BASIC ELECTRONIC MEASURING INSTRUMENTS: PRINCIPLES AND PRACTICE

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INTRODUCTION

Measurement refers to the act of comparing an unknown quantity with a known quantity (standard) to ascertain its value or worth. The technological advancement of any nation depends largely on its ability to measure, calculate and finally, estimate the unknown. So also, the success of any electrical and electronic expert can be judged by his ability to precisely and accurately measure and interpret electrical and electronic circuit performance. This may be why literatures have it that,the science of measurement isin consonance with human level of technological advancement.

For instance, to cope with some of the technological challenges of his time,a German scientist,George Simon Ohm (1787 – 1854)had to build his own measuring instruments and apparatus. To measure current, for example, Ohm constructed a primitive electrical measuring instrument called ‘galvanometer’ which made practical use of a discovery that a current would cause a nearby compass needle to deflect and the greater the current, the greater the amount of deflection. In fact, galvanometers were one of the very few electrical instruments available commercially in those days, and consisted of a vertical coil of wire enclosing a horizontal, balanced, magnetized needle. But, as Ohm realized, galvanometers built by different people would not produce standard measurements. To preclude these difficulties, the instrument had to be carefully aligned so that the earth’s magnetic field would provide a restraining torque on the needle. Furthermore, the deflection of the magnetic needle was notproportional to that current. So Ohm had to make his own instruments to measure voltage and current, for which there were no units of measurement, and whose scales were not even proportional to the values being measured.

In light of all these difficulties, we can only appreciate the creative imaginations of researchers such as Ohm, and be in awe at the results they were able to achieve. Today, we have a standard and internationally-accepted set of both electrical andelectronics measuring instruments that can measure values with great accuracy and precision. The technological feats in electronic measurements have made our dreams of going to the moon a reality. Certainly, the various electrical and electronics luxuries we enjoy today were only possible through advancements in the measurement science that has produced precision devices. These devices utilize the movements of electrons to measure values with overwhelming accuracy. However, one of the differences being that, the control of electronic movements is more effective in electronic instruments than in their electrical counterparts.

The electronic measuring instruments are equipped with amplification, displayand storage elements such as diodes, transistors, vacuum tubes, plasmas and flip-flops devices that make them more robust and user friendly. They can detect, display and store respectively, small values of signals to be measured. The multimeter, for example, as one of the basic electronic measuring devices, incorporates semiconductors, diodes and ICs that help enhance its performance to measure electrical quantities in milliamps and so on. However, the question is: What are the electronic instrument performance limitations?

Through the following discussions on practical application as well as principles of operation of electronic measuring instruments, alongside lively, interesting and relevant case studies, readers will learn how the basic electronic measuring instruments can be employed to measure or test electronic components accurately. This book will further reveal to the readers, the significance of good measurement practices using Multimeters, Logic Probes, Oscilloscopes, Signal Generators and Frequency Counters to carry out measurements with negligible errors in our various areas of electronic troubleshooting. With the invention of these basic electronic measuring instruments, we can say confidently that depending on how keen one’s wits are and observing the stated guidelines, one can perform measurement of electrical quantities with little or negligible error.

CHAPTER ONE

ERROR IN ELECTRONIC MEASUREMENT

1.2 Introduction

Error refers to the deviation of a reading (or set of readings) from the expected truevalue of the measuredvariable. When we make measurements, some errors are unavoidable because ideally, nomeasurement can yield the exact value of any quantity. The difference between the true value and the result obtained through measurement is the error. Error in electronic measurement is therefore defined as the algebraic difference between the result of the measurement and the true value of the quantity being measured.

Error = measured value – true value

The error is said to be positive if the measured value is greater than the true value and negative if it is less than the true value. The percentage error is the error expressed as a percentage of the true value. It is given by:

$$\%\ Error = \frac{error}{truevalue} \times 100\%$$

In electronic measurements, errors may come up from different sources and are usually classified as being either of the following:

1. Gross Error,
2. Systematic Error,
3. Random Error.

1.1.1 Gross Error: This is an error in electronic measurement that occurs due to bad measurement practices. It is largely a human factor error, which may be caused for example,due to Parallax Error (or Misreading Error) thathappens when taking a reading from a scale at a wrong angle instead of looking directly over the scale as illustrated in Figure 1.1. It can be seen that only the reading taken directly over the scale is correct (at a position where the pointer and its shadow on the mirror are aligned); whereas readings from the remaining positions are wrong. Another example of Gross Error is when an analogue multimeter or similar type of instrument is used to take measurement without ‘zeroing’ the instrument from the beginning, resulting to a measured value that is higher or lower than the actual worth of the variable. Other examples of Gross Error include:Calculations Error, as a result of wrong calculations of measurement results, Incorrect Instrument Error and Incorrect Adjustment Error.Although there may be other examples of Gross Error in electronicmeasurement, it suffices to state that in order to eliminate them; some good measurement practices must be applied.

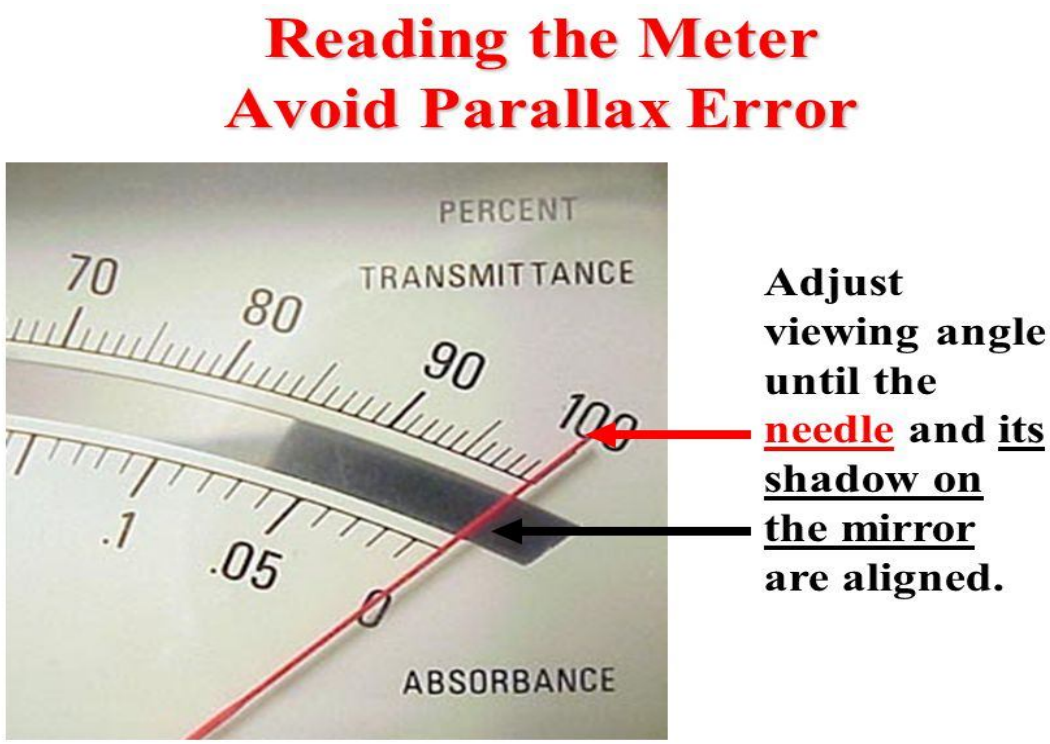


Fig 1.1 Parallax error: Caused Due to Taking Measurement from Wrong Viewing Angle
Source: slideplayer.com

1.1.2 Systematic Errors: This error occursas a result of some defects or ageing of the measuring instruments (Instrumental Error) andsometimes due to external conditions (Environmental Error) affecting the measurement. For instance, when the damping or control spring of a moving coil meter starts losing its elastic propertiesdue to excessive use, measurements performed using such instruments will constitute some Systemic Error. Furthermore, the manufacturers of the same type of instrumentshas to take into cognisance the fact that some changes in the length of springs used in the instrument occur (linear expansion) due to excessive variation of temperature at a wide range that can cause Environmental (SystemicError). This is why instruments used on Ships, Aircrafts or Spacecrafts that change locations (environments) within a short period of time are manufactured with greater accuracy using special materials that are flexible enough to withstand sudden environmental changes (example, a spring whose temperature coefficient is very low) to avoid 'Temperature Error'. Similarly, Systemic Error may occur as theresult of lack of proper maintenance of electronic measuring instruments (i.e greasing, oiling of moving parts and so on).

Hysteresis Error, which is another type of Systemic Error,occurs due to hysteresis effect on the reading of the instrument, especially the moving iron instruments. When the current isdecreasing, the flux produced will not decrease suddenly. Due to this, the meter reads a highervalue of current. Also, when the current increases the meter reads a lower value of current.This produces error in deflection. This error can be eliminated by using soft iron parts with narrow hysteresis loop so that the demagnetization takes place very quickly.This will be discussed much better in the subsequent chapters.

Eddy Current Error is another form of Systemic Error. The eddy currents induced in the moving iron affect the deflection of the pointer. This error can be reduced by increasing the resistance of the iron. Stray Field Error also, being another type of Instrumental Error, occurs when the operating field of a moving iron instrument is weak causing the effect of stray field to be more than necessary. Due to this, error is produced in deflection. However, this can be eliminated by shielding the parts of the instrument.

Loading Error is another example of Instrumental Error. When a measuring instrument is connected to the system to be measured, some loading effects happen due to the power sharing of the two systems. The Loading Error for an ammeter and voltmeter can be calculated as follows, respectively.

$$\frac{\Delta I}{I} = \frac{r}{r+Rn} \qquad \textit{and} \qquad \frac{\Delta V}{V} = \frac{Rth}{r+Rth}$$

Where ***'r'*** is the internal resistance of the meter, ***Rn*** is the Norton and ***Rth*** Thevenin equivalent resistance of the circuit. Since the internal resistance of analogue voltmeter change with the selected range, instead of the internal resistance usually the sensitivity of the instrument, ***'S'*** (input resistance-per-volt), is given such as "20kΩ/V". This value is indicated on the panel of the instrument. If the range of the voltmeter is set to ***'VR'***, then the internal resistance of analogue voltmeter is:

$$r = VR \times S$$

The internal resistance of a digital voltmeter is usually constant and greater than 1MΩ. The internal resistance of an ammeter changes with the range of the instrument and should be obtained from the user's manual of the instrument.

The relative worst case or Limiting Error of a measurement is the sum of the Loading Error and Instrument (accuracy) Error assuming other errors are negligible, which is generally given by:

$$\left|\frac{\Delta X}{X}\right|_{worst\ case} = \left|\frac{\Delta X}{X}\right|_{Instrument} + \left|\frac{\Delta X}{X}\right|_{Loading}$$

Where ***'X'*** is the variable being measured.

Usually, Instrumental Error is given in the user's manual of the instrument for maximum reading as:

$$\pounds_o = \frac{\Delta V}{Vmax}$$

Where $\pounds_o$ is the error of the instrument. Error of the analogue instrument is usually expressed as the class of the instrument. The class of the instrument shows the relative error for full-scale deflection (maximum reading).

1.1.3 Random Error: This type of error exists due to the possibility of uncertainties associated with randomization of measurements. As stated earlier, efforts to reduce other types of error make us to repeat measurements as much as possible resulting to Random Error. In other words, if we perform many measurements and every time we obtain a slightly different result (with difference exceeding the assumed value) we can conclude that there is a random error in that measurement.

The percentage of the entire measurement, which will fall within a specificrange of values, can be predicted quite accurately from the statistical analysis of the sample.Under ideal conditions, a very large number of measurements will provide a distribution ofreadings, with the greatest number of readings approximately equal to the actual value. Oneither side of the actual value, the frequency of readings will decrease, producing anapproximately normal distribution.Arithmetic mean of the number of measurements(n) is the best estimate of the true value (or accuracy). It can beformulated as:

$$\bar{X} = \frac{X1 + X2 + X3 + \cdots + Xn}{n}$$

$$= \frac{\sum_{i=1}^{n} Xi}{n}$$

Where **'n'** is the number of measurements and **'X_i'** is the reading of the**'i'th'** measurement.

Standard Deviation or root-mean-square deviation of the n measurementswill further give the best estimateof the precision formulated as:

$$d = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots + d_n^2}{n-1}}$$

Where **'n'** is the number of measurement, **'di'** is the deviation from the mean.

From the ongoing,it is important to take note of all thatwas mentionedincluding the stated formulas so as to improve accuracy and precision in electronic measurements. It should also be noted that the manufacturers of electronic instruments are doing their best to reduce errors in measurement. Therefore, what remains is to complement such efforts by using the right electronic measuring instruments for the right job. We can see that errors in electronic measurements occur largely due to inefficiency of the users to follow the appropriate guidelines, using the right electronic measuring instruments such as Multimeters and so on.

EXERCISES

Exercise 1.1: A multimeter was used to measure the amount of current passing through a certain load in a circuit yielding a value of 0.67 A. If the true value of the current is 0.56 A, calculate the error involved in the measurement.

(a) 0.22
(b) 0.11
(c) 0.33
(d) 0.44

Exercise 1.2: The current passing through a resistor of 100 ± 0.2 ohms is 200 ± 0.01 A. Using the relationship $P = I^2 R$, calculate the Limiting Error in the computed value of power dissipation.

(a) 400 ± 4.8 W
(b) 800 ± 4.8 W
(c) 200 ± 4.8 W
(d) 300 ± 4.8 W

Exercise 1.3: Figure 'a' shows the Norton's equivalent circuit in which an Ammeter with internal resistance of 0.02 Ohms was used to measure current passing through a resistor. Calculate the Loading Error of the device.

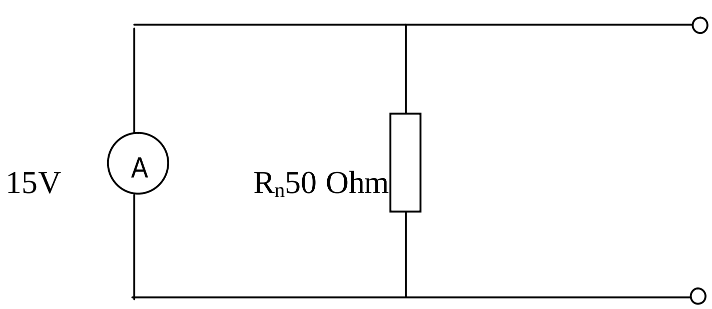


Figure (a): Norton's Equivalent Circuit Arrangement

(a) 0.0001

(b) 0.0002

(c) 0.0003

(d) 0.0004

Exercise 1.4:A 150 V voltmeter has a guaranteed accuracy of 1 % full scale reading. The voltage measured using the instrument is 83 V. Calculate the Limiting Error in percentage.

(a) 1.61%

(b) 1.71%

(c) 1.81%

(d) 1.91%

Exercise 1.5: Calculate the percentage error of a measurement of potential difference between two points on a current carrying conductor when the true value is 50.2 V against 50.6 V obtained using a measuring device.

(a) 0.797%

(b) 1.797%

(c) 2.797%

(d) 3.797%

Exercise 1.6: Figure ‘b’ shows the Thevenin’s equivalent circuit in which a Voltmeter with high internal resistance of 1000 Ohms was used to measure voltage across a resistor. Calculate the Loading Error of the device.

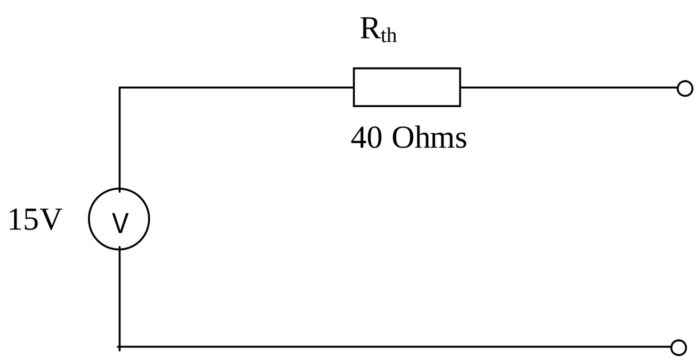


Figure (b): Thevenin’s Equivalent Circuit Arrangement

(a) 0.01V

(b) 0.02V

(c) 0.03V

(d) 0.04V

Exercise 1.7: The characteristics or properties of the materials selected to be used for the manufacture of electronic measuring devices is very important to avoid which type of measurement error?

(a) Misreading Error
(b) Instrument Error
(c) Random Error
(d) Gross Error

Exercise 1.8:A technician obtains the following results after using an Ammeter to measure current: 50.2, 50.3, 50.5, 50.4, 50.6, and 50.9 A. Calculate the best estimate of the true value of these measurements.

(a) 50.3A
(b) 50.4A
(c) 50.5A
(d) 50.6A

Exercise 1.9: Table ‘a’ shows the resistances of a resistor obtained from ten measurements.Use the data to calculate: (i) The Mean or True Resistance and (ii) The deviation from the True Resistance.

Table (a) Resistances of a resistor

Readings	**Deviations**
10.20	0.01
10.70	0.16
10.30	0.00
10.00	0.09
10.50	0.04
10.30	0.00
10.20	0.01
10.40	0.01
10.30	0.00
10.10	0.04

(a) 10.3Ω and 0.2Ω
(b) 10.4Ω and 0.3Ω
(c) 10.5Ω and 0.4Ω
(d) 10.6Ω and 0.5Ω

Exercise 1.10: The type of error caused by human misreading or bad measurement habits is called?

(a) Misreading Error

(b) Instrument Error

(c) Random Error

(d) Gross Error

CHAPTER TWO

MULTIMETERS

2.1 Features of Multimeters

Multimeter is one of the basic electronic measuring instruments that are popularly used in electronic workshops, laboratories, houses and industries. We have two types of multimeters, the analogue and the digital. The term, 'digital' applies, not only to an instrument's digital readout, but also to the technology it employs. For a long time, analogue instruments have reached their limits. Meaning, theaccuracy of their movements and an ease of reading have become about as good as they can possibly get. Digital instruments have now overtaken analogue instruments in terms of their robustness, potential accuracy, and the elimination of reading errors, such as Parallax Error, Zero Errors and so on (as previously discussed in chapter one of this book). Some digital multimeters can also measure additional quantities, such as Frequency, Capacitance, Temperature, etc. Therefore, because of improved precision, ease of use and simpler user interface, the digital multimeters have now largely replaced their analogue counterparts. However, for scholarly purpose, it is essential to include the principle of operation and practical applications of both type multimeters. After all, the analogue multimeters are cheaper in the market, making them more popular among students and practicing technicians. That is why in this book, both types of multimeter (analogues and digital) are discussed comprehensively.

As shown in Figure 2.1, analogue and digital multimeters come with two test-leads (usually black and red) that are equipped with metallic probes. The black test lead is for ground connection while the red is for positive connection to the multimeter box. The black test-lead is inserted into the common terminal (socket), and the red lead inserted into the appropriate function terminal: current (amperes), current (milli/microamperes), or voltage/resistance.Furthermore, digital multimeters have a display panel(readout) where the digital output of the measured variable is shown. The analogue multimeter on the other hand, has some graduating scales with a precision pointer on the same type of panel. Multimeters are also featured with a rotary ‘selector’ switch that is meant for the selection of the type of variable to be tested (voltage, resistance, current, AC, DC and so on) as well as the range of the variable. However, this selection is automatic in some new models of multimeters.

Other features of multimeters include a rotating knob for the adjustment of the precision pointer to zero ohms before use (on analogue meters without an auto-zero capability). Similarly, some digital meters have a button that, when pressed, sets the meter to zero.Again, most multimeters use an internal fuse to protect themselves against excessive voltage or current. Also, except for really old analogue models that only test voltage or current, all multimeters are equipped with a battery of one type or another. The most convenient multimeters use a standard-size battery, such as a 9-volt or AA cell. Pocket meters typically use a coin-type battery. Figure 2.1 shows the rest of the features of both analogue and digital multimeters.

Figure 2.1: Features of Analogue and Digital Multimeters
Source: www.technologyuk.net

The comparison of digital multimeters with analogue multimeters can be summarized as follows:

1. Analogue multimeters have several scales for measuring current, voltage, and resistance and, often, separate scales for measuring AC and DC. They are, therefore, relatively difficult to read, require practice and are prone to mistakes by the user: such as reading the wrong scale or misinterpreting a particular reading.
2. Digital multimeters, on the other hand, have a single, simple, digital, readout (often with automatic range adjustment) which is very easy to read with virtually no chance of making a reading error.
3. Analogue multimeters movements are relatively delicate and must be treated with care to prevent them from becoming miscalibrated or their movement damaged.
4. Digital multimeters, however, are tough and robust, and are far less likely to become damaged. Even relatively-severe external physical damage is unlikely to affect their accuracy.

5. Analogue multimeters require a careful set-up routine prior to taking a measurement, as will be discussed later in this chapter.
6. Digital multimeters on the other hand must be set to the appropriate function setting (current, voltage, or resistance), but many types will then automatically select the most appropriate range within that function, will compensate for an aging battery, and all will automatically self-zero when set to measure resistance.
7. Analogue multimeters require a battery only to measure resistance, and will read current and voltage without a battery.
8. Digital multimeters, on the other hand, require a battery for all their functions, and will not operate at all once its battery is exhausted.

2.2 Principles of Operation of Multimeters

It is not only the features of the two types of multimeters that differ but also their principles of operation. The analogue multimeters differ remarkably from their digital counterpart; therefore, this section of the book is further broken into the following sub-sections.

2.2.1 Principles of Operation of Analogue Multimeters

Analogue multimeters incorporateprecision elements such as rectifiers to measure both DC and AC currents and voltages, together with resistance. Because of their versatility, analoguemultimeters are far more widely-used in the field than separate Ammeters, Voltmeters, and Ohmmeters, which are mainly found in laboratories. Figure 2.2 shows the block diagram of a combined structure of an analogue multimeter incorporating Ammeter, Voltmeter and Ohmmeter all put together as one unit.

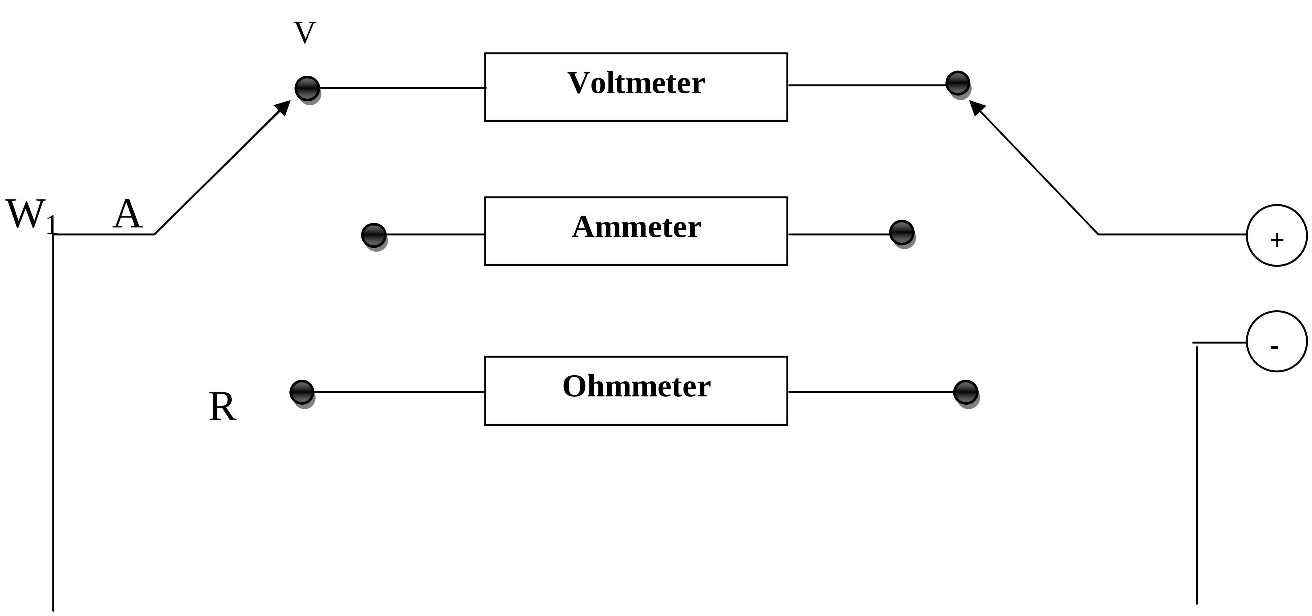


Figure 2.2: Block Diagram of a Simplified Analogue Multimeter

As shown in the block diagram, two different band switches W_1 and W_2 can be used to select the desired meter (physically this function is done by a single wiper switch). Additional provision for individual range selection of Ohms, Amperes and Volts is also available.

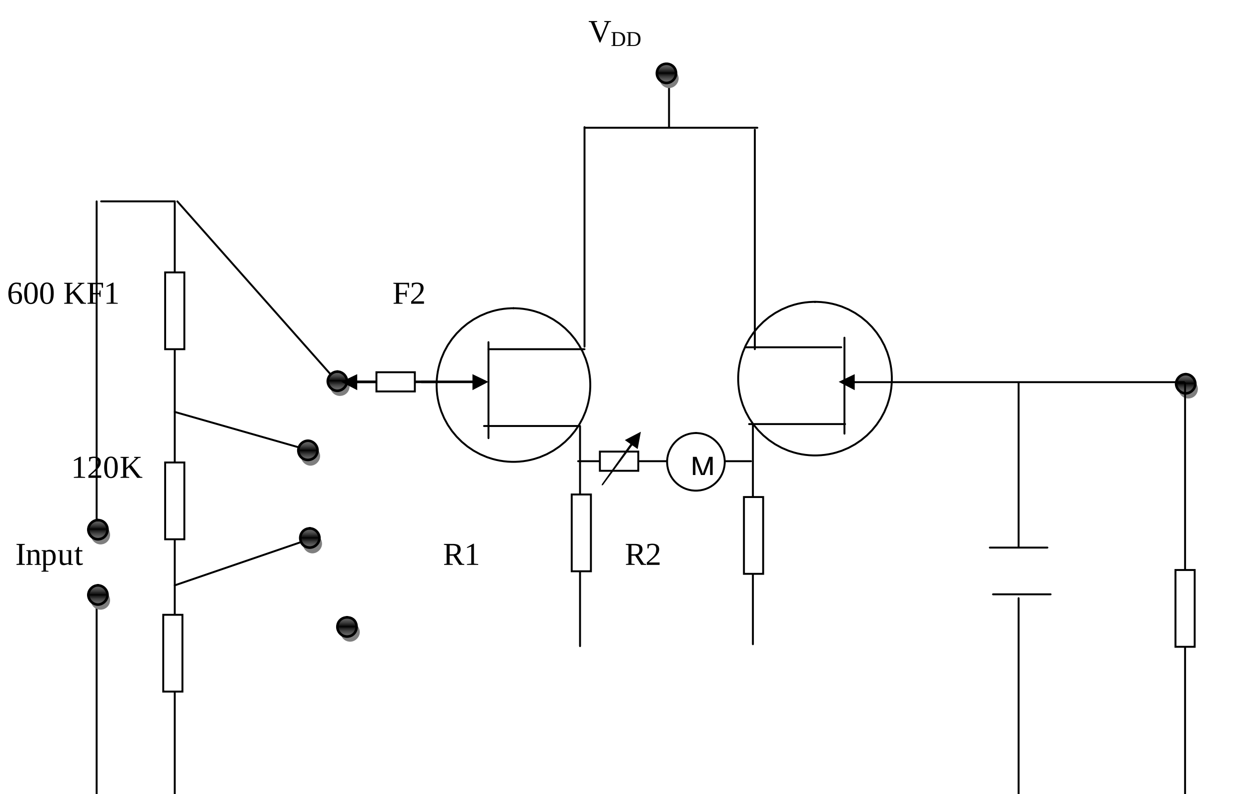
However, as stated earlier, the block diagram presented in Figure 2.2 is only a simplification of the principles of operation of analogue multimeters. Some multimeters can test other electronic components such as diodes, transistors, capacitors and so on, hence the need for a more complex arrangement of additional elements. Generally, analogue multimeters constitute the following components:

a. A balanced bridge DC amplifier and Permanent Magnet Moving Coil (PMMC) indicating instrument;
b. A rectifier to convert AC to a equivalent DC quantity;
c. A range Switch that act as attenuator to limit the value of input voltage to the desired value;
d. A function switch to select various measurement functions of the instrument like current, voltage and resistance;
e. Internal battery to additional circuitry for the measurement of resistance.

