in one or more input signals over time in an X-Y display.

Other instruments convert the results of their measurements to a repetitive electrical signal, and incorporate an oscilloscope as a display element. Such complex measurement systems includespectrum analyzers, transistor analyzers, and time domain reflectometers (TDRs). Unlike an oscilloscope, these instruments automatically generate stimulus or sweep a measurement parameter.

LED-BACKLIT LCD TELEVISION

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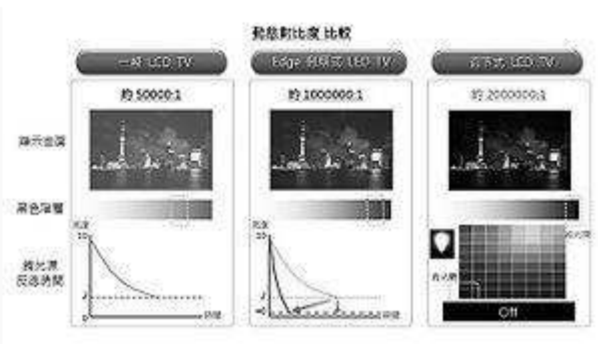

Comparison of LCD, edge lit LED and LED TVs

LED-backlight LCD television (incorrectly called **LED TV** by (CCFLs) used in traditional LCD televisions. This has a dramatic impact resulting in a thinner panel and less power consumption, brighter display with better contrast levels. It also generates less heat than regular LCD TVs.

The LEDs can come in three forms: dynamic RGB LEDs which are positioned behind the panel, white Edge-LEDs positioned around the rim of the screen which use a special diffusion panel to spread the light evenly behind the screen (the most common) and full-array which are arranged behind the screen but they are incapable of dimming or brightening individually

LED backlighting techniques

RGB dynamic LEDs

This method of backlighting allows dimming to occur in locally specific areas of darkness on the screen. This can show truer blacks, whites and PRs[*clarification needed*] at much higher dynamic contrast ratios, at the cost of less detail in small bright objects on a dark background, such as star fields.[5]

Edge-LEDs

This method of backlighting allows for LED-backlit TVs to become extremely thin. The light is diffused across the screen by a special panel which produces a uniform color range across the screen.

Full Array LEDs

Sharp, and now other brands, also have LED backlighting technology that aligns the LEDs on back of the TV like the RGB Dynamic LED backlight, but it lacks the local dimming of other sets.[6] The main benefit of its LED backlight is simply reduced energy consumption and may not improve quality over non-LED LCD TVs.[7]

Differences between LED-backlit and CCFL-backlit LCD displays

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LED-backlit LCD TVs differ from conventional CCFL-backlit LCD TVs in the following:

- Produce images with greater dynamic contrastWith Edge-LED lighting they can be extremely slim. Models on the market can be approximately one inch thick. Offer a wider color gamut, especially when RGB-LED backlighting is usedLess environmental pollution on disposal.
- Higher sales priceGenerally 20-30% lower power consumption]

Technology

TV manufacturers can use an LED backlight instead of the standard Cold Cathode Fluorescent Lamps (LCD-CCFL) used in most LCD televisions. It is important to distinguish this method of simply backlighting a conventional LCD panel, from a hypothetical true LED display, or an Organic light-emitting diode (OLED) display. LCD-based televisions described as 'LED TVs' are vastly different from self-illuminating OLED, OEL or AMOLED display technologies. In terms of the use of the term 'LED TV' in the UK, the ASA (Advertising Standards Authority) has made it clear in prior correspondence that it does not object to the use of the term, but does require it to be clarified in any advertising. There are several methods of backlighting an LCD panel using LEDs including the use of either White or RGB (Red, Green and Blue) LED arrays positioned behind the panel; and Edge-LED lighting, which uses white LEDs arranged around the inside frame of the TV along with a special light diffusion panel designed to spread the light evenly behind the LCD panel.

An LED backlight offers several general benefits over regular CCFL backlight TVs, typically higher brightness. Compared to regular CCFL backlighting, there may also be benefits to color gamut. However advancements in CCFL technology mean wide color gamuts and lower power consumption are also possible. The principal barrier to wide use of LED backlighting on LCD televisions is cost.

The variations of LED backlighting do offer different benefits. The first commercial LED backlit LCD TV was the Sony Qualia 005 (introduced in 2004). This featured RGB LED arrays to offer a color gamut around twice that of a conventional CCFL LCD television (the combined light output from red, green and blue LEDs produces a more pure white light than is possible with a single white light LED). RGB LED technology continues to be used on selected Sony BRAVIA LCD models, with the addition of 'local dimming' which enables excellent on-screen contrast through selectively turning off the LEDs behind dark parts of a picture frame.

Edge LED lighting was also first introduced by Sony (September 2008) on the 40 inch BRAVIA KLV-40ZX1M (referred to as the ZX1 in Europe). The principal benefit of Edge-LED lighting for LCD televisions is the ability to build thinner housings (the BRAVIA KLV-40ZX1M is as thin as 9.9mm). Samsung has also introduced a range of Edge-LED lit LCD televisions with extremely thin housings.

LED-backlit LCD TVs are considered a more sustainable choice, with a longer life and better energy efficiency than plasmas and conventional LCD TVs.[10] Unlike CCFL backlights, LEDs also use nomercury in their manufacture. However, other elements such as gallium and arsenic are used in the manufacture of the LED emitters themselves, meaning there is some debate over whether they are a significantly better long term solution to the problem of TV disposal.

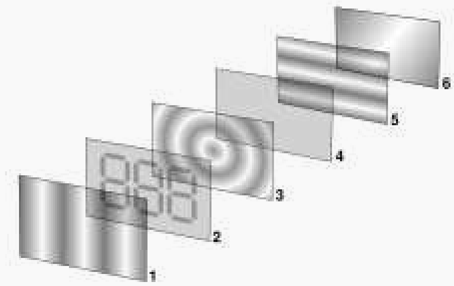
Because LEDs are able to be switched on and off more quickly than CCFL displays and can offer a higher light output, it is theoretically possible to offer very high contrast ratios. They can produce deep blacks (LEDs off) and a high brightness (LEDs on), however care should be taken with measurements made from pure black and pure white outputs, as technologies like Edge-LED lighting do not allow these outputs to be reproduced simultaneously on-screen.

In September 2009 Nanoco Group announced that it has signed a joint development agreement with a major Japanese electronics company under which it will design and develop quantum dots for LED Backlights in LCD televisions.[11] Quantum dots are valued for displays, because they emit light in very specific gaussian distributions. This can result in a display that more accurately renders the colors than the human eye can perceive. Quantum dots also require very little power since they are not color filtered. In September 2010, LG Electronics revealed their new product which claimed as the world's slimmest full LED 3D TV at the IFA consumer electronics trade show in Berlin

LIQUID CRYSTAL DISPLAY

From Wikipedia, the free encyclopedia

"LCD" redirects here. For other uses, see LCD (disambiguation).



Reflective twisted nematic liquid crystal display.

1. Polarizing filter film with a vertical axis to polarize light as it enters.
2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is turned ON. Vertical ridges etched on the surface are smooth.
3. Twisted nematic liquid crystal.
4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.
5. Polarizing filter film with a horizontal axis to block/pass light.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced with a light source.)

A **liquid crystal display** (**LCD**) is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly.

They are used in a wide range of applications including: computer monitors, television, instrument panels, aircraft cockpit displays, signage, etc. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones. LCDs have displaced cathode ray tube (CRT) displays in most applications. They are usually more compact, lightweight, portable, less expensive, more reliable, and easier on the eyes.[*citation needed*] They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they cannot suffer image burn-in.

LCDs are more energy efficient and offer safer disposal than CRTs. Its low electrical power consumption enables it to be used in battery-poweredelectronic equipment. It is an electronically-modulated optical device made up of any number of pixels filled with liquid crystals and arrayed in front of alight source (backlight) or reflector to produce images in colour or monochrome. The earliest discovery leading to the development of LCD technology, the discovery of liquid crystals, dates from 1888.[1] By 2008, worldwide sales of televisions with LCD screens had surpassed the sale of CRT units.

