Electronics measurement tools

1 Multimeter or multitester

A multimeter or a multitester, also known as a VOM (Volt-Ohm meter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter would include basic features such as the ability to measure voltage, current, and resistance. Multimeters may use analog or digital circuits—analog multimeters (AMM) and digital multimeters (often abbreviated DMM or DVOM.) Analog instruments are usually based on a microammeter whose pointer moves over a scale calibrated for all the different measurements that can be made. Digital instruments usually display digits, but may display a bar of a length proportional to the quantity being measured. Digital multimeters have all but replaced analog moving coil multimeters in most situations. Analog multimeters are still manufactured but by few manufacturers.

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

1.1 Quantities measured

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

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

Additionally, some multimeters measure:

- Capacitance in farads.
- Decibels
- Frequency in hertz.
- Inductance in henrys.
- Temperature in degrees Celsius or Fahrenheit, with an appropriate temperature test probe, often a thermocouple.
- Continuity tester; sounds when a circuit conducts
- Diodes (measuring forward drop of diode junctions), and transistors (measuring current gain and other parameters)

1.2 Digital multimeters (DMM or DVOM)

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

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

- **Auto-ranging**, which selects the correct range for the quantity under test so that the most significant digits are shown. For example, a four-digit multimeter would automatically select an appropriate range to display 1.234 instead of 0.012, or overloading. Auto-ranging meters usually include a facility to hold the meter to a particular range, because a measurement that causes frequent range changes can be distracting to the user. Other factors being equal, an autoranging meter will have more circuitry than an equivalent non-auto-ranging meter, and so will be more costly, but will be more convenient to use.
- **Auto-polarity** for direct-current readings, shows if the applied voltage is positive (agrees with meter lead labels) or negative (opposite polarity to meter leads).
- **Sample and hold**, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- Current-limited tests for voltage drop across semiconductor junctions While not a replacement for a transistor tester, this facilitates testing diodes and a variety of transistor types.
- **A graphic representation** of the quantity under test, as a bar graph. This makes go/no-go testing easy, and also allows spotting of fast-moving trends.

1.3 Analog multimeters

The meter movement in a moving pointer analog multimeter is practically always a moving-coil galvanometer. In a basic analog multimeter the current to deflect the coil and pointer is drawn from the circuit being measured.

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

1.4 Operation

A multimeter is a combination of a multirange DC voltmeter, multirange AC voltmeter, multirange ammeter, and multirange ohmmeter. An un-amplified analog multimeter combines a meter movement, range resistors and switches.

For an analog meter movement, DC voltage is measured with a series resistor connected between the meter movement and the circuit under test. A set of switches allows greater resistance to be inserted for higher voltage ranges. For analog current ranges, low-resistance shunts are connected in parallel with the meter movement to divert most of the current around the coil.

Moving coil instruments respond only to the average value of the current through them. To measure alternating current, a rectifier diode is inserted in the circuit so that the average value of current is nonzero. Since the rectified average value and the root-mean-square value of a waveform need not be the same, simple rectifier-type circuits may only be accurate for sinusoidal waveforms. Other wave shapes require a different calibration factor to relate RMS and average value. Since practical rectifiers have non-zero voltage drop, accuracy and sensitivity is poor at low values.

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

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

To measure resistance, a small battery within the instrument passes a current through the device under test and the meter coil. Since the current available depends on the state of charge of the battery, a multimeter usually has an adjustment for the ohms scale to zero it.

1.5 Resolution

The resolution of a multimeter is the smallest part of the scale which can be shown. The resolution is scale dependent.

For example, a multimeter that has a 1mV resolution on a 10V scale can show changes in measurements in 1mV increments.

Absolute accuracy is the error of the measurement compared to a perfect measurement. Relative accuracy is the error of the measurement compared to the device used to calibrate the multimeter. Most multimeter datasheets provide relative accuracy.

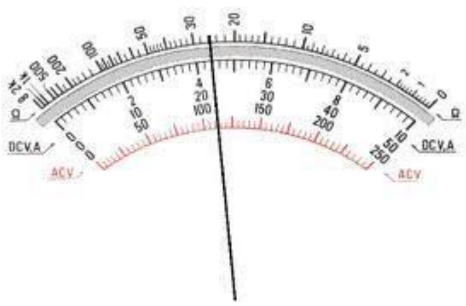
1.5.1 Digital

The resolution of a multimeter is often specified in the number of decimal digits resolved and displayed. If the most significant digit cannot take all values from 0 to 9 is often termed a fractional digit. For example, a multimeter which can read up to 19999 (plus an embedded decimal point) is said to read 4½ digits.

By convention, if the most significant digit can be either 0 or 1, it is termed a half-digit; if it can take higher values without reaching 9 (often 3 or 5), it may be called three-quarters of a digit. A 5½ digit multimeter would display one "half digit" that could only display 0 or 1, followed by five digits taking all values from 0 to 9. Such a meter could show positive or negative values from 0 to 199,999. A 3¾ digit meter can display a quantity from 0 to 3,999 or 5,999, depending on the manufacturer.

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

1.5.2 Analog



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

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

1.6 Accuracy

Digital multimeters generally take measurements with accuracy superior to their analog counterparts. Standard analog multimeters measure with typically ±3% accuracy, though instruments of higher accuracy are made. Standard portable digital multimeters are specified to have an accuracy of typically 0.5% on the DC voltage ranges. Mainstream bench-top multimeters are available with specified accuracy of better than ±0.01%. Laboratory grade instruments can have accuracies of a few parts per million.

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

Test equipment tends to drift out of calibration over time, and the specified accuracy cannot be relied upon indefinitely. For more expensive equipment, manufacturers and third parties provide calibration services so that older equipment may be recalibrated and recertified.

A multimeter can be assumed to be "average responding" to AC waveforms unless stated as being a "True RMS" type. An average responding multimeter will only meet it's specified accuracy on AC volts and amps for purely sinusoidal waveforms. A True RMS responding multimeter on the other hand will meet it's specified accuracy on AC volts and current with any waveform type up to a specified crest factor.

A meters AC voltage and current accuracy may have different specifications for different ranges of frequency.

1.7 Sensitivity and input impedance

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

Meters with electronic amplifiers (all digital multimeters and some analog meters) have a fixed input impedance that is high enough not to disturb most circuits. This is often either one or ten megohms; the standardization of the input resistance allows the use of external high-resistance probes which form a voltage divider with the input resistance to extend voltage range up to tens of thousands of volts. High-end multimeters generally provide an input impedance >10 Gigaohms for ranges less than or equal to 10V. Some high-end multimeters provide >10 Gigaohms of impedance to ranges greater than 10V.

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

Sensitivity should not be confused with resolution of a meter, which is defined as the lowest signal change (voltage, current, resistance...) that can change the observed reading.

For general-purpose digital multimeters, the lowest voltage range is typically several hundred millivolts AC or DC, but the lowest current range may be several hundred microamperes, although instruments with greater current sensitivity are available. Multimeters designed for (mains) "electrical" use instead of general electronics engineering use will typically forego the microamps current ranges.

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

2 Function generator

Function generators are items of test equipment that are able to generate a variety of simple repetitive waveforms. Straightforward signal generators such as RF signal generators or simple audio oscillators focus on producing a good sine waves, but in many cases other waveforms are needed.

In addition to producing sine waves, function generators may typically produce other repetitive waveforms including sawtooth and triangular waveforms, square waves, and pulses. Another feature included on many function generators is the ability to add a DC offset.

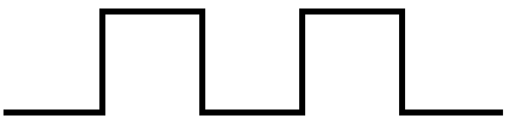
Often some of the low end function generators may only operate up to frequencies of possibly around 100 kHz. However many other more comprehensive function generators are able to operate at much higher frequencies, often up to 10 or 20 MHz.

2.1 Function generator capabilities

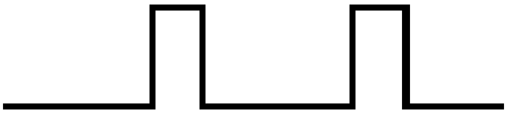
Function generators are capable of producing a variety of repetitive waveforms, generally from the list below:

Sine wave: A function generator will normally have the capability to produce a standard sine wave output. This is the standard waveform that oscillates between two levels with a standard sinusoidal shape.

Square wave: A square wave is normally relatively easy for a function generator to produce. It consists of a signal moving directly between high and low levels.

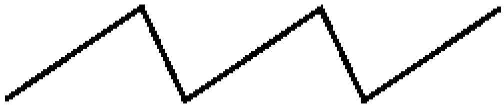


Pulse: A pulse waveform is another type that can be produced by a function generator. It is effectively the same as a square wave, but with the mark space ratio very different to 1:1.



Triangular wave: This form of signal produced by the function generator linearly moves between a high and low point.

Sawtooth wave: Again, this is a triangular waveform, but with the rise edge of the waveform faster or slower than the fall, making a form of shape similar to a sawtooth.



2.2 Function generator controls

In addition to a selection of the basic waveforms that are available, other controls on the function generator may include:

- **Frequency:** As would be expected, this control alters the basic frequency at which the waveform repeats. It is independent of the waveform type.
- **Waveform type:** This enables the different basic waveform types to be selected: Sine wave, Square wave, Triangular wave
- **DC offset:** This alters the average voltage of a signal relative to 0V or ground.
- **Duty cycle:** This control on the function generator changes the ratio of high voltage to low voltage time in a square wave signal, i.e. changing the waveform from a square wave with a 1:1 duty cycle to a pulse waveform, or a triangular waveform with equal rise and fall times to a sawtooth.

2.3 Types of function generator

There are a number of ways of designing function generator circuits. However there are two main approaches that may be used:

Analogue function generator: This type of function generator was the first type to be developed. First models appeared in the early 1950s when digital technology was not widely used. Despite the fact that they use analogue technology, these analogue function generators offer a number of advantages: Cost effective: Analogue function generators are very cost effective, being at the lower end of the function generator price range. Simple to use: Analogue function generators provide an effective test instrument that is able to meet most user needs, while remaining simple and easy to use. Maximum frequencies: The analogue function generators do not have the high frequency limitations on nonsinusoidal waveforms such as triangles and ramps as do the digital function generators.

Digital function generator: As the name indicates, digital function generators utilise digital technology to generate the waveforms. There are a number of ways in which this can be done, but the most versatile and most widely used technique for digital function generators is to use direct digital synthesis, DDS.

DDS uses a phase accumulator, a look-up table containing a digital representation of the waveform, and a DAC. The phase accumulator moves another position each time it receives a clock pulse. The next position in the look-up table is then accessed giving the digital value for the waveform at that point. This digital value is then converted into an analogue value using a digital to analogue converter, DAC.

Digital function generators are able to offer high levels of accuracy and stability because the clock for the system is crystal controlled. Also digital function generators provide a high spectral purity and low phase noise. A DDS based digital function generator can also can be swept over a much wider frequency range than an analogue function generator. It can also perform a number of other functions such as phase continuous frequency hopping because of the action of the direct digital synthesizer.