Figure 2.2 shows the schematic diagram of a balanced differential amplifier circuit that utilizes two Field Effect Transistors (FETs) that are properly matched to measure electrical quantities at different input ranges. The two identical FETs F1 and F2 form the upper arm of the bridge circuit so that increase in the current of one FET is offset by corresponding decrease in the source current of the other. The drain resistors R1 and R2, together with the ZERO adjustment resistor R3 form the offer arm of the circuit. The meter movement is connected across the drain terminals of the FETs.

The circuit is balanced under zero-input-voltage condition provided the two FETs remain identical (balanced). Under that condition, there would be no current flowing through the meter (M). Zero-adjustment potentiometer is used to get null deflection in case there is a small current through the meter (M) under zero-signal condition. Also, full scale calibration is adjusted with the help of variable resistor R.

When, for instance, a positive voltage is applied to the gate of the input FET F1, its drain current increases which cause the voltage at the source terminal to rise. The resulting mismatch between F1 and F2 source voltages is indicated by the meter movement, whose scale is calibrated to indicate the magnitude of the applied input voltage. The voltage to be applied to the gate F1 is determined by the selected range as also shown in Figure 2.3.



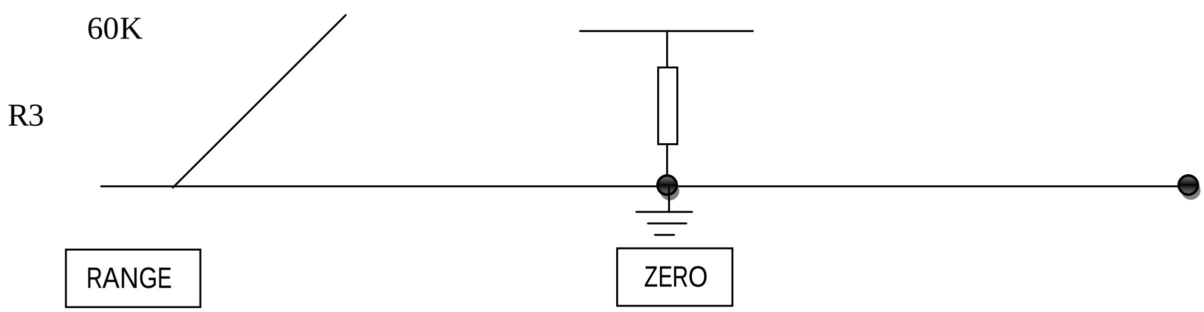
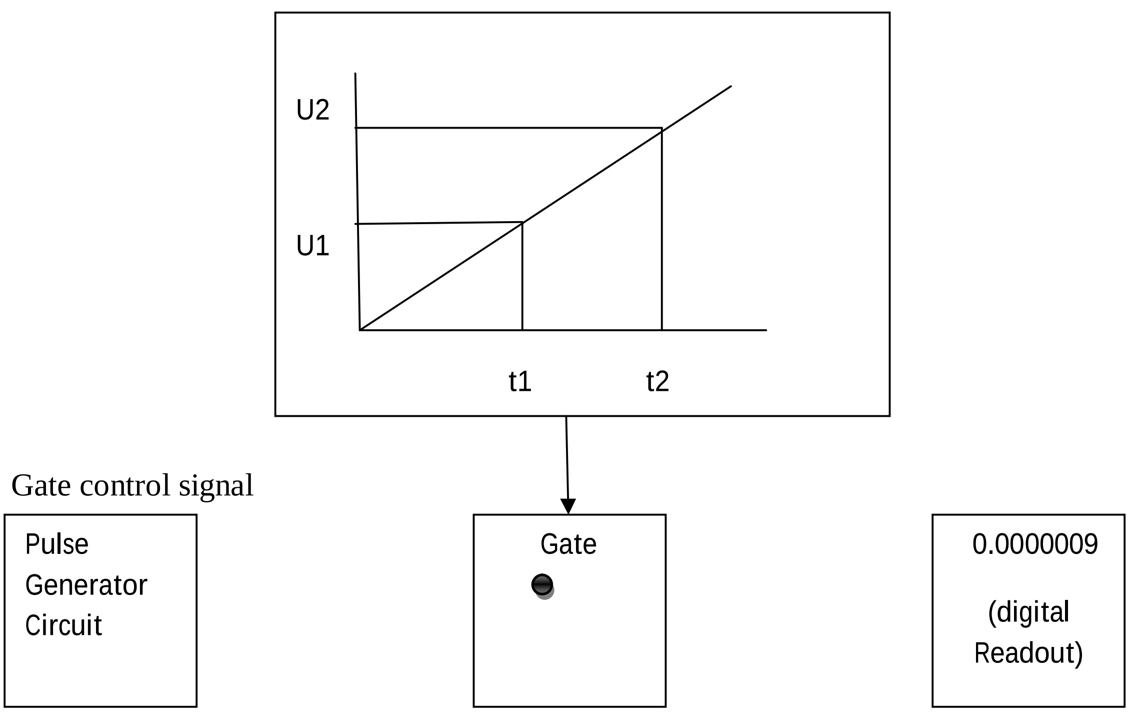


Figure 2.3: The Schematic Diagram of a Balanced Differential Amplifier Circuitry
Source: Sawhney (2010)

2.2.2The Principles of Operation of a Digital Multimeter

Essentially, all digital multimeters are voltmeters which can also be used to measure current by analyzing the voltage drop produced across an internal standard resistor. There are three major component circuits to a digital voltmeter: a pulse generator, and an electronic switch (termed a ‘gate’) which controls the flow of pulses to a counter circuit as illustrated in Figure 2.4.



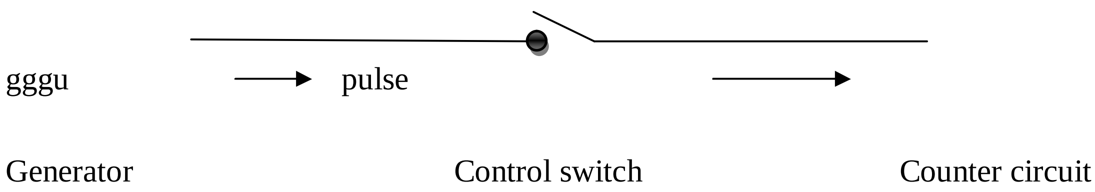


Figure 2.4: Block of the Digital Multimeter

The electronic switch is controlled by a ‘ramp generator’, which is a circuit that produces a linear signal, called a ‘ramp’. The ramp illustrated in the above circuit is a gross oversimplification, but is descriptive of the general principle involved.

When small external (test) voltage, U1, is applied to the ramp, the resulting control signal closes the electronic switch for the period (0 – t1). If a larger external voltage, U2, is applied to the ramp, then the control signal keeps the electronic switch closed for a longer time, (0 –t2). In other words, the time for which the electronic switch is held closed is proportional to the magnitude of the external test voltage applied to the ramp. The longer the electronic switch is held closed, the greater the number of pulses allowed to pass through to the counter circuit. The number of pulses counted, therefore, is proportional to the external test voltage applied to the ramp generator circuit. All that is remainingnow is to calibrate the counter circuit’s digital readout to indicate the voltage rather than the number of pulses counted.

The ammeter function of a digital multimeter works in slightly-different way. By passing the external test current through a very accurate resistor (built into the meter), the resulting voltage-drop across that resistor will be proportional to that current, and this voltage drop is then applied to the ramp generator –from then on, the ammeter works just like the voltmeter already described, except that it is then calibrated in terms of amperes, milli-amperes, or micro-amperes, rather than in volts, milli-volts, or micro-volts. Of course, the operating principle of an actual digital multimeter is significantly more complicated than this explanation as it must be capable of measuring DC and AC voltages and currents over a wide-range of values, as well as measuring resistance and, in some cases, other quantities too.

2.3 Practical Applications of Multimeters

Having learnt the features and principle of operation of analog and digital multimeters in the previous sections of this chapter, we are now ready for its basic practical applications to measures voltage, current and resistance. Furthermore, elaborate multimeters, such as the Fluke 78, or Fluke 88 can be used to check other things such as frequency, transistors and diode tests, and even test some simple logic circuits.

There’s a limit to what a multimeter can be used to measure (maximumrange). These days, most multimeters have more-or-less the samemaximum range for voltage, current, and resistance. Multimeters that have thefollowing maximum ratings are more popular in electronic workshops: DC voltswithin the range of about 1000 V; AC volts within 500 V; DC current within 200 mA (milliamperes); and resistance of Resistance: 2 MΩ (two megohms, or 2 million ohms) range.

Most analog and digital multimeters, require manual selectionof therange before the meter can make an accurate measurement.For example, if you’re measuring the voltage of a 15 volt output of a circuit, the range should be set closest to, or above 15 volts. This means 20 or 50 volt range should be selected using the selector switch. Thereafter, the voltage is read from the proper scale. This means if the range selected was 50 volts for instance, the voltage measured must be read on the 50 volt scale. Otherwise, there would be inaccurate results.However, if the meter is equipped with an auto-range capability, there is no need to select the range manually as stated earlier. This feature makes them inherentlyeasier to use and a little less prone to error.

2.3.1 Multimeter Serviceability Status Test

Before using a multimeter for any electronic measurement, it is essential to verify its serviceability status. The following steps are guidelines for preparing both types of multimeters for use:

1. Make sure the two metallic probes of the test-leads are clean and proceed to the next step;
2. Using the ‘power’ and rotary ‘selector’ switches respectively, turn on the multimeter and dial it to ‘ohms’ setting (lowest range);
3. Using the ‘zeroing’ knob, adjust the meter reading to zero;
4. If the multimeter is not auto-range, set it to low ohms;

5. Insert the two test-lead into their appropriate places in the meter box, that is, black lead to the common (‘com’) and red to the ‘ohms’ sockets.
6. Touch the two metallic probes of the test-leads together to observe a ‘zero’ ohms reading (or very close to zero) on the meter panel, if not, set the pointer to zero position using the adjustment knob provided;
7. Alternatively, if a sound capability is featured on the meter, a beeping sound should be heard when the above (1 – 5) procedure is repeated one step after the other (except that the selector switch nowhas to be set to the speaker sign ‘BUZZ’ on the meter).
8. This proves that both the meter and the test-leads are ok and ready for use.

2.3.2 Using Multimeter to Measure Electric Current

Electric current measurements are rarely taken in an electronic circuit, however most multimeters have DC current ranges such as 0.5mA, 50mA, 500mA and 10Amp (via the extra banana socket) and some meters have AC current ranges. Measuring the current of a circuit is very essential. If the normal current is measured, a high or low current can let you know if the circuit is overloaded or not fully operational. To measure the amount of electric current passing through an electronic component such as a resistor, inductor, transistor or a capacitor, follow the procedure stated below:

1. Carry out the serviceability status test stated in 2.3.1 above;
2. Reposition the red test-lead by inserting it into the current socket (mA or 10A) depending on the perceived range of the current to be measured (the black test-lead should remain in the ‘com’ socket);
3. Set the selector switch to ‘current’ position at the appropriate ‘range’ to be measured (Ac or DC, example, 10-20mA, 200mA and so on);
4. Break the circuit at the point where the current is to be measured and insert the metallic probes (red test lead to positive polarity of the circuit being tested and black into the negative)as shown in Figure 2.5;
5. For analogue multimeters, the reading should be taken on the DCV A scale (Figure 2.6) and then converted using the reference table in Table 2.1, while the digital type will display the value in digits as explained earlier.

6. Return the selector switch to either ‘off’ or ‘ohms’ position after taking the reading and turn the meter off.

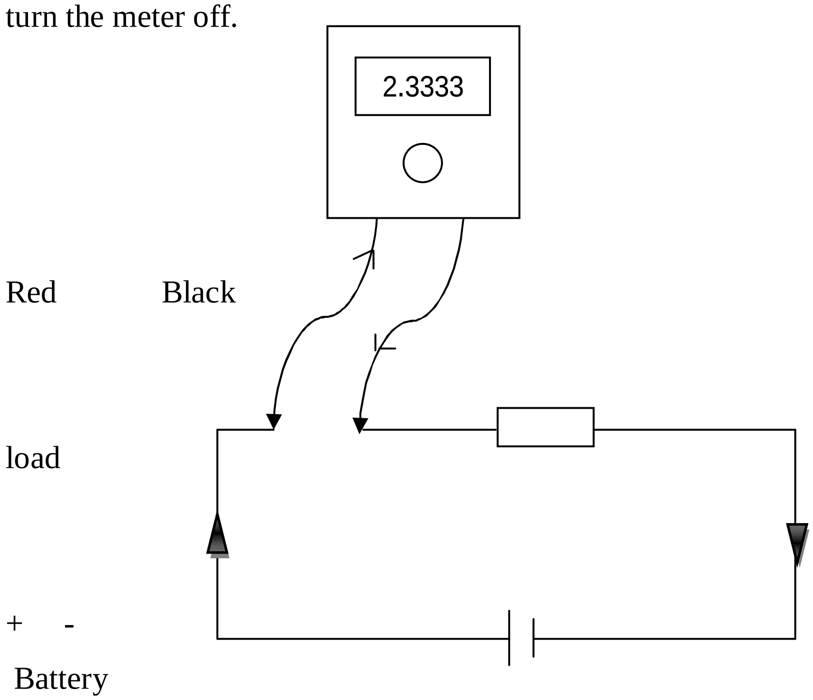


Figure 2.5: Circuit arrangement for the measurement of electric current using a multimeter

Note:
Remember that by setting the selector switch to ‘current’ position as explained in (3) above, the multimeter is converted to an Ammeter with a very low internal resistance to allow smooth passage of current when connected in series with the load as shown in Figure 2.5. It is therefore strictly prohibited to connect multimeters under this (current) selection in parallel with the load. This will definitely result to short circuit thereby resulting to damages in the instrument and consequent injuries to the user.

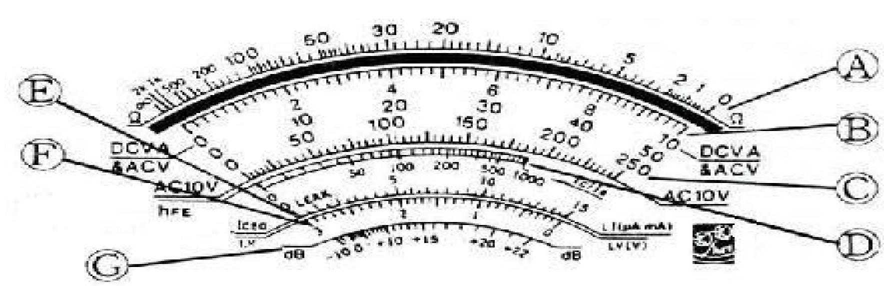


Figure 2.6: Analogue Multimeter Reading Scale (Source: YX-360 Owner’s Manual)

Table 2.1: Analogue Multimeter Reference Table

Test	Range Position	Scale to Read		Multiplier
DC Volt	DC:			
	0.1v	B	10	× 0.01
	0.5v	B	50	× 0.01
	10v	B	10	× 0.01
	50v	B	50	× 1
	250v	B	250	× 1
	1000v	B	10	× 100
AC Volt	AC:			
	10v	C	10	× 1
	50v	B	50	× 1
	250v	B	250	× 1
	1000v	B	10	× 100
DC Current	DC:			
	50uA	B	50	× 1
	2.55mA	B	250	× 0.01
	25mA	B	250	× 0.1
	0.25A	B	250	× 0.001
	10A	B	10	× 1
Resistance	× 1	A		× 1
	× 10	A		× 10
	× 100	A		× 100
	× 1K	A		× 1000
	× 10K	A		× 10000
Decibel	AC:			
	10V	G		× 1
	50V	G		× 1+14dB
	250V	G		× 1+28dB
I_{CEO}	×1	E		× 1 (for big TR)
	×10	E		× 1 (for small TR)
hFE	×10	D		×1
Diode	×1K	E		μA × 10
		F		× 1
	×10	E		mA × 1
		F		× 1
	×1	E		mA × 10
		F		× 10

Source: YX-360 Owner's Manual

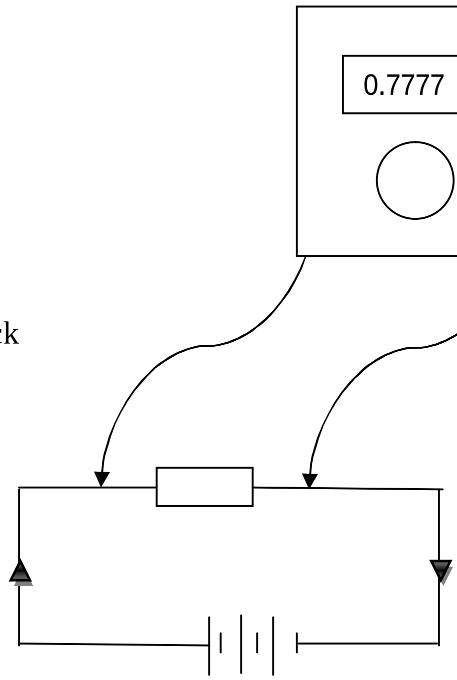
2.3.3 Using Multimeter to Measure Voltage

To measure the amount of potential difference (voltage) across an electronic component such as a resistor, diode, transistor or a capacitor, follow the procedure stated below:

1. Carry out the serviceability status test stated in 2.3.1 above;
2. Reposition the red test-lead by inserting it into the volts socket (In some meters, it's the same with the 'ohm' socket). The black test-lead should remain in the 'com' socket;
3. Set the selector switch to 'volt' position at the appropriate 'range' to be measured (AC or DC, example, 20V-700V and so on);

4. Place the metallic probes across the component to be tested (In parallel) as shown in Figure 2.7, regardless of the polarities;
5. For analogue multimeters, the reading should be taken on the ACV scale with reference to Table 2.1, while the digital type will display the value in digits as explained earlier.
6. Return the selector switch to either ‘off’ or ‘ohms’ position after taking the reading and turn the meter off.

Red Black



+ -

Figure 2.7: Circuit Arrangement for the Measurement of Potential Difference Using a Multimeter

Note:

1. Here, as the multimeter is selected to function like a voltmeter, it must draw some operational current from the circuit under test. Therefore, to avoid loading effect by the multimeter (power sharing effect), which could lead to inaccurate result, multimeters are equipped with a very high internal resistance to minimize the operating current (usually many mega ohms).
2. The best electronic instruments to be used for proper circuit analysis are the oscilloscopes and logic probes (to be discussed in the subsequent chapters of this book). Multimeters could also be used for simple voltage analysis. Hence, to measure supply or output

voltage across the entire circuit or a component within the circuit (example, a 555 IC timer) the black test-lead should touch the 'earth' of the electronic circuit while the red should touch the V-out of the component (a) or the circuit (b) respectively as shown in Figure 2.8.

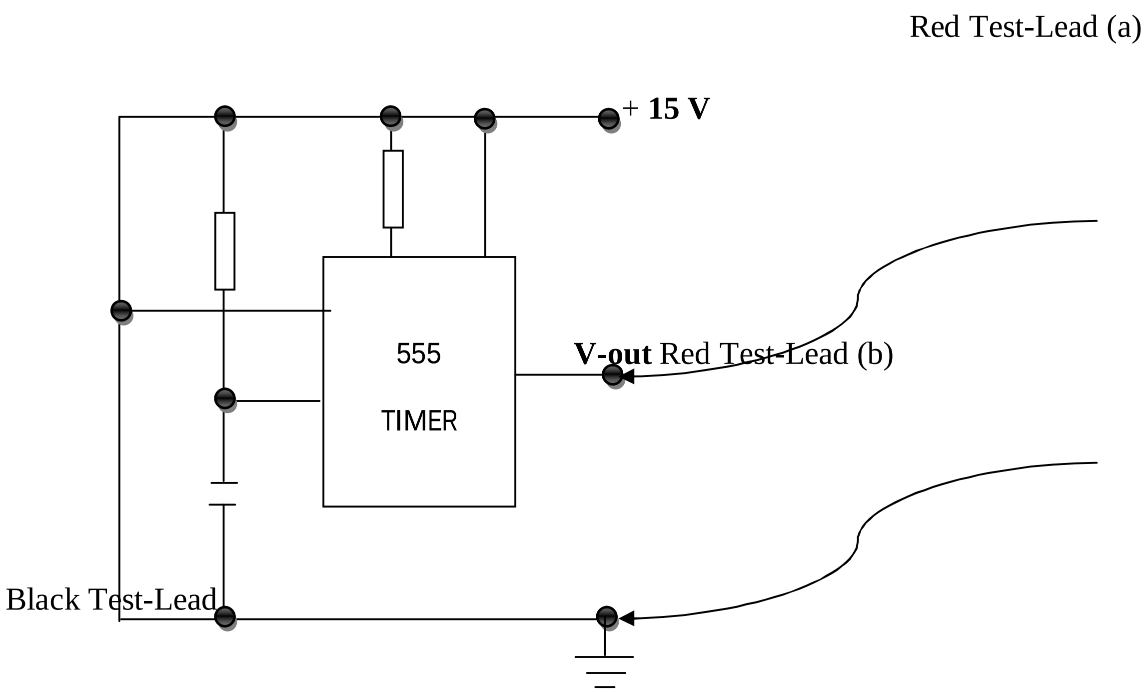


Figure 2.8: Voltage Test Performed in a 555 IC Timer Circuit

2.3.4 Using Multimeter to Measure Resistance

To measure resistance of an electronic circuit or component in a circuit, the following steps will serve as guidelines:

1. Repeat the usual serviceability status test of the meter as outlined in 2.3.1 above;
2. Since the meter is to be used for resistance measurement, the rotary 'selector' switch should be left at 'ohms' setting;
3. Using the 'zeroing' knob, adjust the meter reading to zero;
4. If the multimeter is not auto-range, set it to the required resistance to be measured (example, 200 ohms, 2K, 20K, 200K and so on);

5. The two test-leads should also remain where they are since we are still measuring resistance (i.e black lead to the common ‘com’ and red to the ‘ohms’ sockets).
6. Remove the component whose resistance is to be measured (from the circuit) and touch the two metallic probes of the test-leads to both ends of the component as shown in Figure 2.9;
7. Analogue meters have different scales for voltage, current and resistance. The ‘A’ scale that features the Ohms sign should be read in the present case (refer to Table 2.1).
8. Take the reading. A bad resistor can be either completely open inside, in which case you mayget a reading of infinite ohms, or it can be shorted out, in which case you geta reading of zero ohms.When testing a resistor, ensure that the marked value corresponds with the reading providedby the meter. The reading should fall within the tolerance range of the resistor.For example, if the resistor has a tolerance of 20 percent and is marked as 1K ohms,acceptable test readings fall in the range of 800 to 1,000 ohms. Toleranceis 20 percent of 1,000, or 200 ohms.If the resistor has a tolerance of one percent (you call these low-tolerance resistors or precision resistors), acceptable test readings fall in the range of 990 to 1,010 ohms. Tolerance is one percent of 1,000, or 10 ohms.

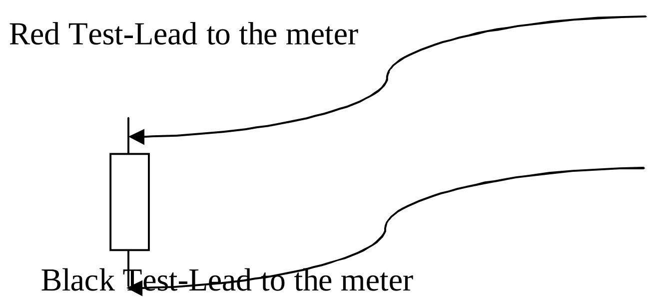


Figure 2.9: Measuring the Resistance of a Circuit Component

Note:

1. Never connect a multimeter to a live circuit when it is set at ‘ohms’ selection;

2. The resistance of the component can still be measured while still connected in the circuit. However, in this case, beware of measuring the resistance of a component that is connected in parallel with another component.

2.3.5 Using Multimeter to Test Wires or Cables for Continuity

Continuity tests on electric wires indicate whether a circuit (or a circuit component such as fuse or switch) is broken or not. We can describe continuitymost clearly using a wire as the circuit:

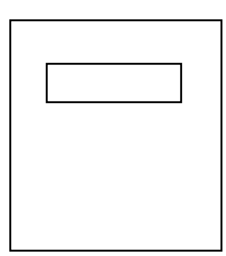
- A short circuit shows that your circuit has continuity (not broken) between two points of the same wire. The meter shows this state as zero (or very close to zero) ohms.
- An open circuit means that your circuit doesn't have continuity (broken). The meter shows this situation as infinite ohms, which means so many ohms that the meter can't register.

When testing a cable with many wires, multimeters can be used to find out whether any of the individual wires are touching each other. When this situation happens, the wires short out. If a short happens, your circuit fails.The following procedure should serve as a guideline for continuity test:

1. By now it is assumed that the reader is used to the usual serviceability status test of the meter described in 2.3.1 above;
2. Connect the multimeter probes to either end of the wire as shown in Figure 2.9 (a);
3. A reading of zero ohms, or very low ohms should be seen on the meter. A reading of more than just a few ohms indicates a possible open circuit.

To test for a short between two or more different wires that shouldn't be electrically connected, proceed as follows:

1. Connect the multimeter probes to any exposed conductor ofthe two wires as shown in Figure 2.10 (b);
2. A reading other than zero ohms indicates open circuit, which means the wires are actually not electrically connected. If the readingshows zero or very low ohms, it indicates a possible short circuit.