Overview

LCD alarm clock

Each pixel of an LCD typically consists of a layer of molecules aligned between two transparent electrodes, and two polarizing filters, the axes of transmission of which are (in most of the cases) perpendicular to each other. With no actual liquid crystal between the polarizing filters, light passing through the first filter would be blocked by the second (crossed) polarizer. In most of the cases the liquid crystal has double refraction.

The surface of the electrodes that are in contact with the liquid crystal material are treated so as to align the liquid crystal molecules in a particular direction. This treatment typically consists of a thin polymer layer that is unidirectionally rubbed using, for example, a cloth. The direction of the liquid crystal alignment is then defined by the direction of rubbing. Electrodes are made of a transparent conductor called Indium Tin Oxide (ITO).

Before applying an electric field, the orientation of the liquid crystal molecules is determined by the alignment at the surfaces of electrodes. In a twisted nematic device (still the most common liquid crystal device), the surface alignment directions at the two electrodes are perpendicular to each other, and so the molecules arrange themselves in a helical structure, or twist. This reduces the rotation of the polarization of the incident light, and the device appears grey. If the applied voltage is large enough, the liquid crystal molecules in the center of the layer are almost completely untwisted and the polarization of the incident light is not rotated as it passes through the liquid crystal layer. This light will then be mainly polarized perpendicular to the second filter, and thus be blocked and the pixel will appear black. By controlling the voltage applied across the liquid crystal layer in each pixel, light can be allowed to pass through in varying amounts thus constituting different levels of gray. This electric field also controls (reduces) the double refraction properties of the liquid crystal.

LCD with top polarizer removed from device and placed on top, such that the top and bottom polarizers are parallel.

The optical effect of a twisted nematic device in the voltage-on state is far less dependent on variations in the device thickness than that in the voltage-off state. Because of this, these devices are usually operated between crossed polarizers such that they appear bright with no voltage (the eye is much more sensitive to variations in the dark state than the bright state). These devices can also be operated between parallel polarizers, in which case the bright and dark states are reversed. The voltage-off dark state in this configuration appears blotchy, however, because of small variations of thickness across the device.

Both the liquid crystal material and the alignment layer material contain ionic compounds. If an electric field of one particular polarity is applied for a long period of time, this ionic material is attracted to the surfaces and degrades the device performance. This is avoided either by applying an alternating current or by reversing the polarity of the electric field as the device is addressed (the response of the liquid crystal layer is identical, regardless of the polarity of the applied field).

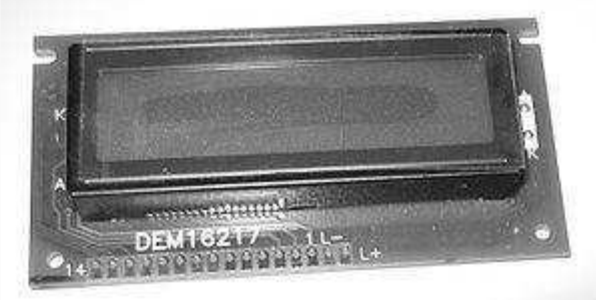
When a large number of pixels are needed in a display, it is not technically possible to drive each directly since then each pixel would require independent electrodes. Instead, the display is *multiplexed*. In a multiplexed display, electrodes on one side of the display are grouped and wired together (typically in columns), and each group gets its own voltage source. On the other side, the electrodes are also grouped (typically in rows), with each group getting a voltage sink. The groups are designed so each pixel has a unique, unshared combination of source and sink. The electronics, or the software driving the electronics then turns on sinks in sequence, and drives sources for the pixels of each sink.

ILLUMINATION

As LCD panels produce no light of their own, they require an external lighting mechanism to be easily visible. On most displays, this consists of a cold cathode fluorescent lamp that is situated behind the LCD panel. Passive-matrix displays are usually not backlit, but active-matrix displays almost always are, with a few exceptions such as the display in the original Gameboy Advance.

Recently, two types of LED backlit LCD displays have appeared in some televisions as an alternative to conventional backlit LCDs. In one scheme, the LEDs are used to backlight the entire LCD panel. In another scheme, a set of green red and blue LEDs is used to illuminate a small cluster of pixels, which can improve contrast and black level in some situations. For example, the LEDs in one section of the screen can be dimmed to produce a dark section of the image while the LEDs in another section are kept bright. Both schemes also allows for a slimmer panel than on conventional displays.

Passive-matrix and active-matrix addressed LCDs



A general purpose alphanumeric LCD, with two lines of 16 characters.

LCDs with a small number of segments, such as those used in digital watches and pocket calculators, have individual electrical contacts for each segment. An external dedicated circuit supplies an electric charge to control each segment. This display structure is unwieldy for more than a few display elements.

Small monochrome displays such as those found in personal organizers, electronic weighing scales, older laptop screens, and the originalGameboy have a passive-matrix structure employing super-twisted nematic (STN) or double-layer STN (DSTN) technology (the latter of which addresses a colour-shifting problem with the former), and colour-STN (CSTN) in which colour is added by using an internal filter. Each row or column of the display has a single electrical circuit. The pixels are addressed one at a time by row and column addresses. This type of display is called *passive-matrix addressed* because the pixel must retain its state between refreshes without the benefit of a steady electrical charge. As the number of pixels (and, correspondingly, columns and rows) increases, this type of display becomes less feasible. Very slow response times and poor contrast are typical of passive-matrix addressed LCDs.

Monochrome passive-matrix LCDs were standard in most early laptops (although a few used plasma displays). The commercially unsuccessful Macintosh Portable (released in 1989) was one of the first to use an active-matrix display (though still monochrome), but passive-matrix was the norm until the mid-1990s, when colour active-matrix became standard on all laptops.

High-resolution colour displays such as modern LCD computer monitors and televisions use an active matrix structure. A matrix of thin-film transistors (TFTs) is added to the polarizing and colour filters. Each pixel has its own dedicated transistor, allowing each column line to access one pixel. When a row line is activated, all of the column lines are connected to a row of pixels and the correct voltage is driven onto all of the column lines. The row line is then deactivated and the next row line is activated. All of the row lines are activated in sequence during a refresh operation. Active-matrix addressed displays look "brighter" and "sharper" than passive-matrix addressed displays of the same size, and generally have quicker response times, producing much better images.

ACTIVE MATRIX TECHNOLOGIES

A Casio 1.8 in colour TFT liquid crystal display which equips the SonyCyber-shot DSC-P93A

Twisted nematic (TN)

Twisted nematic displays contain liquid crystal elements which twist and untwist at varying degrees to allow light to pass through. When no voltage is applied to a TN liquid crystal cell, the light is polarized to pass through the cell. In proportion to the voltage applied, the LC cells twist up to 90 degrees changing the polarization and blocking the light's path. By properly adjusting the level of the voltage almost any grey level or transmission can be achieved.

In-plane switching (IPS)

In-plane switching is an LCD technology which aligns the liquid crystal cells in a horizontal direction. In this method, the electrical field is applied through each end of the crystal, but this requires two transistors for each pixel instead of the single transistor needed for a standard thin-film transistor (TFT) display. Before LGEnhanced IPS was introduced in 2009, the additional transistors resulted in blocking more transmission area, thus requiring a brighter backlight, which consumed more power, and made this type of display less desirable for notebook computers. This newer, lower power technology can be found in the AppleiMac, iPad, and iPhone 4, as well as the Hewlett-Packard EliteBook 8740w. Currently Panasonic is using an enhanced version eIPS for their large size LCD-TV products.Advanced fringe field switching (AFFS)

Known as fringe field switching (FFS) until 2003, advanced fringe field switching is a technology similar to IPS or S-IPS offering superior performance and colour gamut with high luminosity. AFFS is developed by HYDIS TECHNOLOGIES CO.,LTD, Korea (formally Hyundai Electronics, LCD Task Force). AFFS-applied notebook applications minimize colour distortion while maintaining its superior wide viewing angle for a professional display. Colour shift and deviation caused by light leakage is corrected by optimizing the white gamut which also enhances white/grey reproduction.