The disadvantage of the digital function generators is that they are more comprehensive than their analogue cousins, they require a high performance DAC and other digital circuitry and this means they are more costly and also more complicated

2.4 Arbitrary Waveform Generator, AWG

Arbitrary waveforms generators are a form of function or signal generator that is able to produce an arbitrary waveform defined by a set of values, i.e. "waypoints" entered to set the value of the waveform at different times.

As a result an arbitrary waveform generator is a form of test equipment that is able to produce virtually any waveshape that is required. An arbitrary waveform generator may also run in either a repetitive or a single shot mode.

Arbitrary waveform generators are very similar to function generators, but offer much greater levels of flexibility in terms of waveform generation and they are generally more sophisticated and hence costly.

Arbitrary waveform generators operate by storing the points of a waveform in digital format, and then recalling them to generate the waveform. These points can be on any form of repetitive waveform that is required. The rate at which the DDS completes one waveform governs the frequency.

2.5 Arbitrary waveform generator resolution and speed

Two of the main specifications for an arbitrary waveform generator are their resolution and also the speed. These two parameters determine the precision with which the waveform can be reproduced. They are governed by different elements within the arbitrary waveform generator circuit.

The amplitude resolution is governed by the resolution of the digital to analogue converter. This is described in terms of the number of bits. A 12 bit resolution provides 4096 amplitude steps.

The speed of the arbitrary waveform generator is also very important. The maximum repetition rate for the waveform is governed by two factors: the length of the waveform in terms of the number of samples required to simulate the waveform and the maximum clock frequency. For example if the arbitrary waveform generator had a maximum clock frequency of 25 MHz and the waveform had 1000 points, then the maximum repetition rate would be 25 kHz. If a higher repetition rate was required, then it would be necessary to decrease the number of samples as it would not be possible to increase the clock frequency in the arbitrary waveform generator!

3 RF Signal generator

Radio frequency signal generators (RF signal generators) are a particularly useful item of test equipment widely used in RF microwave design and test applications.

These microwave and RF signal generators come in a variety of forms and with a host of facilities and capabilities.

In order to gain the most from any RF signal generator or microwave signal generator, it is necessary to have an understanding of its operation and the capabilities it possesses.

3.1 Types of RF signal generator

Today, digital technology is used to develop synthesized radio frequency (RF) signal generators: Virtually all radio frequency signal generators used today employ frequency synthesizers. Using this technique enables frequencies to be entered directly from a keypad, or via remote control and it also enables the output signal to be determined very accurately. The accuracy being dependent upon either an internal reference oscillator that can have a very high degree of accuracy, or the signal can be locked to an external frequency reference which can be exceedingly accurate.

There are two main techniques that are used within synthesized RF signal generators:

1. **Phase locked loop synthesizer:** Phase locked loop synthesizers are used within most RF signal generators as they enable signals to be generated over a wide range of frequencies with

a relatively low level of spurious signals. Phase locked loop synthesizer technology is well developed and enables high performance RF signal generators to be produced using them.

2. **Direct Digital Synthesizer, DDS:** Direct digital synthesis techniques may be used in RF signal generators. They enable very fine frequency increments to be achieved relatively easily. However the maximum limit of a DDS is normally much lower than the top frequencies required for the signal generator, so they are used in conjunction with phase locked loops to give the required frequency range

3.2 RF signal generator functions

Microwave and RF signal generators are able to offer a large variety of functions and facilities these days. These include some that are detailed below:

- **Frequency range:** Naturally the frequency range of the RF signal generator is of paramount importance. It must be able to cover all the frequencies that are likely to need to be generated. For example when testing a receiver in an item of equipment, be it a mobile phone or any other radio receiver, it is necessary to be able to check not only the operating frequency, but other frequencies where the issues such as image rejection, etc.
- **Output level:** The output range for an RF and microwave signal generator is normally controlled to a relatively high degree of accuracy. The output within the generator itself is maintained at a constant level and then passed through a high grade variable attenuator.

  These are normally switch to give the highest degree of accuracy. The range is normally limited at the top end by the final amplifier in the RF signal generator.
- **Modulation:** Some RF or microwave signal generators have inbuilt oscillators that can apply modulation to the output signal. Others also have the ability to apply modulation from an external source. With modulation formats for applications such as mobile communications becoming more complicated, so the capabilities of RF signal generators have had to become more flexible, some allowing complex modulation formats such as QPSK, QAM and the like. Signal generators that support complex modulation are often referred to as vector signal generators.
- **Sweep:** On some RF signal generators it is necessary to sweep the signal over a range. Some generators offer this capability.
- **Control:** There are many options for controlling RF and microwave signal generators these days. While they tend to have traditional front panel controls, there are also many options for remote control. Most items of laboratory bench test equipment come with GPIB fitted as standard, but options such as RS-232, and Ethernet / LXI. Rack technologies where instrument cards are slotted into a rack with other items of test equipment are also popular. The first of these was VXI, but cheaper options such as PXI and PXI express are more widely used.

Radio frequency signal generators are a form of electronic test equipment found in virtually every radio frequency design or test laboratory. These signal generators are used wherever an RF signal needs to be supplied to a circuit or unit that is being developed or tested. As such RF signal generators are essential items for RF development and testing.

3.3 RF signal generator specifications

When choosing the correct RF signal generator to purchase, either new or as a used signal generator or possibly to hire from a test equipment rental company is not always easy. A knowledge of RF signal generator specifications is needed to be able to make the right choice for any given application.

RF signal generators are an essential item of test equipment for any RF design or test laboratory. They enable RF signals to be generated that enable signals to be fed into RF circuits so that their operation can be viewed when operating under various signal conditions.

There are a number of important specifications associated with any RF signal generator. While some are fairly common to all applications, it is necessary to ensure that all the requirements for the signal generator are captured and noted. However a list of some of the more common RF signal generator parameters are listed below:

A) Frequency range

One of the obvious key specifications for any radio frequency signal generator is the frequency range that it covers. When choosing the band required for a signal generator it is necessary to consider all the testing that will be needed. The frequency coverage required for the signal generator may not be just that of the unit under test. For example, when testing radio receivers it is necessary to test their susceptibility to out of band signals at image and other frequencies. These may be will outside the operating frequency range of the unit under test, and the signal generator will need to accommodate these and any other requirements.

B) Harmonics and spurious signals

All signal generators produce some level of spurious signals. Harmonics are generally much higher as considerable effort is spent in reducing intermodulation and other non-harmonically related spurious signals.

C) Signal generator power output

Another important signal generator specification is its power output. For most RF signal generators, the power output specification is defined in dBm, i.e. dB relative to one milliwatt.

Although different signal generators have different output levels, the most common maximum output level is +13 dBm, although whatever the exact maximum level is, it is normally in the range 10 to 100 milliwatts, i.e. 10 to 20 dBm.

D) Phase noise

One items that has to be noted on many signal generators these days is the level of phase noise that is produced. The importance arises because many signal generators are fall into the category of a synthesized signal generator. While a synthesized signal generator offers many advantages from exact frequency selection to stability, and high levels of programmability, the issue of phase noise can be a problem in some generators, and the phase noise spec needs to be carefully considered.

3.4 Accuracy - short and long term

The accuracy of an signal generator is often important. With most RF signal generators using frequency synthesizers, this means that the frequency accuracy is determined by the frequency standard used within the generator. Frequency standards have their accuracy defined with a number of different specifications and these have to be combined in the correct manner to give the overall "accuracy". All accuracy measurements are specified in terms of parts per million (PPM).

However there are elements including temperature stability, line voltage stability, ageing (i.e. the steady drift with time over many months of the crystal within the reference standard, etc. These need to be added statistically to gain the overall "accuracy" for the radio frequency signal generator.

3.5 Modulation formats supported

In order that many tests can be undertaken by the signal generator, it is necessary in many instances that the signal can be modulated. In this way real signals can be more fully simulated and the required tests undertaken. Most signal generators have the ability to modulate signals in a variety of ways, some providing greater levels of flexibility than others. As a result it is necessary to check the signal generator specifications to ensure that it has the required capabilities.

Originally many signal generators had the capability to have amplitude modulation, AM , and frequency modulation, FM applied. However with radio and wireless systems using far more advanced forms of modulation, many signal generators have very comprehensive modulation capabilities. Some of these may be provided by the use of additional options. Today a variety of modulation formats may be available in a signal generator. These may include: various forms of phase shift keying, PSK (including BPSK, QPSK, 8PSK, etc) as well as other more complicated modulation formats including quadrature amplitude modulation, QAM (including 16 and 64 point QAM) need to be used. Other modulation types including CDMA and OFDM may also be available. It is necessary to ensure that the radio frequency signal generator being considered is able to offer the required modulation formats.

3.6 Test equipment calibration interval

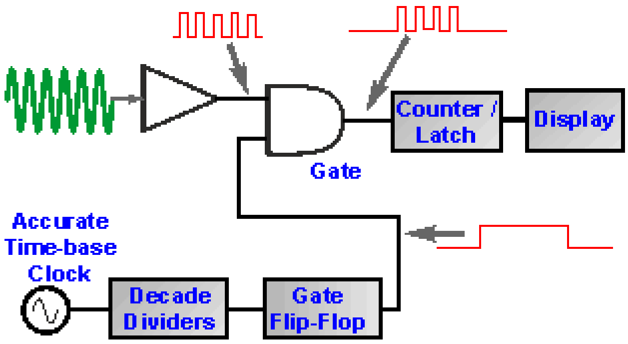
The calibration interval for any item of test equipment is important, and this is the case for any signal generator, whether it is new or a used signal generator. Test equipment calibration can add a significant amount to the cost of ownership, so it is necessary to consider the calibration interval. For many signal generators the interval will be a year, but if higher degrees of accuracy of any of the signal generator specifications are needed, then shorter time intervals may be needed.

4 Frequency counter

A frequency counter is an electronic instrument, or component of one, that is used for measuring frequency. Frequency is defined as the number of events of a particular sort occurring in a set period of time. Frequency counters usually measure the number of oscillations or pulses per second in a repetitive electronic signal.

4.1 Operating principle

Most frequency counters work by using a counter which accumulates the number of events (which produces an internal oscillator) occurring within a specific period of time. After a preset period (1 second, for example), the value in the counter is transferred to a display and the counter is reset to zero. The internal oscillator which provides the time signals is called the timebase, and must be calibrated very accurately.



4.2 Frequency Counter Specifications

Like any other item of test equipment, it is necessary to specify the performance of the frequency counter, so that prospective users can match it to their requirements.

As with any item to test equipment, the specifications of the frequency need to be fully understood to enable their performance to be correctly judged to ensure they will be able to under take the measurements that they will need to make.

Many of the frequency counter specifications are easily understood, but still have some finer points that need to be kept in mind when making any decisions. Other frequency counter specifications are specific to the type of test equipment and are not always so easily understood.

A) Frequency counter frequency range specification

One of the first frequency counter specifications is the input frequency range. This is the range over the input amplifier is specified. Often the input will be selectable coupled between AC and DC. When this is the case, both must be specified separately as they will be different.