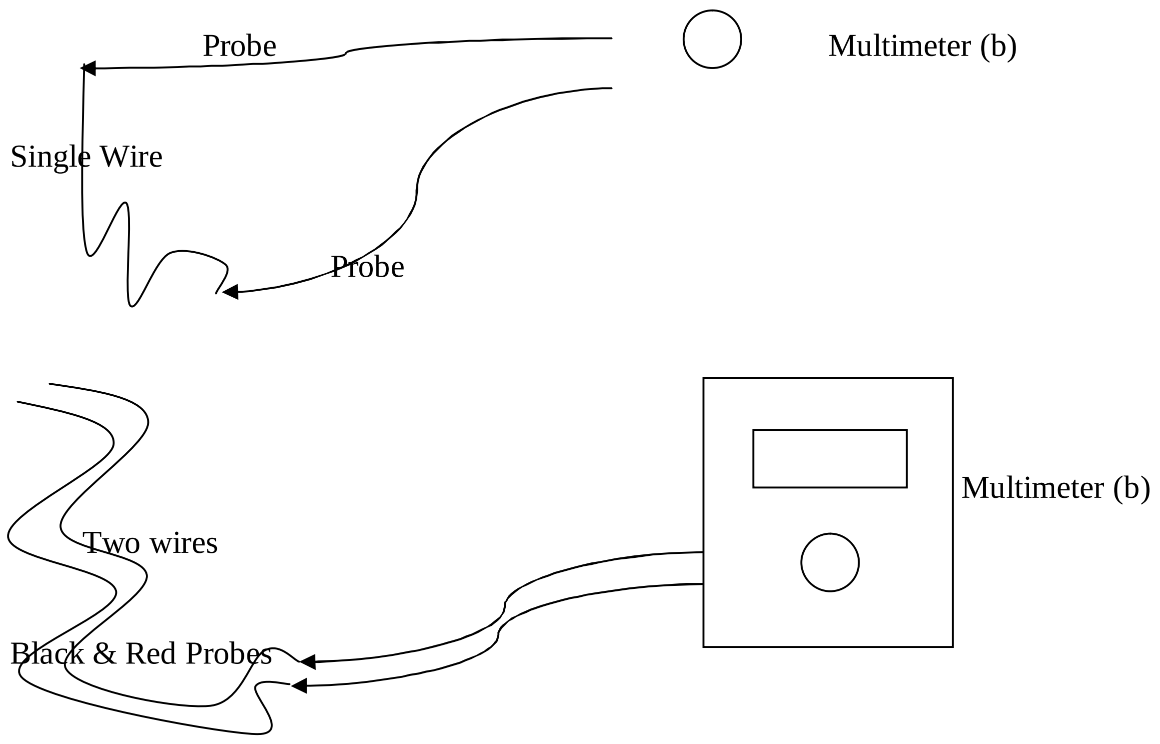


Figure 2.10:Continuity Test on (a) Single Wire and (b) Two or More Wires

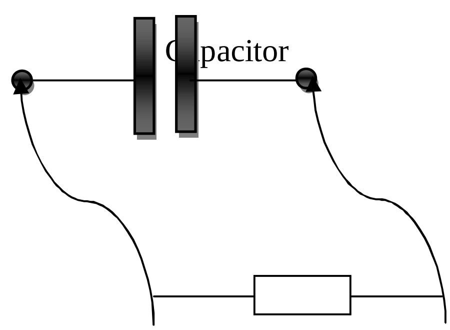
Note:

When testing two different wires that shouldn't be electrically connected in a circuit, a reading of infinite ohms shows an open circuit. In ideal situation this is true butpractically, it is not always the case. The reason is that even though the wires may not be directly joined, they're both connected to the circuit. This connection, whatever it is, may show a certain resistance when tested on the multimeter. So when looking for shorts across wires, one should not be too worried if one gets a reading other than infinite ohms.

2.3.5 Using Multimeter to Test a Capacitor

There are multimeters that are featured with a provision for testing capacitor. These types of mutimeters are very easy to use. However, the good news is that even ordinary multimeters without this feature can be used for the same purpose. There are three major tests one can use a mutimeter to do on the capacitor. The first is to test an open circuit within the capacitor (When it is damaged), the second is to short circuit and the third is to determine the value of the capacitor itself that is above 1 micro farad. To accomplish these tests using ordinary multimeter, proceed as follows:

1. Before testing, use an insulated bleeder jumper (Figure 2.11) to short out the terminals of the capacitor. A bleeder jumper is simply a wire with a 1 or 2 mega ohm resistor attached. The resistor prevents the capacitor from being shorted out, which makes it unusable. This step discharges the capacitor. You need to short out the terminalsbecause large capacitors can retain a charge for long periods of time,even after you remove power;
2. Set the meter to Ohms;
3. Touch the meter probes to the terminals of the capacitor;
4. Wait a second or two and then note the reading. A good capacitor shows a reading of infinity when you get to this step.A reading of zero may mean that the capacitor has shorted out. Aleaky capacitor, one that is losing its ability to hold its charge, gives anohms reading that is somewhere between infinity and zero.If you are working with a polarized capacitor, connect the black lead to the –ve terminal of the capacitor and the red lead to the + ve terminal. For unpolarized capacitors, it doesn’t matter how you connect the leads.



2M Insulated Bleeder Jumper

Figure 2.11: Insulated Bleeder Jumper Connected to a Capacitor

Note:

1. This test does not tell if the capacitor is open, which can happen if the component becomes structurally damaged inside or if its dielectric (insulating material) dries out or leaks. An open capacitor will read infinite ohms. For a conclusive test, use a multimeter

with a capacitor-testing function. If your multimeter has a capacitor-testing feature, by all means use it rather than the method given above.

2. Be sure to observe proper polarity when connecting the capacitor to the test points on the meter. You get another advantage by using a multimeter with a capacitor testing feature because the meter displays the value of the capacitor. You may find this measurement handy if you need to determine whether a capacitor falls within the tolerance range for your circuit. This feature also helps to verify the value markings on the component because not all capacitors follow the industry standard identification schemes.

2.3.6 Using Multimerter to Test Diode

Analogue multimeter without diode measuring capability can be used to test diodes for short and open circuit as well as forward current using the resistance setting. Most of the digital meters can be used directly to measure diodes. For clarity, these two methods will be discussed separately under this section.

Using an Analogue Multimeter:

The following test procedure can be carried out using ‘ordinary’ multimeters:

1. As usual, test the multimeter’s integrity by conducting the serviceability status test described in 2.3.1 above;
2. Set the meter to the diode-check position (×1K for 0-150uA; ×10 for 0-15mA; ×1 for 0-150mA test);
3. Apply the test probes of the meter to the diode. Observe proper polarity: For ‘I_F’ (forward current), touch the blacktest lead to the positive terminal of the diode, and the red test lead to the negative terminal(the cathode has a stripe so that you can identify it);
4. For I_R (reverse current) test, reverse the connections. Remember to avoid touching the test probes with your fingers;
5. Read I_F or I_R on the L1 scale provided (Figure 2.6);
6. Read the linear (forward) voltage of the diode on the LV scale while testing I_F or $I_{R.}$

Using a Digital Multimeter:

The following procedure is for digital multimeters that have feature for testing diodes:

1. Set the meter to the diode-check setting (×1K for 0-150uA; ×10 for 0-15mA; ×1 for 0-150mA test);

2. Apply the test probes of the meter to the diode. Observe proper polarity: For 'I_F' (forward current), touch the blacktest lead to the positive terminal of the diode, and the red test lead to the negative terminal(the cathode has a stripe so that you can identify it);
3. For I_R (reverse current) test, reverse the connections. Remember to avoid touching the test probes with your fingers;
4. Observe the reading of about 0.5 V (which is about the required voltage to turn on a **good** diode). An over range reading (when the digital read out shows maximum range) indicates a **bad** (open-circuited) diode. Also, a zero reading means **bad** but short-circuited diode.
5. Reverse the probes and test again. In this case, an over range (infinity) reading means **Good,** while a zero reading still means **bad** diode.

2.3.7 Using Multimeter to Identify and Test Transistors

For the fact that some transistors are manufactured without clear description of the type (PNP or NPN), it is essential to discuss some clues on the use of multimeters to identify a transistor before testing it. Therefore, the first part of this section will take care of the processes involved in identifying an unknown transistor while the second part will deal with the procedure for testing the transistor.

Identifying an Unknown Bipolar Transistor

To identify an unknown bipolar transistor using analogue multimeter, proceed as follows:

1. Set the meter to 'X10' setting;
2. Try touching the black test lead on one pin and the red lead to the remaining two pins of the unknown transistor in turn. At the point when the meter pointer swings to nearly full scale, you have an NPN transistor. The black probe is on the Base (B).
3. If the red touches a pin and the black test lead produces a swing on touching either of the remaining pins, you have a PNP transistor. The red probe is on the Base (B), as shown in Figure 2.12;

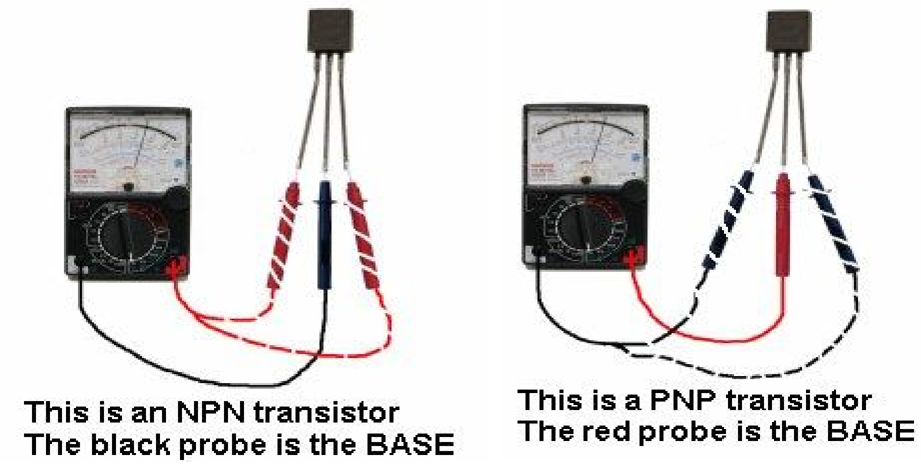


Figure 2.12: Identifying the Bases (B) of NPN and PNP Bipolar Transistors
Source: Colins (2012)

4. Having identified the Base (B), to get the Collector (C) and Emitter (E), set the meter to 'X10K' setting;
5. For the NPN transistor, place the two leads of the meter on the remaining transistor pins and press hard as shown in Figure 2.13, the pointer will swing to almost full scale;

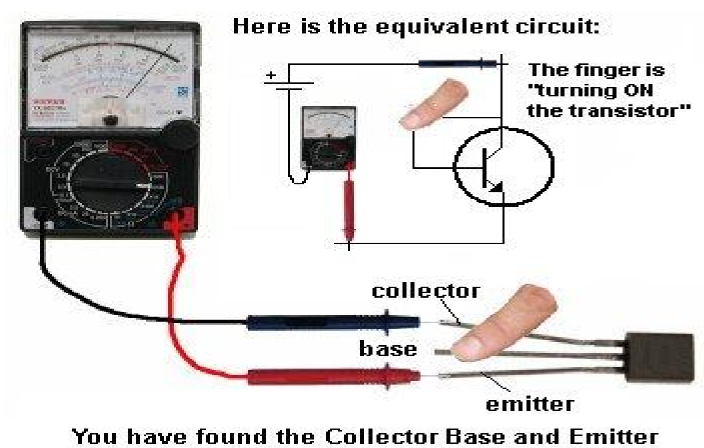


Figure 2.13: Identifying the Collector and Emitter of an NPN transistor
Source: Colins (2012)

6. Alternatively, for a PNP transistor, place the two leads of the meter on the remaining two pins of the transistor and press hard, the pointer will swing to almost full scale as shown in Figure 2.14.

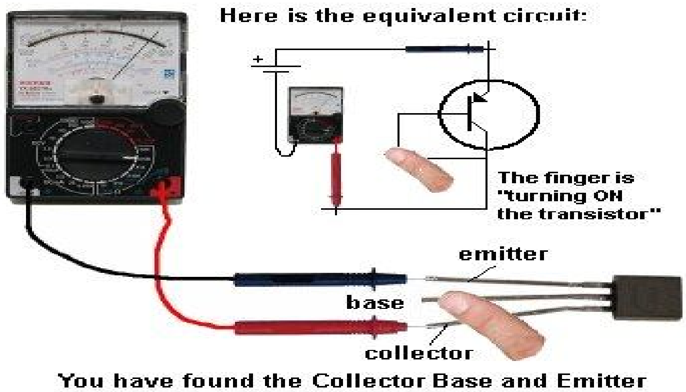


Figure 2.14: Identifying the Collector and Emitter of a PNP transistor
Source: Colins (2012)

Testing a Typical Transistor

Figure 2.15(a) and (b) shows a typical bipolar transistor. For leakage current (I_{CEO}) test proceed as follows:

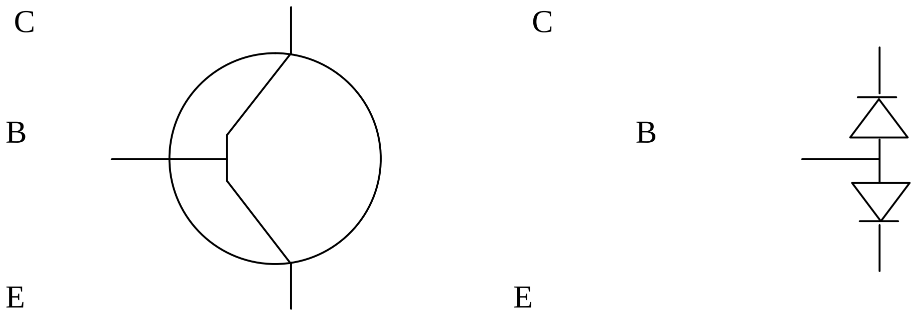
1. Plug the test leads into the + and – COM sockets;
2. Set the range selector to ×10 (15mA) for small size transistor, or to ×1 (150mA) for a big size transistor;
3. Adjust the zero Ohm knob to set the pointer to zero position of the Ohm scale (A in Figure 2.6);
4. Connect the transistor with the tester: for NPN transistor, the black test lead is connected to the Collector (C) of the transistor and the red test lead to the Emitter (E) of the transistor. For PNP transistor, reverse the connection;
5. Read the I_{CEO} range. If the pointer is not within the LEAK zone or the pointer moves up near to the full scale, the transistor tested is not good, otherwise, it is a good transistor.

For hFE (DC amplification) test on bipolar transistors, do the following:

1. Dial the range selector to ×10;
2. Adjust the pointer using the zero Ohm ADJ knob to zero position;
3. Connect the transistor to the tester: For NPN transistor, (a) connect the ‘P’ terminal of the meter to the emitter of the transistor with the hFE test lead, (b) plug the hFE connector into the ‘N’ terminal and connect its red clip to the collector and black one to the base of the transistor. For the PNP transistor, (a) connect the ‘N’ terminal of the meter to the

emitter of the transistor, (b) plug the hFE connector into the ‘P’ terminal and connect the clips in the same way as for NPN transistor connection;

4. Read the hFE scale. The value of the reading is I_C/I_B, which is the DC amplification degree of the transistor tested.



(a) (b)

Figure 2.15: A Typical Bipolar Transistor (a) with the Equivalent Diode Circuit (b)

Note:

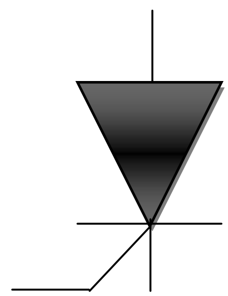
1. Testing with a multimeter can permanently damage some types of transistors,especially the FET (field effect transistor) type.Therefore use the above stated test procedure for bipolar transistorsonly.
2. If your multimeter is equipped with a transistor-checking feature, use thatfeature rather than the method given here. Consult the manualthat came with your meter for the exact procedure because it varies fromone model to another.

2.3.7 Using Multimeter to Test Silicon Controlled Rectifier (SCR)

A typical Silicon Controlled Rectifier (SCR), also referred to as thyristor in some literatures is either an NPNP or PNPN type semiconductor with three terminals, which are: Anode, Cathode and the Gate as illustrated in Figure 2.16. It requires a minimum current at the gate to keep it turned on. That is why an SCR tester is recommended for the testing of the device. However, some multimeters that can provide this current can be used to test an SCR when properly utilized. To test an SCR using multimeters, the following guidelines can serve:

1. Having ascertained the serviceability status of the meter, set it to diode testing setting;
2. Forward-bias the SCR with the meter by connecting the black lead to the anode and the red lead to the cathode (because the +ve terminal of the meter battery is connected to the –ve lead in most meters);
3. Immediately, touch the gate lead to the anode while the probes are still touching both leads; this provides a small positive turn-on voltage to the gate;
4. Reverse-bias the SCR by alternating the positions of the leads as described in 2 above;
5. Measure the Anode-to-Cathode resistance in both forward and reverse directions; a **good SCR** should measure near infinity in both directions.

Anode



GateCathode

Figure 2.16: A Typical Silicon Controlled Rectifier (SCR)

Note:

When carrying out the above test, the meter impedance acts as the SCR load. Therefore, on larger SCRs, it may not latch ON because the test current is not above the SCR holding current.

From the ongoing, we can see how multimeters can be used to test so many components of electronic circuit. Moreover, the use of multimeters is not only limited to component level troubleshooting as it could also be used to read out different voltage levels in digital circuit. However, this type of diagnosis is more accurate when we employ the use of Logic Probes that will be discussed in the next chapter. This is because, with multimeters, one must pay attention to the pointer or the digital read out at every instance of such measurement. But with more versatile electronic measuring instruments such as Logic Probes, the testing of logic circuits can be much easier.

EXERCISES

Exercise 2.1: A multimeter can be used to:

(a) Check battery current

(b) Troubleshoot motor control circuit

(c) Check open and short circuits

(d) All of the above

Exercise 2.2: Which of the following steps should be included in the procedure for measuring current in 50 V transformer circuit using a multimeter?

(a) Make sure the red test-lead is inserted in the ‘Amps’ socket and the black in ‘com’

(b) Set the range switch to ‘ohms’

(c) Set the range switch to ‘amps’

(d) Set the range switch to ‘amps’, plug the red test lead into ‘amps’ and lack into ‘com’

A multimeter was used to measure current, voltage and resistance and the pointer settled at the position in Figure (a). Use this information to answer exercises 2.3, 2.4 and 2.5

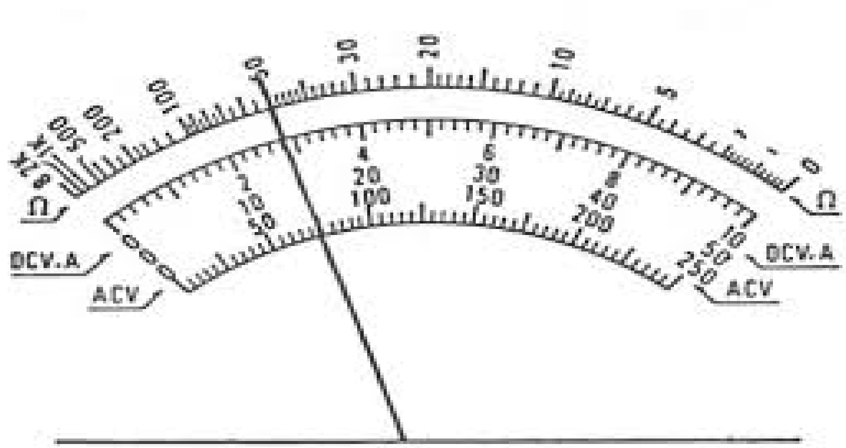


Figure (a): Pointer Indication

Exercise 2.3: If the multimeter was set to measure alternating voltage within the range of 50V, the reading in Figure (a) is:

(a) 2.8 V

(b) 14.0V

(c) 50.0V

(d) 75.0V

Exercise 2.4: If the multimeter was set to measure direct current within the range of 25mA, the reading in Figure (a) is:

(a) 0.28A

(b) 0.14A

(c) 0.50A

(d) 0.75A

Exercise 2.5: If the multimeter was set to measure resistance at the range of 1KΩ, the reading in Figure (a) is:

(a) 50 KΩ

(b) 50 Ω

(c) 50 MΩ

(d) None of the above

Exercise 2.6: A multimeter with …………set to measure voltage will provide more accurate reading.

(a) High internal resistance

(b) Low internal resistance

(c) An internal battery

(d) Overload protection

Exercise 2.7: Which of the following are considerations for selecting a digital multimeter over analogue?

(a) Auto-range selection capability

(b) Robustness and toughness

(c) Accuracy and resolution

(d) All of the above

Exercise 2.8: It is a good practice to ……….after using multimeter to measure voltage

(a) Leave the test leads in any socket

(b) Leave the test leads in the voltage input sockets

(c) Return the selector switch to ‘amps’ position

(d) Return the selector switch to ‘ohms’ position

Exercise 2.9: Using a digital multimeter to test diode, the following are correct except:

(a) Setting the multimeter to ×1K for 0 to 150mA range

(b) Touching the black test lead to the +ve terminal of the diode for I_F

(c) Touching the red test lead to the -ve terminal of the diode for I_F

(d) Touching the red test lead to the +ve terminal of the diode for I_R

Exercise 2.10: If a full scale deflection was made by the pointer of a multimeter when the black test lead was used to touch one of the pins of a transistor while the red was on another pin. The transistor is said to be:

(a) NPN

(b) PNP

(c) Good

(d) Bad

CHAPTER THREE

LOGIC PROBES

3.1 Features of Logic Probes

The Logic Probe is a simple and commercially economical ‘pen like’ device that is used for testing logic circuits. It has some metal clips (test leads) usually red and black similar to those of a multimeter. It brings out audiblesignals and displays different colored LEDs at HIGH, LOWand PULSATING voltage test points of a digital circuit. The colored LEDs are: red LED (for HI voltages), green LED (for LO voltages) and yellow LED (for PULSE/MEMORY signals). It also features a control (switch) thatlets the userselect (before testing) between the two popular logic families of Complementary Metal-Oxide Semiconductor (CMOS) and Transistor-Transistor Logic (TTL) circuits. This selection is necessary as these families have different thresholds for logic-high (V_H)and logic-low (V_L) circuit voltages. These voltages are in most cases given as: {TTL ($5V_{cc}$): LO = 0.8V ± 0.2V; HI = 2.2V ± 0.2V} and {CMOS (V_{cc} range: 4.7V to 15V): LO = 30%; HI= 70%}.

In logic terms, the LO and HI levels mean 0 and 1. The same numbers (0 and 1) can also be interpreted as: True and False, Closed and Open, On and Off and so on respectively, depending on the type of logicalapplication. The full explanation of logic circuit is not within the scope of this book. However, for easy understanding of how logic probes operate, it is important to give a brief example of how they work. While testing any of the above logic circuit families using the logic probe, you may see a low signal indicated by a logical 0 (zero) and a high signal indicated by a logical 1 (one). Primarily, every digital circuit or computer only allows the two states of 0 and 1. Therefore, the term 'logic' comes from how you combine these two states, 0 and 1, to create useful information. For example, an OR logic gate analyses two input signals. Hence, the output of the OR gate is 1 (high) if, and only if,either of the two inputs is 1. There are various other logic gates, including NAND,AND, NOR, and XOR that are found in the logic circuit applications that can be tested using the Logic Probes. Figure 3.1 shows a typical model of a logic probe.

Figure 3.1 Logic Probe(Model LP 900)
Source: www.elenco.com

3.2 Principles of Operation of Logic Probes

As explained earlier, the Logic Probe is a convenient and precise instrument for use in the measurement of electronic logic circuits. As shown in Figure 3.2, the three LEDs (LOW, HIGH and PULSE) are turn off when no input is fed via the tip of the probe to the rest of the circuit. This is ensured by the 'voltage set' gate. The HIGH and LOW conditions are indicated as outputs when the incoming signal is fed through a non-inverting buffer. Also, within a unit microsecond, a pulse-stretcher circuit arrangement is made for the indication of pulsating signal. The outputs of HIGH and LOW drivers are fed via a tone circuit to operate the PIEZO (piezoelectric). Similarly, the pulsating circuit is passed into pulse-tone pair of oscillator (monostable) to enable a beep sound for the PIEZO.

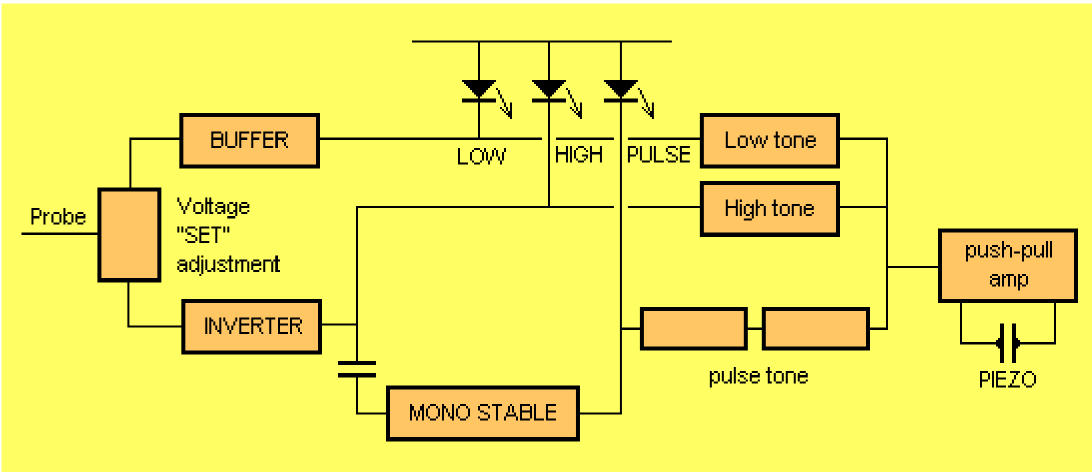


Figure 3.2: Block Diagram of a Typical Logic Probe Circuit
Source: talkingelectronics.com

3.3 Practical Applications of Logic Probe

Digital electronic circuits are made up of non-linear logic devices that operate at saturation level. Therefore, using logic probes to troubleshoot them may be a little bit challenging to inexperienced users. Due to this reason, this section of the book is broken into sub-sections for easy understanding of the practical applications of the logic probes.

3.3.1 Connecting the Logic Probe

Most of the Logic Probes have been designed to operate from any power supply within the range of about 4.7 to 15 volts. During testing, attach the longer clip leads of the Logic Probe to the power supply (see a typical logic probe in Figure 3.3). Connect the black lead to the negative (-) and red lead to the positive (+) terminal of the power supply. The short black ground lead should be attached to a ground near the point to be tested to ensure exact performance of the Logic Probe. Specifically, to connect a Logic Probe to the circuit under test, depending on the logic family, proceed as follows:

1. With CMOS devices, connect all unused inputs to Vcc or ground. "Floating" inputs may cause erratic device operation.

2. With TTL devices, all inputs must be connected to something. If an input should always be HIGH, connect it to Vcc. If an input should always be LOW, connect it to ground. If the TTL devices contain OR, AND, or NAND gates, connect all unused inputs to a used input on the same device.
3. Power supply problems often cause trouble in digital circuits. Make sure the power supplied to each device is within the limits specified for the device.
4. Often the quickest way to locate a problem in a digital circuit is to start at output and work back. If the circuit is driven by a multivibrator, first check the output of the multivibrator and then go to the output and work back.