In 2004, HYDIS TECHNOLOGIES CO.,LTD licenses AFFS patent to Japan's Hitachi Displays. Hitachi is using AFFS to manufacture high end panels in their product line. In 2006, HYDIS also licenses AFFS to Sanyo Epson Imaging Devices Corporation.
HYDIS introduced AFFS+ which improved outdoor readability in 2007.

Vertical alignment (VA)

Vertical alignment displays are a form of LCDs in which the liquid crystal material naturally exists in a vertical state removing the need for extra transistors (as in IPS). When no voltage is applied, the liquid crystal cell remains perpendicular to the substrate creating a black display. When voltage is applied, the liquid crystal cells shift to a horizontal position, parallel to the substrate, allowing light to pass through and create a white display. VA liquid crystal displays provide some of the same advantages as IPS panels, particularly an improved viewing angle and improved black level

Blue Phase mode

Blue phase LCDs do not require a liquid crystal top layer. Blue phase LCDs are relatively new to the market, and very expensive because of the low volume of production. They provide a higher refresh rate than normal LCDs, but normal LCDs are still cheaper to make and actually provide better colours and a sharper image
]

Military use of LCD monitors

LCD monitors have been adopted by the United States of America military instead of CRT displays because they are smaller, lighter and more efficient, although monochrome plasma displays are also used, notably for their M1 Abrams tanks. For use with night vision imaging systems a US military LCD monitor must be compliant with MIL-L-3009 (formerly MIL-L-85762A). These LCD monitors go through extensive certification so that they pass the standards for the military. These include MIL-STD-901D - High Shock (Sea Vessels), MIL-

STD-167B - Vibration (Sea Vessels), MIL-STD-810F – Field Environmental Conditions (Ground Vehicles and Systems), MIL-STD-461E/F – EMI/RFI (Electromagnetic Interference/Radio Frequency Interference), MIL-STD-740B – Airborne/Structureborne Noise, and TEMPEST - Telecommunications Electronics Material Protected from Emanating Spurious Transmissions

Quality control

Some LCD panels have defective transistors, causing permanently lit or unlit pixels which are commonly referred to as stuck pixels or dead pixels respectively. Unlike integrated circuits (ICs), LCD panels with a few defective transistors are usually still usable. It is claimed that it is economically prohibitive to discard a panel with just a few defective pixels because LCD panels are much larger than ICs, but this has never been proven. Manufacturers' policies for the acceptable number of defective pixels vary greatly. At one point, Samsung held a zero-tolerance policy for LCD monitors sold in Korea.[5] Currently, though, Samsung adheres to the less restrictive ISO 13406-2 standard.[6] Other companies have been known to tolerate as many as 11 dead pixels in their policies.[7] Dead pixel policies are often hotly debated between manufacturers and customers. To regulate the acceptability of defects and to protect the end user, ISO released the ISO 13406-2 standard.

However, not every LCD manufacturer conforms to the ISO standard and the ISO standard is quite often interpreted in different ways.

LCD panels are more likely to have defects than most ICs due to their larger size. For example, a 300 mm SVGA LCD has 8 defects and a 150 mm wafer has only 3 defects. However, 134 of the 137 dies on the wafer will be acceptable, whereas rejection of the LCD panel would be a 0% yield. Due to competition between manufacturers quality control has been improved. An SVGA LCD panel with 4 defective pixels is usually considered defective and customers can request an exchange for a new one. Some manufacturers, notably in South Korea where some of the largest LCD panel manufacturers, such as LG, are located, now have "zero defective pixel guarantee", which is an extra screening process which can then determine "A" and "B" grade panels. Many manufacturers would replace a product even with one defective pixel. Even where such guarantees do not exist, the location of defective pixels is important. A display with only a few defective pixels may be unacceptable if the defective pixels are near each other. Manufacturers may also relax their replacement criteria when defective pixels are in the center of the viewing area.

LCD panels also have defects known as *clouding* (or less commonly *mura*), which describes the uneven patches of changes in luminance. It is most visible in dark or black areas of displayed scenes

]ZERO-POWER (BISTABLE) DISPLAYS

The zenithal bistable device (ZBD), developed by QinetiQ (formerly DERA), can retain an image without power. The crystals may exist in one of two stable orientations ("Black" and "White") and power is only required to change the image. ZBD Displays is a spin-off company from QinetiQ who manufacture both grayscale and colour ZBD devices.

A French company, Nemoptic, has developed the BiNem zero-power, paper-like LCD technology which has been mass-produced in partnership with Seiko since 2007.

This technology is intended for use in applications such as Electronic Shelf Labels, E-books, E-documents, E-newspapers, E-dictionaries, Industrial sensors, Ultra-Mobile PCs, etc.

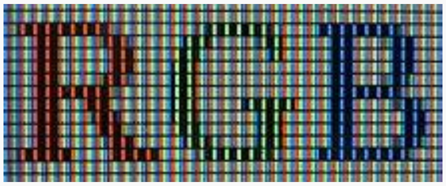
Kent Displays has also developed a "no power" display that uses Polymer Stabilized Cholesteric Liquid Crystals (ChLCD). A major drawback of ChLCD screens are their slow refresh rate, especially at low temperatures[*citation needed*]. Kent has recently demonstrated the use of a ChLCD to cover the entire surface of a mobile phone, allowing it to change colours, and keep that colour even when power is cut off.

In 2004 researchers at the University of Oxford demonstrated two new types of zero-power bistable LCDs based on Zenithal bistable techniques.

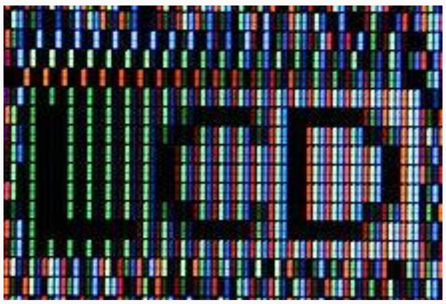
Several bistable technologies, like the 360° BTN and the bistable cholesteric, depend mainly on the bulk properties of the liquid crystal (LC) and use standard strong anchoring, with alignment films and LC mixtures similar to the traditional monostable materials. Other bistable technologies (i.e. Binem Technology) are based mainly on the surface properties and need specific weak anchoring materials.

[

Comparison of the OLPC XO-1 display (left) with a typical colour LCD. The images show 1×1 mm of each screen. A typical LCD addresses groups of 3 locations as pixels. The XO-1 display addresses each location as a separate pixel.



Example of how the colours are generated (R-red, G-green and B-blue)



In colour LCDs each individual pixel is divided into three cells, or subpixels, which are coloured red, green, and blue, respectively, by additional filters (pigment filters, dye filters and metal oxide filters). Each subpixel can be controlled independently to yield thousands or millions of possible colours for each pixel. CRT monitors employ a similar 'subpixel' structures *via* phosphors, although the electron beam employed in CRTs do not hit exact *subpixels*. The figure at the left shows the twisted nematic (TN) type of LCD.

DATA LOGGERS

A **data logger** (also **datalogger** or **data recorder**) is an electronic device that records data over time or in relation to location either with a built in instrumentor sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer). They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

Data loggers vary between general purpose types for a range of measurement applications to very specific devices for measuring in one environment or application type only. It is common for general purpose types to be programmable; however, many remain as static machines with only a limited number or no changeable parameters. Electronic dataloggers have replaced chart recorders in many applications.

One of the primary benefits of using data loggers is the ability to automatically collect data on a 24-hour basis. Upon activation, data loggers are typically deployed and left unattended to measure and record information for the duration of the monitoring period. This allows for a comprehensive, accurate picture of the environmental conditions being monitored, such as air temperature and relative humidity.