The AC coupling is useful when it may be necessary to measure signals that have a DC component on them.

B) Input impedance specification

Like other instruments, frequency counters have a specification for their input impedance. This is the impedance of the signal input to the counter. There are two forms of frequency counter specification for the input:

- **Standard input specification:** Most frequency counters have a high input impedance. This is specified in terms of a resistance and the capacitance that is in parallel with it. Typically this might be 1MΩ / 20pF, i.e. 1 MΩ resistance and 20pF capacitance. This form of input is normally used for frequencies up to 10 to 30 MHz or so.
- **RF / microwave input specification:** Inputs used for frequencies above 30 MHz or so, especially those intended particularly for RF or microwave measurement applications only often have a matched input. This is typically 50 Ω. These are used with matched impedance systems. When using these inputs, care must be taken not to apply signals that are too large otherwise the terminating resistor may blow.

C) Sensitivity specification

The sensitivity specification for the frequency counter defines the lowest signal amplitude that he counter will count. If there is a trigger level setting, it assumes that this will have been set for a value equal to the midpoint of the input signal.

The sensitivity specification is actually a measure of the level of hysteresis in the input comparator. As this may vary with frequency, the sensitivity specification may be split into two or more frequency ranges.

To look at how this frequency counter specification is derived it is necessary to look at the input and triggering of the frequency counter.

The input consists of an amplifier followed by a Schmitt trigger circuit. The signal, shown as a sine wave, enters the circuit and triggers, typically on the positive going edge causing the Schmitt trigger to change state.

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The input consists of an amplifier followed by a Schmitt trigger circuit. The signal, shown as a sine wave, enters the circuit and triggers, typically on the positive going edge causing the Schmitt trigger to change state. Then at a point on the negative going edge, the Schmitt trigger will change state again. There is a difference between the two called the hysteresis which prevents small levels of noise from spuriously triggering the counter.

D) Signal operating range

This specification, sometimes called the dynamic range refers to the input voltage operating range for the frequency counter.

The input stages of the frequency counter or timer will only be able operate correctly up to a certain voltage. Beyond this distortion and overload issues will arise.

Issues associated with overload may include miscounting or timing inaccuracies. Often (but not always) these will be gross inaccuracies so the problem may quickly become obvious.

E) Frequency counter time base specification

One of the key elements of any frequency counter or counter timer is the accuracy of the measurements made.

The accuracy of the measurements are fundamentally governed by the accuracy of the oscillator used for the timebase.

There are three main types of time base or clock oscillator that are generally used for frequency counters and time interval counter-timers:

- **Crystal oscillator:** A basic or room temperature crystal oscillator will only be used in the budget frequency counters and counter timers. Although very accurate by some standards, they are often not sufficiently accurate for laboratory measurements.
- **Temperature compensated crystal oscillator, TCXO:** This form of crystal oscillator has compensation for any temperature variations.
- **Oven controlled crystal oscillator, OCXO:** The OCXO oscillator is contained within a small insulated box and its temperature is accurately maintained to ensure that the crystal resonant frequency remains as constant as possible.

Although sometimes there are forms of oscillator, these are the most widely used.

These are some of the main frequency counter specifications used to defined the performance of a particular test instrument. The resolution and accuracy parameters are addressed on the following page as they are interlinked and require a more involved treatment.

4.3 Frequency counter accuracy and resolution

Frequency counters are widely used for the accurate measurement of frequency of radio frequency, RF, signals, or for that matter the frequency of any repetitive electronic signal.

Frequency counters are widely available for comparatively low prices and within an electronic repair or development laboratory a wide variety may be available. Accordingly it is necessary to choose the best counter for a given applications.

The accuracy and resolution of frequency counters are two important elements of the overall specification. The resolution and accuracy are two completely different aspects of the performance of the frequency counter although they are often equated with each other.

In order to be able to interpret the readings of a frequency counter, it is necessary to have an understanding of the difference between accuracy and resolution.

The resolution of a frequency counter is its ability to differentiate between two signals that are close to each other. It is a measure of the number of digits in the reading of the signal frequency.

Most frequency counters are what are termed direct reading counters, and the resolution is determined by the gate time. This is the time for which the counter is counting the number of pulses or transition crossings.

As the number of crossings in a second is equal to the frequency, a one second gate time will enable frequencies to be read down to a resolution on 1 Hz. It can be seen that for other gate times, a 0.1 second gate time will allow a resolution of 10 Hz to be achieved, whereas a 10 second gate time will enable a resolution of 0.1 Hz to be achieved.

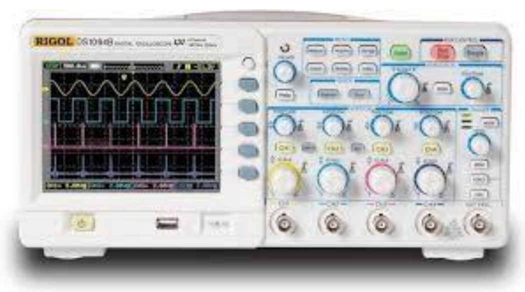
Thus it can be seen that for a direct reading frequency counter, the resolution is a function of the gate time.

The accuracy of a frequency counter is a little more difficult to determine as it is a function of a number of factors. There are several categories of measurement error that can occur some of which affect the counter timer when making different types of measurement.

5 Oscilloscope

The oscilloscope or scope must be one of the most widely used and famous test instruments. The oscilloscope is a type of test equipment that allows signal voltages to be display on a screen in a two dimensional format. In this way it is possible to see waveforms on the screen and understand how a circuit is performing.

The basic concept of the oscilloscope is that it displays waveforms in a two dimensional format. The vertical axis is normally used to plot the incoming voltage, and the horizontal axis is normally used as a time axis. In this way the waveform voltage can be displayed as a function of time. In this way a sine wave would be displayed in its well known graphical format with a line undulating line with time on the horizontal axis. This is the most common way of using an oscilloscope.



While it is useful to display a single waveform, many measurements and measurement techniques require more than on waveform to be displayed at any one time. This can be used to compare waveforms and look at how different waveforms interact or when events occur on more than one waveform. Many dual channel or multi-channel oscilloscopes exist that allow two or more waveforms to be displayed at the same time.

The oscilloscope is a particularly useful item of test equipment that can be used for testing and faultfinding a variety of electronics circuits from logic circuits through analogue circuits to radio circuits. It is necessary to know how to use an oscilloscope properly to be able to make the best use of it. By knowing the basics of using an oscilloscope it is possible to fault find circuits more effectively and more swiftly as well as gaining a better understanding of how they the circuits work.

Although oscilloscopes are more expensive than some other items of test equipment including multimeters, they are often found in the homes and workshops of electronics enthusiasts. As a result it is important that people are aware of how to use an oscilloscope.

5.1 Basic oscilloscope controls

In view of the flexibility and level of control required to use an oscilloscope, there are a large number of controls that are present. These need to be set correctly if the required view of the signal is to be obtained.

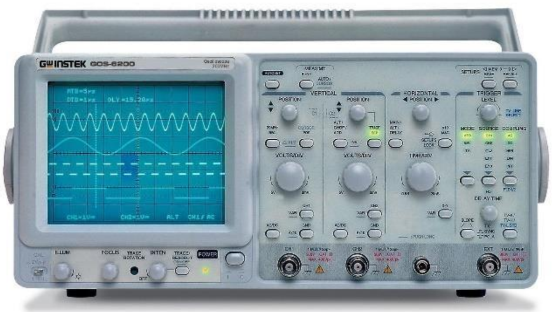
Fortunately it is quite easy to get used to operating an oscilloscope and using the controls to be able to view the waveform correctly.

A summary of the main controls on an oscilloscope is given below:

Nevertheless, a short overview of some of the controls is given below:

- **Vertical gain:** This control on the oscilloscope alters the gain of the amplifier that controls the size of the signal in the vertical axis. It is generally calibrated in terms of a certain number of volts per centimetre. Therefore by setting the vertical gain switch so that a lower number of volts per centimetre is selected, then the vertical gain is increased and the amplitude of the visible waveform on the screen is increased. When using the oscilloscope, the vertical gain is normally set so that the waveform fills the vertical plane as best as possible, i.e. as large as possible without going outside the visible or calibrated area.
- **Vertical position:** This control on the oscilloscope governs the position of trace when no signal is present. It is normally set to a convenient line on the graticule so that measurements above and below the "zero" position can be measured easily. It also has an equivalent horizontal position control that sets the horizontal position. Again this one should be set to a convenient position for making any timing measurements.

- **Timebase:** The timebase control sets the speed at which the screen is scanned. It is calibrated in terms of a certain a certain time for each centimetre calibration on the screen. From this the period of a waveform can be calculated. This if a full cycle of a waveform too 10 microseconds to complete, this means that its period is 10 microseconds, and the frequency is the reciprocal of the time period, i.e. 1 / 10 microseconds = 100 kHz. Normally the timebase is adjusted so that the waveform or a particular point on the waveform under investigation can be seen at its best.



- **Trigger:** The trigger control on the oscilloscope sets the point at which the scan on the waveform starts. On analogue oscilloscopes, only when a certain voltage level had been reached by the waveform would the scan start. This would enable the scan on the waveform to start at the same time on each cycle, enabling a steady waveform to be displayed. By altering the trigger voltage, the scan can be made to start at a different point on the waveform. It is also possible to choose whether to trigger the oscilloscope on a positive, or a negative going part of the waveform. This may be provided by a separate switch marked with + and - signs.
- **Trigger hold-off:** This is another important control associated with the trigger function. Known as the "hold-off" function it adds a delay to the trigger to prevent it triggering too soon after the completion of the previous scan. This function is sometimes required because there are several points on a waveform on which the oscilloscope can trigger. By adjusting the holdoff function a stable display can be achieved.
- **Beam finder:** Some oscilloscopes possess a beam finder function. This can be particularly useful as it is possible that sometimes the trace may not be visible. Pressing the beam finder button enables the beam to be found and adjusted so that it is in the centre of the screen.

Although there are many other controls, these are the main ones to understand when learning how to use an oscilloscope. Nevertheless it is very useful to understand the other controls on an oscilloscope, but some will vary from one type to another.

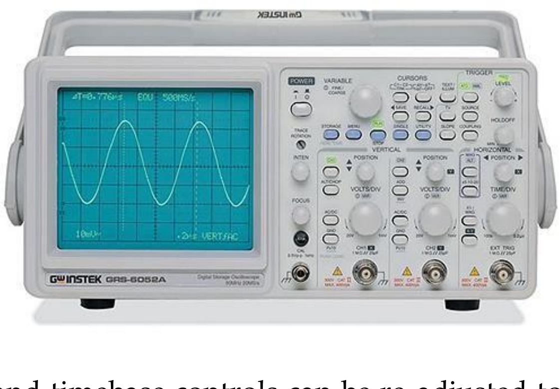
5.2 Operating an oscilloscope

Like any other piece of complicated test equipment, an oscilloscope can take a few minutes to get used to if one has not been used before. However once familiar with it, the controls soon become second nature and it becomes very easy to use.