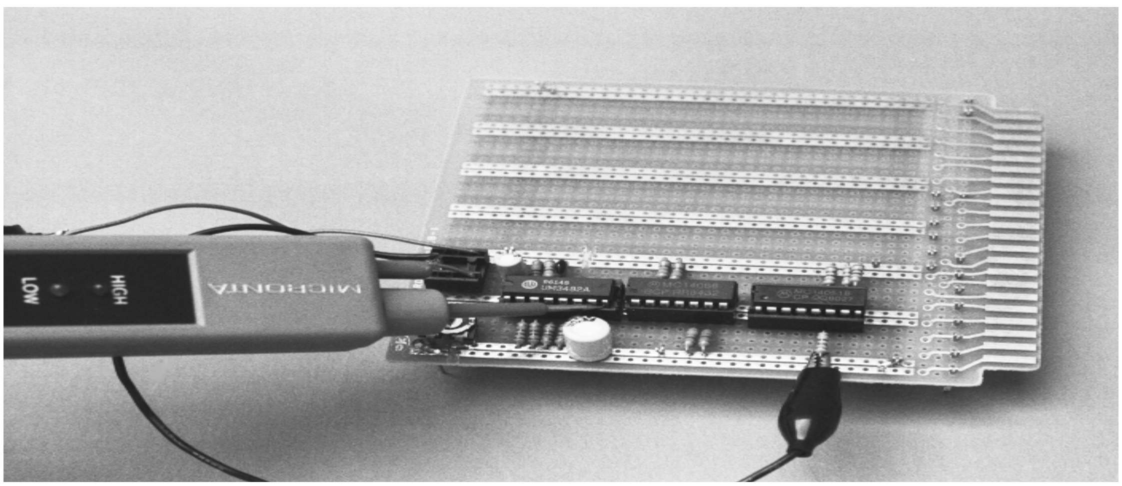


Figure 3.3: Connecting the Logic Probe
Source: MICRONTA Electronics

Furthermore, thresholds will deviate if the same power supply for Logic Probe and the systems to be tested is used simultaneously. It is strongly prohibited to use the logic probe in a power supply that is above the given specification (usually contained in the user's manual).

Note:
Most of the components inside logic circuits are made to use from 1 to 12 volts ofDC power, so it is no wonder that an electric charge with higher voltage from Electrostatic Discharge (ESD) may cause some damages. Thesafest thing to do is to always wear an antistatic wrist strap (see Figure 4.18 in Chapter 4) anytime you want to carry out tests on logic circuits.ESD for instance gives some shock after walking across carpets in our homes. Also, certain fabrics andmaterials

naturally generate static electricity, and the human body has a tendency toabsorb and hold it until it finds a way to discharge it as an electrical flow in a circuit during tests.

3.3.2 Using the Logic Probes

To use the logic probes for the troubleshooting of logic circuits, proceed as follows:

1. Connect the Logic Probe as described in section 3.3.1 overleaf;
2. Set the device type switch to CMOS or TTL, depending upon which "family" of logic devices is to be tested;
3. Set the mode switch to either NORMAL or PULSE. In the PULSE mode, the Logic Probe will indicate the logic level of the pulse train. In the NORMAL mode, the unit will indicate the DC Logic state (HI or LO);
4. Touch the exposed metal tip of your Logic Probe to the circuit at the particular point to be tested. If the LO (green LED) lights and the unit makes a low tone sound (beep), it indicates a level lower than the threshold voltage of about 0.8 volts. If the HI (red LED) lights and a high tone sound (beep), itindicates a level above the threshold of about 2.2 volts. If the circuit to be tested is the CMOS circuit:LOW = 30% Vcc; HlGH = 70% Vcc. If there is no LED lit and no sound (beep) emitted, the level is either between the threshold voltagesor the circuit is “open”. If the PULSE (yellow LED) is blinking, it indicates a pulse train at the testing node (when the mode switch is in PULSE position).
5. To analyze the duty cycle of a pulse train, you cancompare the brightness level of the HI (red LED) with the LO(green LED).If the HI (red LED) is brighter than the LO(green LED),the pulse form has a longer high-duration. If the LO (green LED) is brighter than the HI (red LED), thelow-duration of the pulse is longer.

3.3.3 A Practical Example on How to Use the Logic Probes in a Circuit

We started this chapter by stating that there are different logic families that are employed for the construction of logic circuits. These logic families are of different types. For example, we have the Transistor-Transistor Logic (TTL), Complementary Metal-Oxide Semiconductor (CMOS), Diode-Transistor Logic (DTL), the Resistance-Transistor Logic (RTL), Schottky Logic, Emitter-Coupled Logic and so on. This book, concentrates on the most popular of these families which are the TTL and CMOS as stated earlier. Let us start with the various voltage thresholds for these logic families.

Consider the logic circuit given inFigure 3.4, if the voltage is increased on ‘A’ then, at a certain stage, the state of ‘C’ will change from a logic 0 to a logic 1. The actual voltage at which this occurs is termed the threshold voltage for the family. (Typically, 0.8V for low and 2.2 V for high in the TTL family or 30% for low and 70% for high in the CMOS family), where we define:

$$\% = \frac{\boldsymbol{V_T}}{(+\boldsymbol{V}) - (-\boldsymbol{V})} \times \mathbf{100}$$

(Where $\boldsymbol{V_T}$ refers to the voltage at which ‘C’ changes state from logic 0 to logic 1).

When testing a gate statically, ‘A’ would be caused to go HIGH (+V) and ‘C’ monitored (changes from LOW to HIGH). When testing the gate dynamically, ‘A’ might be pulsed with a square wave and ‘C’ monitored. The gate is bad if no change occurs, provided the amplitude of the square wave at ‘A’ passes through the VTL level.

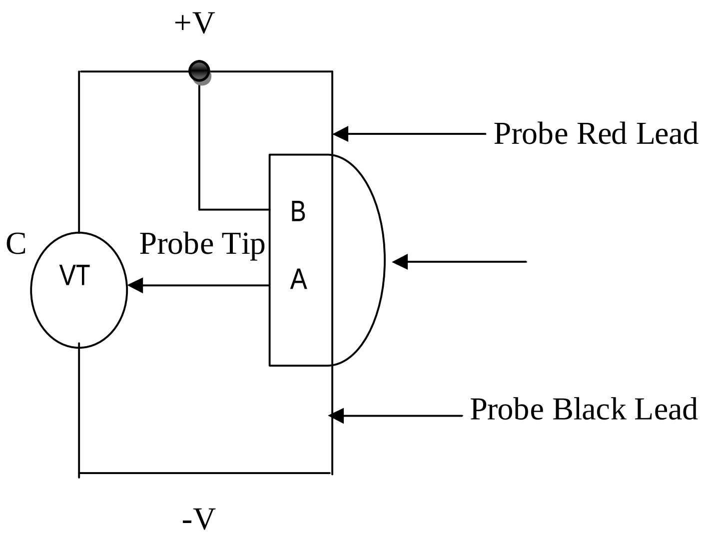


Figure 3.4: Voltage Thresholds for Static and Dynamic Testing of Logic Circuits

Within a given family, the gate is bad if it gives rise to transitions that occur in the undefined region (See Figure 3.5 for CMOS). For example, the HTL has thresholds of 8.5V and 6.5V, which compares favorably to the 70% - 30% programming of the CMOS switch position.

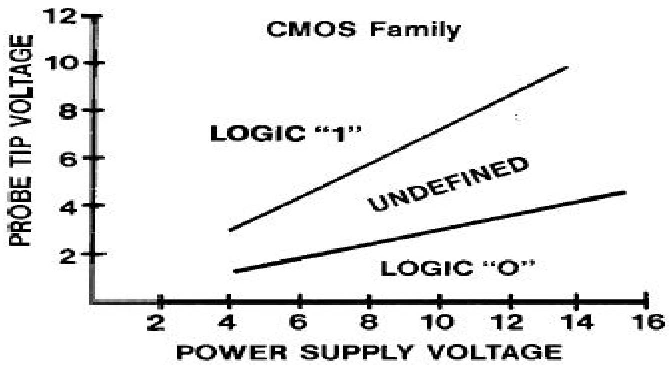


Figure 3.5: Probe Tip Voltages versus Power Supply Voltage for CMOS Family
Source: kitsrus.com

Furthermore, analysis of a wave train incorporates two aspects: the repetition rate and the duration (as shown in Figure 3.6).

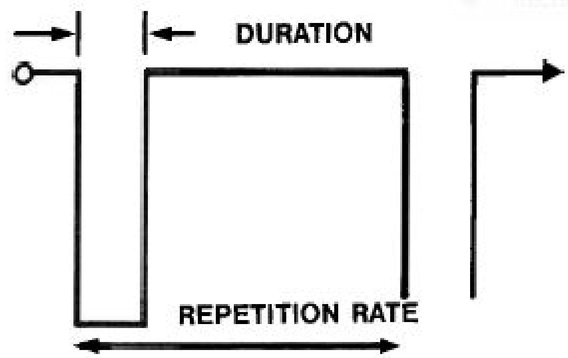


Figure 3.6: Negative-Going Pulse
Source: kitsrus.com

The ratio of the duration to the repetition rate is often called the % duty cycle. For example, in the analysis of a square wave, the duration is half of the repetition rate and consequently has a 50% duty cycle. The repetition rate is the same as the frequency of the wave train. In addition, the pulse is termed as negative (Low) if the logic level remains high for most of the cycle and pulse low as shown in Figure 3.6. The converse is termed a positive (HIGH) pulse as shown in Figure 3.7.

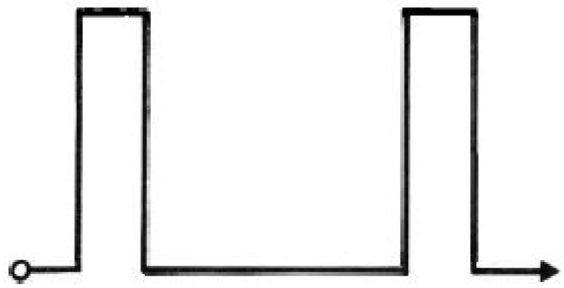


Figure 3.7: Positive-Going Pulse
Source: kitsrus.com

The (HIGH, LOW) LEDs will have relative intensitiesproportional to the duty cycle. For example, if the dutycycle is 10% and a negative exists, then the HIGH LEDwill have the greatest intensity because the LOW LEDis on only 10% of the time. As the frequency becomeslower (below 40 Hz) the actual transitions of the (HIGH,LOW) LEDs can be resolved by the human eye.However, the duration of the HIGH LED with respectto the LOW LED is still proportional to the duty cycle.A positive pulsing wave train with duty cycle above 50%becomes a negative pulsing wave train with a duty cycleof less than 50%. For example, a positive wave trainwith a 75% duty cycle is equivalent to a negative wavetrain with a duty cycle of 25%.Finally, it must be stated at this point that one should be very sure to read the manual or instruction booklet that comes with any logic probe for additional precautions, warnings and operating instructions. This is because even though many logic probes are similar in design, some little differences can influence the types of circuits that a particular probe best works with.

We have so far learnt how **Logic** Probes can be used to test logic circuits to indicate logic HIGH, LOW and even PULSATING signals. However, the logic probes cannot tell us how fast a signal is pulsing, even though in most tests weonly simply need to know whether the signal is even pulsing at all. At least, a Logic Probe can tell us that a signal that is expected to be PULSATING, HI or LO is in that state, andif it is not, then we know that there is a problem somewhere. To determine the rate of pulsing, amplitude and so on however, or even what the signal waveform looks like, the use of an oscilloscope needs to be employed. Therefore, this aspect of circuit analysis will be covered in the next chapter on oscilloscopes.

EXERCISES

Exercise 3.1: The logic ‘HI’ for a typical CMOS circuit ranges from?

(a) 2.0V to 2.4V

(b) 0.6V to 1.0V

(c) 70% of Vcc

(d) 30% 0f Vcc

Exercise 3.2: The logic ‘LO’ of a typical TTL (5Vcc) circuit is?

(a) 0.6V to 1.0V

(b) 2.0V to 2.4V

(c) 3.3V to 8.0V

(d) All of the above

Exercise 3.3: In logic terms, the ‘LO’ and ‘HI’ levels may mean:

(a) 0 and 1

(b) True and False

(c) Closed and Open

(d) All of the above

Use Figure (a) to answer exercises 3.4, 3.5 and 3.6.

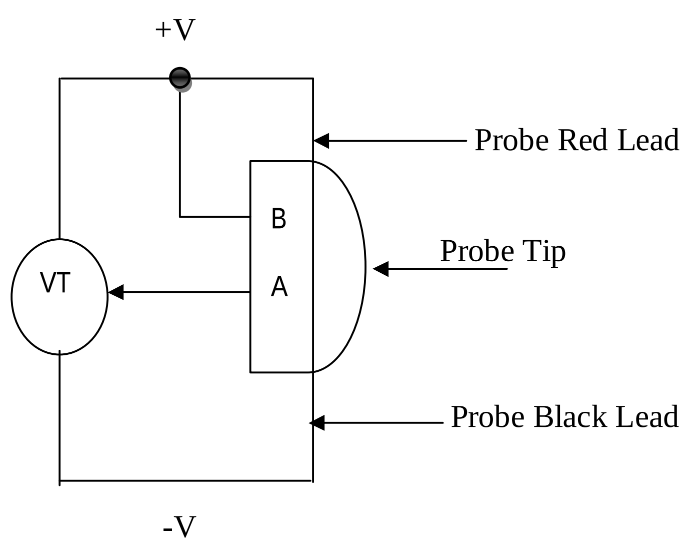


Figure (a): Voltage Thresholds for Static and Dynamic Testing of Logic Circuits

Exercise 3.4: If voltage is increased at ‘A’ then:

(a) At a certain stage, the gate ‘C’ will change from logic 1 to 0

(b) At a certain stage, the gate ‘C’ will change from logic 0 to 1

(c) At a certain stage, the gate ‘B’ will change from logic 1 to 0

(d) At a certain stage, the gate ‘B’ will change from logic 0 to 1

Exercise 3.5: When carrying out a static test in the circuit, the following is correct:

(a) ‘A’ will be caused to go ‘HI’ and ‘C’ monitored

(b) ‘C’ will be caused to go ‘HI’ and ‘A’ monitored

(c) ‘A’ will be caused to go ‘LO’ and ‘C’ monitored

(d) ‘C’ will be caused to go ‘LO’ and ‘A’ monitored

Exercise 3.6: When carrying out a dynamic test on the circuit, the following is correct:

(a) ‘C’ may be pulsed with square wave and ‘A’ monitored

(b) ‘A’ may be pulsed with square wave and ‘C’ monitored

(c) ‘C’ may be charged with sine wave and ‘A’ monitored

(d) ‘A’ may be charged with sine wave and ‘C’ monitored

Exercise 3.7: While analyzing the duty cycle of a pulse train in a logic circuit the red LED was brighter than the green LED. This means that?

(a) The ‘LO’ duration of the pulse was longer

(b) The pulse form has a longer ‘HI’ duration

(c) The logic circuit is CMOS

(d) The logic circuit is TTL

Exercise 3.8: What is the full meaning of RTL

(a) Rheostat Transistor Logic

(b) Relay Transistor Logic

(c) Resistor Transistor Logic

(d) None of the above

Exercise 3.9: The following is correct about connecting a logic probe for troubleshooting:

(a) Power supply should be within the specifications of the device

(b) If an input should always be ‘LO’ connect to the ground for TLL family

(c) Connect all unused inputs to Vcc or ground for TLL family

(d) None of the above

Exercise 3.10: The essence of switching the logic probe to either mode of the two popular logic families is:

(a) To activate the sound system

(b) To provide for the difference in voltage threshold for logic ‘HI’ and ‘LO’

(c) To avoid the effects of earth leakage

(d) All of the above

CHAPTER FOUR

OSCILLOSCOPES

4.1 Features of Oscilloscope

Oscilloscope is an essential instrument that can be used to test electronic systems. It lets us visualize electrical signals for easy analysis. Additionally, with the aid of transducers that can convert various forces and energies into electrical signals,oscilloscopes can be used to observe many physical phenomena. In electronic measurement terms, a transducer refers to any element that creates an electricalsignal in response to physical stimuli, such assound, mechanical stress, pressure, light, or heat. Forexample, the altitude sensor of an aircraft is a transducer (Aneroid Capsules) that can convert atmospheric pressure into electrical signal for measuring the altitude and attitude of that aircraft.This is why the applications of oscilloscopes are not limitedtothe world of electronicsalone. The possibilities are endless as an auto technician can useoscilloscope tomeasure engine vibrations.Hence, it becomes imperative for scientists, engineersand technicians to know how to make good use an oscilloscope.

Oscilloscope is basically a graph-displaying device. Meaning, it draws a graph of an electrical signal and displays it on a ‘television like’ screen. In most applications the graph shows how signals change over time: the vertical axis represents voltage and the horizontal axis represents time. The intensity or brightness of the display is sometimes called the Z axis. Thegraph can inform the user of many things about the signal. For instance, it tells the user about the time and voltage values of a signal; the frequency of an oscillating signal; and the ‘moving parts’ of a circuit represented by the signal. It can also tell the userhow often a particular portion of the signal is occurring relative to other portions and if a malfunctioning component is distorting the signal. Furthermore, the display on oscilloscopes can tell the user how much of the signal is a direct current DC or alternating current AC; as well as how much of it is noise and whether the noise is changing with time and so on. Hence, the significance of oscilloscopes cannot be over emphasized when it comes to electrical signal analysis. To this end, we have single and double trace oscilloscopes. The later can display the result of the analysis of two input signals unlike the former which shows only a single signal as the names imply.

Oscilloscopes are often found as portable electronic boxes that can be placed comfortably on a test bench even though some new models come as hand-held. An oscilloscope’s front panel includes a display screen, the knobs, buttons, switches, and indicators used to control signal acquisition and display. Front-panel controls normally are divided into Vertical, Horizontal, and Trigger sections, and in addition, there are display controls and input connectors as shown in Figure 4.1.

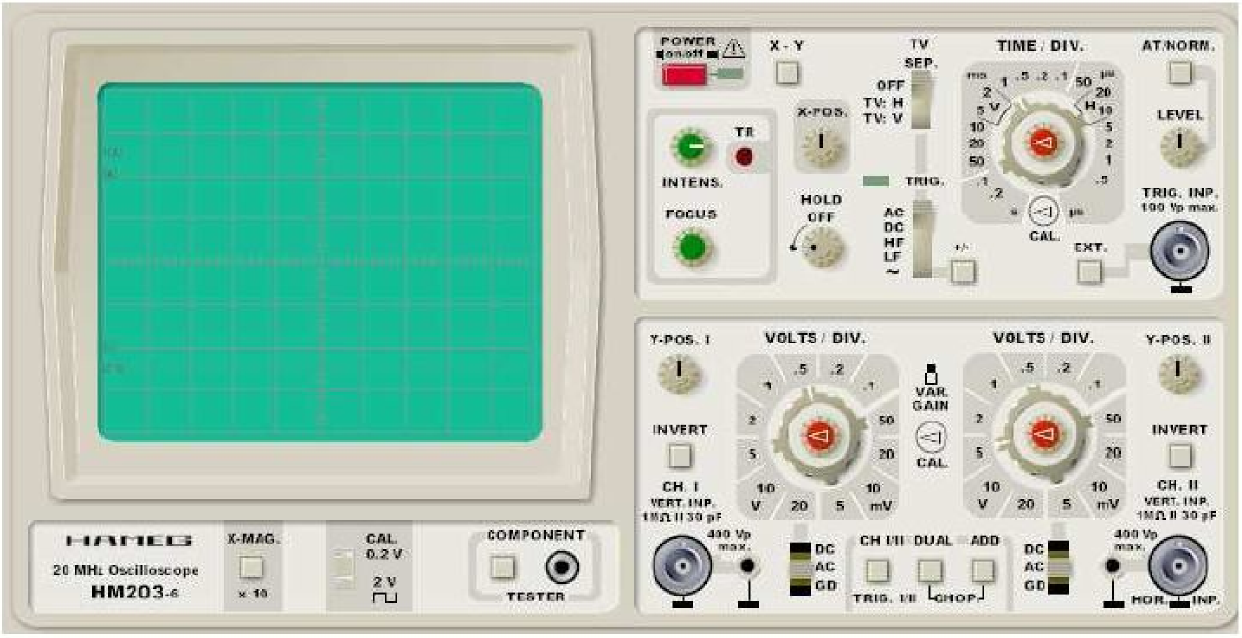


Figure 4.1: The Front View of a Typical HM203-7Model Oscilloscope
Source: HM203-7 CRO Instruction Manual

Although different types of oscilloscopes may have these operator control knobs positioned at different locations, the commonest among them include the following:

1. **Intensity Control**: Controls the brightness of the beam (too bright beam can damage the tube);
2. **Focus:** Allows for the adjustment of the beam on thinness and sharpness;
3. **VERT & HOR Position**: Controls the vertical and horizontal position of the display respectively;
4. **VERT V/div**: Controls the vertical sensitivity;
5. **HOR Sweep Speed**: Controls the horizontal sensitivity;
6. **VERT & HOR Vernier**: Allows for the adjustments of the vertical and horizontal sensitivity settings to be varied in small steps;
7. **Astigmatism Control**: Allows for the adjustment of the trace so as to make it uniform across the sweep. This adjustment compensates for the curvature of the CRT;

Other control surfaces include: Trace Rotation Control; DC BAL Control (DC Balance); High Voltage Adjustment (HV ADJ) and so on (as shown in Figure 4.2). The use of these controls will be explained further in the practical application section of this chapter.

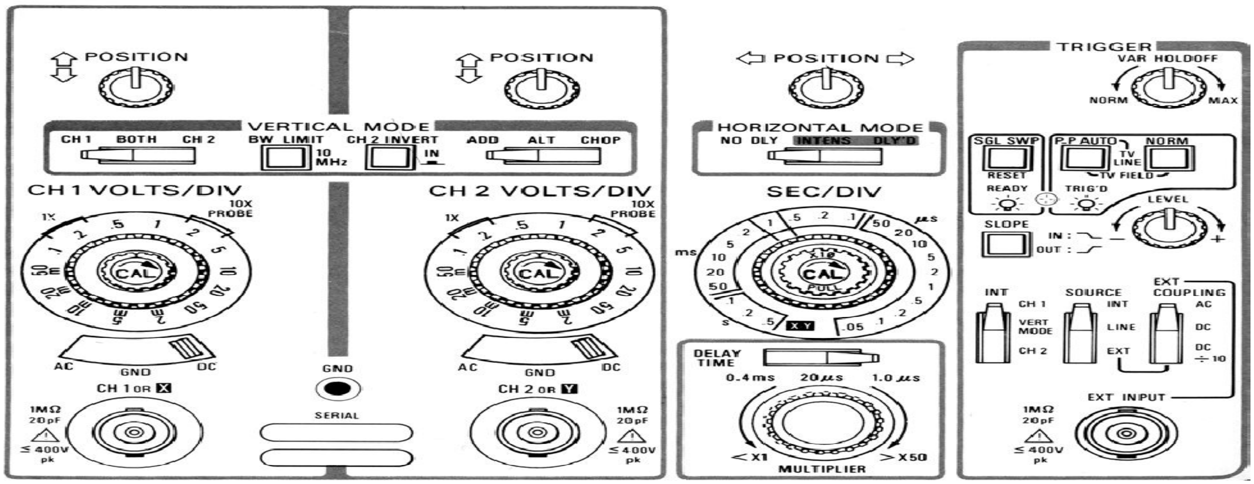


Figure 4.2: Front View of the Control Units of a Typical CRO
Source: TEKTRONIX - Manual

4.2 Principles of Operation of Oscilloscope

Like multimeters, oscilloscopes are of two types, which are the analogue and the digital.An analogue oscilloscope works by directlyapplying a voltage being measured to an electron beammoving across the oscilloscope screen. The voltagedeflects the beam up or down proportionally, tracingthe waveform on the screen. This gives an immediatepicture of the waveform.In contrast, a digital oscilloscope samples thewaveform and uses an analogue to digital converterto transform the voltagebeing measured into digital information. It then usesthis digital information to reconstruct the waveform onthe screen.For many applications either an analogue or digitaloscilloscope is appropriate. However, each type doespossess some unique characteristics making it more orless suitable for specific tasks.Analogue oscilloscopes are often preferred when itis important to display rapidly varying signals in 'realtime' (i.e. as they occur).Digital oscilloscopes allow the capture and viewingof events that happen only once. They can process thedigital waveform data or send the data to a computerfor processing. Also, they can store the digital waveformdata for later viewing and printing.

4.2.1 Analogue Oscilloscopes

The block diagram of a general purpose Cathode Ray Oscilloscope (CRO) is shown in Figure 4.3. It can be seen that signals from the input terminals are processed through the three basic elements (simplified CRO). These are the Vertical Amplifier, Trigger Circuit and Sweep

Circuit.The signal to be viewed is fed to the vertical deflection plate via the vertical amplifier, so that it the signal can be amplified to a level that will give usable deflection of the electron beam.

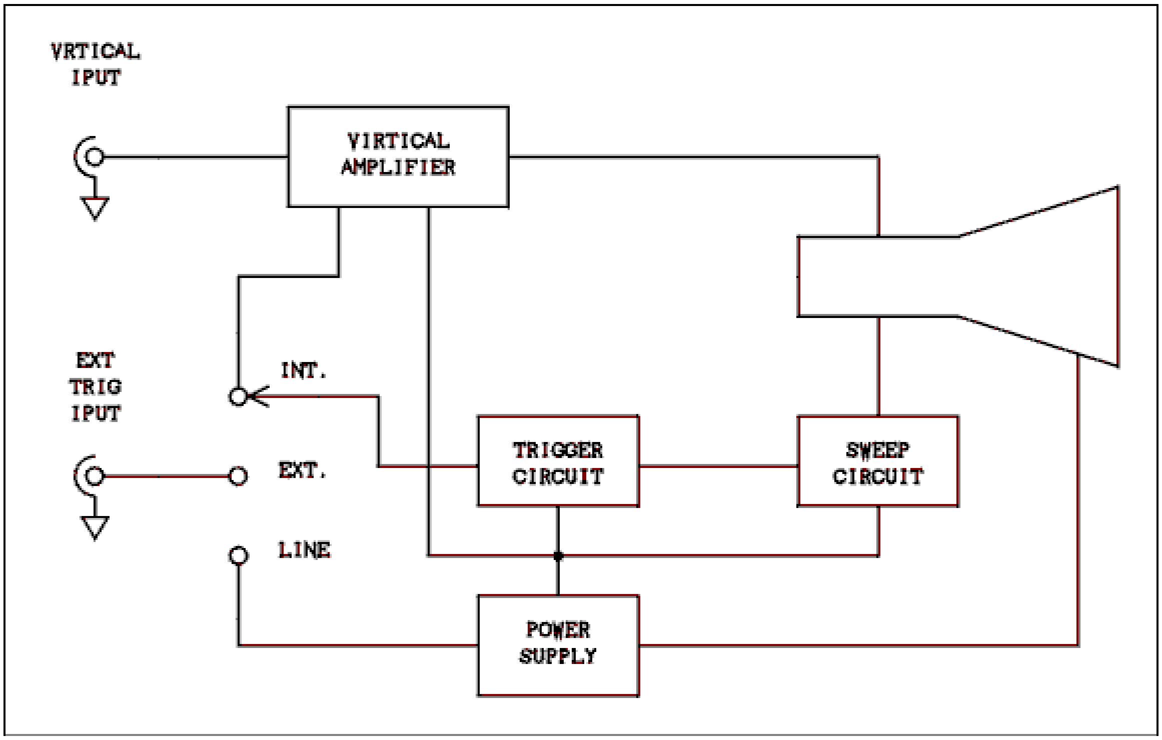


Figure 4.3: Simplified Block Diagram of a General Purpose CRO

As the electron beam is deflected in X-axis as well as Y-axis, a triggering circuit is provided for synchronizing these two types of deflections so that horizontal deflection starts at the same point of the input vertical signal each time it sweeps (sweep circuit). Although what happen in the CRO is more complex than the information shown in the block diagram of Figure 4.3, the principles of operation is better understood by studying the cathode ray tube.