The cost of data loggers has been declining over the years as technology improves and costs are reduced. Simple single channel data loggers cost as little as $25. More complicated loggers may costs hundreds or thousands of dollars.

Data Formats

Standardisation of protocols and data formats has been a problem but is now growing in the industry and XML is increasingly being adopted for data exchange. The development of the Semantic Web is likely to accelerate this trend.

Instrumentation Protocols

Several protocols have been standardised including a smart protocol, SDI-12, exists that allows some instrumentation to be connected to a variety of data loggers. The use of this standard has not gained much acceptance outside the environmental industry. SDI-12 also supports multi drop instruments. Some datalogging companies are also now supporting the MODBUS standard, this has been used traditionally in the industrial control area there are many industrial instruments which support this communication standard. Another multi drop protocol which is now starting to become more widely used is based upon Canbus (ISO 11898) Some data loggers utilize a flexible scripting environment to adapt themselves to various non-standard protocols.

Data logging versus data acquisition

The terms data logging and data acquisition are often used interchangeably. However, in a historical context they are quite different. A data logger is a data acquisition system, but a data acquisition system is not necessarily a data logger.

- Data loggers typically have slower sample rates. A maximum sample rate of 1 Hz may be considered to be very fast for a data logger, yet very slow for a typical data acquisition system.
- Data loggers are implicitly stand-alone devices, while typical data acquisition system must remain tethered to a computer to acquire data. This stand-alone aspect of data loggers implies on-board memory that is used to store acquired data. Sometimes this memory is very large to accommodate many days, or even months, of unattended recording. This memory may be battery-backed static random access memory, flash memory or EEPROM. Earlier data loggers used magnetic tape, punched paper tape, or directly viewable records such as "strip chart recorders".
- Given the extended recording times of data loggers, they typically feature a time- and date-stamping mechanism to ensure that each recorded data value is associated with a date and time of acquisition. As such, data loggers typically employ built-in real-time clocks whose published drift can be an important consideration when choosing between data loggers.
- Data loggers range from simple single-channel input to complex multi-channel instruments. Typically, the simpler the device the less programming flexibility. Some more sophisticated instruments allow for cross-channel computations and alarms based on predetermined conditions. The newest of data loggers can serve web pages, allowing numerous people to monitor a system remotely.
- The unattended and remote nature of many data logger applications implies the need in some applications to operate from a DC power source, such as a battery. Solar power may be

used to supplement these power sources. These constraints have generally led to ensure that the devices they market are extremely power efficient relative to computers. In many cases they are required to operate in harsh environmental conditions where computers will not function reliably.

- This unattended nature also dictates that data loggers must be extremely reliable. Since they may operate for long periods nonstop with little or no human supervision, and may be installed in harsh or remote locations, it is imperative that so long as they have power, they will not fail to log data for any reason. Manufacturers go to great length to ensure that the devices can be depended on in these applications. As such dataloggers are almost completely immune to the problems that might affect a general-purpose computer in the same application, such as program crashes and the instability of some operating systems.

Applications

Applications of data logging include:

- Unattended weather station recording (such as wind speed / direction, temperature, relative humidity, solar radiation).
- Unattended hydrographic recording (such as water level, water depth, water flow, water pH, water conductivity).
- Unattended soil moisture level recording.
- Unattended gas pressure recording.
- Offshore buoys for recording a variety of environmental conditions.
- Road traffic counting.
- Measure temperatures (humidity, etc) of perishables during shipments: Cold chain.[1]
- Process monitoring for maintenance and troubleshooting applications.
- Process monitoring to verify warranty conditions
- Wildlife research with pop-up archival tags
- Measure vibration and handling shock (drop height) environment of distribution packaging.[2]
- Tank level monitoring.

- Deformation monitoring of any object with geodetic or geotechnical sensors controlled by an automatic deformation monitoring system.
- Environmental monitoring.
- Vehicle Testing
- Monitoring of relay status in railway signalling.
- For science education enabling 'measurement', 'scientific investigation' and an appreciation of 'change'
- Record trend data at regular intervals in veterinary vital signs monitoring.
- Load profile recording for energy consumption management.

Future Directions

Data Loggers are changing more rapidly now than ever before. The original model of a stand alone data logger is changing to one of a device that collects data but also has access to wireless communications for alarming of events, automatic reporting of data and remote control. Dataloggers are beginning to serve web pages for current readings, e-mail their alarms and FTP their daily results into databases or direct to the users.

Examples

- A flight data recorder (FDR), a piece of recording equipment used to collect specific aircraft performance data. The term may also be used, albeit less accurately, to describe the cockpit voice recorder (CVR), another type of data recording device found onboard aircraft.
- An event data recorder (EDR), a device installed by the manufacturer in some automobiles which collects and stores various data during the timeframe immediately before and after a crash.
- A voyage data recorder (VDR), a data recording system designed to collect data from various sensors on board a ship.

- Ultra Wideband Data Recorder, high-speed data recording up to 2 GigaSamples per second.
- The growing, preparation, storage and transportation of food. Data logger is generally used for data storage and these are small in size.
- In automobiles, all diagnostic trouble codes (DTCs) are logged in engine control units (ECUs) so that at the time of service of a vehicle, a service engineer will read all the DTCs using Tech-II or similar tools and will come to know problems occurred in the vehicle.
- A Temperature Recorder for monitoring the performance of a heating and air conditioning system.
- A Depth Recorder for tracking changes in the water table.

STORAGE AND DISPLAY DEVICES

PART – A

1. What is meant by deflection sensitivity of a CRT? (2)
2. Write two advantages of LED in electronic displays. (2)
3. State the features of ink-jet printers. (2)
4. Differentiate between LED and LCD. (2)
5. What are the different types of magnetic recording? (2)
6. What are the different materials used in LED? Also name the Colours emitted. (2)
7. Give a short note on LED. (2)
8. What is delayed sweep? (2)
9. Explain the characteristics of Time domain output device using In measurements. (2)
10. Explain the following term as applied to digital displays. (2)

3 ½ digit and 4 ½ digit displays.

11. What is a recorder and what are the types of it? (2)
12. What is magnetc tape recorder? (2)
13. What are the basic components of a tape recorder? (2)
14. List the advantages and disadvantages of direct recording? (2)
15. What are display devices? (2)
16. What are the advantages and disadvantages of digital data recording?
17. Compare line printer and dot matrix printer. (2)
18. What is CRO? What are the sections of a CRO? (2)
19. List the advantages of digital storage oscilloscope. (2)
20. Differentiate between dual trace and dual beam CRO. (2)
21. List out the advantages of X-Y records over strip chart recorder. (2)
22. List the advantages of laser printer. (2)
23. List the two advantages of digital X-Y recorder. (2)
24. What is power requirement of LCD? (2)
25. What are Lissajous patterns? (2)

PART – B

1. Describe the construction and working of LCDs, mention the difference between light scattering and field effect types of

LCDs,also explain the advantages of LCDs (16)

2. (i) Give the basic block diagram of a digital data recording

3. system (8)

(ii) Explain with a neat sketch

a) Dot matrix displays

b) Bar graph displays (8)

3. (i) Explain the basic elements of a magnetic tape recorder. (8)

(ii) Explain the block diagram of oscilloscope with a neat sketch (8)

4. (i) Describe the basic components of a CRT. (10)

(ii) Write short notes on liquid crystal displays. (6)

5.(i) With a neat block diagram, explain the working of digital storageoscilloscope. (8)

(ii) Discuss briefly about the applications of LED. (8)

6. (i) What are the various types of oscilloscopes? (4)

(ii) Discuss in detail the construction of a storage type oscilloscope.