It is obviously necessary to turn the oscilloscope power on, and then once it is running it may be necessary to adjust the intensity of the trace so that it is easily visible - often oscilloscopes will free run when no signal is present. If the oscilloscope does not free run, then no trace will be seen yet.

Then the next control to set is the vertical gain control. Set is so that the anticipated waveform will fill a reasonable amount of the screen. Leave some margin so that if it is bigger than expected, it will not go wildly off the screen.

Next set the timebase of the oscilloscope. This is often set so that a period of the waveform will fill most of the horizontal axis of the screen. If it is initially set to this then it can be adjusted to suit later.



Connect the signal to be viewed. The oscilloscope will posses a connector for the input - this is normally a BNC connector. In most cases where a connection to a circuit board is required, a scope probe will be used, so that they are easy to connect to pins or connection points on the board.

With the signal now present it is necessary to adjust the trigger control to gain a stable trace of the signal.

With a trace of the signal now visible, the vertical gain and timebase controls can be re-adjusted to produce the best picture of the signal.

Although these instructions do not give an exhaustive description of how to use an oscilloscope, the exact number of controls and operation will depend upon the particular scope in use. However they should enable the scope to be used in a basic but reasonable manner.

Oscilloscopes are widely used for test and repair of electronics equipment of all types. However it is necessary to have a method of connecting the input of the oscilloscope to the point on the equipment under test that needs monitoring.

To connect the scope to the point to be monitored it is necessary to use screened cable to prevent any pick-up of unwanted signals and in addition to this the inputs to most oscilloscopes use coaxial BNC connectors. While it is possible to use an odd length of coax cable with a BNC connector on one end and open wires with crocodile / alligator clips on the other, this is not ideal and purpose made oscilloscope probes provide a far more satisfactory solution.

5.3 Oscilloscope Types

An oscilloscope is one of the major tools available for testing electronic circuitry. The oscilloscope is able to display waveforms and as a result it gives a particularly useful view of what is happening in an electronic circuit. While the basic philosophy behind all oscilloscopes is the same, there are a number of different variants that are available, each possessing slightly different capabilities and being suited for a given application or set of applications.

Oscilloscopes fall into a variety of categories. The biggest distinction is whether they are analogue or digital, but within the digital oscilloscope arena there are ordinary digital oscilloscopes, digital storage oscilloscopes, digital phosphor oscilloscopes, and digital sampling oscilloscopes.

A) Analogue oscilloscope

Although analogue oscilloscopes are now deemed to be old technology, they are still used in a number of areas.

Older analog scopes may be all that is available, especially as a result of cost restrictions, or for other reasons.

However, these older analogue instruments are still able to provide a good account of themselves and they should not be ignored. Often they may be put to one side in a stock of laboratory equipment.

However they can still be used to good effect in many situations, some people preferring to sue them against more advanced digital scopes.

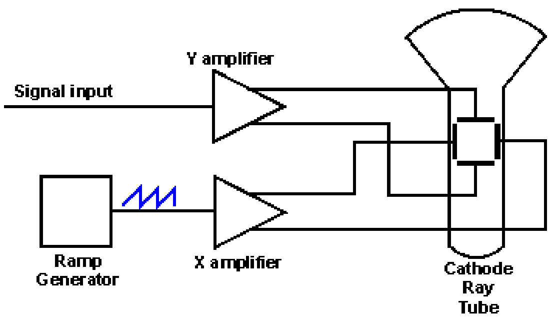
The analogue oscilloscope of the original type of oscilloscope. As the name implies it uses analogue techniques throughout to create the pattern on the display. Typically they use a cathode ray tube where the voltages on the x and y plats cause a dot on the screen to move. In the horizontal direction this is controlled by the time base, whereas in the vertical direction the deflection is proportional to the signal input. Essentially the signal is amplified and applied to the Y plates of the cathode ray tube using analogue technology.

The key to the operation of an analog scope is its display. It uses the cathode ray tube or CRT. This form of display was for many years the only viable form of display that could be used to display images. Accordingly it was used in television sets for many years, although other forms of display including LCDs, LEDs and many other format are now used, but these all require digital signal inputs to the display.

A cathode ray tube consists of a number of elements. There is an electron gun that generates an electron beam that is fired along the length of the tube. This beam passes by deflection plates that are used to deflect the beam, as a result of electrostatic attraction and repulsion, and finally the beam hits a phosphor coating on the "screen" creating a small dot of light.

The analogue scope uses the cathode ray tube to display signals in both X (horizontal) and Y (vertical) axes. Typically the Y axis is the instantaneous value of the incoming voltage and the X axis is ramp waveform.

As the ramp waveform increases in voltage so the trace moves across the screen in a horizontal direction. When it reaches the end of the screen, the waveform returns to zero and the trace moves back to the beginning.

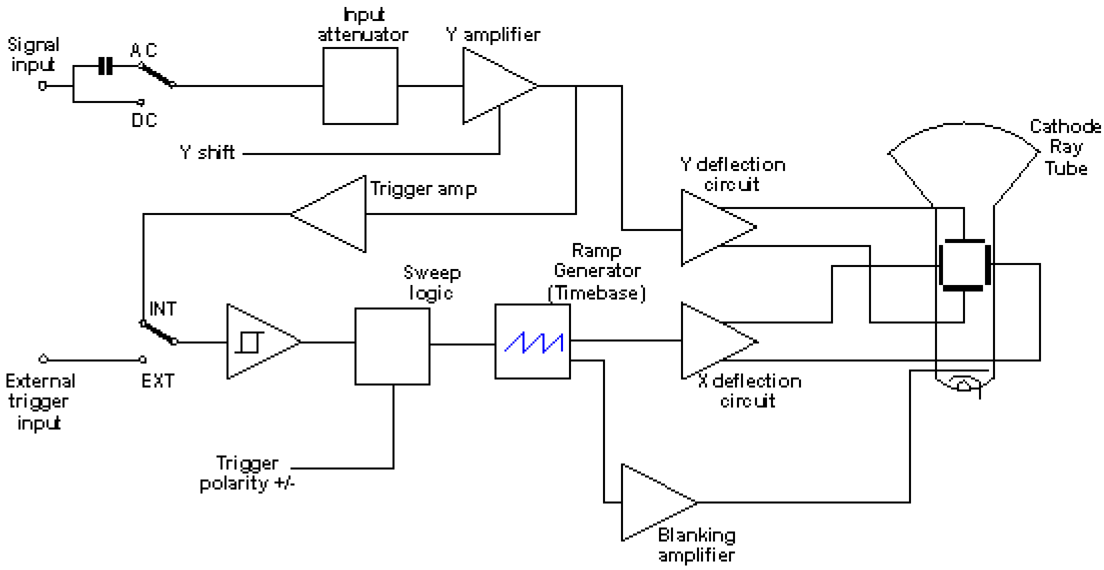


Basic analogue oscilloscope block diagram Using this approach it can be seen that as the X axis corresponds to time, and the Y axis to amplitude. In this way the familiar plots of waveforms can be displayed on the cathode ray tube.

The cathode ray tubes use electrostatic deflection to cause the electron beam position and hence the trace position to change. This method rather than the electromagnetic deflection system used in many CRT based television sets is used to ensure that a sufficiently high speed of operation is attained. The magnetic deflection used in televisions does not enable the very high speeds needed for oscilloscopes to be achieved.

Trigger capability In order to ensure that a steady waveform is displayed on the display, it is necessary to set the ramp waveform to start at the same point on each cycle of the incoming signal to be monitored. In this way the same point on the waveform will be displayed at the same position on the display.

To achieve this the trigger circuit is used to start the ramp. The trigger picks off the signal from the incoming signal and when a particular voltage level is reached, it starts the ramp. This trigger point is adjustable on most oscilloscopes.



Blanking amplifier A form of blanking is required to ensure that when the ramp or time-base circuit flies back to restart the trace again, it does not cause any illumination on the screen. In order to prevent this happening, a blanking amplifier is used to blank the screen during this fly-back phase. It simply takes the reset element of the ramp to generate a pulse that is applied to the grid of the cathode ray tube. This inhibits the electron flow and effectively blanks the screen for this period.

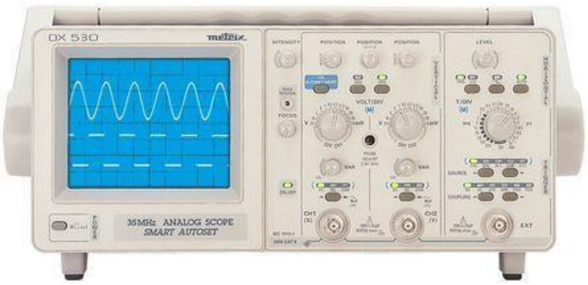
Analogue scope controls To assist in making the trace as clear as possible, intensity and focus controls are included. The focus ensures that the dot that scans the screen remains as sharp as possible and in this way it can deliver a clear trace. The intensity control is required because the intensity of the dot or trace varies according to the speed at which the scan is made. Controlling the intensity enables a clear trace to be obtained.

When the scan is very slow the dot is seen to traverse the screen and it is difficult to visualize the waveform. As the speed increases, it ceases to be seen as a dot, but instead it traces out a line and the signal waveform, which when triggered correctly remains static on the screen. The trace may be scanned across the screen many times a second. In many instances it my traverse the screen 100 000, 500 000 or more times a second.

However as the writing speed increases, the trace becomes steadily more dim, and ultimately becomes difficult to see despite the intensity control. For higher frequency signals faster writing speeds are required, and as a result analogue oscilloscopes have a limited frequency range. Typically the maximum frequency that can be seen by an analogue oscilloscope is around 1 GHz. Above this other types of oscilloscope are required.

B) Digital oscilloscopes

The concept behind the digital oscilloscope is somewhat different to an analogue scope. Rather than processing the signals in an analogue fashion, this type of scope converts the signal into a digital format using an analogue to digital converter and then processes the signals digitally. With digital signal processing hardware and software becoming more powerful, this enables the processing of the signals to be undertaken in a far more flexible manner, and enables many additional features to be included within the scope. Updates and additional functionality can then be made by simply upgrading the software or firmware within the scope



There are several different types of digital oscilloscope that can be encountered. With many manufacturers trying to gain an edge on their competitors, new names tend to be developed to try to bring over the new levels of functionality and features.

Digital oscilloscope / Digital Storage Oscilloscope, DSO : The boundary between these two types of oscilloscopes has become very indistinct in recent years. Originally te storage scopes, DSO had additional memory to enable the storage of waveforms. Now most scopes have memory incorporated as standard, the only difference being the size. As a result, both names are often used to describe the same instrument, and therefore they are now virtually synonymous. The digital scope or digital storage scope is now the basic type of oscilloscope used, containing all the basic functions expected these days.

The basic concept behind digital oscilloscopes / DSOs is the conversion of the incoming analogue signal into a digital format where it can be processed using digital signal processing techniques.

When the signal enters the scope it is first pre-conditioned by some analogue circuits to ensure that the optimum signal is presented to the next stage.

This next stage involves the acquisition of the digital samples. To achieve this, an analog-to-digital converter, ADC, takes samples are discrete regular time intervals.