The set-up of an oscilloscope tube is shown in Figure 4.4, the real shapes of the single component are considerably more complex (Figure 4.5). The grounded cathode K (0 V) is heated indirectly by a heating spiral (at a heating voltage of U_H) until thermal electron emission occurs. The anode (A), drilled in its centre, is placed at a distance d_A from the cathode. Between A and K a positive high voltage $U_A$of up to a few 1000 Volts is applied to give rise toan electrical field E_A between K and A with the magnitude of:$\mathbf{E_A} = \frac{UA}{dA}$andexerting a force $\mathbf{F_A}$on the electrons (having charge e) of magnitude: $\mathbf{F_A = e\, E_A}$.

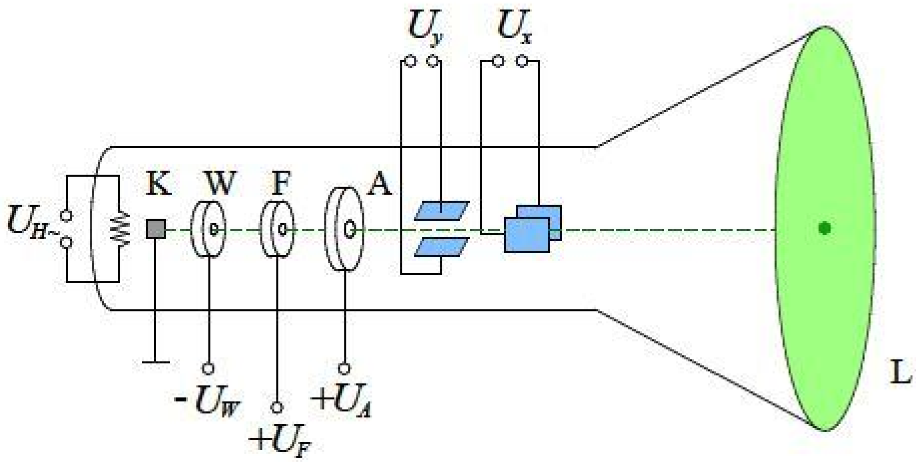


Figure 4.4: Set-up of a Cathode Ray Oscilloscope Tube
Source: Carl(2010)

The force $F_A$accelerates the electrons in the direction of the anode. After travelling through the hole in the anode the electrons hit the luminescent screen, causing them to slow down and excite the phosphor in the screen to fluorescence. This causes a visible point of light, the size of which can be minimized with the help of the voltage $U_F$across the focusing device. The intensity of the point of light can be varied using a negative voltage $U_W$between K and the cylinder W. The electrical field E_W, resulting from $U_W$is oriented in the opposite direction of E_A, thus decelerating the electrons. Because of this, only electrons having sufficient kinetic energy can reach the anode.

Figure 4.5: Photograph of a Typical Cathode Ray Oscilloscope Tube
Source: Carl (2010)

The X and Y deflector plates each form a parallel-plate capacitor and are used for horizontal and vertical deflection of the electron beam. If a deflection voltage $U_Y$is applied to the Y-deflector plates (separated by a distance d_Y), an electrical field $E_Y$will form between the plates. The magnitude $E_Y$of this field is given by:$\mathbf{E_Y = \frac{UY}{dY}}$ **,** exerting a force $F_Y$on the electrons during their transit with a magnitude: $\mathbf{F_Y = e\ E_Y = e\ \frac{UY}{dY}}$ **.** The electrons are thus deflected up or down by some amount, depending on the amplitude and sign of applied voltage U_Y causing them to contact the screen at different positions in the vertical direction. The samething applies analogously to the *X*-deflector plates, which are used to deflect the electrons in the horizontal direction.

4.2.2 Digital Storage Oscilloscopes (DSOs)

Some of the systems that make up DSOs are the same as those in analogue oscilloscopes; however, digitizing oscilloscopes contain additional data processing systems as shown in Figure 4.6. With the added systems, the digitizing oscilloscope collects data for the entire waveform and then displays it.

Figure 4.6: Block Diagram of a Typical Digital Storage Oscilloscope

The first (input) stage of a DSO is a vertical amplifier, just like in the analogue oscilloscopes. Vertical attenuation controls allow you to adjust the amplitude range of this stage. Next, the analogue-to-digital converter (ADC) in the acquisition system samples the signal at discrete points in time and converts the signal's voltage at these points to digital values called sample points. The horizontal system's sample clock determines how often the ADC takes a sample. The rate at which the clock "ticks" is called the sample rate and is expressed in samples per second. The sample points from the ADC are stored in memory as waveform points. More than one sample point may make up one waveform point. Together, the waveform points make up one waveform record. The number of waveform points used to make a waveform record is called the record length. The trigger system determines the start and stop points of the record. The display receives these record points after being stored in memory.

Depending on the capabilities of your oscilloscope, additional processing of the sample points may take place, enhancing the display. Pre-trigger may be available, allowing you to see events before the trigger point.Note that the DSO’s signal path includes a microprocessor. The measured signal passes through this device on its way to the display. In addition to processing the signal, the microprocessor coordinates display activities, manages the front-panel controls, and more. This is known as a “serial processing” architecture.

4.2.3 Digital Phosphor Oscilloscopes

The Digital Phosphor Oscilloscope (DPO) offers a new approach to oscilloscope architecture. Also, like their analogue counterparts, the first stage is a vertical amplifier; and like the DSO, its second stage is an Analogue Digital Converter (ADC). But after the analog-to-digital conversion, the DPO looks quite different from the DSO. It has special features designed to recreate the intensity grading of an analogue CRT. Rather than relying on a chemical phosphor as the analogue scope does, the DPO has a purely electronic Digital Phosphor that forms a continuously updated data base. This data base has a separate “cell” of information for every single pixel in the scope’s display. Each time a waveform is captured, in other words, every time the scope triggers, it is mapped into the Digital Phosphor database’s cells. Each cell representing a screen location that is touched by the waveform gets reinforced with intensity information. Others do not. Thus intensity information builds up in cells where the waveform passes most often.When the Digital Phosphor database is fed to the oscilloscope’s display, the display reveals intensified waveform areas, in proportion to the signal’s frequency of occurrence at each point – much like the intensity grading characteristics of an analogue oscilloscope. Unlike the analogue scope, however, the DPO allows the varying levels to be expressed in contrasting colors if you wish. With a DPO, it’s easy to see the difference between a waveform that occurs on almost every trigger and one that occurs, say, every 100th trigger.

Importantly, the DPO uses a parallel processing architecture to achieve all this manipulation without slowing down the whole acquisition process. Like the DSO, the DPO uses a microprocessor for display management, measurement automation, and analysis. But the DPO’s microprocessor is outside the acquisition/display signal path as shown in Figure 4.7, where it doesn’t affect the acquisition speed.

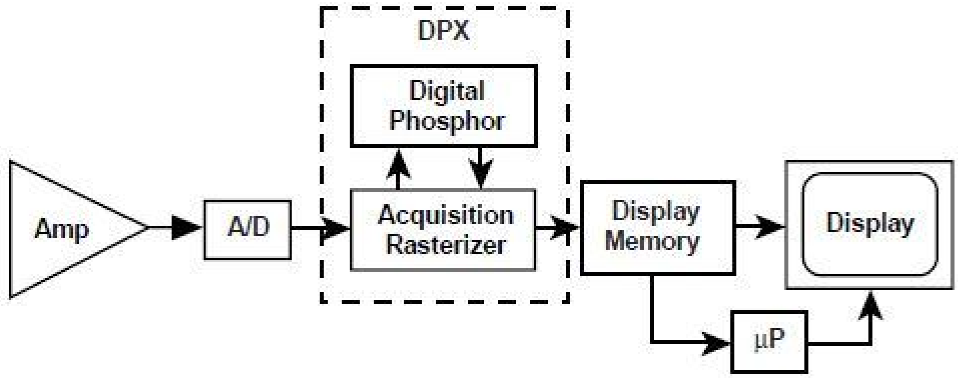


Figure 4.7: Block Diagram of a Typical Digital Phosphor Oscilloscope

4.2.4 Sampling Methods

Digitizing oscilloscopes – DSO or DPO – can use either real-time, interpolated real-time, or equivalent-time sampling to collect sample points. Real-timesampling is ideal for signals whose frequency is less than half the scope's maximum sample rate. Here, the oscilloscope can acquire more than enough points in one "sweep" of the waveform to construct an accurate picture as shown in figure 4.8. Note that real-time sampling is the only way to capture single-shot transient signals with a digitizing scope. When measuring high-frequency signals, the oscilloscope may not be able to collect enough samples in one sweep. There are two solutions for accurately acquiring signals whose frequency exceeds half the oscilloscope's sample rate:

- Collecting a few sample points of the signal in a single pass (in real-time mode) and usinginterpolation to fill in the gaps. Interpolation is a processing technique to estimate what the waveform looks like based on a few points;
- Build a picture of the waveform by acquiring samples from successive cycles of the waveform, assuming the signal repeats itself (equivalent-time sampling mode)

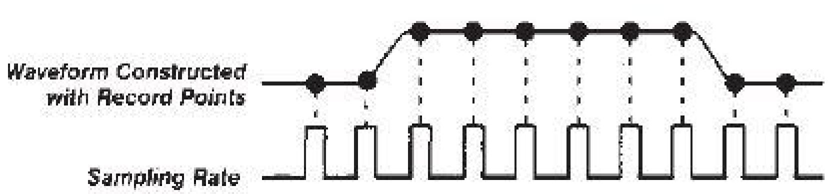


Figure 4.8: Real-Time Sampling

4.2.5 Real-Time Sampling with Interpolation

Digitizing oscilloscopes take discrete samples of the signal which can be displayed. However, it can be difficult to visualize the signal represented as dots, especially because there may be only a few dots representing high-frequency portions of the signal. To aid in the visualization of signals, digitizing oscilloscopes typically have interpolation display modes. In simple terms, interpolation “connects the dots.” Using this process, a signal that is sampled only a few times in each cycle can be accurately displayed. However, for accurate representation of the signal, the sample rate should be at least four times the bandwidth of the signal.

Linear interpolation connects sample points with straight lines. This approach is limited to reconstructing straight-edged signals such as square waves. The more versatile sin x/x interpolation connects sample points with curves as shown in Figure 4.9. Sin x/x interpolation is a mathematical process in which points are calculated to fill in the time between the real samples.

This form of interpolation lends itself to curved and irregular signal shapes, which are far more common in the real world than pure square waves and pulses.

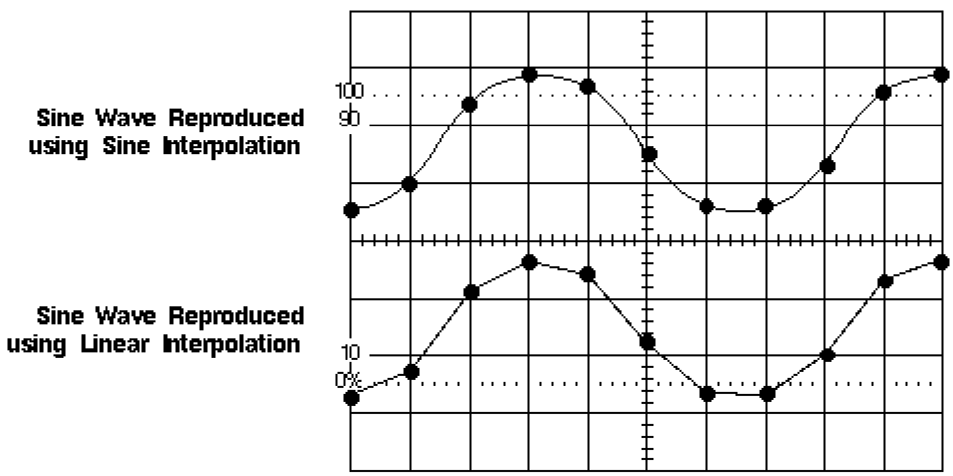


Figure 4.9: Linear and Sine Interpretation

Consequently, sin x /x interpolation is the preferred method for most applications. Some digitizing oscilloscopes can use equivalent time sampling to capture very fast repeating signals. Equivalent-time sampling constructs a picture of a repetitive signal by capturing a little bit of information from each repetition as shown in Figure 4.10. The waveform slowly builds up like a string of lights going on one-by-one. With sequential sampling, the points appear from left to right in sequence; with random sampling, the points appear randomly along the waveform.

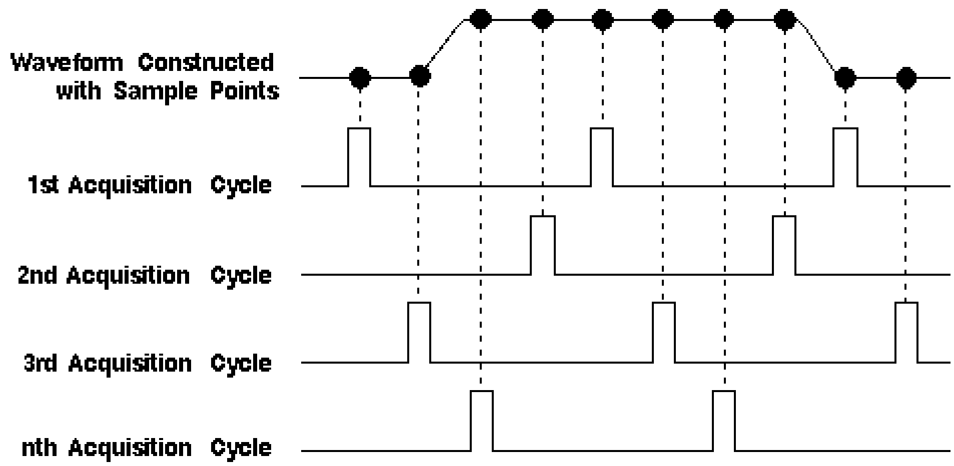


Figure 4.10: Equivalent-Time Sampling

In terms of principles of operation, oscilloscopes can further be classified into Dual Trace Oscilloscopes, Dual Beam Oscilloscopes, Special Storage Oscilloscopes, Sampling Oscilloscopes, Digital Read-out Oscilloscopes, Hand-Held Battery Operated Oscilloscopes, Lissajous Figures, and so on.

4.2.6 Measurement Terms Associated with the Use of Oscilloscopes

Learning a new skill often involves learning a new vocabulary. This idea holds true for learning how to use an oscilloscope. This section describes some useful measurement and oscilloscope performance terms.The generic term for a pattern that repeats over time is a wave – sound waves, light waves, ocean waves, and voltage waves are all repeating patterns. An oscilloscope measures voltage waves. One cycle of a wave is the portion of the wave that repeats. A waveform is a graphic representation of a wave. A voltage waveform shows time on the horizontal axis and voltage on the vertical axis. Waveform shapes tell you a great deal about a signal. Any time you see a change in the height of the waveform, you know the voltage has changed. Any time there’s a flat horizontal line, you know that there’s no change for that length of time. Straight diagonal lines mean a linear change – rise or fall of voltage at a steady rate. Sharp angles on a waveform mean sudden change. Waves can be classified mostly into these types:

- Sine waves
- Square and rectangular waves
- Triangle and saw-tooth waves
- Step and pulse shapes
- Complex waves

Sine Waves

The sine wave is the fundamental wave shape for several reasons. It has harmonious mathematical properties – it's the same sine shape you may have studied in the senior secondary school trigonometry class. The power line voltage at your wall outlet varies as a sine wave. Test signals produced by the oscillator circuit of a signal generator are often sine waves. Most AC power sources produce sine waves. (AC stands for alternating current, although the voltage alternates too. DC stands for direct current, which means asteady current and voltage, such as a batteryproduces).The damped sine wave is a special case you may seein a circuit that oscillates but winds down over time.Figure 4.11 shows examples of sine and damped sinewaves.

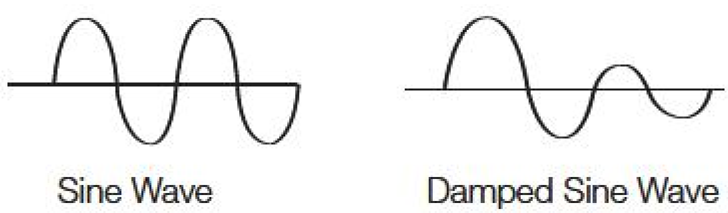


Figure 4.11: Sine and Damped Sine Waves

Square and Rectangular Waves

The square wave is another common wave shape. Basically, a square wave is a voltage that turns on and off (or goes high and low) at regular intervals. It's a standard wave for testing amplifiers – good amplifiers increase the amplitude of a square wave with minimum distortion. Television, radio, and computer circuitry often use square waves for timing signals. The rectangular wave is like the square wave except that the high and low time intervals are not of equal length. It is particularly important when analyzing digital circuitry.Figure 4.12 shows examples of square and rectangular waves.

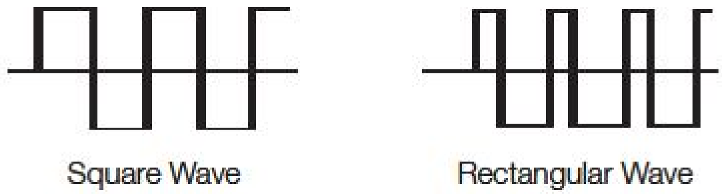


Figure 4.12: Square and Rectangular Waves

Saw-tooth and Triangle Waves

Saw-tooth and triangle waves result from circuits designed to control voltages linearly, such as the horizontal sweep of an analog oscilloscope or the raster scan of a television. The transitions between voltage levels of these waves change at a constant rate. These transitions are called ramps. Figure 4.13 shows examples of saw-tooth and triangle waves.

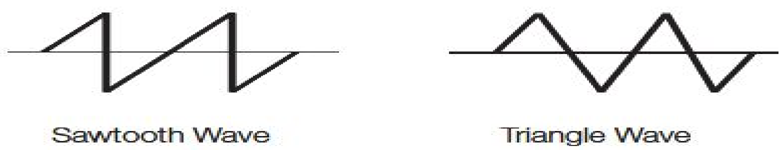


Figure 4.13: Saw-tooth and Triangular Waves

Step and Pulse Shape

Signals such as steps and pulses that only occur once are called single-shot or transient signals. The step indicates a sudden change in voltage, like what you would see if you turned on a power switch. The pulse indicates what you would see if you turned a power switch on and then off again. It might represent one bit of information traveling through a computer circuit or it might be a defect in a circuit.

A collection of pulses travelling together creates a pulse train. Digital components in a computer communicate with each other using pulses. Pulses are also common in x-ray and communications equipment.Figure 4.14 shows examples of step and pulse shapes and a pulse train.

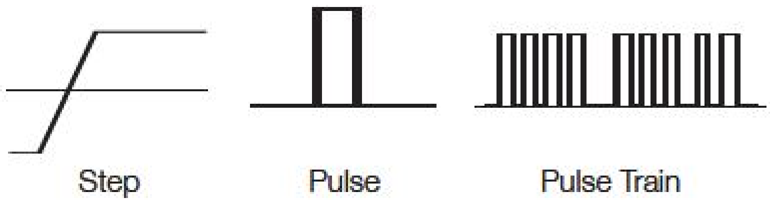


Figure 4.14: Step, Pulse and Pulse Train Shapes

Complex Waves

Some waveforms combine the characteristics of sines, squares, steps, and pulses to produce a wave-shape that challenges many oscilloscopes. The signal information may be embedded in the form of amplitude, phase, and/or frequency variations. For example, look at Figure 4.15 – although it's an ordinary composite video signal, it is made up of many cycles of higher-frequency waveforms embedded in a lower-frequency "envelope." In this example it's usually most important to understand the relative levels and timing relationships of the steps. What's needed to view this signal is an oscilloscope that captures the low-frequency envelope and blends in the higher-frequency waves in an intensity-graded fashion so you can see their overall level.Analogue instruments and DPOs are most suited to viewing complex waves such as video signals. Their displays provide the necessary intensity grading.Often, the frequency-of-occurrence information that their displays express is essential to understanding what the waveform is really doing.

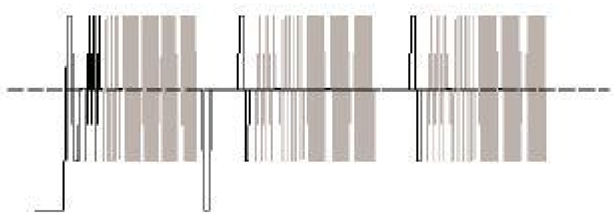


Figure 4.15: Complex Wave Form

Frequency and Period

Frequency is measured in Hertz (Hz) and equals the number oftimes the signal repeats itself in one second (thecycles per second). A repeating signal also has aperiod – this is the amount of time it takes the signalto complete one cycle. Period and frequency are reciprocalsof each other, so that 1/period equals thefrequency and 1/frequency equals the period. So, forexample, the sine wave in Figure 4.16 has a frequencyof 3 Hz and a period of 1/3 second.

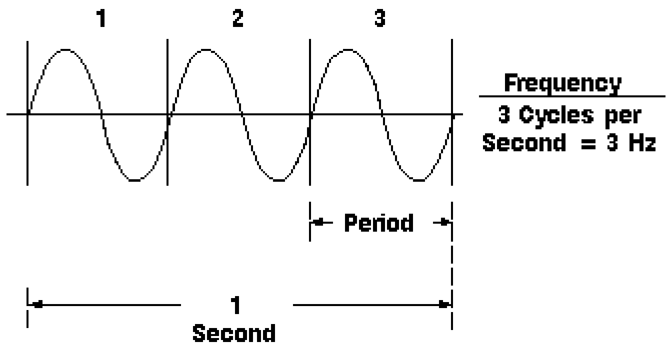


Figure 4.16: Frequency and Period of Sine Wave

Voltage

Voltage is the amount of electric potential (a kind ofsignal strength) between two points in a circuit.Usually one of these points is ground (zero volts) butnot always – you may want to measure the voltagefrom the maximum peak to the minimum peak of awaveform, referred to as the peak-to-peak voltage.The word amplitude commonly refers to themaximum voltage of a signal measured from groundor zero volts. The waveform shown in Figure 4.17 hasamplitude of one volt and a peak-to-peak voltageof two volts.

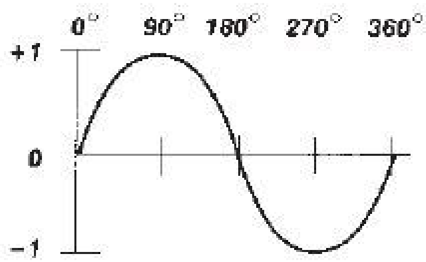


Figure 4.17: Sine Wave Degrees

Phase

Phase is best explained by looking at a sine wave.The voltage level of sine waves is based on circularmotion, and a circle has 360 degrees (°). One cycle ofa sine wave has 360°, as shown in Figure 21. Usingdegrees, you can refer to the phase angle of a sinewave when you want to describe how much of theperiod has elapsed. Phase shift describes the difference in timingbetween two otherwise similar signals. In Figure 4.18,the waveform labeled “current” is said to be 90° outof phase with the waveform labeled “voltage,” sincethe waves reach similar points in their cycles exactly 1/4 of a cycle apart (360°/4 = 90°). Phase shifts arecommon in electronics.

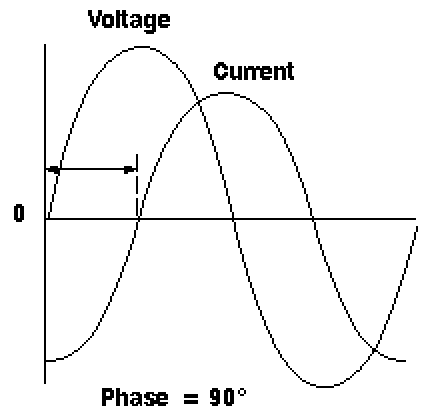


Figure 4.18: Phase Shift

Performance Terms

The terms described in this section may come up inyour discussions about oscilloscope performance.Understanding these terms will help you evaluateand compare your oscilloscope with other models.

Bandwidth

The bandwidth specification tells you the frequencyrange the oscilloscope accurately measures.
As signal frequency increases, the capability of theoscilloscope to accurately respond decreases. Byconvention, the bandwidth tells you the frequency atwhich the displayed signal reduces to 70.7% of theapplied sine wave signal. (This 70.7% point isreferred to as the “–3 dB point” – a term based on alogarithmic scale.)

Rise Time

Rise time is another way of describing the usefulfrequency range of an oscilloscope. Rise time may bea more appropriate performance consideration whenyou expect to measure pulses and steps. An oscilloscopecannot accurately display pulses with risetimes faster than the specified rise time of the oscilloscope.

Effective Bits

Effective bits are the measure of a digitizing oscilloscope’sability to accurately reconstruct a signal byconsidering the quality of the oscilloscope’s ADCand amplifiers. This measurement compares theoscilloscope’s actual error to that of an ideal digitizer.Because the actual errors include noise anddistortion, the frequency and amplitude of the signalas well as the bandwidth of the instrument must bespecified.

Frequency Response

Bandwidth alone is not enough to ensure that anoscilloscope can accurately capture a high frequencysignal. The goal of oscilloscope design is to haveMaximally Flat Envelope Delay (MFED). Afrequency response of this type has excellent pulsefidelity with minimum overshoot and ringing. Sincea digitizing oscilloscope is composed of real amplifiers,attenuators, ADCs, interconnect and relays, theMFED response is a goal which can only beapproached. Pulse fidelity varies considerably withmodel and manufacturer.

Vertical Sensitivity

The vertical sensitivity indicates how much thevertical amplifier can amplify a weak signal. Verticalsensitivity is usually given in millivolts (mV) perdivision. The smallest voltage a general purposeoscilloscope can detect is typically about 1 mV pervertical screen division.

Sweep Speed

This is the horizontal sensitivity of the oscilloscope. For analogue oscilloscopes, this specification indicateshow fast the trace can sweep across the screen,allowing you to see fine details. The fastest sweepspeed of an oscilloscope is usually given in nanoseconds/div.

Gain Accuracy

The gain accuracy indicates how accurately thevertical system attenuates or amplifies a signal. Thisis usually listed as a percentage error.

Time Base or Horizontal Accuracy

The time base or horizontal accuracy indicates howaccurately the horizontal system displays the timingof a signal. This is usually listed as a percentageerror.

Sample Rate

On digitizing oscilloscopes, the sample rate indicateshow many samples per second the ADC (and thereforethe oscilloscope) can acquire. Maximum samplerates are usually given in megasamples per second(MS/s). The faster the oscilloscope can sample, themore accurately it can represent fine details in a fastsignal. The minimum sample rate may also beimportant if you need to look at slowly changingsignals over long periods of time. Typically, thesample rate changes with changes made to thevertical sensitivity control to maintain a constantnumber of waveform points in the waveform record.

ADC Resolution (or Vertical Resolution)

The resolution, in bits, of the ADC (and therefore thedigitizing oscilloscope) indicates how precisely itcan turn input voltages into digital values.Calculation techniques can improve the effectiveresolution.

Record Length

The record length of a digitizing oscilloscope indicateshow many waveform points the oscilloscope isable to acquire for one waveform record. Some digitizingoscilloscopes let you adjust the record length.The maximum record length depends on the amountof memory in your oscilloscope and its ability tocombine memory length from unused channels.Since the oscilloscope can only store a finite numberof waveform points, there is a trade-off betweenrecord detail and record length. You can acquireeither a detailed picture of a signal for a short periodof time (the oscilloscope “fills up” on waveformpoints quickly) or a less detailed picture for a longerperiod of time. Some oscilloscopes let you add morememory to increase the record length for specialapplications.