What are the accessories for a CRO? (12)

7. (i) Explain in detail, how the data is stored in a magnetic disk and tape? (10)

(ii) Describe the performance of digital plotter. (6)

8. (i) Explain the block diagram of a general purpose oscilloscope andalso describe about the observation of waveform on CRO. (10)

(ii) Write short notes on Printers. (6)

UNIT V TRANSDUCERS AND DATA ACQUISITION SYSTEMS

Classification of transducers – Selection of transducers – Resistive, capacitive and inductive transducers – Piezoelectric, optical and digital transducers – Elements of data acquisition system– A/D, D/A converters – Smart sensors.

CLASSIFICATION OF TRANSDUCERS

Transducers – Introduction

The study of sensors is multidisciplinary and requires a comprehensive knowledge of generalphysics, solid-state physics, electronics, technology and semiconductor-manufacturingtechniques.

Energy *information* conversion is the objective of a sensor. The information available in oneenergy form must be converted into the same or another energy form, with exactly the sameinformation content as the originating energy form.

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The identification unit contains a device which reacts to the desired physical quantity andconverts it into an electrical quantity. The input transducer can be found here, normally called asensor. In the modifier stage the electrical energy is converted into another shape. In thepresentation unit, two possibilities arise depending on the nature of the 'system' to be served.If a machine or process must be supplied with new information, the output transducer mustbe able to provide it. In that case, often a type of actuator may be required to execute the rightaction. In measurement systems to be perceived by humans, we need a type of display to whichour senses react, or can take action. So if we state that the output transducer is an actuator we arealways right, whether it activates a technical system or a living (biological) system.

CLASSIFICATION OF TRANSDUCERS

A *transducer* can be defined as a device capable of converting energy from one form intoanother. Transducers can be found both at the input as well as at the output stage of a measuringsystem.
The input transducer is called the *sensor*, because it senses the desired physical quantity andconverts it into another energy form.

The output transducer is called the *actuator,* because it converts the energy into a form to whichanother independent system can react, whether it is a biological system or a technical system. So,for a biological system the actuator can be a numerical display or a loudspeaker to which thevisual or aural senses react respectively. For a technical system the actuator could be a recorderor a laser, producing holes in a ceramic material. The results can be interpreted by humans.

Types of energy form

We can distinguish six different energy domains: (1) radiant, (2) mechanical, (3) thermal, (4)electrical, (5) magnetic and (6) chemical.

If certain information is already available in the electrical domain it can be claimed that it requires no energy conversion, but in general there is 'shape' conversion left and this is just the domain which belongs to the field of electronics and electrical science and engineering. A good example of such a sensor only sensitive to electrical energy is the probe of an oscilloscope, with which a good adaptation to the signal source is realized. In the modifier stage we meet other xamples of shape converters, for instance the A/D and D/A converters.

In the same way, the six different domain conversions at the output can be drawn. This isillustrated in figure above, where compared with previous figure the only difference is the reversed direction of the arrows.

Types of energy source

If the energy sources at the input, or the actuators are acting on at the output, are considered, we can distinguish between *technical* systems and *biological* systems.

Technical systems can produce all six energy forms. Hence at the input side the six different types of energy source can always be recognized.

For biological systems this is not so clear, but a more careful consideration will reveal the same six different types of energy form.

1. Radiant energy is produced by all biological systems. This is normally infrared radiation and can be detected although it is not visible, for instance, with the rmographic cameras.
2. Biological systems can also produce mechanical energy as a result of movements or the liquid pressure in the vessels

3. Thermal energy is produced by all systems in which oxidation takes place.

4. Electrical energy for instance is produced by the heart muscle at a potential of several mV.

5. Magnetic energy is also produced by the human heart muscle. Also, magnetic brainactivities can be monitored with the help of superconducting quantum interference devices,so-called SQUIDs.

6. In biological systems chemical energy is produced in all types of process and they can act asan energy source also.

At the output we can find the same six energy domains for both types of system. Again for technical systems this will be clear, but biological systems require more explanation.

1. Biological systems with their vision sense can react to radiant energy, as for
instance is the case with the information displayed on a cathode-ray tube (CRT).

2.Biological systems are sensitive to mechanical forces and will react to them.

3.Thermal energy influences biological systems to a large extent and for instance determines the velocity of growth and movement

4.Biological systems are sensitive to electrical energy and muscles for instance will react to electrical pulses or even produce electrical energy.

5.It is already known that magnetic fields can cause chemical changes in biological tissues and cell structures and so change the information content.

6.Numerous examples exist in which biological systems are sensitive to chemical actuators(substances). Examples are all types of medicine.

Measuring biological quantities gave rise to a huge effort to manufacture so-called
biosensors.

Modulating and self-generating transducers

Another important characteristic related to transducers implies the distinction of transducers into two categories. This is because some transducers require an auxiliary energy source to become operational. Hence a distinction is made between *modulating* and *self-generating* transducers.

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A *modulating* transducer is defined as a transducer which requires an auxiliary energy sourceto convert energy from one domain into another. A good example of a modulating transducerwhich is found at the input of a system is a strain gauge. This type of transducer requires anelectrical energy source to become operational. The electrical current flowing in the strain gaugeis modulated by a mechanical force which is converted into an electrical voltage change via achange of the resistive elements. As a consequence the input energy modulates the energy of theauxiliary energy source. At the output of a system a liquid-crystal display (LCD) is an exampleof a modulating transducer, because again an auxiliary energy source is required to perform thecorrect transduction.

Resistance Transducer

A potentiometric transducer that converts the measured quantities—such as displacements, geometric dimensions, or angles of rotation—into changes in the electrical resistance of a rheostat. Resistance transducers can be classed as linear or functional and may have translational or rotational displacement of the contact blade. In DC resistance transducers, the output signal *y* may be a change in current (with transducer connected as a rheostat) or a change in voltage (with transducer connected as a potentiometer).

Linear rheostatic transducers exhibit a constant ratio of the increment of the output signal Δy to the displacement of the contact blade Δx within the measurement range. In the case of functional rheostatic transducers, the relationship $y = F(x)$ is given in advance. For such transducers, the accuracy of measurement (or conversion) depends on a number of factors, including the homogeneity and diameter of the rheostat conductor, the density and uniformity of the conductor winding on the frame, and the ratio of the internal resistance r_{int} of the transducer to the load resistance r_{load}. To ensure a low conversion error, it is necessary that the ratio r_{int}/r_{load} be a minimum. For this purpose, an electronic signal amplifier with a sufficiently large input resistance is often connected to the output of the transducer.

CAPACITIVE TRANSDUCER

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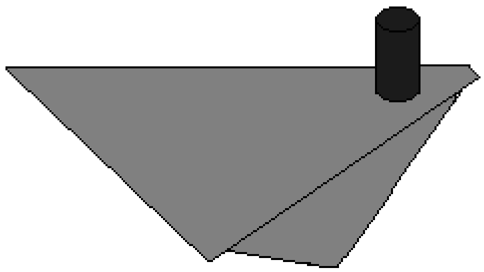
The value of capacitance is determined by:

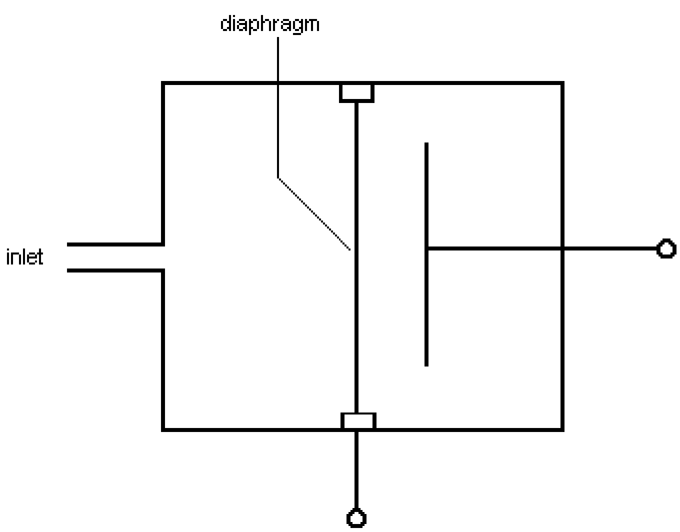
(a) the area of the plates

(b) the distance between the plates

(c) the type of dielectric between the plates

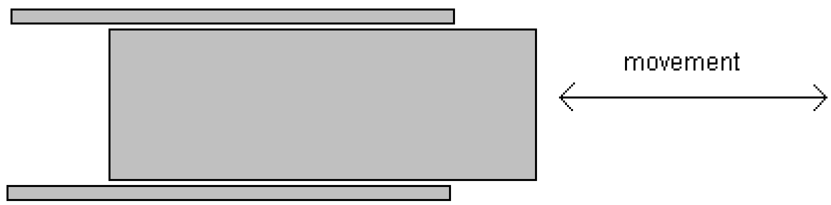


The picture above shows how the area of the plates can be adjusted by varying the overlap.