Digital oscilloscope sampling The times and rate at which samples are taken is determined by the system clock. The rate at which samples are taken is often defined as part of the specification of the scope. This is measured in samples per second, and often quoted in Mega samples per second M samples per second.

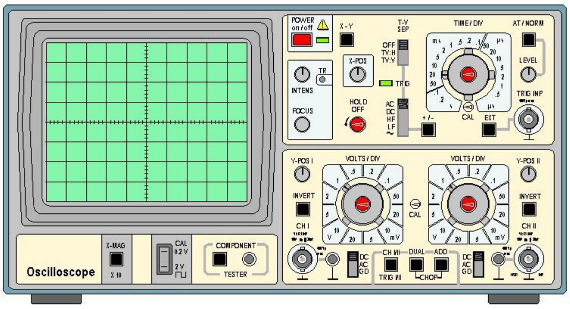
The samples from the ADC are stored in memory and referred to as waveform points and together these points make up the overall waveform record. The number of waveform points within the record is referred to as the waveform length.

The waveform record is initiated by the trigger and again stopped by the timebase circuit after the given amount of time.

The waveform record is then processed by the processing circuitry and presented to the display for visual inspection by the user.

5.4 PC USB Oscilloscope Tutorial

USB oscilloscopes using the power of a PC, personal computer, have become a very popular way of buying a relatively high performance oscilloscope for a low cost.



The PC USB scope utilises the processing power, display and often gains power from the PC. In this way it is able to utilise widespread low cost items to perform many of the functions of the scope, and considerably reduce the cost for a given level of performance.

Why USB for digital scopes: It is possible for scopes using personal computers, PCs, to use a variety of methods to link to PCs. However in recent years USB has become standard on virtually all computers and as a result it does not require the use of an additional card like a Firewire card, etc to use one of these oscilloscopes.

Using USB means that it is possible to use a scope using the PC processing power on virtually any PC.

The other advantage is that having a digital USB scope design enables the advantages and cost savings of quantity can be made. Fewer variants are required for different interfaces, and therefore it is possible to focus on optimising the design for USB.

One of the key elements of the PC oscilloscope is naturally the USB link. This provides a convenient and sufficiently high speed data link by which the USB scope and computer can communicate.

The USB or Universal Serial Bus Interface is a well-established interface for computer communications. Combining speed and simplicity, this robust interface is available on most computers and is used for connecting many peripherals from cameras and mobile phones to test instruments and many other items to computers.

Although the oscilloscopes from different manufacturers will differ, and USB scopes providing different levels of functionality will naturally be different, there are some common aspects of these scopes that can be outlined.

The PC USB scope architecture, as would be expected, has many similarities to that of a standard digital oscilloscope. It is just that a portion of the functionality is contained within the PC.

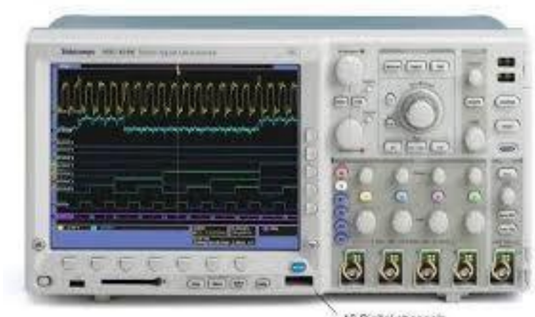
When the signals enter the scope they enter an analogue section where they are pre-conditioned by amplifying them, attenuating them or adding a DC offset as required. This ensures that the signals are within the required range for the further stages.

The next stage is where the signals are converted into a digital format by analogue-to-digital converters. The sample logic circuitry controls the sampling process and the subsequent storage of the data in a memory area called the capture memory.

Like other digital scopes, the USB versions also include triggers which control the start and end of the samples. Additionally internal controller sets signal gain levels and offset, as well as controlling the sample logic, selecting trigger source, trigger level, and trigger polarity, and communicating with the PC.

5.5 Oscilloscope Specifications

Oscilloscopes are one of the most versatile items of test equipment. Oscilloscopes provide a graphical view of the waveforms within a circuit and this gives a particularly useful view of what is happening within a circuit. This makes them an essential item of test equipment for use within electronics design, production test and also for use within service organizations.



Oscilloscopes are relatively complicated items of test equipment. As a result they are more expensive than items such as digital multimeters and this means that choosing the correct oscilloscope is important.

In order to choose the right scope for purchase new or as used test equipment, or to obtain as test equipment rental, it is necessary to understand the specifications used. As oscilloscopes are fairly complicated, the oscilloscope specifications can also be fairly involved. These can normally be obtained either from the manufacturer, the used test equipment supplier, of the test equipment rental company. Once obtained they can be viewed and it can be relatively easy to shed some light on them so that the oscilloscope specifications can be understood.

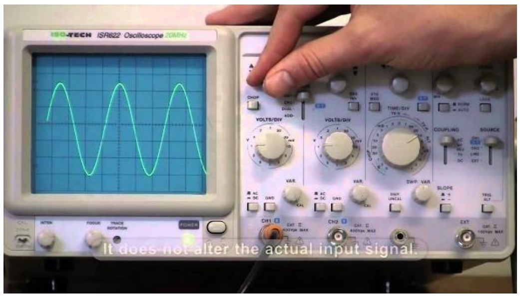
When evaluating an oscilloscope for purchase, either new or as used test equipment or for use as test equipment rental it is necessary to ensure that the unit is suitable for the given application. Often banner specifications are used as promotional material to give a brief overview of the oscilloscope. While these top level specifications are useful in determining the broad level of performance, it is essential to look beyond them to those specifications that are deeper in the literature and give a more exact indication of the performance of the scope and its actual usefulness.

Bandwidth specification One important oscilloscope specification is related to the speed of the waveforms that can be measured. This is determined by the bandwidth of the oscilloscope and it is found that the capability of the oscilloscope to accurately display the waveform falls off with increasing frequency. The way in which this is specified can be seen in IEEE 1057 which defines electrical bandwidth as the point at which the amplitude of a sine wave input is reduced by 3 dB (i.e. attenuated to 70.7% of the true value of the signal - a fall of approximately 30%) relative to its level at a lower reference frequency.

The oscilloscope specification for bandwidth will typically be quoted in the format: Bandwidth = 3dB at 1500 MHz. If the oscilloscope specification for the -3dB point is not sufficiently high it will be found that the edges of pulses and square waves will be slowed as a result of the reduction of the high frequency components.

In order to ensure that the oscilloscope specification is adequate it is necessary to ensure that the bandwidth of the scope is higher than the operating frequency. Often a Five Times Rule is used as a rule of thumb. Here the bandwidth of the oscilloscope should be five times the highest frequency component in the signal. Using this rule, the error due to the frequency limitations will be less than □ 2%.

Vertical DC gain accuracy It is important when measuring the amplitude of signals, to know the accuracy of the measurement that is being made. As oscilloscopes are not intended to be used instead of digital multimeters, it is not anticipated that the voltage elements of the oscilloscope specification will be as accurate.



Vertical DC gain resolution Today, many oscilloscope use all digital techniques, converting the incoming vertical or X axis voltage to a digital format. It is therefore important to know what the resolution of this scale is. Resolution and dynamic range determine, respectively, the "granularity" of measurements and the largest measurement that can be made without clipping the waveform. Most digital oscilloscopes have 8-bit resolution. Eight bits provides 256 digitizing levels (2 to the 8th power) over the dynamic range.

Checking the resolution within the oscilloscope specification will ensure that the instrument will offer the correct dynamic range and resolution.

Rise time specification Another important oscilloscope specification which needs to be accommodated is the rise time of the oscilloscope. This is a particularly important specification for any digital circuits where the edges on square waves and pulses are often of great importance. The oscilloscope must have a sufficiently fast rise time to capture the rapid transitions accurately, otherwise important information may not be displayed and the results could be misleading.

Although the bandwidth of the scope must be sufficiently high, the rise time is also important. It can be seen as being akin to the slew rate on operational amplifiers where the rate of voltage change is the limiting factor. As a result the rise time of the scope must be sufficiently high to capture the required detail.

In order to be able to capture the detail sufficiently a similar equation to that used for the bandwidth calculations is used:

$$\text{Fastest signal rise time} \geq \text{Oscilloscope rise time} \times 5$$

This equation is only a guideline and enables signals to be viewed as accurately as required. Although in some instances where very fast rise times are required this may not be feasible.

Oscilloscope sample rate With the proportion of digital oscilloscopes rising, the sample rate oscilloscope specification is becoming a more widespread and important specification. The sample rate is specified in samples per second (S/s). The faster the oscilloscope samples the waveform, the greater the resolution of the detail on the waveform and with greater sample rates the less the likelihood that any critical information will be lost. While the maximum sample rate tends to be the headline rate, the minimum sample rate may also be important. This is occurs when looking at slowly changing signals over longer periods of time. It is also important to note that the displayed sample rate changes with changes made to the horizontal scale control. This is to maintain a constant number of waveform points in the displayed waveform display.

For most applications it is necessary to define the minimum number of samples that are required and this should be used when looking at the overall oscilloscope specification. The oscilloscope takes in the waveform from the voltage input and then digitizes it, after which it is processed. For the display it is necessary to construct the waveform. To avoid aliasing, the Nyquist theorem dictates that the sampling frequency should be twice that of the highest frequency components to be displayed. However this makes some assumptions about repetitive waveforms, anomalous events such as glitches and interpolation methods. In reality it is better to assume that when using sin(x)/x interpolation (a common option), the oscilloscope should have a sample rate at least 2.5 times that of the highest frequency component within the signal. If linear interpolation is used, then it is often accepted that the sample rate should be at least ten times the highest frequency signal component.

5.6 Oscilloscope Trigger / Triggering Tutorial

The oscilloscope trigger facility is one of the key functions within the oscilloscope. Triggering enables the scope, whether digital or analogue, to display a steady image on the screen that can be viewed by the user / engineer investigating a particular circuit.

Without a trigger, or other form of synchronization, it would not be possible to display a steady signal on the screen.

Scope triggering basics As described, the trigger is used to enable the scope to display changing waveforms to be displayed on the screen of the scope in a steady fashion.

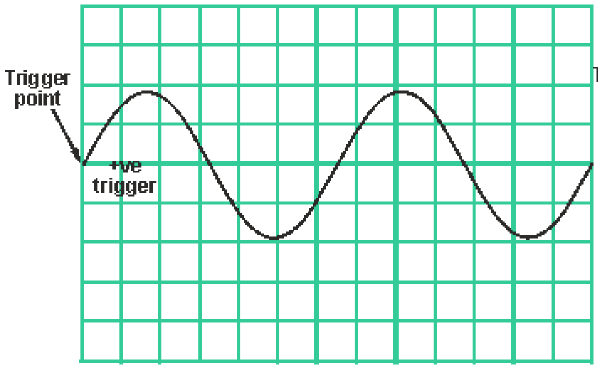
This is achieved by starting the time-base sweep at a selected point on the signal. As a result, triggering allows the display of periodic signals such as sine waves and square waves, as well as nonperiodic signals such as single pulses, or pulses that do not recur at a fixed rate.