Waveform Capture Rate

Waveform capture rate is the rate at which an oscilloscopetriggers, acquires, and displays waveforms.On DSOs, the rate is a few hundred times per secondat the most, due to their serial processing architecture.All in all, most DSOs sample about 1% of thetotal time the signal is available to them. The limitationof this approach is that signal activity continueseven though the oscilloscope isn’t sampling veryoften. And an important waveform aberration mightoccur during that lapse. A new digitizing oscilloscopearchitecture, the DPO, has emerged to solvethis problem. On a DPO, signal acquisition isrepeated hundreds of thousands of times per second– as fast as an analogue oscilloscope. The DPO'sextremely high waveform capture rate (as well astheir digital phosphor technology) makes it possibleto view rare, erratic signal events.

4.3 Practical Applications of Oscilloscopes

This section briefly describes how to set up and startusing an oscilloscope – specifically, how to groundthe oscilloscope, set the controls in standard positions,and compensate the probe before making the various measurements.Proper grounding is an important step when settingup to take measurements or work on a circuit.Properly grounding the oscilloscope protects youfrom a hazardous shock and grounding yourselfprotects your circuits from damage.

4.3.1 Preparatory Steps

Grounding the Oscilloscope

Grounding the oscilloscope is necessary for safety. Ifa high voltage contacts the case of an ungroundedoscilloscope, any part of the case including knobsthat appear insulated, can give you a shock.However, with a properly grounded oscilloscope, thecurrent travels through the grounding path to earthground rather than through you to earth ground.To ground the oscilloscope means to connect it to anelectrically neutral reference point (such as earthground). Ground your oscilloscope by plugging itsthree-pronged power cord into an outlet grounded toearth ground.Grounding is also necessary for taking accuratemeasurements with your oscilloscope. The oscilloscopeneeds to share the same ground as any circuitsyou are testing.Some oscilloscopes do not require the separateconnection to earth ground. These oscilloscopeshave insulated cases and controls, which keeps anypossible shock hazard away from the user.

Grounding the User

If you are working with Integrated Circuits (ICs), youalso need to ground yourself. Integrated circuits havetiny conduction paths that can be damaged by staticelectricity that builds up on your body. You can ruinan expensive IC simply by walking across a carpet ortaking off a sweater and then touching the leads ofthe IC. To solve this problem, wear a grounding strap(see Figure 4.19). This strap safely sends static chargeson your body to earth ground.

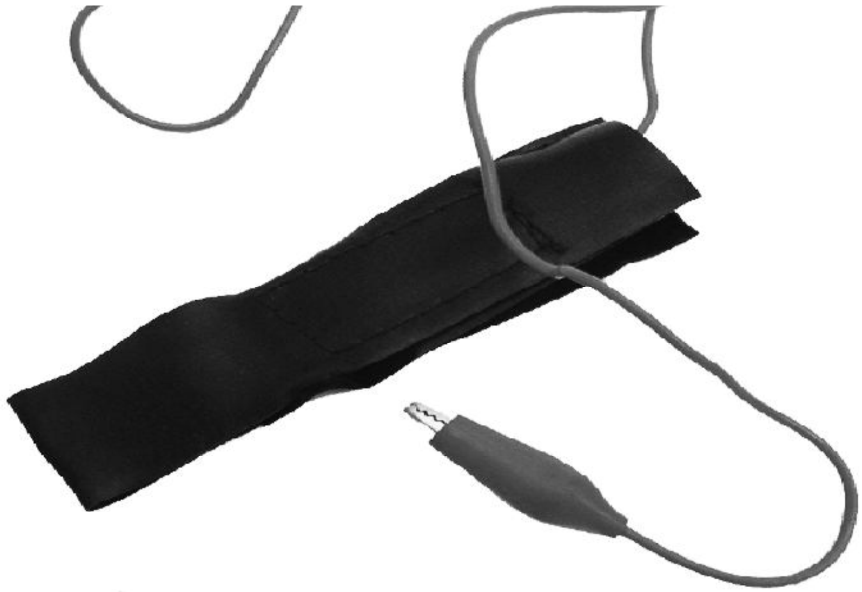


Figure 4.19: Typical Wrist Type Grounding Strap
Source:TEKTRONIX-Manual

The Probes

Now you are ready to connect a probe to your oscilloscope.It's important to use a probe designed towork with your oscilloscope. A probe is more than acable with a clip-on tip. It's a high-quality connector,carefully designed not to pick up stray radio andpower-line noise.Probes are designed not to influence the behavior ofthe circuit you are testing. However, no measurementdevice can act as a perfectly invisible observer.The unintentional interaction of the probe and oscilloscopewith the circuit being tested is called circuitloading (loading effect as discussed in chapter one of this book that dealt with errors in electronic measurement). To minimize circuit loading, you will probablyuse a 10X attenuator (passive) probe.Your oscilloscope probably arrived with a passiveprobe as a standard accessory. Passive probesprovide you with an excellent tool for generalpurposetesting and troubleshooting. For morespecific measurements or tests, many other types ofprobes exist. Two examples are active and currentprobes.Descriptions of these probes follow, with moreemphasis given to the passive probe since this is theprobe type that allows the most flexibility of use.

Probe Interfaces

Many modern oscilloscopes provide special automatedfeatures built into the input and mating probeconnectors. The act of connecting the probe to theinstrument notifies the oscilloscope about theprobe’s attenuation factor, which in turn scales thedisplay so that the probe’s attenuation is figured intothe readout on the screen.Some probe interfaces also recognize the type ofprobe; that is, passive, active, or current. Lastly, theinterface may act as a DC power source for probes.Active probes have their own amplifier and buffer circuitry that requires DC power.

Using Passive Probes

Most passive probes have some attenuation factor,such as 10X, 100X, and so on. By convention, attenuationfactors, such as for the 10X attenuator probe,have the X after the factor. In contrast, magnificationfactors like X10 have the X first.The 10X (read as “ten times”) attenuator probe minimizescircuit loading and is an excellent generalpurposepassive probe. Circuit loading becomesmore pronounced at higher frequencies, so be sure touse this type of probe when measuring signals above5 kHz. The 10X attenuator probe improves the accuracyof your measurements, but it also reduces theamplitude of the signal seen on the screen by a factorof 10.Because it attenuates the signal, the 10X attenuatorprobe makes it difficult to look at signals less than 10millivolts. The 1X probe is similar to the 10X attenuatorprobe but lacks the attenuation circuitry.Without this circuitry, more interference is introducedinto the circuit being tested. Use the 10Xattenuator probe as your standard probe, but keep the 1X probe as it is good for measuring weak signals.

Some probes have a convenient feature for switchingbetween 1X and 10X attenuation at the probe tip. Ifyour probe has this feature, make sure you are usingthe correct setting before taking measurements.Many oscilloscopes can detect whether you are using a 1X or 10X probe and adjust their screen readoutsaccordingly. However with some oscilloscopes, youmust set the type of probe you are using or read fromthe proper 1X or 10X marking on the volts/divcontrol.

The 10X attenuator probe works by balancing theprobe’s electrical properties against the oscilloscope’selectrical properties. Before using a 10Xattenuator probe, you need to adjust this balance foryour particular oscilloscope. This adjustment iscalled compensating the probe and is further described later in this chapter. Figure 4.20shows a simple diagram of the internal workings of aprobe, its adjustment, and the input of an oscilloscope.Figure 4.20 shows a typical passive probe and someaccessories to use with the probe.

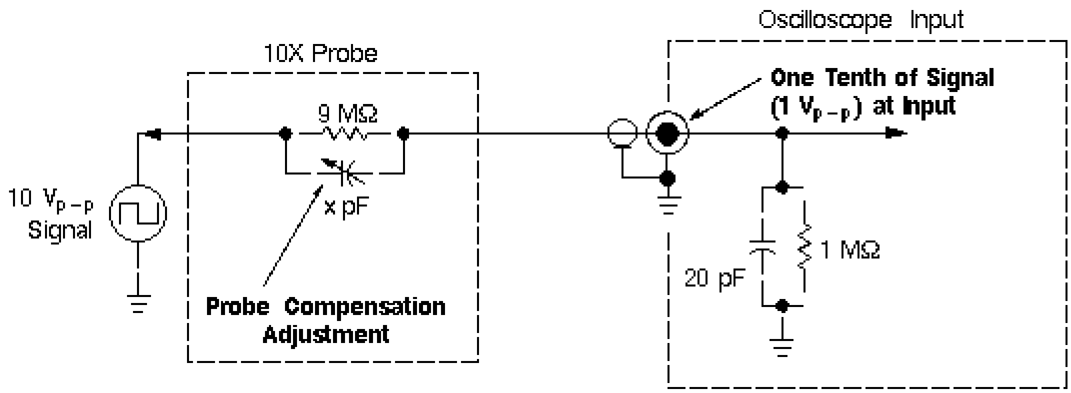


Figure 4.20: Typical Probe/Oscilloscope

Figure 4.21: A Typical Passive Probe with Accessories

Source: TEKTRONIX-Manual

Using Active Probes

Active probes provide their own amplification orperform some other type of operation to process thesignal before applying it to the oscilloscope. Thesetypes of probes can solve problems such as circuitloading or can perform tests on signals, sending theresults to the oscilloscope. Active probes require apower source for their operation.

Using Current Probes

Current probes enable you to directly observe andmeasure current waveforms. They are available formeasuring both AC and DC current. Current probesuse jaws that clip around the wire carrying thecurrent. This makes them unique since they are notconnected in series with the circuit; therefore, theycause little or no interference in the circuit.

Where to Clip the Ground Clip

Measuring a signal requires two connections: theprobe tip connection and a ground connection. Probes come with an alligator-clip attachment forgrounding the probe to the circuit under test. Inpractice, you clip the grounding clip to a knownground point in the circuit, such as the metal chassisof a stereo you are testing, and touch the probe tipto a test point in the circuit.

Compensating the Probes

Before using a passive probe, you need to compensateit – to balance its electrical properties to aparticular oscilloscope. You should get into the habitof compensating the probe every time you set upyour oscilloscope. A poorly adjusted probe can makeyour measurements less accurate. Figure 4.22 showswhat happens to measured waveforms when using aprobe that is not properly compensated.Most oscilloscopes have a square-wave referencesignal available at a terminal on the front panelwhich can be used to compensate the probe. Youcompensate a probe by:

• Attaching the probe to an input connector;

• Connecting the probe tip to the probe compensationsignal;

• Attaching the ground clip of the probe to ground;

• Viewing the square wave reference signal;

• Making the proper adjustments on the probe sothat the corners of the square wave are square.

When you compensate the probe, always first attachany accessory tips you will use and connect theprobe to the vertical channel you plan to use. Thisway, the oscilloscope has the same electrical propertiesfor compensation as it does when you makemeasurements.

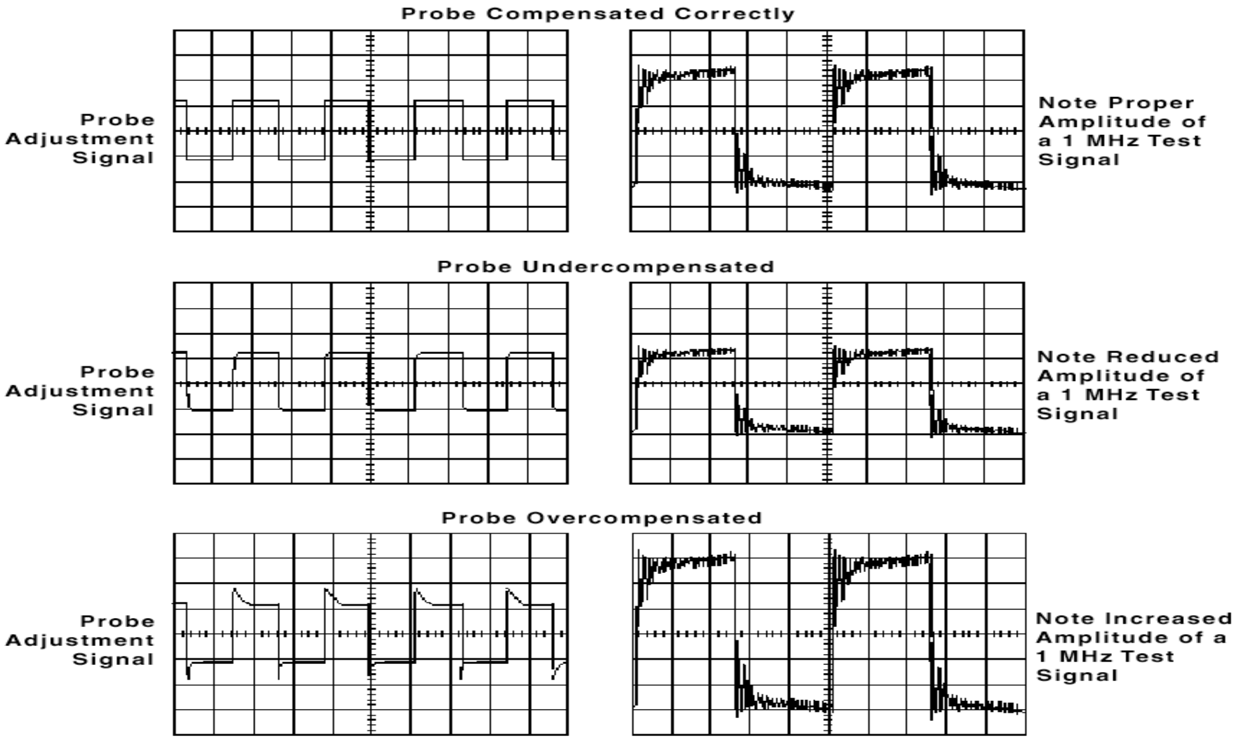


Figure 4.22: The Effects of Improper Probe Compensation

Signal Path Compensation (SPC)

This is a repeated exercise that is due whenever the ambient temperature of the environment where the oscilloscope is kept changes by 10^0 or more. It optimizes the oscilloscope signal path for maximum measurement accuracy. In fact, some oscilloscopes user's manuals stated that this routine should be repeated from time to time to enhance the performance of the device. To compensate the signal path, proceed as follows:

1. Disconnect any probe or cable from the channel input connectors;
2. Push the utility button;
3. Push the system screen button to select CALIBRATION;
4. Push the signal path screen button;
5. Push 'OK COMPENSATE SIGNAL PATH'

It should be noted that this procedure takes many minutes complete. Also, it is not all oscilloscopes that feature this type of signal path compensation.

4.3.2 Measurements Techniques

This section teaches you basic measurement techniques.The two most basic measurements you canmake are voltage and time measurements. Just aboutevery other measurement is based on one of thesetwo fundamental techniques.This section discusses methods for making measurementsvisually with the oscilloscope screen. This is acommon technique with analogue instruments, andalso may be useful for “at-a-glance” interpretation ofDSO or DPO displays. Note that most digitizing oscilloscopes include automatedmeasurement tools. Knowing how to makemeasurements manually as described here will helpyou understand and check the automatic measurementsof DSOs and DPOs. Automated measurementsare explained later in this section.

The Display

Take a look at the oscilloscope display. Notice thegrid markings on the screen – these markings createthe graticule. Each vertical and horizontal lineconstitutes a major division. The graticule is usuallylaid out in an 8-by-10 division pattern. Labeling onthe oscilloscope controls (such as volts/div andsec/div) always refer to major divisions. The tickmarks on the center horizontal and vertical graticulelines as shown in Figure 4.23 are called minor divisions.Many oscilloscopes display on the screen how manyvolts each vertical division represents and howmany seconds each horizontal division represents.

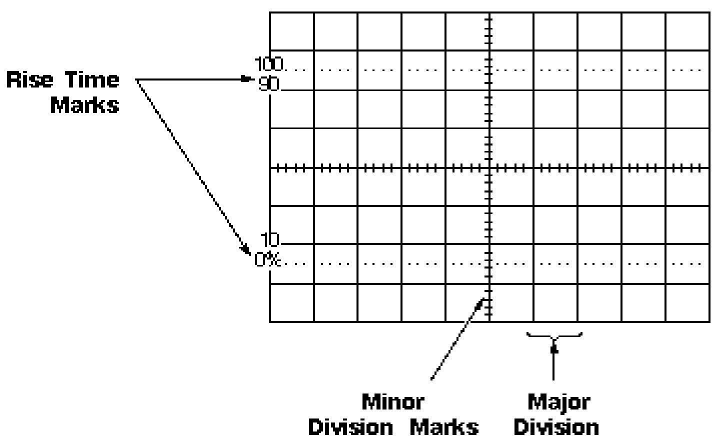


Figure 4.23: An Oscilloscope Graticule

Voltage Measurement

After plugging in the oscilloscope, take a look at thefront panel. It is divided into three main sectionslabeled Vertical, Horizontal, and Trigger (see Figure 4.2). Your oscilloscope may have other sections,depending on the model and type (analogue or digital).Notice the input connectors on your oscilloscope.This is where you attach probes. Most oscilloscopeshave at least two input channels and each channel can display a waveform on the screen. Multiplechannels are important for comparing waveforms.Some oscilloscopes have an AUTOSET or PRESETbutton that sets up the controls in one step to accommodatea signal. If your oscilloscope does not havethis feature, it is helpful to set the controls to standardpositions before taking measurements.Standard positions include the following:

1. Set the oscilloscope to display channel 1;
2. Set the volts/division scale to a mid-range position;
3. Turn off the variable volts/division;
4. Turn off all magnification settings;
5. Set the channel 1 input coupling to DC;
6. Set the trigger mode to auto;
7. Set the trigger source to channel 1;
8. Turn trigger hold/off to minimum or off;
9. Set the intensity control to a nominal viewing level;
10. Ensure that the power button is off before you connect to power supply;
11. When the power is put on allow the scope some five minutes to bring out a horizontal trace;
12. If no trace is seen on the screen, use the vertical and horizontal shifts to locate the trace;
13. Adjust the focus control to get a sharp horizontal trace;

These are general instructions for setting up your oscilloscope. If you are not sure how to do any of these steps, refer to the manual that came with your oscilloscope. **The Controls** section describes the controls in more detail.

As stated earlier under the ‘measurement terms section’, voltage refers to the amount of electric potential, expressedin volts, between two points in a circuit. Usually oneof these points is ground (zero volts) but not always.Voltage measurements are only meaningful if you know what the voltages are supposed to be. That implies that you need a voltage chart for the particular piece of equipment. However, experienced technicians may be able to reason from the circuit diagram what the voltages should be. Voltages can be measured from peak-to-peak –from the maximum point of a signal to its minimumpoint. You must be careful to specify which voltageyou mean.The oscilloscope is primarily a voltage-measuringdevice. Once you have measured the voltage, otherquantities are just a calculation away. For example,Ohm’s law states that voltage between two points ina circuit equals the product of current and resistance.From any two of these quantities, you can calculatethe third using the following formula:

Ohm's Law:

Voltage = Current × Resistance

Current =Voltage/Resistance

Resistance =Voltage/Current

Power Law:

Power = Voltage × Current

Another important formula is the power law: the powerof a DC signal equals the voltage times the current.Calculations are more complicated for AC signals,but the point here is that measuring the voltage is thefirst step toward calculating other quantities.Figure 4.24 shows the voltage of one peak (or $V_{maximum}$) and thepeak-to-peak voltage (Vp-p), which is usually twiceVp. We can use the RMS (root-mean-square) voltage (Vrms)to calculate the power of an AC signal. In Nigeria, the AC supply in our homes is usually 240 ± 10V. This is a Vrms of our electrical supply system which may be different from other countries. Vrms is defined as the amount of voltage that will cause the same heating effect as its DC equivalent. Vrms is therefore one of the most useful values of voltages that electronic students are expected to get use to.Another important value is the average value. Although this book is not on alternating current theories, the following formula provides easy means of conversion between these values:

$$V_{average} = 0.637 \times V_{max} \text{ and } V_{rms} = 0.7071 \times V_{max}$$

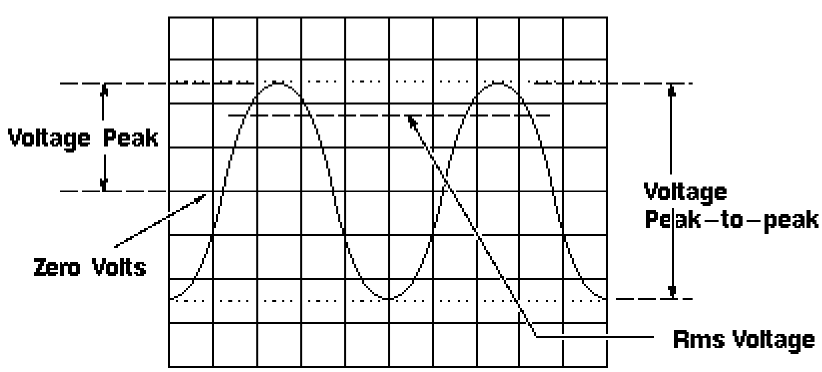


Figure 4.24: Voltage Peak and Peak to Peak Voltage

The most basic method of taking voltage measurementsis to count the number of divisions a waveformspans on the oscilloscope’s vertical scale.Adjust the signal to cover most of the screen vertically, and then take the measurement along thecenter vertical graticule line having the smaller divisionsfor the best voltage measurements (seeFigure 4.25). The more screen area you use, the moreaccurately you can read from the screen.Many oscilloscopes have on-screen cursors that letyou take waveform measurements automatically onscreen,without having to count graticule marks. Acursor is simply a line that you can move across thescreen. Two horizontal cursor lines can be moved upand down to bracket a waveform’s amplitude forvoltage measurements, and two vertical lines moveright and left for time measurements. Thereafter, a readoutshows the voltage or time at the positions of thecursors.

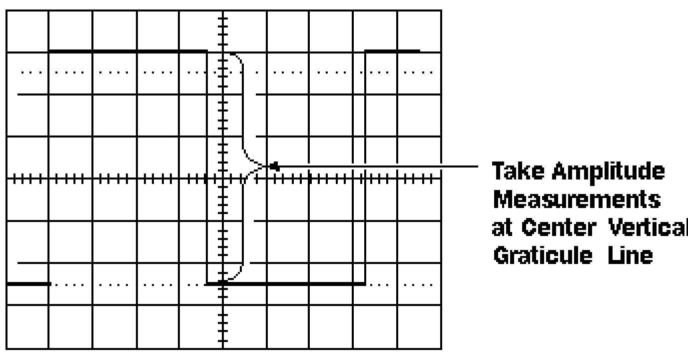


Figure 4.25: Measure Voltage on the Center Vertical Graticule Line

Frequency Measurements

To measure frequency proceed as stated in the above procedure for measuring voltage except item 5 where frequency should be selected instead of voltage. Frequency is the reciprocal of theperiod, so once you know the period, the frequencyis one divided by the period. Like voltage measurements,time measurements are more accurate whenyou adjust the portion of the signal to be measured tocover a large area of the screen. Take time measurementsalong the center horizontal graticule line that ishaving smaller divisions as shown in Figure 4.25.

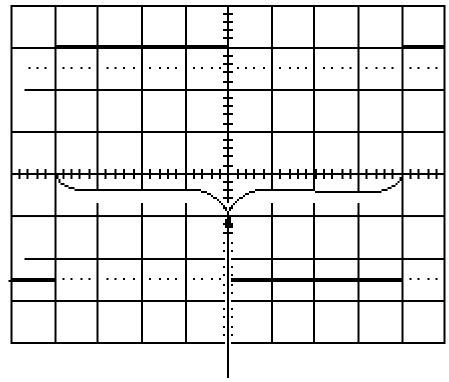


Figure 4.26: Measure Time on the Horizontal Graticule Line

Pulse and Rise Time Measurements

In many applications, the details of a pulse's shapeare important. Pulses can become distorted andcause a digital circuit to malfunction, and the timingof pulses in a pulse train is often significant.Standard pulse measurements are pulse width andpulse rise time. Rise time is the amount of time apulse takes to go from the low to high voltage. Byconvention, the rise time is measured from 10% to90% of the full voltage of the pulse. This eliminatesany irregularities at the pulse's transition corners.This also explains why most oscilloscopes have 10%and 90% markings on their screen. Pulse width isthe amount of time the pulse takes to go from low tohigh and back to low again. By convention, the pulsewidth is measured at 50% of full voltage. See Figure4.27 for these measurement points.Pulse measurements often require fine-tuning thetriggering. To become an expert at capturing pulses,you should learn how to use trigger holdoff and howto set the digitizing oscilloscope to capture pre-triggerdata.Horizontal magnification is another useful feature formeasuring pulses, since it allows you to see finedetails of a fast pulse.

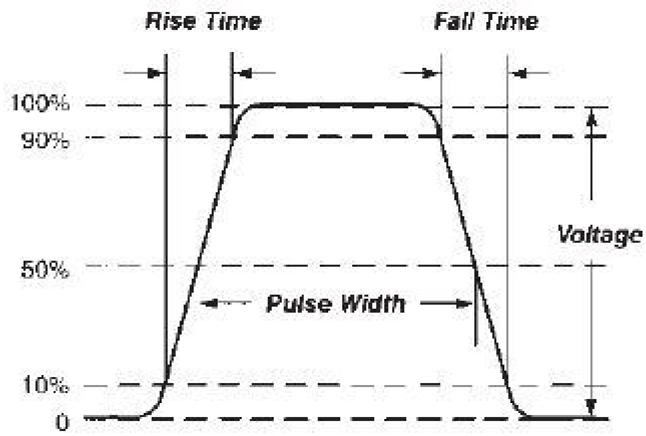


Figure 4.27: Rise Time and Pulse Width Measurement

Phase Shift Measurement

The horizontal control section may have an XYmode that lets you display an input signal ratherthan the time base on the horizontal axis. This modeof operation opens up a whole new area of phaseshiftmeasurement techniques.The phase of a wave is the amount of time thatpasses from the beginning of a cycle to the beginningof the next cycle, measured in degrees. Phase shiftdescribes the difference in timing between twootherwise identical periodic signals.One method for measuring phase shift is to use XYmode. This involves connecting one signal to thevertical system as usual and then another signal tothe horizontal system. (This method only works ifboth signals are sinusoidal). This set up is called anXY measurement because both the X and Y axis aretracing voltages. The waveform resulting from thisarrangement is called a Lissajous pattern (named after aFrench physicist Jules Antoine Lissajous andpronounced LEE-sa-zhoo). From the shape of theLissajous pattern, you can tell the phase difference between the two signals. You can also tell theirfrequency ratio. Figure 4.28 shows Lissajous patternsfor various frequency ratios and phase shifts.The XY measurement mode originated with analogueoscilloscopes. Due to their relatively low sampledensity, DSOs may have difficulty creating real-timeXY displays. Some DSOs create an XY image byaccumulating data points over time, then displayingthe composite. Digital Phosphor Oscilloscopes, onthe other hand, are able to acquire and display agenuine XY mode image in real-time, using a continuousstream of digitized data. DPOs can also displayan XYZ image with intensified areas.