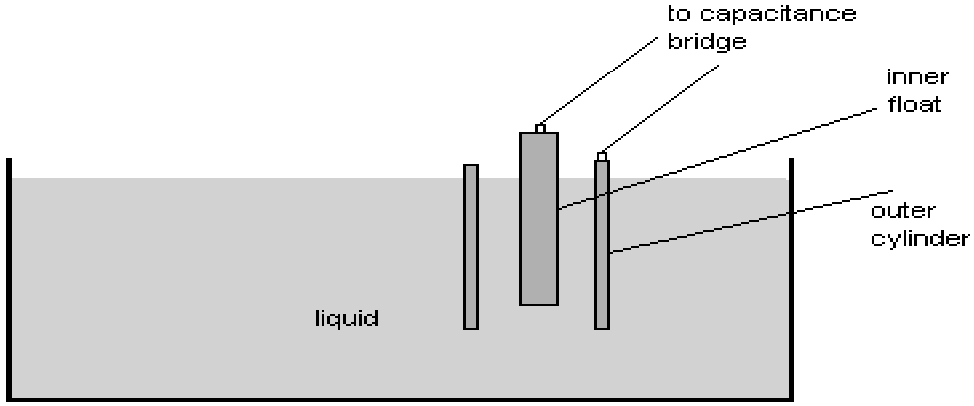
In the above diagram the flexible diaphragm act capacitor plates.

As pressure is applied to the input it bends towards the fixed plate thus increasing the capacitance.

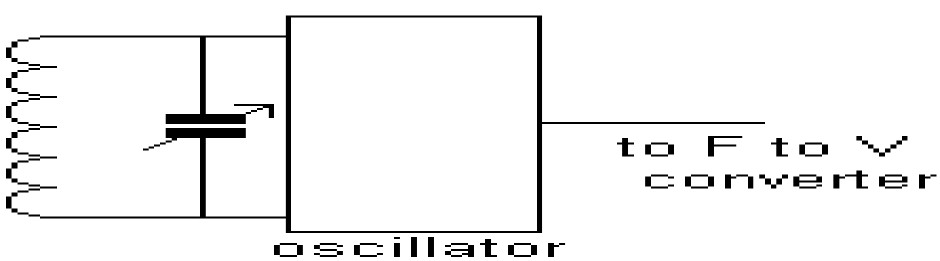


In the above capacitor the position of the dielectric is varied to vary the capacitance.

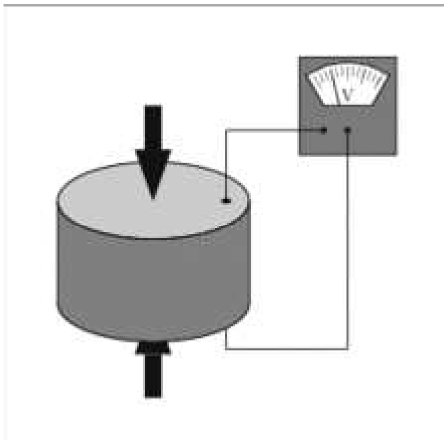
The picture below shows an application of this.



The last diagram shows an application for capacitive transducers.The frequency of the oscillator is determined by the LC combination.The output of the oscillator is converted to a DC voltage.The value of the voltage can be displayed on a digital meter as inches.



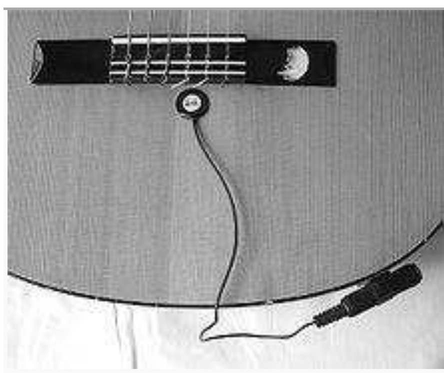
Piezoelectric sensor



A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated)

A **piezoelectric sensor** is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electricalsignal.

Applications



Piezoelectric disk used as a guitar pickup

Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance, process control and for research and development in many different industries. Although the piezoelectric effect was discovered by Curie in 1880, it was only in the 1950s that the piezoelectric effect started to be used for industrial sensing applications. Since then, this measuring principle has been increasingly used and can be regarded as a mature technology with an outstanding inherent reliability. It has been successfully used in various applications, such as in medical,aerospace, nuclear instrumentation, and as a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built in miniature piezoelectric sensor .

The rise of piezoelectric technology is directly related to a set of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 10e6 N/m^2[*dubious – discuss*]. Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection. This is the reason why piezoelectric sensors are so rugged, have an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive to electromagnetic fields andradiation, enabling measurements under harsh conditions. Some materials used (especially gallium phosphate or tourmaline) have an extreme stability even at high temperature, enabling sensors to have a working range of up to 1000°C. Tourmaline shows pyroelectricity in addition to the piezoelectric effect; this is the ability to generate an electrical signal when the temperature of the crystal changes. This effect is also common to piezoceramic materials.

Principle	Strain Sensitivity [V/µ*]	Threshold [µ*]	Span to threshold ratio
Piezoelectric	5.0	0.00001	100,000,000
Piezoresistive	0.0001	0.0001	2,500,000
Inductive	0.001	0.0005	2,000,000
Capacitive	0.005	0.0001	750,000

One disadvantage of piezoelectric sensors is that they cannot be used for truly static measurements. A static force will result in a fixed amount of charges on the piezoelectric material. While working with conventional readout electronics, imperfect insulating materials, and reduction in internal sensor resistance will result in a constant loss of electrons, and yield a decreasing signal. Elevated temperatures cause an additional drop in internal resistance and sensitivity. The main effect on the piezoelectric effect is that with increasing pressure loads and temperature, the sensitivity is reduced due to twin-formation. While quartz sensors need to be cooled during measurements at temperatures above 300°C, special types of crystals like GaPO4 gallium phosphate do not show any twin formation up to the melting point of the material itself.

However, it is not true that piezoelectric sensors can only be used for very fast processes or at ambient conditions. In fact, there are numerous applications that show quasi-static measurements, while there are other applications with temperatures higher than 500°C.

Piezoelectric sensors are also seen in nature. Dry bone is piezoelectric, and is thought by some to act as a biological force sensor.

Principle of operation

Depending on how a piezoelectric material is cut, three main modes of operation can be distinguished: transverse, longitudinal, and shear.

Transverse effect

A force is applied along a neutral axis (y) and the charges are generated along the (x) direction, perpendicular to the line of force. The amount of charge depends on the geometrical dimensions of the respective piezoelectric element. When dimensions *a*,*b*,*c* apply,

$$C_x = d_{xy} F_y b / a,$$

where *a* is the dimension in line with the neutral axis, *b* is in line with the charge generating axis and *d* is the corresponding piezoelectric coefficient.

Longitudinal effect

The amount of charge produced is strictly proportional to the applied force and is independent of size and shape of the piezoelectric element. Using several elements that are mechanically in series and electrically in parallel is the only way to increase the charge output. The resulting charge is

$$C_x = d_{xx} F_x n,$$

where d_{xx} is the piezoelectric coefficient for a charge in x-direction released by forces applied along x-direction (in pC/N). F_x is the applied Force in x-direction [N] and n corresponds to the number of stacked elements .