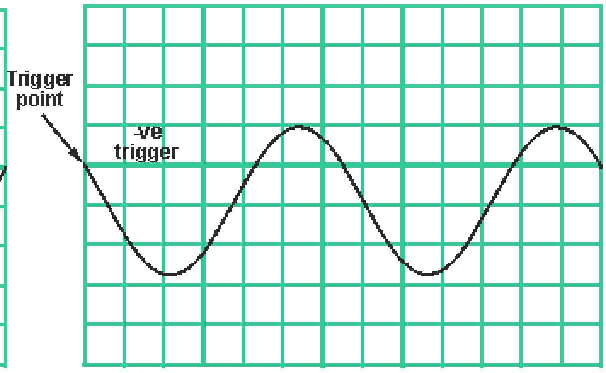
Many oscilloscopes have a variety of trigger controls that enable the required waveform to be presented in the manner required. These operate in a variety of ways and many are described below. Trigger level & trigger slope

The trigger level and trigger slope are the two basic trigger controls on any oscilloscope whether digital or analogue.

The trigger level detects when a certain voltage level has been reached and at this point sets the timebase in operation to sweep across the screen. In effect, the trigger level is like a comparator which switches the time-base to start when a voltage level has been reached.

The trigger slope, as the name indicates, determines whether the time-base sweep is triggered on a positive or negative going edge or slope.





As can be seen, the setting of both the oscilloscope trigger levels and slope determine the image that is seen on the screen. Careful adjustment of both controls ensures that the required portion of the waveform is seen.

In addition to the trigger level and +/- slope triggering, there is also likely to be an option to select whether AC or DC coupling is used.

Trigger sources There are several ways in which oscilloscopes can obtain their trigger points. These may be labelled on the front panel and the correct selection needs to be made for the application and signal being viewed.

- **Signal channel:** This is the most usual method for triggering an oscilloscope trace. However for multiple trace scopes, it is possible to trigger of the different channels. The most common is the A channel, but those with two channels may also be able to trigger of the B channel as well, therefore it is necessary to check and ensure the correct one is selected.
- **External:** On most scopes there is the possibility to trigger from an external source. This can be very convenient when the triggering needs to be synchronised to an external signal, possibly one operating the circuit under test for example. The trigger level and + / - controls still apply.
- **Line:** This is useful for looking at power line related signals. It can be used for investigating power related interference or looking at the signals themselves.
- **Video:** This was used for looking at analogue video signals. The scope extracted the video sync pulses and used these to trigger the scope.

Trigger holdoff One facility that is incorporated on virtually all modern scopes is referred to as the hold-off control. First introduced in the early 1970s, the control adds delay after a trace has finished before the next trace or sweep starts.

In analogue operation terms, once the scope sweep is completed, the beam is blanked and the scope returns the sweep voltage back to the starting point. In this way the trace moves back to the left hand side of the screen in what is termed as the 'retrace'. After the sweep and retrace are completed the trigger circuit is ready for another trigger impulse to start the sweep again.

Although achieved rather differently in digital scopes, the same overall operation is seen.

While the sweep and retrace are in operation, the trigger circuit will ignore any further trigger pulses that may arrive and it is 'held-off' until the sweep and the retrace are complete. Then, the trigger circuit is re-armed and will respond to any impulses that may trigger the sweep again.

The Trigger Hold-off control provides for an additional, user-defined delay to the re-arming of the trigger circuit, beyond the end of the sweep/retrace period. This gives the user some control over how rapidly, or how often, the oscilloscope can be triggered and it can often add clarity to the display seen on the scope.

Trigger auto facility One of the disadvantages of an oscilloscope trigger is that if the trigger level has not been set for the incoming signal, or there is no incoming signal, then no trace will be seen. This can be an issue when wanting to set the trace position before applying the signal, or if the trace needs to be found.

To overcome this an 'auto trigger' facility is normally included on the scope. This auto-trigger will start the sweep if no signal is present a timer within the scope triggers the sweep. In this way the trace will not disappear if no signal is present.

Often, for general use, the scope may be left in the auto-trigger mode. However for more exacting investigations, once the trace has been located the 'Normal' mode is often the required option. In this mode, the sweep will not start until the trigger has been activated.

5.7 Oscilloscope Probes

Oscilloscope, or scope for short, is essential tool for fault finding for electronics development, repair or diagnostics work. The oscilloscope enables the waveforms on various parts of the circuit to be viewed in a graphical format. To enable the oscilloscope to connect to the required points, oscilloscope probes or scope probes are required.

Although it is possible to use a signal line and earth return connection to form a simple oscilloscope probe, this approach does not provide the optimum performance as both electrical and mechanical aspects need to be considered to meet the necessary requirements.

A whole variety of scope probes can be bought and used. Fortunately, there is a high degree of interchangeability between scopes and scope probes. However it is necessary to know which types to use, and what the scope probe specifications may be when choosing the correct type to use for a given application.

Oscilloscope probe types Oscilloscope probes may be categorised into two main types, and they can fall into one of two main areas:

- **Passive oscilloscope probes:** This type of probe is the one that is in most widespread use. It only includes passive elements and may provide 1:1, i.e. straight through connectivity from the point under test, to the scope input. Other types may provide a defined degree of attenuation.
- **Active oscilloscope probes:** As indicated by the name, this type of scope probe has active components incorporated within the probe itself. This enables greater levels of functionality and higher levels of performance to be attained. However they are much more expensive and normally reserved for more exacting or specialist requirements.

These two main types of oscilloscope probes can be further categorised, and fuller descriptions are given below.

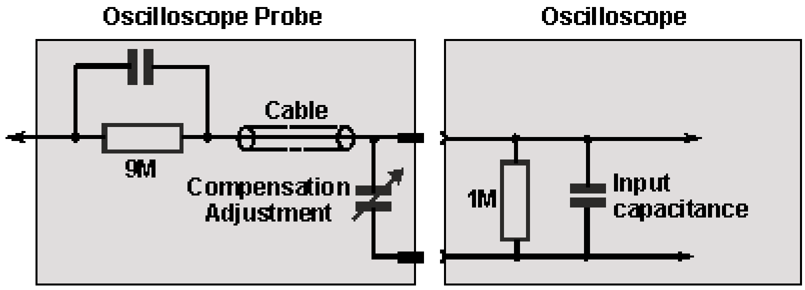
Passive oscilloscope probes: The great majority of test scope probes used with oscilloscopes are the passive variety. They enable a wide range of measurements to be made, and cover most applications. In addition to this, passive test probes are far cheaper than active ones as would be expected.

Oscilloscope probe Scope probes are generally classified according to the level of attenuation of the signal they provide. Types including 1X (giving a 1 : 1 attenuation ratio), 10X (giving a 10 : 1 attenuation ratio) and 100X (giving a 100 : 1 attenuation ratio) are available:

- **1X scope probes** The most basic form of oscilloscope probe, or scope probe, is what is often termed the 1X probe. It is so called because this type of scope probe does not attenuate the incoming voltage as many other probes do. It consists of a connector to interface to the oscilloscope (generally a BNC connector), and a length of coax which is connected to the probe itself. This comprises a mechanical clip arrangement so that the probe can be attached to the appropriate test point, and an earth or ground clip to be attached to the appropriate ground point on the circuit under test. The 1X probes are suitable for many low frequency applications. They typically offer the same input impedance of the oscilloscope which is normally 1 M Ohm. However for applications where better accuracy is needed and as frequencies start to rise, other test probes are needed.
- **10X scope probes** To enable better accuracy to be achieved higher levels of impedance are required. To achieve this attenuators are built into the end of the probe that connects with the circuit under test. The most common type of probe with a built in attenuator gives an attenuation of ten, and it is known as a 10X oscilloscope probe. The attenuation enables the impedance presented to the circuit under test to be increased by a factor of ten, and this enables more accurate measurements to be made. In particular the level of capacitance seen by the circuit is reduced and this is reduces the high frequency loading of the circuit by the probe.

As the 10X probe attenuates the signal by a factor of ten, this obviously means that the signal entering the scope itself is reduced. This has to be taken into account. Some oscilloscopes automatically adjust the scales according to the probe present, although not all are able to do this. It is worth checking before making a reading.

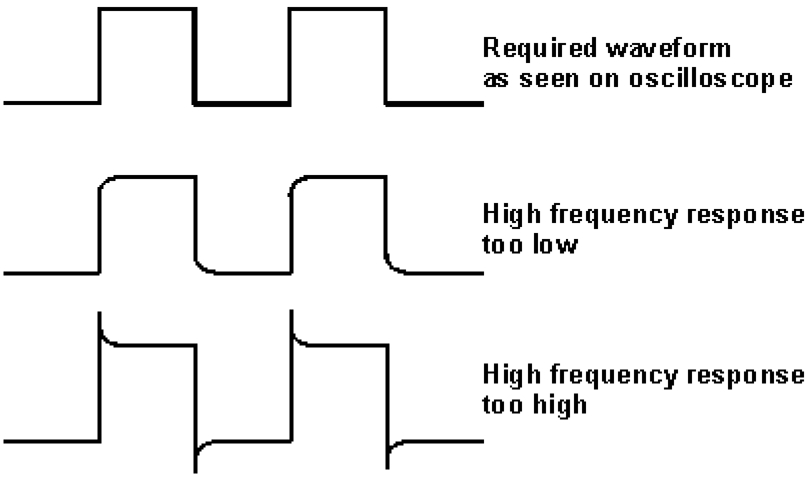
The 10X scope probe uses a series resistor (9 M Ohms) to provide a 10 : 1 attenuation when it is used with the 1 M Ohm input impedance of the scope itself. A 1 M Ohm impedance is the standard impedance used for oscilloscope inputs and therefore this enables scope probes to be interchanged between oscilloscopes of different manufacturers.



Typical oscilloscope probe schematic

10X oscilloscope probes also allow some compensation for frequency variations present. A capacitor network is embodied into the probe as shown. The capacitor connected to ground can then be used to equalise the frequency performance of the probe.

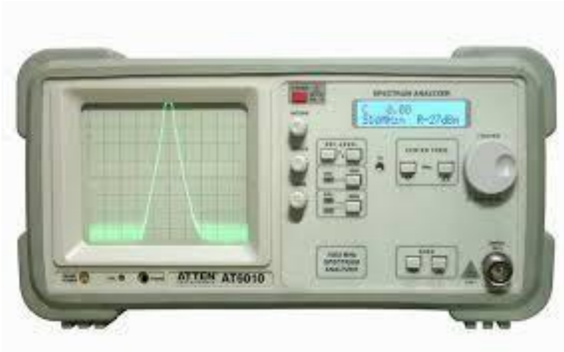
Most oscilloscopes have a small square wave oscillator output. By attaching the oscilloscope probe to this a quick adjustment can be made. As the square wave requires all the harmonics to be present in the correct proportions to provide a "square" wave, the probe can be quickly adjusted accordingly. If the leading edges of square wave, when viewed on the screen has rounded corners, then the high frequency response of the probe is low and an adjustment can be made. However if the leading edges have spikes and rise too high, falling back to the required level, then the high frequency response has been enhanced and this needs to be adjusted. Only when the square wave is truly square is the frequency response correct.