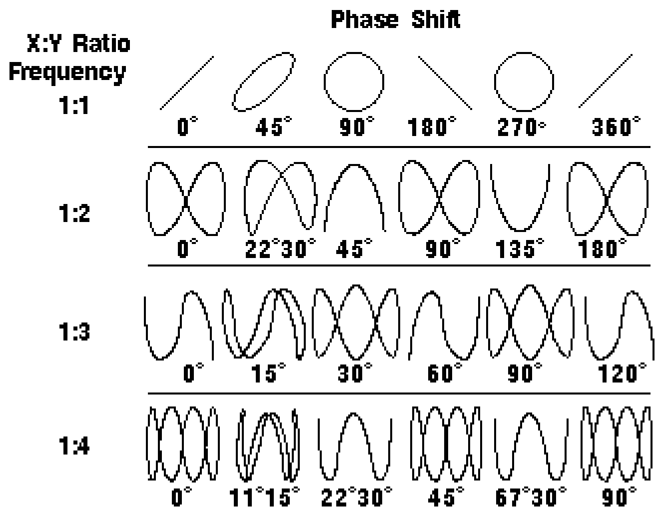


Figure 4.28: Lissajous Pattern

Wave Form Measurement with Digitalizing Oscilloscope

Digitizing oscilloscopes have functions that makewaveform measurements easier. Modern DSOs andDPOs have front-panel buttons or screen-basedmenus from which you can select fully automatedmeasurements. These include amplitude, period,rise/fall time, and much more. Many digitizinginstruments also provide mean and RMS calculations,duty cycle, and other math operations.Automated measurements appear as on-screenalphanumeric readouts. Typically these readings aremore accurate than it's possible to obtain with directgraticule interpretation.

EXERCISES

Figure (a) shows a waveform displayed on the screen of an oscilloscope. Assuming the vertical sensitivity was set at 1.5 Volts per division. Use the information to answer exercises 4.1, 4.2 and 4.3.

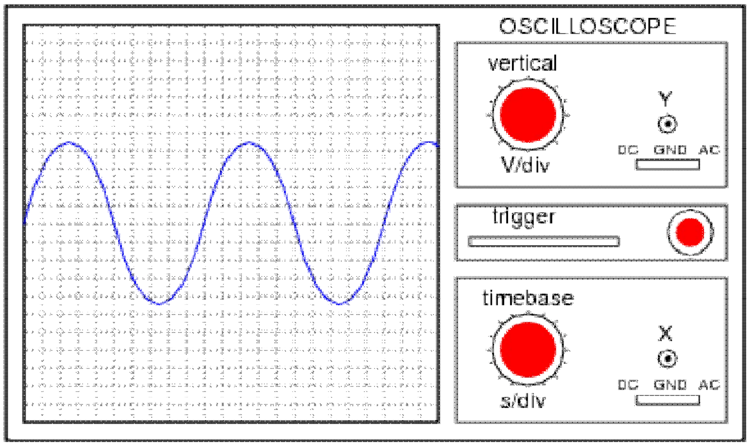


Figure (a) Oscilloscope Screen

Exercise 4.1: The peak value of the signal is:

(a) 6.75 Volts

(b) 4.50 Volts

(c) -6.75 Volts

(d) -4.50 Volts

Exercise 4.2: The peak-to-peak value of the signal is:

(a) 9.0 Volts

(b) -9.0 Volts

(c) 13.5 Volts

(d) -13.5 Volts

Exercise 4.3: The Root Mean Square value of the signal is:

(a) 4.77 Volts

(b) 9.19 Volts

(c) 2.20 Volts

(d) 1.14 Volts

Exercise 4.4: The Cathode Ray Oscilloscope can be used to measure:

(a) Frequency

(b) Voltage

(c) Phase angles

(d) All of the above

Exercise 4.5: The DSO utilizes some additional data processing systems such as……to process signals:

(a) Analogue Digital Converter

(b) Acquisition memory

(c) Display memory

(d) All of the above

Exercise 4.6: The ideal difference between DSO and DPO is the presence of:

(a) Electronic digital phosphor

(b) Analogue Digital Converter

(c) Vertical amplifier

(d) None of the above

Exercise 4.7: Digital oscilloscopes use one of the following sampling methods to capture very fast repeating signals:

(a) Equivalent time sampling

(b) Linear interpolation sampling

(c) Sine interpolation sampling

(d) Real time sampling

Exercise 4.8: Figure (b) shows the display of a signal on oscilloscope screen. Which of the following best represents the properties of the signal?

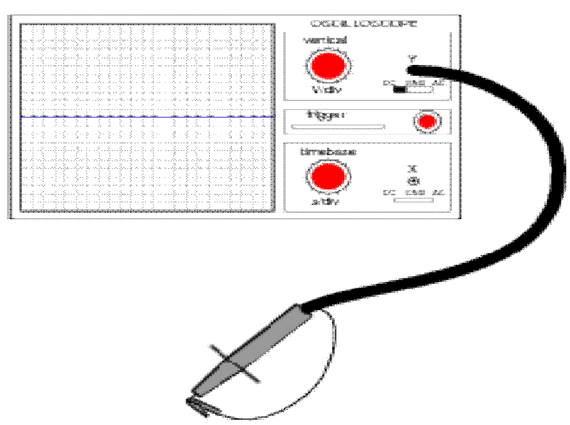


Figure (b): Oscilloscope Screen Showing a Horizontal Line

(a) Rise and fall of a voltage at a steady rate

(b) A constant voltage value

(c) A DC voltage source

(d) A shorted Y-axis

Exercise 4.9: What is the amplitude (Vmax) of the voltage shown in Figure (c) if the Volt/Div control is set at 2 Volts/Div?

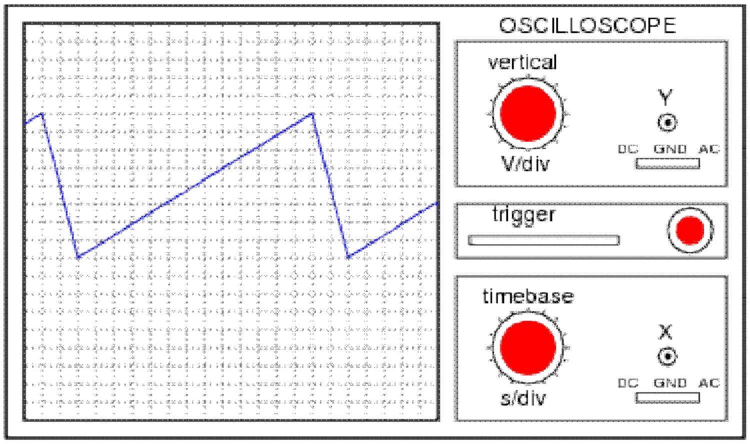


Figure (c): Oscilloscope Screen Showing a Waveform

(a) 8.0 Volts
(b) 4.0 Volts
(c) -4.0 Volts
(d) -8,0 Volts

Exercise 4.10: Figure (d) shows the Lissajous pattern of an XY phase shift measurement. If the XY frequency ratio was 1:1, what is the phase shift angle?

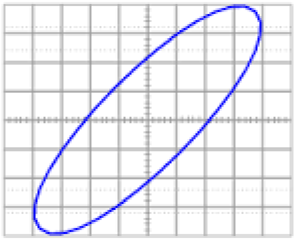


Figure (d): Lissajous Pattern

(a) 0^0
(b) 45^0
(c) 90^0
(d) 180^0

Exercise 4.11: Which control of an oscilloscope needs to be adjusted to get a better signal display than the one presented in Figure (e)?

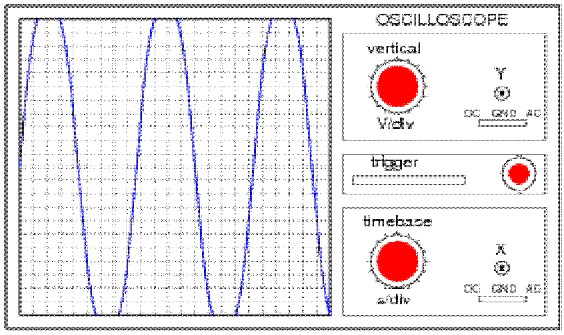


Figure (e): Unwanted Signal Display

(a) Vertical control

(b) Time base control

(c) Both vertical and time base controls

(d) None of the above

Exercise 4.12: Which control of an oscilloscope needs to be adjusted to get a better signal display than the one presented in Figure (f)?

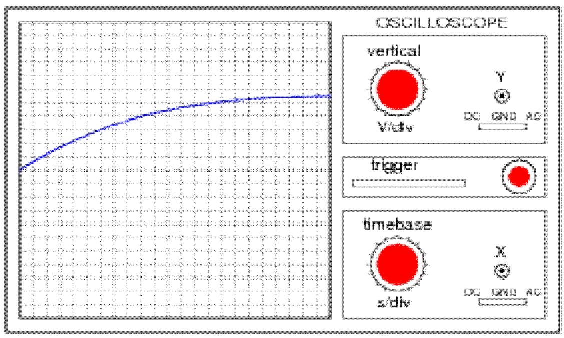


Figure (f): Unwanted Signal Display

(a) Vertical control

(b) Time base control

(c) Both vertical and time base controls

(d) None of the above

Exercise 4.13: Which control of an oscilloscope needs to be adjusted to get a better signal display than the one presented in Figure (g)?

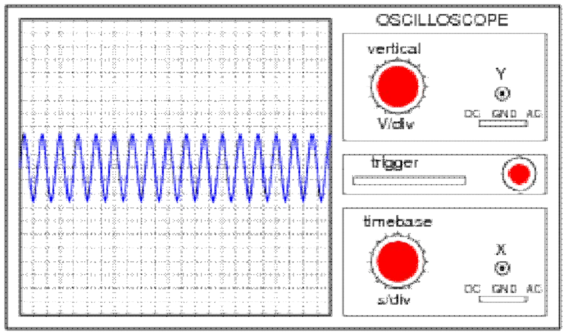


Figure (g): Unwanted Signal Display

(a) Vertical control

(b) Time base control

(c) Both vertical and time base controls

(d) None of the above

Exercise 4.14: The ‘10X’ passive probe is essential in testing circuits that have frequencies above?

(a) 5KHz

(b) 10KHz

(c) 100KHz

(d) 1000KHz

Exercise 3.15: The difference between active and passive probes is that:

(a) Active probes have their own circuits

(b) Passive probes do not need extra power

(c) Active probes can perform certain tests on signals

(d) All of the above

CHAPTER FIVE

SIGNAL GENERATORS

5.1 Features of Signal Generator

A signal generator is an electronic measuring instrument that produces a controlled output in a wave form for use in testing, aligning or measurement of other circuits or electronic systems. Signal generators can be classified into Audio Generators, Pulse Generators, Function Generators, Sweep Frequency Generators, Frequency Synthesizers and RF Generators. Others include Arbitrary Waveform Generators (AWG) that can be used as sources ofstimulussignal for computer buses, digital telecom elements, and many other electronic gadgets and circuits.Like the Oscilloscopes, Signal Generators come in different shapes. They are portable electronic boxes that can be placed comfortably on a test bench even though we still have some hand-held sizes. Generally, the Signal Generator's front panel includes a display screen and the knobs, buttons, switches, and indicators. A typical AWG with many control knobs is shown in Figure 5.1.

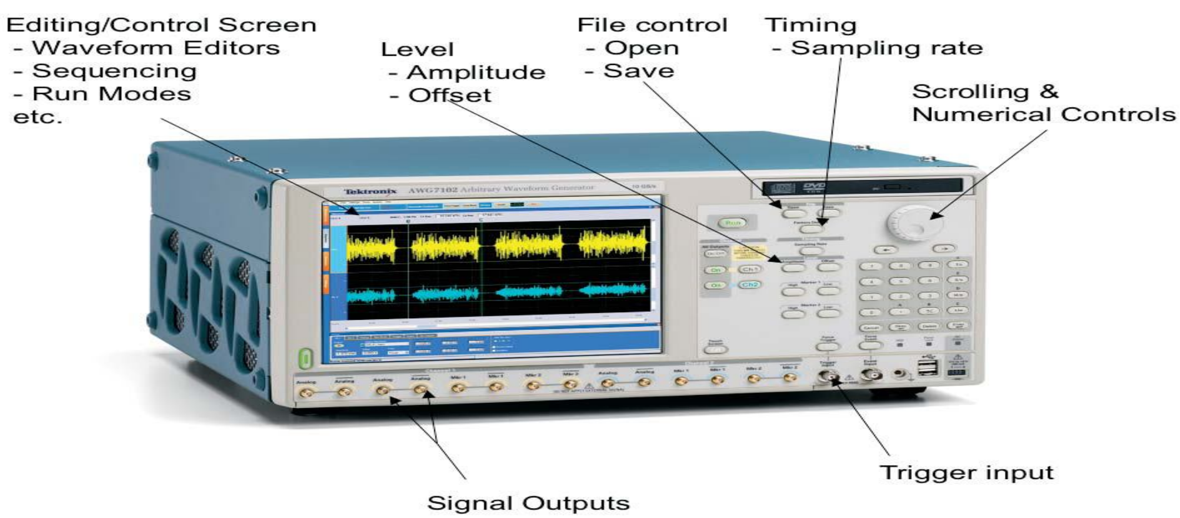


Figure 5.1: Arbitrary Waveform Generator (Tektronix AWG7000)
Source: TEKNOTRONIX-Manual

As shown in Figure 5.1, some of the control knobs on the front panel include the **Level Control,**which is responsible for setting the amplitude andoffset level of the output signal. The **Timing Control** on the other hand sets the frequency of the outputsignal by controlling the sample rate. Here, too, dedicatedhardware-based controls simplify setup of the essentialhorizontal parameters.Note that none of the parameters above control the actualwave shape that the instrument produces. This functionalityresides in menus on the **Editing/Control Screen**. The touchpanel or mouse selects the view of interest, which might offercontrols to define sequences, or digital output settings in thegraphical user interface. After bringingup such a page, you simply fill in the blanks using the numericalkeypad and/or the general-purpose scrolling knobs.Many instruments provide front-panel **Shortcut Buttons** for themost commonly-adjusted functions: setting data values, andsetting timing and amplitude values. These buttons eliminatethe need to go through a series of menus to set the values,saving time.

The **Run/Stop Sequence** button initiates a stored sequence.Assuming certain conditions are in effect, pressing the buttoncauses the pattern data to begin streaming from the mainoutput connectors. Normally the assumed conditions are: atrigger exists (provided by either the **Manual Trigger** button orthe **External Trigger** input); and the output is enabled via the**Output On/Off** button. The Output On/Off button is typicallyused to shut off the output signal when developing a test program,to prevent the data from being sent to a connected circuit under test.

5.2 Principles of Operation of Signal Generator

As stated clearly in section 5.1 on the features of signal generators, there are several types of signal generators, depending on the type of signal produced by such generators. To this end, the present section will dwell on the principles of operations of some of the stated classes of signal generators.

5.2.1 Audio Generators

The audio generators cover the frequency of about 20 Hz to 20 KHz, although few models produce signals up to 100 KHz. Audio frequency generators always produce pure sine waves and most also produce square waves. They use 600 ohms output impedance and produce output levels from -40dB mW to +4dB mW.

Two methods of frequency selections are typically used in audio signal generator, which are the continuous and step selections. On the continuous type dial, we turn a knob to the desired frequency. Many such audio generators have a scale that reads 20 – 200 (or 2 – 20) and a range selector switch determines whether the output frequencies will be 20 – 200 Hz, 200 – 2000 Hz or 2000 – 20,000 Hz. In a step-frequency tuned generator, these controls are replaced by a rotary or push button switch bank. As many as four decode switches might be used, although ‘three’ is a more common number. These will be marked 0 through 100, 0 through 10 and 0.1 through 1.0 in decade steps. A multiplier switch determines whether the actual frequency will be × 1, ×10, ×100, ×1000 the frequency indicated on the selector switch.The audio oscillator selection is usually an RC phase-shift oscillator (or a Wien Bridge Oscillator) circuit. A power amplifier stage provides buffering between the load and the oscillator and it develops the output amplitude as shown in Figure 5.2. The AC voltmeter at the output is strictly optional, but in some models it is used with a level control to set precisely the input signal to the attenuator. Not all quality audio signal generators use this feature. So the lack of an output meter is not, in itself, indication of quality. In some models, an audio digital frequency counter is used ahead of the attenuator to provide digital display of the output frequency.

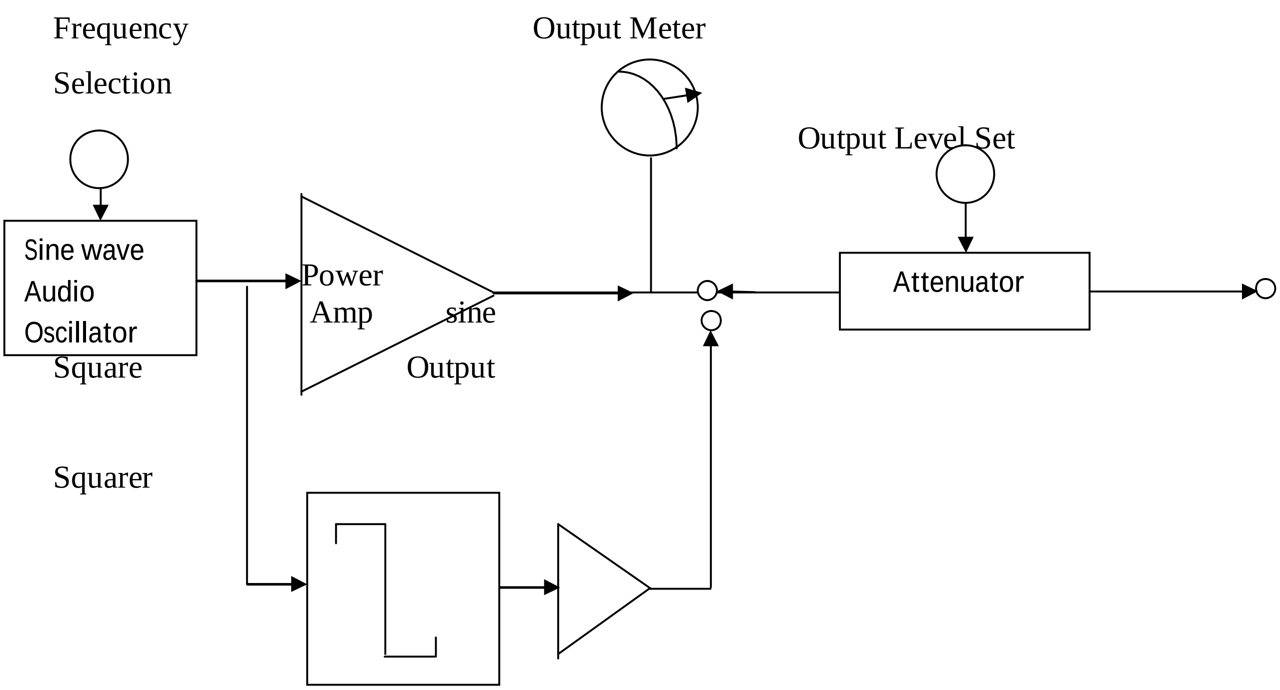


Figure 5.2: Block Diagramme of an Audio Signal Generator

5.2.2 Function Generator

These generators typically, cover at least the same frequency range as audio signal generators (i.e 20Hz to 20KHz) but most modern designs have extended frequency ranges. A very common frequency range for function generator is 0.01Hz to 3MHz. The major difference between a function generator and audio frequency generator is the number of output waveforms. The audio signal generator produces only sine waves and square waves. While, almost all function generators produce these basic waveforms plus triangular waves. Beside this, some function generators also produce saw tooth, pulse and non-symmetrical square waves.

The major parts of a function generator are Schmitt trigger, integrator, sine-wave converter and an attenuator. The Schmitt trigger converts a slowly varying input signal to a square wave signal. This square wave signal is available at the output as well as it is also connected to the integrator as an input through a potentiometer (R) as shown in Figure 5.3. The potentiometer is used to adjust the frequency of the output signal. The frequency range is adjusted by selecting the appropriate capacitor connection in the integrator circuit. The sine wave converter is a six level (or more) diode-resistor loading circuit.

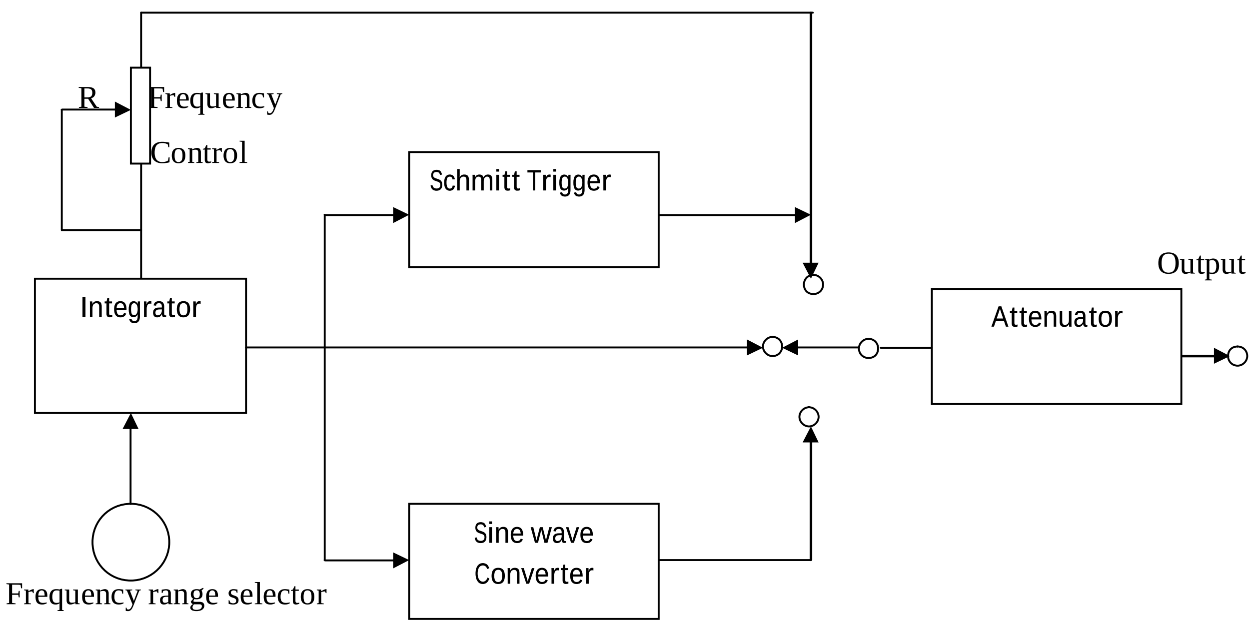


Figure 5.3: Block Diagramme of a Function Generator

5.2.3 Pulse Generator

Figure 5.4 shows the block diagramme of a pulse generator. As seen, an Astable Multivibrator generates square waves. This is used to trigger Monostable Multivibrator (i.e one-shot). The pulse repetition rate is set by the square wave frequency. The one-shot trigger on the leading edge of the square wave produces one output pulse for each input cycle. The duration of each output pulse is set by the on-time of the one-shot. It may be very short or may approach the period of the square wave. The attenuator facilitates output amplitude control and DC level shifting.

A typical pulse generator will allow the user to select the repetition rate, duration, amplitude and number of output pulse to be output in a given burst. The most common frequency range is from 1 Hz to 50MHz. The pulse width is adjustable from 10ns to over 10ms and the output is variable from 3mv to 30v.

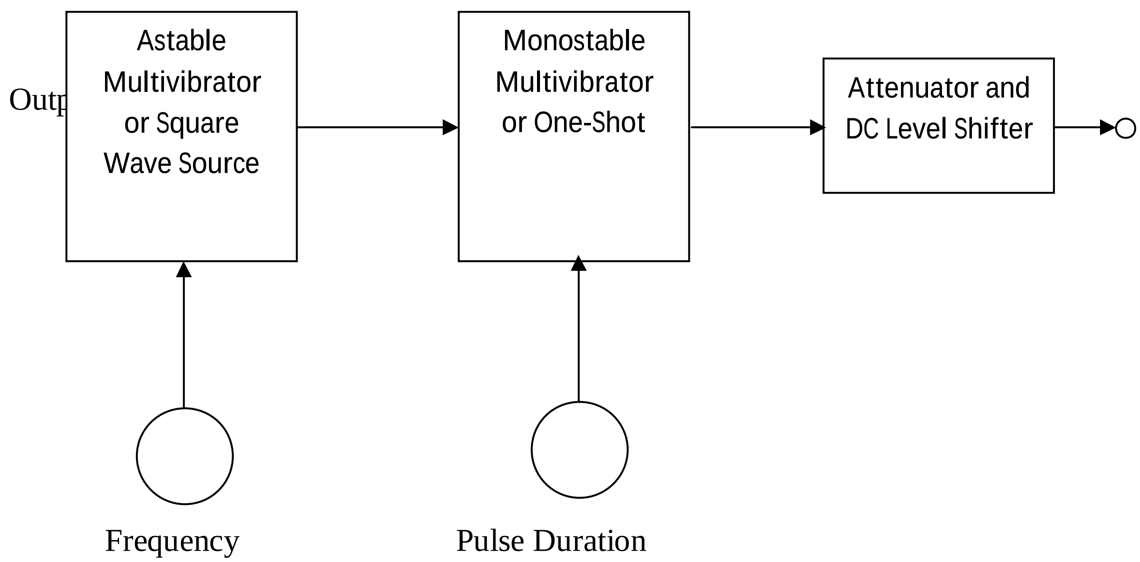


Figure 5.4: Block Diagramme of a Pulse Generator

5.3 Practical Applications of Signal Generators

As discussed earlier in the previous section, signal generators come in many forms, but their core functionality usually incorporates some universal behaviours. They create constantly varying outputs signals. Users can then feed these impulses into circuits to see how they respond in the course of testing, aligning, or troubleshooting of electronic systems. This section of the book therefore, deals with the practical application of signal generators.

5.3.1 Fine Tuning the Stimulus

Most circuits incorporate inductive components like inductors, capacitors, or digital ICs, which perform predetermined logic tasks. The one thing they all have in common is that they typically respond differently to unique or varying inputs. To accommodate such behavioural trends, most function generators are multi-functional units. Users may adjust waveforms amplitude, frequency, duty cycle and other aspects that define the mathematical structure of a given test waveform. Some devices even feature programming functionality or USB inputs so that users can create their own custom waveforms for testing purposes. Other common features include sweep functionality, frequency and phase modulation and PWM (Pulse Width Modulation) outputs. With highly capable devices, users can generally emulate and evaluate the majority of input types that circuits are likely to encounter in the real world.

5.3.2 Using the Signal Generator for Testing

In order to quantify how a circuit responds to a waveform, it is usually necessary to use signal generators in conjunction with oscilloscope, frequency counters, or other measuring devices. Signal generators can be used to inject or substitute signals in electronic circuits. Thereafter, oscilloscopes may be used to read the outputs to detect the trouble. Signal substitution is required in a situation whereby a part of the electronic circuit under test has been electrically removed from its source. For instance, supposing an electronic troubleshooter is working on a radio receiver and suspects that the right signal is not received at the Intermediate Frequency Amplifier (IF Amp) stage. This means that the mixer circuit is faulty due to wrong inputs from either the tuned Radio Frequency Amplifier (RF Amp) or the local oscillator. He can separate these parts of the radio in turn and then use a signal generator to substitute these signals so as to detect the actual problem. Oscilloscopes are most common, as they permit the user to actually see the waveforms before and after they pass through a circuit, but frequency counters and multimeters are also appropriate for those who do not mind doing math.