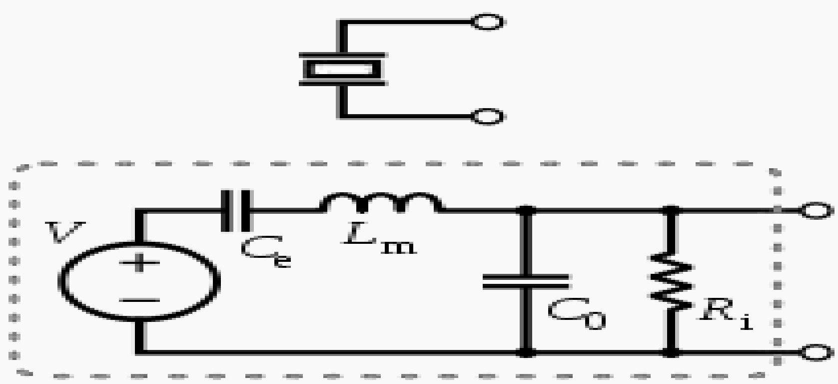
Shear effect

Again, the charges produced are strictly proportional to the applied forces and are independent of the element's size and shape. For n elements mechanically in series and electrically in parallel the charge is

$$C_x = 2 d_{xx} F_x n.$$

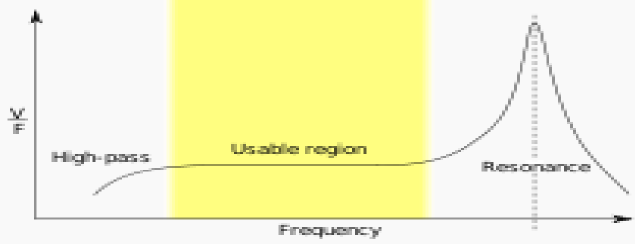
In contrast to the longitudinal and shear effects, the transverse effect opens the possibility to fine-tune sensitivity on the force applied and the element dimension.

Electrical properties



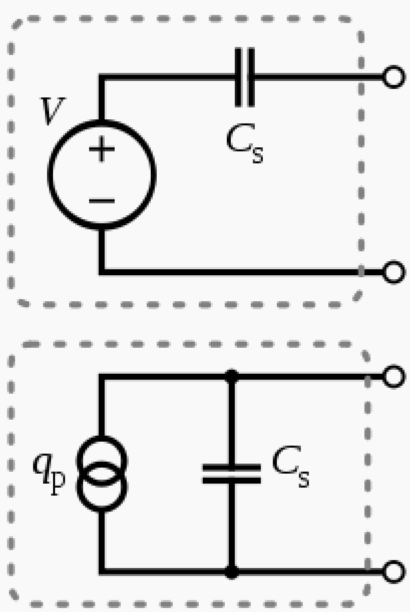
Schematic symbol and electronic model of a piezoelectric sensor

A piezoelectric transducer has very high DC output impedance and can be modeled as a proportional voltage source and filter network. The voltage V at the source is directly proportional to the applied force, pressure, or strain.[2] The output signal is then related to this mechanical force as if it had passed through the equivalent circuit.



Frequency response of a piezoelectric sensor; output voltage vs applied force

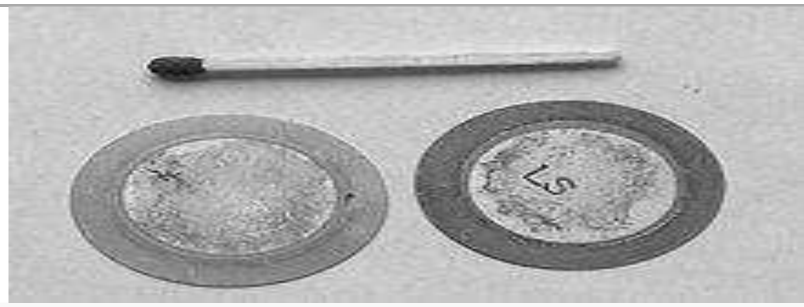
A detailed model includes the effects of the sensor's mechanical construction and other non-idealities.[3] The inductance L_m is due to the seismic mass andinertia of the sensor itself. C_e is inversely proportional to the mechanical elasticity of the sensor. C_0 represents the static capacitance of the transducer, resulting from an inertial mass of infinite size.[3] R_i is the insulation leakage resistance of the transducer element. If the sensor is connected to a load resistance, this also acts in parallel with the insulation resistance, both increasing the high-pass cutoff frequency.



In the flat region, the sensor can be modeled as a voltage source in series with the sensor's capacitance or a charge source in parallel with the capacitance

For use as a sensor, the flat region of the frequency response plot is typically used, between the high-pass cutoff and the resonant peak. The load and leakage resistance need to be large enough that low frequencies of interest are not lost. A simplified equivalent circuit model can be used in this region, in which C_s represents the capacitance of the sensor surface itself, determined by the standard formula for capacitance of parallel plates.[3][4] It can also be modeled as a charge source in parallel with the source capacitance, with the charge directly proportional to the applied force, as above.

Sensor design



Metal disks with piezo material, used in buzzers or as contact microphones

Based on piezoelectric technology various physical quantities can be measured; the most common are pressure and acceleration. For pressure sensors, a thin membrane and a massive base is used, ensuring that an applied pressure specifically loads the elements in one direction. For accelerometers, a seismic mass is attached to the crystal elements. When the accelerometer experiences a motion, the invariant seismic mass loads the elements according to Newton's second law of motion $F = ma$.

The main difference in the working principle between these two cases is the way forces are applied to the sensing elements. In a pressure sensor a thin membrane is used to transfer the force to the elements, while in accelerometers the forces are applied by an attached seismic mass.

Sensors often tend to be sensitive to more than one physical quantity. Pressure sensors show false signal when they are exposed to vibrations. Sophisticated pressure sensors therefore use acceleration compensation elements in addition to the pressure sensing elements. By carefully matching those elements, the acceleration signal (released from the compensation element) is subtracted from the combined signal of pressure and acceleration to derive the true pressure information.

Vibration sensors can also be used to harvest otherwise wasted energy from mechanical vibrations. This is accomplished by using piezoelectric materials to convert mechanical strain into usable electrical energy.

ANALOG TO DIGITAL CONVERTER

An **analog-to-digital converter** (abbreviated **ADC**, **A/D** or **A to D**) is a device that converts a continuous quantity to a discrete digital number. The reverse operation is performed by a digital-to-analog converter (**DAC**).

Typically, an ADC is an electronic device that converts an input analog voltage (or current) to a digital number proportional to the magnitude of the voltage or current. However, some non-electronic or only partially electronic devices, such as rotary encoders, can also be considered ADCs.

The digital output may use different coding schemes. Typically the digital output will be a two's complement binary number that is proportional to the input, but there are other possibilities. An encoder, for example, might output a Gray code.

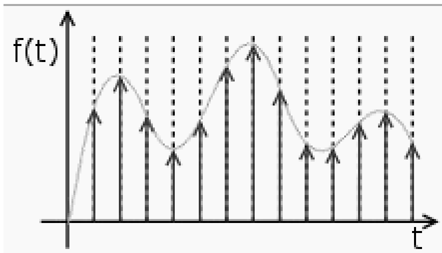
An ADC might be used to make an isolated measurement. ADCs are also used to quantize time-varying signals by turning them into a sequence of digital samples. The result is quantized in both time and value.

Digital-to-analog converter

8-channel digital-to-analog converterCirrus Logic CS4382 as used in a soundcard.

In electronics, a **digital-to-analog converter** (**DAC** or **D-to-A**) is a device that converts a digital (usually binary) code to an analog signal (current, voltage, orelectric charge). An analog-to-digital converter (ADC) performs the reverse operation.

Basic ideal operation



Ideally sampled signal.