Oscilloscope probe compensation waveforms

Often the choice of scope probe that is used will depend on what is available, in the laboratory however for most applications a 10X probe is the best all round type of probe, and as a result, these are the most commonly found and purchased. Switchable probes that can switch between 1X and 10X may be another solution.

6 Spectrum analyzer



A spectrum analyzer is a very important item of test equipment for someone designing or repairing electronic equipment that uses radio frequency signals.

Spectrum analyzers are widely used in applications where RF testing is needed: in development, verification and validation testing; production; base service and repair, and increasingly in field installation and service.

In these applications, spectrum analyzers are able to provide an effective insight into the RF performance of a circuit, module or system.

6.1 What is a spectrum analyser

The most natural way to look at waveforms is in the time domain - looking at how a signal varies in amplitude as time progresses, i.e. in the time domain. This is what an oscilloscope is used for, and it is quite natural to look at waveforms on an oscilloscope display. However this is not the only way in which signals can be displayed.

A French mathematician and physicist, named Jean Baptiste Joseph Fourier, who lived from 1768 to 1830 also started to look at how signals are seen in another format, in the frequency domain where signals are viewed as a function of their frequency rather than time. He discovered that any waveform seen in the time domain, there is an equivalent representation in the frequency domain. Expressed differently, any signal is made up from a variety of components of different frequencies. One common example is a square waveform. This is made up from signal comprising the fundamental as well as third, fifth, seventh, ... harmonics in the correct proportions.

Essentially a spectrum analyser scans a band of frequencies set by the user, and notes the signal levels, displaying them on a screen. In this way it is possible to obtain a plot of the signals appearing in any band of frequencies.

Unlike an oscilloscope that plots signal amplitude against time, i.e. in the time domain, the spectrum analyzer plots signal amplitude against frequency, i.e. in the frequency domain.

6.2 Spectrum analyser types

Like any item of test equipment, there are several types of spectrum analyzer that can be found. The various types perform in different ways, although their purpose is the same: to analyze the frequency spectrum, looking at the signals.

- **Analogue spectrum analyzer:** an analogue spectrum analyzer is the traditional form of unit. Using analogue techniques it converts the frequency down to a fixed intermediate frequency which has filters of the required bandwidths. These can be switched to the required value. The scan is generated by a saw tooth generator that drives the scan across the screen at the same time as varying the local oscillator linearly across the frequency band. The amplitude of the signal at any frequency is displayed in the vertical axis.
- **Digital FFT spectrum analyzer:** Digital technology is now widely used in spectrum analyzers. It is more cost effective and can provide better performance than ones using all analogue techniques. In a digital spectrum analyzer, the signals are converted into a digital format, and the signals analysed using Fast Fourier Transforms, FFTs. The signals are then converted into a format to be displayed or analysed further by a test system.

6.3 Spectrum analyser advantages and disadvantages

Both swept / superheterodyne and FFT analyzer technologies have their own advantages. The more commonly used technology is the swept spectrum analyser as it the type used in a general-purpose test instruments and this technology is able to operate at frequencies up to many GHz. However it is only capable of detecting continuous signals, i.e. CW as time is required to capture a given sweep, and they are not able to capture any phase information.

FFT analyser technology is able to capture a sample very quickly and then analyze it. As a result an FFT analyzer is able to capture short lived, or one-shot phenomena. They are also able to capture phase information. However the disadvantage of the FFT analyzer is that its frequency range is limited by the sampling rate of the analogue to digital converter, ADC. While ADC technology has improved considerably, this places a major limitation on the bandwidths available using these analyzers.

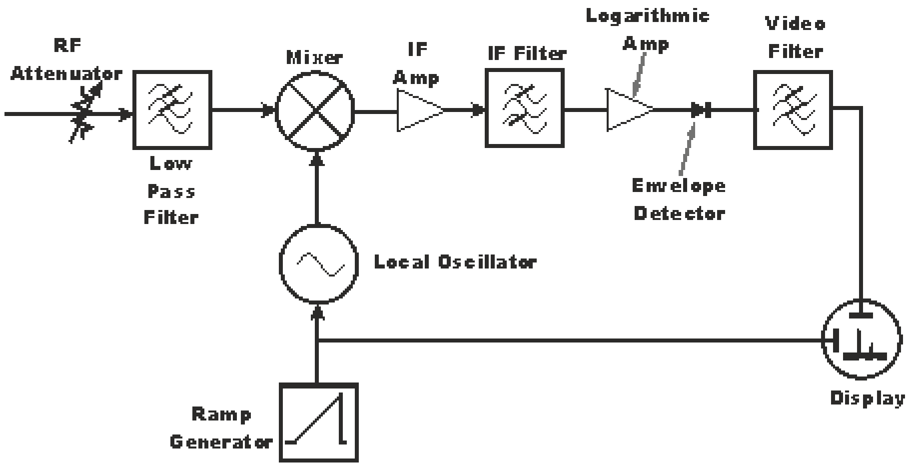
In view of the fact that both FFT and superheterodyne / swept instrument technologies have their own advantages, many modern analyzers utilize both technologies, the internal software within the unit determining the best combinations for making particular measurements. The superheterodyne circuitry enabling basic measurements and allowing the high frequency capabilities, whereas the FFT capabilities are introduced for narrower band measurements, and those where fast capture is needed. The difference between the two measurement techniques as seen by the user is that using a traditional sweep approach, the result will be seen as sweep progresses, when an FFT measurement is made, the result cannot be displayed until the FFT processing is complete.

Of the two types of RF spectrum analyzer that are available, namely the swept or superheterodyne spectrum analyzer and the Fast Fourier Transform, FFT spectrum analyzer, it is the swept or sweep spectrum analyzer that is the most widely used.

The swept spectrum analyzer is the general workhorse RF test equipment of the spectrum analyzer family. It is a widely used item of RF test equipment that is capable of looking at signals in the frequency domain. In this way this form of spectrum analyzer is able to reveal signals that are not visible when using other items of test equipment.

6.4 Sweep spectrum analyser basics

The swept spectrum analyzer uses the same superheterodyne principle used in many radio receivers as the underlying principle on which its operation depends. The superheterodyne principle uses a mixer and a second locally generated local oscillator signal to translate the frequency.



The mixing principle used in the analyzer operates in exactly the same manner as it does for a superheterodyne radio. The signal entering the front end is translated to another frequency, typically lower in frequency. Using a fixed frequency filter in the intermediate frequency section of the equipment enables high performance filters to be used, and the analyzer or receiver input frequency can be changed by altering the frequency of the local oscillator signal entering the mixer. Although the basic concept of the spectrum analyzer is exactly the same as the superheterodyne radio, the particular implementation differs slightly to enable it to perform is function.

The frequency of the local oscillator governs the frequency of the signal that will pass through the intermediate frequency filter. This is swept in frequency so that it covers the required band. The sweep voltage used to control the frequency of the local oscillator also controls the sweep of the scan on the display. In this way the position of the scanned point on the screen relates to the position or frequency of the local oscillator and hence the frequency of the incoming signal. Also any signals passing through the filter are further amplified, detected and often compressed to create an output on a logarithmic scale and then passed to the display Y axis.

Elements of a sweep spectrum analyzer Although the basic concept of the sweep spectrum analyser is fairly straightforward a few of the circuit blocks may need a little further explanation.

- **RF attenuator:** The first element a signal reaches on entering the test instrument is an RF attenuator. Its purpose is to adjust the level of the signal entering the mixer to its optimum level. If the signal level is too high, not only may the reading fall outside the display, but also the mixer performance may not be optimum. It is possible that the mixer may run outside is specified operating region and additional mix products may be visible and false signals may be seen on the display.In fact when false signals are suspected, the input attenuator can be adjusted to give additional attenuation, e.g. +10 dB. If the signal level falls by more than this amount then it is likely to be an unwanted mix product and insufficient RF attenuation was included for the input signal level.The input RF attenuator also serves to provide some protection to very large signals. It is quite possible for very large signals to damage the mixer. As these mixers are very high performance components, they are not cheap to replace. A further element of protection is added. Often the input RF attenuator includes a capacitor and this protects the mixer from any DC that may be present on the line being measured.

- **Low pass filter and pre-selector:** This circuit follows the attenuator and is included to remove out-of-band signals which it prevents from mixing with the local oscillator and generating unwanted responses at the IF. These would appear as signals on the display and as such must be removed.Microwave spectrum analyzers often replace the low pass filter with a more comprehensive pre-selector. This allows through a band of frequencies, and its response is obviously tailored to the band of interest
- **Mixer:** The mixer is naturally key to the success of the analyser. As such the mixers are high performance items and are generally very expensive. They must be able to operate over a very wide range of signals and offer very low levels of spurious responses. Any spurious signals that are generated may mix with incoming signals and result in spurious signals being seen on the display. Thus the dynamic range performance of the mixer is of crucial importance to the analyser as a whole. Great care must be taken when using a sweep spectrum analyzer not to feed excessive power directly into the mixer otherwise damage can easily occur. This can happen when testing radio transmitters where power levels can be high and accidentally turning the attenuator to a low value setting so that higher power levels reach the mixer. As a result it is often good practice to use an external fixed attenuator that is capable of handling the power. If damage occurs to the mixer it will disable the spectrum analyzer and repairs can be costly in view of the high performance levels of the mixer.
- **IF amplifier:** Despite the fact that attenuation is provided at the RF stage, there is also a necessity to be able to alter the gain at the intermediate frequency stages. This is often used and ensures that the IF stages provide the required level of gain. It has to be used in conjunction with the RF gain control. Too high a level of IF gain will increase the front end noise level which may result in low level signals being masked. Accordingly the RF gain control should generally be kept as high as possible without overloading the mixer. In this way the noise performance of the overall test instrument is optimised.
- **IF filter:** The IF filters restrict the bandwidth that is viewed, effectively increasing the frequency resolution. However this is at the cost of a slower scan rate. Narrowing the IF bandwidth reduces the noise floor and enables lower level spurious signals to be viewed.
- **Local oscillator:** The local oscillator within the spectrum analyzer is naturally a key element in the whole operation of the unit. Its performance governs many of the overall performance parameters of the whole analyser. It must be capable of being tuned over a very wide range of frequencies to enable the analyzer to scan over the required range. It must also have a very good phase noise performance. If the oscillator has a poor phase noise performance then it will not only result in the unit not being able to make narrow band measurements as the close in phase noise on the local oscillator will translate onto the measurements of the signal under test, but it will also prevent it making any meaningful measurements of phase noise itself - a measurement being made increasingly these days.

- **Ramp generator:** The ramp generator drives the sweep of the local oscillator and also the display. In this way the horizontal axis of the display is directly linked to the frequency. In other words the ramp generator is controlled by the sweep rate adjustment on the spectrum analyser.