5.3.3 Making Connections

All signal generators feature output terminals that allow users to send signals to circuits via test leads similar to those found on oscilloscopes. The following can serve as guideline for using signal generators in a circuit:

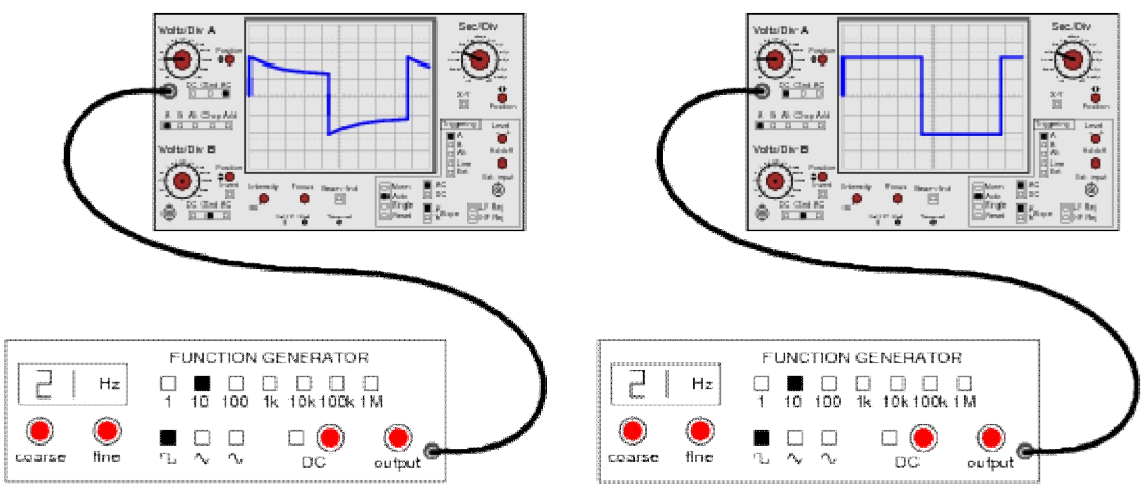
1. Before powering the generator or the circuit, connect the ground and signal leads firmly to the appropriate tie points on the breadboard or circuit board;
2. Use stable connectors, such as grounding screws to reduce the effects of distortion noise and so on;
3. Choose a point on the signal path that meets the requirements of the device being tested. For instance, when evaluating the frequency response of an op-amps analogue-to-digital converter, or similar IC, users often connect to the input pin of the device in question and disconnect its normal input to get a clean signal;
4. Next, connect the oscilloscope. Ideally, testing will be performed with a scope that has a minimum of two independent channels; one should be connected to the input test signal, and the other should be connected into the output of the circuit block being tested;
5. To avoid damaging the oscilloscope, signal generator or circuit, ensure that all the devices are grounded uniformly. Even if it is necessary to make a floating measurement where the circuit is not connected to the earth ground, be certain to avoid shock by connecting the oscilloscope's earth grounding terminal appropriately.

5.3.4 Making Observations

1. After following the above procedure properly, turn on the testing components and the circuit to be tested;
2. Watch the displays on the oscilloscope screen and adjust the graphing aptitude and scale variables using control surfaces on both signal generator and oscilloscope, so that both signals images can be viewed simultaneously;
3. Note the differences in the real-world measurements and compare them to the expected behaviour. (While no electrical device performs ideally, properly designed and constructed circuits should produce recognizable or at least, understandable results);
4. If the output waveform looks different than it should, users can disconnect the oscilloscope leads from the output signal and move it back towards the signal generator source;
5. Along the way, stop at the output of each component in the chain to see how the signal appears there;
6. At some points in this process, users will find a component or block that is not behaving as predicted. They can then rework, redesign or try a replacement;

7. In this fashion, it is possible to drastically simplify complex circuits and behaviours in order to get to the root of any fault in an electronic circuit.

However, it is very important to be warned that in order to use signal generators in conjunction with oscilloscopes as stated repeatedly in this chapter, caution must be observed in selecting the appropriate controls on both instruments for the right signal. For instance, consider the arrangement in Figure 5.5 (a) and (b). A troubleshooter wanted to observe the output of a Function Generator that was set out to produce square waves. Figure 5.5 (a) shows what appeared on the screen of the oscilloscope connected to the output of the Function Generator when the 'Coupling' control of the former was set at 'AC'. Figure 5.5 (b) on the other hand shows the same arrangement but with the oscilloscope's Coupling control set at DC this time around. This shows the significance of using the right settings of the control knobs for the right purpose as emphasized in the previous sections of this book.



(a) (b)

Figure 5.5: The Output of a Function Generator on the Screen of an Oscilloscope

EXERCISES

Exercise 5.1: A signal generator produces different types of waveforms for which of the following purposes?

(a) Testing of circuit components

(b) Adjustment of circuit behavior

(c) Measurement of electronic systems

(d) All of the above

Exercise 5.2: The function of level control in a signal generator is for one of the following

(a) Setting the amplitude and offset levels of the output signal

(b) Setting the frequency of the output signal by controlling the sample rate

(c) Controlling the wave shape of the signal

(d) Adjustment of the function of the output signal

Exercise 5.3: All the following are the specification of Audio Generators except

(a) They cover a frequency range of 0.01Hz to 3MHz

(b) They produce pure sine waves and square waves

(c) They use a 600Ω output impedance

(d) They produce output levels of -40dBmW to 4dBmW

Exercise 5.4: Two methods of frequency selection in Audio Generators are

(a) Continuous and step selection

(b) Automatic and manual selection

(c) Progressive and retrogressive selection

(d) High level and low level selection

Exercise 5.5: Which of the controls of the oscilloscope/function generator shown in Figure (a) needs to be adjusted to get the right waveform on the oscilloscope screen?

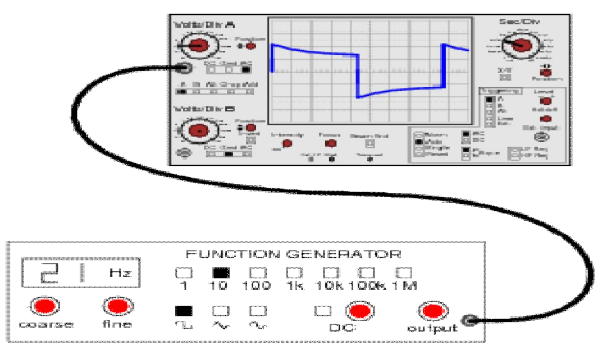


Figure (a): Bad Setting of Instrument Control

(a) Coupling control

(b) Level control

(c) External trigger

(d) Internal trigger

Exercise 5.6: One of the following signal generators produces higher number of different waveforms

(a) Audio generator

(b) Function generator

(c) Pulse generator

(d) Arbitrary Waveform Generator

Exercise 5.7: The part of Function Generator that converts very slowly varying signal to a square wave is

(a) Integrator

(b) Sine wave converter

(c) Schmitt trigger

(d) Attenuator

Exercise 5.8: The part of the Pulse Generator that controls the amplitude of the output signal is

(a) Astable multivibrator

(b) Monostable multivibrator

(c) Attenuator

(d) None of the above

Exercise 5.9: One of the nuts and bolts associated with the use of a signal generator in conjunction with oscilloscopes is

(a) Setting the appropriate control on both instruments

(b) Grounding both instruments appropriately

(c) Having a good idea of the expected output

(d) All of the above

Exercise 5.10: While preparing a signal generator to test a circuit all of the following is correct except

(a) Connect the ground and the signal leads firmly to the right parts

(b) Use stable connectors such as grounding screws to reduce distortion

(c) Off the electrical power source from the mains of the workshop

(d) Choose a point on the signal path that meets the requirements of the circuit being tested

CHAPTER SIX

FREQUENCY COUNTERS

5.1 Features of Frequency Counter

Frequency counter is an electronic device which measures the frequency of an input signal. It also performs some related basic measurements including the periodof the input signal, ratio of the frequency of two input signals, time interval between two eventsand totalizing a specific group of events. Frequency countershave a display panel which shows the measured parameter in numerical or ‘digital’ form. Apart from the display panel, the front of the counter showcases some important switches and knobs similar to those on oscilloscopes and signal generators discussed earlier that are used for adjustments to achieve accuracy and resolution. A typical frequency counter is shown in Figure 6.1.

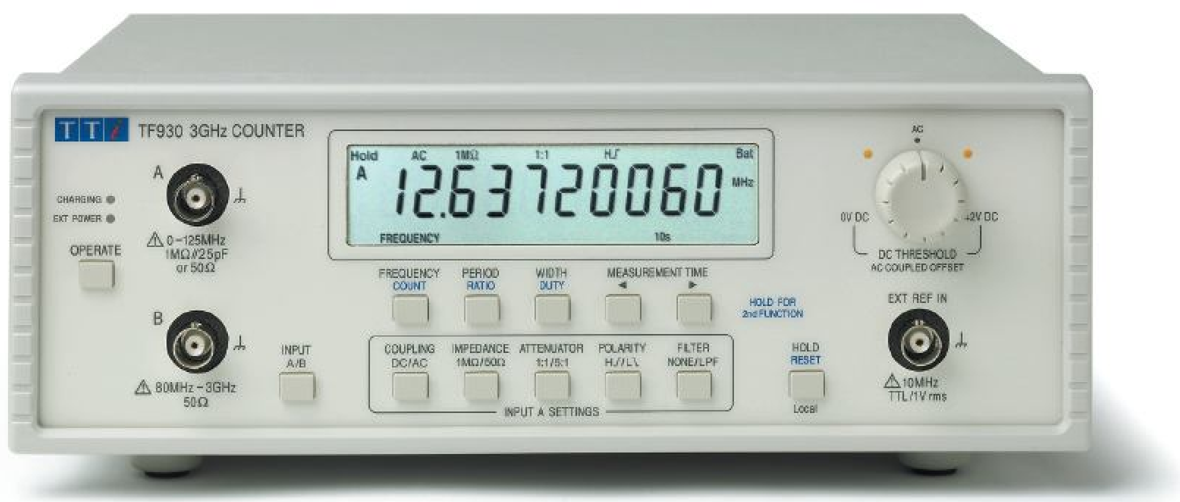


Figure 6.1: TF 930 – 3GHz Bench Type Universal Counter

Source: Thurlby Thandar Instruments

Although the types of switches and other control knobs may differ from model to model, the commonest and most essential among them includes the following:

1. **Operate/Power Switch:** This is usually a push type switch that when pressed turns the power of the counter ‘on’ (the system is allowed to warm up for about 30 minutes before its subjected to any type of measurement functions).
2. **Filter Switch:** With this switch pushed in, the input signal from A or B inputs is routed through a low pass filter with a -3dB point at approximately 100KHz. When the switch is released, the input signal is applied directly to the counter.
3. **Attenuator:**When this switch is pushed in, the counter is set to attenuate the input signal by a multiple of ten (×10) before application. When released, the input signal is applied or processed unattenuated.
4. **Coupling Switch:** This is used to select the input coupling mode, AC or DC.
5. **Input A, B and C:** Depending on the number of inputs allowed, this provision is made for the insertion of the test probes that is used to input the signals, A, B and C. (Some frequency counters have only two input sockets A and B).
6. **Hold Switch:** In the HOLD function (when the HOLD switch is pressed), the display is held but the counter continues to increment. When released, the display is updated and resumes counting.
7. **Frequency Switch:** When the frequency mode is selected, the counter reads the frequency of the input signal. Resolution is selected using the GATE TIME. Readings are in MHz.
8. **Period Switch:** When this switch is pressed, the counter reads the period of the input signal at A, B or C as the case may be.

Other control switches and indicators that may be found on other types of frequency counters include: The **Gate Indicator** which glow to show that the main gate is open and measurement is in progress and the **Unit Indicator** whichshows the unit of the frequency that is displayed, which may be in MHz, KHz, Hz and the period in nano, micro or milli (n/u/m) seconds. Others are the **Function Switch, Gate-Time Switch** and so on. Most of these switches will be discussed in the practical application section of this chapter.

5.2 Principles of Operation of Frequency Counter

With regards to the method of counting of the frequency of the input signal (which is their basic function), frequency counters fall into two basic types, which are: directcounting and reciprocal counting types. Understanding the principles employed in the two different approaches of frequency counting is very important in any discussion that has to do with electronic counters.Direct counters simply count cycles of the signal for aknown period – the gate time. The resulting count is sentdirectly to the counter’s readout for display.This method is simple and inexpensive, but it means thatthe direct counter’s resolution is fixed in Hertz.

Reciprocal counters, in contrast, measure the inputsignal’s period, then reciprocate it to get frequency.Given the measurement architecture involved, theresulting resolution is fixed in the number of digitsdisplayed (not Hertz) for a given gate time. In other words, a reciprocal counter will always displaythe same number of digits of resolution regardless of theinput frequency. Note that you’ll see the resolution of areciprocal counter specified in terms of the number ofdigits for a particular gate time, such as “10 digits persecond.”You can determine whether a counter is direct orreciprocal by looking at the frequency resolutionspecification. If it specifies resolution in Hertz, it’s adirect counter. If it specifies resolution in digits-per-second,it’s a reciprocal counter.

5.2.1 The Principle of Direct Frequency Counting

The frequency, f, of repetitive signals may be defined by the number of cycles of that signal perunit of time. It may be represented by the equation:

$$f = n / t \qquad (1)$$

Where, n is the number of cycles of the repetitive signal that occurs in time interval, t.If t = 1 second, then the frequency is expressed as n cycles per second or n Hertz.As suggested by equation (1), the frequency, f, of a repetitive signal is measured by the conventionalcounter by counting the number of cycles, n, and dividing it by the time interval, t. The block diagram of the direct frequency counter in its frequency mode of measurement is shown in Figure 6.2. The input signal is initially conditioned to a form that is compatible with the internal circuitry ofthe counter. The conditioned signal appearing at the door of the main gate is a pulse train whereeach pulse corresponds to one cycle or event of the input signal. With the main gate open, pulsesare allowed to pass through and get totalized by the counting register. The time between theopenings to the closing of the main gate or gate time is controlled by the Time Base. The accuracy of the frequency measurement is dependent on the accuracy inwhich‘t’ is determined. Consequently, most counters employ crystal oscillators with frequenciessuch as 1, 5 or 10 MHz as the basic time base element.

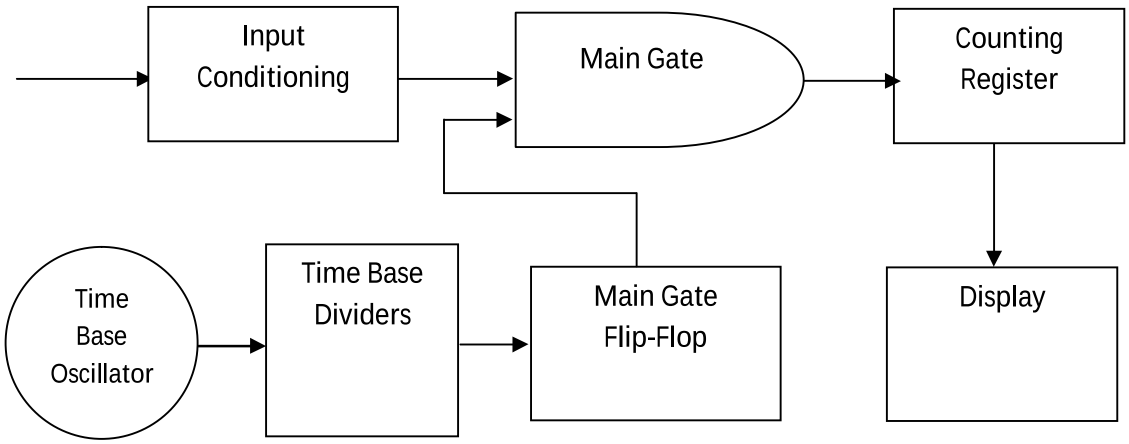


Figure 6.2: Block Diagram of the Direct Type Frequency Counter

The Time Base Divider takes the time base oscillator signal as its input and provides as an output apulse train whose frequency is variable in decade steps made selectable by the Gate Time switch.The time, t, of equation (1) or gate time is determined by the period of the selected pulse trainemanating from the time base dividers. The number of pulses totaled by the counting register forthe selected gate time yields the frequency of the input signal. The frequency counted is displayedon a visual numerical readout. For example, if the number of pulses totaled by the countingregister is 50,000, and the selected gate time is one second, the frequency of the input signal is50,000 Hertz.

5.2.2 The Principle of Reciprocal Frequency Counting

The reciprocal counter is a new class of counter which always makes a period measurement onthe input signal. If frequency information is desired, it can be directly displayed by taking thereciprocal of the period measurement as discussed earlier. The basic block diagram of a reciprocal counter which is shown in Figure 6.3 is essentially similar to the direct frequency counterexcept for the fact that the counting is done in separate registers for time and event counts. Thecontents of these registers are processed and their quotients computed to obtain either the desiredperiod or frequency information which is displayed directly. The Event Counter accumulates counts from the input signal while at the same time; theTime Counter accumulates counts from the internal clock for as long as the main gate is open. In asingle period measurement, the main gate opens for precisely one period under the control of theinput signal. During this time interval, the Event Counter would have accumulated one count whilethe Time Counter would have accumulated a number of clock pulses. The number of accumulatedclock pulses is multiplied by the clock period to give the period of the input signal.

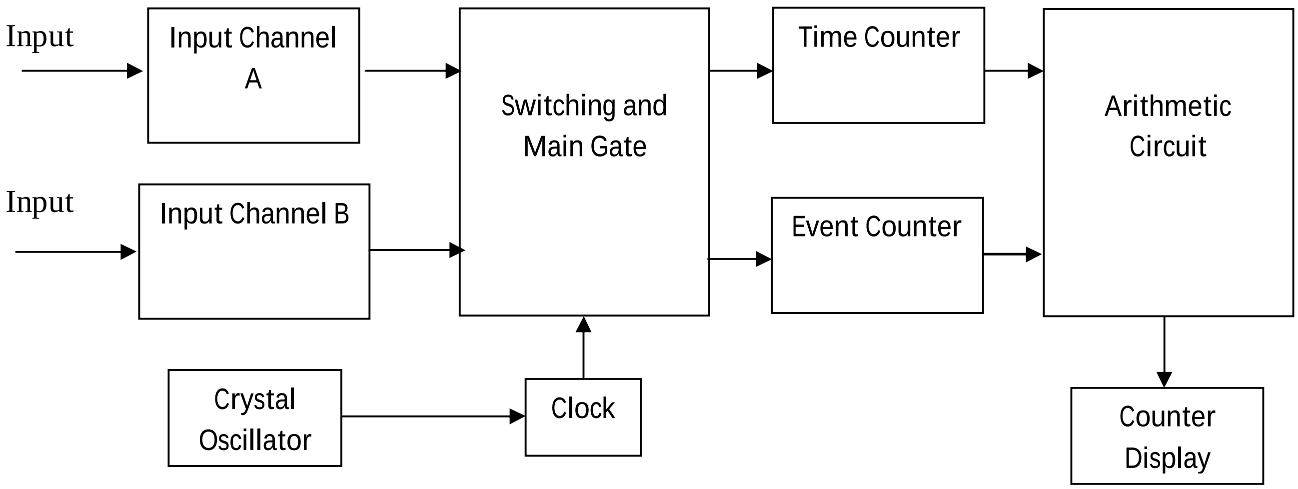


Figure 6.3: The Block Diagramme of a Reciprocal Frequency Counting Method

This computation is done automatically by the arithmetic circuits and the results are displayeddirectly. In period averaging, the main gate is open for more than one cycle of the input signals.The Event and Time Counters accumulate and count pulses from the input signal and the internalclock, respectively, during this time while the gate is open. The quotient of the product of clockperiod and clock count to the event count is the average period of the input signal. In frequencyaveraging, the reciprocal of the quotient is automatically computed and the result is displayed asthe average frequency.

5.3 Practical Applications of Frequency Counter

As mentioned earlier, a frequency counter tests the frequency of a signal. It is used to verify that a circuit is operating correctly by producing the right signal. Forexample, suppose one createsa radio transmitter and the signal from the transmitter is supposed to propagate at say 50,000 cycles per second (50 KHz). With afrequency counter connected to the circuit output of this transmitter, one can verify that the circuit is indeed producing signals at 50 KHz, and not 42 KHz, 100 KHz, or some other frequency.It is also essential for the user of frequency counter to choose the right type for that best meets the needs of specifications of the signal under test.

There are several related products or models of frequency counters that perform a variety of tasks at various frequencies.Universal counters, like the model (TF 930) shown in Figure 6.1, measures frequency and time interval as well as a number of related parameters. It can be called a general purpose counter as the name implies. The RF frequency counters are precisely employed for frequency measurements of up to 3 GHz and beyond. Microwave frequency counters are precisely used for frequency measurements of up to 40 GHzand beyond. Time interval analyzers are optimized for precision time interval measurements. Modulation domain counters are designed to show modulation quantities, such as frequency versus time, phase versus time, and time interval versus time. This is why it is essential to check the specifications of the counter in the users' manual to avoid damages to the devices and the user.

Generally, the following procedure will serve as a guide for using frequency counter to test various parameters of electronic signals:

Setting up the Frequency Counter

To set-up the frequency counter, ready for measurements, proceed as follows:

1. Insert the test probes into the input sockets A, B and C, depending on the available number of signal input provisions on your model;
2. Connect the counter to the AC power supply (remember to strictly adhere to the power and other specifications as stated in the users' manual);
3. Turn on the counter by pushing the 'Power ON/OFF Switch';
4. Allow the system to warm-up for about 30 minutes (the right time is indicated in the operators' manual);
5. Set the 'Function Switch' to the desired operation mode (frequency, period or other available modes);
6. Ensure that the counter is properly earthed to the circuit to be tested using the separate earthing cable provided.

Frequency Measurement

To measure the frequency of the output signal of a typical circuit, proceed as follows:

1. Apply the signal to be measured at input A.
2. Set the 'Function Switch' to 'Frequency Mode' or press in the 'Frequency Switch';

3. Select the resolution using the ‘Gate Time selector’ switch;
4. At this instance, the frequency of the signal is indicated on the display panel in digits. The gate indicator lights on while the measurement is in progress, and the display is updated at the end of each measurement interval;
5. Engaging the ‘Hold Switch’ freezes the display of the existing reading. When HOLD is released, the display is updated and resumes counting;
6. Engage the ‘Attenuator’if necessary. When set to x10 (pushed in), the signal at input A is attenuated by a factor of approximately 10 before it is applied to the counter. This helps prevent miscounting caused by noisy or improperly terminated high amplitude signals.
7. Engage the Low Pass Filter (LPF) if necessary. When this switch is pushed in, the signal at input A is routed through a low pass filter (-3 dB point at approximately 100 KHz) before it is applied to the counter. This helps eliminate counting errors in low frequency measurements by minimizing effects of high frequency noise that may accompany the signal.

Period Measurement

To measure the period of a signal, proceed as follows.

1. Apply the signal to be measured at input A;
2. Set the ‘Function Switch’ to ‘Period Mode’ or press in the ’Period Switch’ if provided;
3. Select the resolution using the GATE TIME selector switch;
4. The period is indicated on the display. The gate indicator comes on while the measurement is in progress;
5. The ATTENUATOR, LPF, and COUPLING switches operate the same as they do in the frequency measurements modes.

Total Measurement

The totalize mode is used to count the total number of events occurring during a specific time period. The maximum frequency is usually 30 MHz. To do this, the following procedure will serve as a guide:

1. Turn the ‘Function Switch’ to select the ‘Total Mode’ or press in the ‘Total Switch’ if available. (Gate and unit settings are ignored);
2. Apply the signal to be measured at input A;

3. The accumulated counts will be displayed on the display panel of the counter. If this is exceeded, the overflow message will be displayed;
4. The ATTENUATOR, LPF, and COUPLING switches operate the same as they do in the frequency measurements modes.

EXERCISES

Exercise 6.1: The purpose of a frequency counter is to provide:

(a) Representation of the frequency of a signal

(b) Accurate measurement of the maximum value of a signal

(c) Direct measurement of the amplitude of a signal

(d) All of the above

Exercise 6.2: A frequency counter counts the number of:

(a) Oscillations of the input signal

(b) Input pulses occurring within a specific period of time

(c) Input resolution of the signal

(d) Root Mean Square value of a signal

Exercise 6.3: The accuracy of the time base of a frequency counter determines

(a) The number of oscillations per second

(b) The amount of variations in the input signal

(c) The accuracy of the frequency counter

(d) None of the above

Exercise 6.4: An alternate method of determining the frequency, other than by direct counting input pulses, that is used by some frequency counters is

(a) Period measurement

(b) Amplitude measurement

(c) Pulse measurement

(d) Sine wave measurement

Exercise 6.5: The advantage of a period-measuring frequency over direct-count type is that

(a) It provides improved resolution of low-frequency signals

(b) It improves speedy means of measurement

(c) It provides the value of frequency in alphabets

(d) It provides the best representation of signal amplitude

Exercise 6.6: The function of the 'Gate-Indicator' is to provide

(a) The indication that the main gate is open

(b) The indication that measurement is in progress

(c) All of the above

(d) None of the above

Exercise 6.7: The unit indicator may show the unit of measurement of frequency in

(a) MHz

(b) KHz

(c) Hz

(d) All of the above

Exercise 6.8: With the aid of a……………circuit a higher frequency than the rating of a frequency counter can be measured

(a) Switching

(b) Pre-scalar

(c) Arithmetic

(d) Clock

Exercise 6.9: In 'period' measurement with a frequency counter, the GATE SWITCH enables one to adjust

(a) The resolution of the counter

(b) The speed of measurement of the counter

(c) The accuracy of the counter

(d) The precision of the counter

Exercise 6.10: The FUNCTION MODE SWITCH enables the operator of a frequency counter to

(a) Select the type of output required

(b) Select the type of input required

(c) Select the rate of data procession of the counter

(d) Select the resolution of the counter

Answers to Exercises

Exercise 1.1 b
Exercise 1.2 a
Exercise 1.3 d
Exercise 1.4 c
Exercise 1.5 a
Exercise 1.6 d
Exercise 1.7 b
Exercise 1.8 c
Exercise 1.9 a
Exercise 1.10 d

Exercise 2.1 d
Exercise 2.2 d
Exercise 2.3 b
Exercise 2.4 a
Exercise 2.5 a
Exercise 2.6 a
Exercise 2.7 d
Exercise 2.8 d
Exercise 2.9 a
Exercise 2.10 a

Exercise 3.1 c
Exercise 3.2 a
Exercise 3.3 d
Exercise 3.4 b
Exercise 3.5 a
Exercise 3.6 b
Exercise 3.7 b
Exercise 3.8 c
Exercise 3.9 c
Exercise 3.10 b

Exercise 4.1 a
Exercise 4.2 c
Exercise 4.3 a
Exercise 4.4 d
Exercise 4.5 d
Exercise 4.6 a
Exercise 4.7 a
Exercise 4.8 d
Exercise 4.9 a
Exercise 4.10 c
Exercise 4.11 a
Exercise 4.12 b
Exercise 4.13 c
Exercise 4.14 a
Exercise 4.15 d

Exercise 5.1 d
Exercise 5.2 a
Exercise 5.3 a
Exercise 5.4 a
Exercise 5.5 a
Exercise 5.6 b
Exercise 5.7 c
Exercise 5.8 c
Exercise 5.9 d
Exercise 5.10 c

Exercise 6.1 a
Exercise 6.2 b
Exercise 6.3 c
Exercise 6.4 a
Exercise 6.5 a
Exercise 6.6 c
Exercise 6.7 d
Exercise 6.8 b
Exercise 6.9 a
Exercise 6.10 a

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