A DAC converts an abstract finite-precision number (usually a fixed-point binary number) into a concrete physical quantity (e.g., a voltage or a pressure). In particular, DACs are often used to convert finite-precision time series data to a continually varying physical signal.

A typical DAC converts the abstract numbers into a concrete sequence of impulses that are then processed by a reconstruction filter using some form ofinterpolation to fill in data between the impulses. Other DAC methods (e.g., methods based on Delta-sigma modulation) produce a pulse-density modulatedsignal that can then be filtered in a similar way to produce a smoothly varying signal.

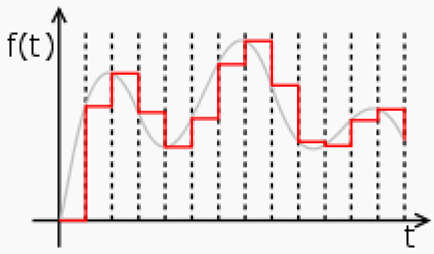
By the Nyquist–Shannon sampling theorem, sampled data can be reconstructed perfectly provided that its bandwidth meets certain requirements (e.g., abaseband signal with bandwidth less than the Nyquist frequency). However, even with an ideal reconstruction filter, digital sampling introduces quantization error that makes perfect reconstruction practically impossible. Increasing the digital resolution (i.e., increasing the number of bits used in each sample) or introducing sampling dither can reduce this error.

Depending on how the DAC is configured, the transfer can be unipolar (only positive output values) or bipolar (positive and negative values).

Practical operation

Instead of impulses, usually the sequence of numbers update the analogue voltage at uniform sampling intervals.

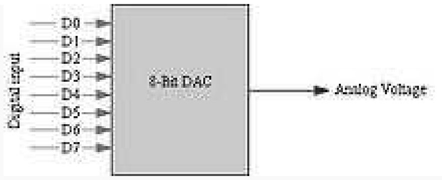
These numbers are written to the DAC, typically with a clock signal that causes each number to be latched in sequence, at which time the DAC output voltage changes rapidly from the previous value to the value represented by the currently latched number. The effect of this is that the output voltage is *held* in time at the current value until the next input number is latched resulting in a piecewise constant or 'staircase' shaped output. This is equivalent to a zero-order hold operation and has an effect on the frequency response of the reconstructed signal.



Piecewise constant output of a conventional practical DAC.

The fact that practical DACs output a sequence of piecewise constant values (known as zero-order hold in sample data textbooks) or rectangular pulseswould cause multiple harmonics above the Nyquist frequency. These are typically removed with a low pass filter acting as a reconstruction filter.

However, this filter means that there is an inherent effect of the zero-order hold on the effective frequency response of the DAC resulting in a mild roll-off of gain at the higher frequencies (often a 3.9224 dB loss at the Nyquist frequency) and depending on the filter, phase distortion. Not all DACs have a zero order response however. This high-frequency roll-off is the output characteristic of the DAC, and is not an inherent property of the sampled data.



A simplified functional diagram of an 8-bit DAC

TRANSDUCERS AND DATA ACQUISITION SYSTEMS

PART – A

1. Give the factors to be considered for selecting a transducer. (2)
2. Why is an A/D converter usually considered as an encoder? (2)
3. Define inverse transducer with example. (2)
4. Explain the principle of piezoelectric transducers and name any twopiezoelectric materials. (2)
5. Name the transducers used for sensing acceleration. (2)
6. Mention the use of capacitive transducers. (2)
7. Classify the transducers and what is the other name of it. (2)
8. What are active and passive transducers? Give examples. (2)
9. What are the characteristics of transducers? (2)
10. What is meant by data acquisition system? List its types. (2)
11. Give the operating principle of a resistive transducer. Also give someexamples (2)
12. What is piezoelectric effect? (2)
13. What is LVDT? (2)
14. List the advantages and disadvantages of LVDT. (2)
15. What is thermocouple? (2)
16. What are the advantages and disadvantages of LVDT? (2)
17. What is seeback voltage? (2)
18. What is strain gauge? List its types. (2)

19. What is gauge factor? Give its expression. (2)
20. What is resistance thermometer? (2)
21. What are the salient features of thermistor? (2)
22. What are capacitive transducers? Give the expression for a capacitance of a capacity transducer. (2)
23. What are optical detectors? List its types. (2)
24. What are photoelectric transducers? (2)
25. List the types of A/D and D/A converters. (2)
26. Draw the transfer characteristics of ADC and DAC. (2)
27. What are the advantages and disadvantages of dual slope ADC? (2)
28. Give a short note on data acquisition system. (2)
29. What is the composition of materials used in thermistor? (2)
30. State the laws of thermoelectric. (2)

PART – B

1. (i) Explain the principle of inductive and capacitive transducer. (8)

(ii) Explain the construction and working of LVDT with a neat sketch

2. (i) Explain different strain gauges with their principle of operation. (8)

(ii) Discuss in detail about resistive transducers. (8)

3. (i) Explain the various types of temperature transducers. (8)

   (ii) Explain the function of piezoelectric transducer. (8)

4. (i) Explain the binary weighted resistor technique of D/A conversion.(8)

   (ii) Define the following terms for D/A converters:

   a) Resolution

   b) Accuracy

   c) Monotonicity

   d) conversion time(8)

5. (i) Explain the resistive transducer with respective to potentiometer.

   (ii) Explain the capacitive transducer. (6)

   (iii) Describe the piezoelectric transducer and give the formula forcoupling coefficient. (6)

1. (i) Explain schematic block diagram of a general data acquisitionsystem (DAS) and give its objectives (6)

   (ii) Discuss R-2R ladder type D/A converter. (6)

   (iii) For a 5 bit ladder, if the input levels are 0 = 0V and 1 = 10Vwhat are the output voltages for each bit? (4)

7. Explain the various types of ADC with suitable sketches. (16)

8. Explain the working principle of various types of DAC with neat sketches. (16)

9. (i) Explain the principle of operation a thermocouple with neat

sketch.

(ii) Give a short note on single and multi channel DAS. (6)

10. (i) Explain the different types of optical encoders. (8)

(ii) Explain the successive approximation type ADC. (8)

Reg. No. :

F 0425

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2010

THIRD SEMESTER

ELECTRICAL AND ELECTRONICS ENGINEERING

EI1202 MEASUREMENTS AND INSTRUMENTATION

(REGULATION 2008)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. Draw the generalized block diagram for temperature measurement system.

2. The value of a resistance is 4.7 K ohm, while measurement of it, yield a value of 4.63 K ohm : calculate % accuracy.

3. Define loading effect in measurement.

4. What is the use of magnetic measurements?

5. Draw the block diagram for Maxwell Bridge.

6. What is the disadvantage of transformer Ratio Bridge?

7. List out the CRT features.

8. What is the purpose of error detector in a recorder?

9. What is the use of sample and hold circuit, in a data acquisition system?

10. What is the application of capacitive transducer?

PART B — (5 × 16 = 80 marks)

11. Explain in detail about importance of statistical analysis of measurement data.

Or

12. The following 10 readings are taken of a certain physical length : 5.3 m, 6.77 m, 5.26 m, 4.53 m, 5.45 m, 6.09 m, 5.64 m, 5.81 m, 5.73 m and 5.75 m. Calculate

(a) Mean

(b) Standard deviation

(c) Range

(d) Error.

13. Describe the construction and working principle of Single phase Energy meter.

Or

14. Write short notes on :

(a) Instrument transformer

(b) Measurement of iron loss.

15. Discuss in detail about electrostatic and electromagnetic interference, and grounding techniques.

Or

16. Write short notes on :

(a) Transformer ratio bridge

(b) Self balancing bridges.

17. Discuss in detail about the working of digital plotters.

Or

18. With help of neat diagram, explain the operation of digital CRO.

19. Explain the construction and working principle of LVDT.

Or

20. With help of neat block diagram, clearly explain how analog data can be converted into digital data using successive approximation type ADC.