- **Envelope or level detector:** The envelope detector converts the signal from the IF filter into a signal voltage that can be passed to the display. As the level detector has to accommodate very large signal differences, linearity and wide dynamic range are essential. The type of detector may also have a bearing on the measurement made. Whether the detector is an average level detector or whether it provides an RMS value.
  An RMS detector calculates the power for each pixel of the displayed trace from samples allocated to the pixel, i.e. for the bandwidth that the pixel represents. The voltage for each sample is squared, summed and the result divided by the number of samples. The square root is then taken to give the RMS value.For an average value, the samples are summed, and the result is divided by the number of samples.
- **Display:** In many respects the display is the heart of the test instrument as this is where the signal spectra are viewed. The overall display section of the spectrum analyser contains a significant amount of processing to enable the signals to be viewed in a fashion that is easy comprehend. Items such as markers for minimum signal, maximum peak, auto peak, highlighting and many more elements are controlled by the signal processing in this area. These features and many more come as the result of significant increases in the amount of processing provided.
  As for the display screens themselves, cathode ray tubes were originally used, but the most common form of display nowadays are forms of liquid crystal displays. The use of liquid crystal displays does have some limitations, but overall with the level of development in this technology they enable the required flexibility to be provided.

The superheterodyne spectrum analyser, or as it is also called the sweep spectrum analyser is still widely used although with the development of processing technology, other forms of analyser such as the FFT spectrum analyser are becoming increasingly widely used. However the superheterodyne analyser is able to provide a particularly useful function within the analyser marketplace.

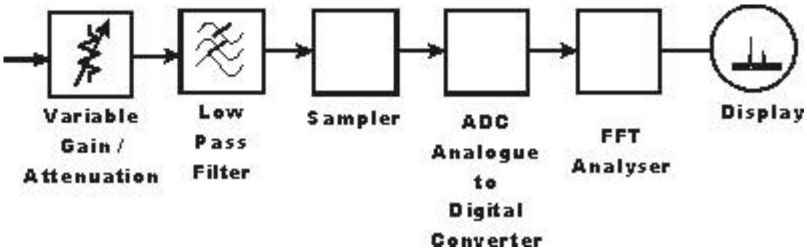
6.5 FFT spectrum analyzer

The FFT or Fast Fourier Transform spectrum analyser uses digital signal processing techniques to analyser a waveform with Fourier transforms to provide in depth analysis of signal waveform spectra.

With the FFT analyzer able to provide facilities that cannot be provided by swept frequency analyzers, enabling fast capture and forms of analysis that are not possible with sweep / superheterodyne techniques alone.

At the very heart of the concept of the FFT analyzer is the fast Fourier Transform itself. The fast Fourier Transform, FFT uses the same basic principles as the Fourier transform, developed by Joseph Fourier (1768 - 1830) in which one value in, say, the continuous time domain is converted into the continuous frequency domain, including both magnitude and phase information.

Block diagram of FFT spectrum analyzer The block diagram and topology of an FFT analyzer are different to that of the more usual superheterodyne or sweep spectrum analyzer. In particular circuitry is required to enable the digital to analogue conversion to be made, and then for processing the signal as a Fast Fourier Transform.



The FFT spectrum analyzer can be considered to comprise of a number of different blocks:

- **Analogue front end attenuators / gain:** The test instrument requires attenuators of gain stages to ensure that the signal is at the right level for the analogue to digital conversion. If the signal level is too high, then clipping and distortion will occur, too low and the resolution of the ADC and noise become a problems. Matching the signal level to the ADC range ensures the optimum performance and maximises the resolution of the ADC.
- **Analogue low pass anti-aliasing filter:** The signal is passed through an anti-aliasing filter. This is required because the rate at which points are taken by the sampling system within the FFT analyzer is particularly important. The waveform must be sampled at a sufficiently high rate. According to the Nyquist theorem a signal must be sampled at a rate equal to twice that of the highest frequency, and also any component whose frequency is higher than the Nyquist rate will appear in the measurement as a lower frequency component - a factor known as "aliasing". This results from the where the actual values of the higher rate fall when the samples are taken. To avoid aliasing a low pass filter is placed ahead of the sampler to remove any unwanted high frequency elements. This filter must have a cut-off frequency which is less than half the sampling rate, although typically to provide some margin, the low pass filter cut-off frequency is at highest 2.5 times less than the sampling rate of the analyzer. In turn this determines the maximum frequency of operation of the overall FFT spectrum analyzer.
- **Sampling and analogue to digital conversion:** In order to perform the analogue to digital conversion, two elements are required. The first is a sampler which takes samples at discrete time intervals - the sampling rate. The importance of this rate has been discussed above. The samples are then passed to an analogue to digital converter which produces the digital format for the samples that is required for the FFT analysis.
- **FFT analyzer:** With the data from the sampler, which is in the time domain, this is then converted into the frequency domain by the FFT analyzer. This is then able to further process the data using digital signal processing techniques to analyze the data in the format required.
- **Display:** With the power of processing it is possible to present the information for display in a variety of ways. Today's displays are very flexible and enable the information to be presented in formats that are easy to comprehend and reveal a variety of facets of the signal. The display elements of the FFT spectrum analyzer are therefore very important so that the information captured and processed can be suitably presented for the user.

6.6 Spectrum Analyzer Specifications

Not only is this useful when buying an analyzer, but it also helps to understand its limitations when using an analyzer as well.

There are several key spectrum analyzer specifications that are useful to understand, each one having its own bearing on performance.

There are very many different spectrum analyzer specifications. For any given application, some will be more important than others.

When selecting or using a given piece of test equipment it is very useful to have a good understanding of which one to choose, but also to understand its limitations and thereby operate it more effectively.

A) Spectrum analyzer frequency coverage

Possibly one of the most important headline specifications for a spectrum analyzer is its frequency coverage.

Typically a spectrum analyzer will be able to measure from very close to zero Hertz right up to its top frequency.

Normally the bottom frequency limit is not an issue for most applications as RF spectrum analyzers are normally used for frequencies well into the RF spectrum and seldom for much below 100kHz. But it is always worth checking.

The main parameter required for the frequency coverage specification is the top limit. This should obviously include at least the fundamental of the signals of interest, but remember that spectrum analyzers are often required to measure spurious signals like intermodulation distortion and harmonics. Often it is advisable for the spectrum analyzer specification for frequency to reach at least the third harmonic.

This may increase the costs and therefore a balance between the specification / performance and the cost may need to be made.

B) Frequency accuracy specification

The frequency accuracy is an important specification for any analyzer.

Often it is called the Frequency Readout Accuracy, and it is made up from errors from a number of sources:

- **Frequency reference inaccuracy:** This error is determined primarily by the internal timebase oscillator within the analyzer. Today virtually all spectrum analyzers use a high performance crystal oven oscillator so this term is normally quite small. Also the internal architecture of the analyzer will also have a bearing on this term. However, when using a spectrum analyzer

  for any frequency measurements, it is worth remembering that the oven does take time to warm up and settle, so any measurements should only be taken once the analyse has settled. Full details for this will be given in the spectrum analyzer specification sheet.
- **Span error:** On older analyzers that may not have used digital techniques, a span error was also a key issue. This error was often split into two specs, based on the fact that many spectrum analyzers were fully synthesized for small spans, but are open-loop tuned for larger spans. Check out the operation of the analyzer, but for most modern ones this is not applicable
- **Centre frequency error:** Again, this form of error specification was applicable to older analyzers. In most cases it was much smaller than the span error.

C) Amplitude accuracy specification

The spectrum analyzer specification for amplitude accuracy is of great importance for any measurements made by the test instrument.

There are two analyzer specifications associated with amplitude accuracy:

- **Absolute accuracy specification:** This spectrum analyzer specification refers to measurements where the absolute level is required. It may be a measurement of the power level of a signal expressed in terms of dBm, etc.
- **Relative accuracy specification:** The relative accuracy specification is slightly different. This specification is used when signals are expressed in terms of decibels when compared to another signal. For example a harmonic may be expressed in terms of decibels down on the carrier. These measurements are generally more accurate than the absolute measurements because the accuracy of the whole signal chain is.

6.7 How to Use a Spectrum Analyzer

One of the key ways to understand how to use a spectrum analyzer is to take a look at the controls.

Although this test instrument may look complicated, it can be easy to understand how to use a spectrum analyzer once a little time has been spent with one..

Although each analyzer type will be different, the basic concepts are the same across every instrument - the same types of measurement can be made and the same basic control functions are available. In this way, once one instrument has been used, the same basic skills can be passed on to the use of other spectrum analyzers.

How to use a spectrum analyzer - the basics: There are a number of different controls and interfaces on a spectrum analyzer. Although these instruments may appear to be complicated, it is possible to make good use of them after a little practice as it is necessary to use the controls correctly.

- **The display:** When looking at how to use a spectrum analyzer, one of the main elements of the unit is the display. The display has a graticule which typically has ten major horizontal and ten major vertical divisions. The horizontal axis of the analyzer is linearly calibrated in frequency with the higher frequency being at the right hand side of the display. The vertical axis is calibrated in amplitude. This scale is normally logarithmic, although it is often possible to have other scales including linear ones for specialized measurements. A logarithmic scale is normally used because it enables signals over a very wide range to be seen on the spectrum analyzer - signals of interest may vary by 70dB, 80dB or more. Typically a value of 10 dB per division is used. This scale is normally calibrated in dBm (i.e. decibels relative 1 milliwatt) and therefore it is possible to see absolute power levels as well as comparing the difference in level between two signals. In addition to the display of the spectrum, modern analyzers using digital technology often have soft keys to provide various functions around the edge of the display.
- **Setting the frequency:** To set the frequency of a spectrum analyzer, there are two selections that can be made. These selections are independent of each other and on different controls or entered via a keypad separately: Centre frequency: The center frequency selection sets the frequency of the center of the scale to the chosen value. It is normally where the signal to be

monitored would be located. In this way the main signal is in the center of the display and the frequencies either side can be monitored. Span: The span selection is the extent of the frequency coverage that is to be viewed or monitored when using the spectrum analyzer. The span may be given as a bandwidth per division on the graticule, or the total span that is seen on the calibrated part of the screen, i.e. within the maximum extents of the calibrations on the graticule. Another option that is often available is to set the start and stop frequencies of the scan. This is another way of expressing the span as the difference between the start and stop frequencies is equal to the span.

- **Gain and attenuation adjustments:** There are other controls to use on a spectrum analyzer. Most of these fall into one of two categories. The first is associated with the gain or attenuation of sections within the spectrum analyzer. If sections are overloaded, then spurious signals may be generated within the instrument. If this occurs then false readings will be given. To prevent this happening it is necessary to ensure that the input stages in particular are not overloaded and an RF attenuator is used. However if too much attenuation is inserted, additional gain is required in the later stages (IF gain) and the background noise level is increased and this can sometimes mask lower level signals. Thus a careful choice of the relevant gain levels within the spectrum analyzer is needed to obtain the optimum performance.
- **Scan rate:** The spectrum analyzer operates by scanning the required frequency span from the low to the high end of the required range. The speed at which it does this is important. Obviously the faster it scans the range the faster the measurement can be made. However the rate of scan of the spectrum analyzer is limited by two other elements within the instrument. These elements are the filter that is used in the IF, and the video filter that may also be used to average the reading. These filters must have time to respond otherwise signals will be missed and the measurements rendered useless. Nevertheless it is still essential to keep the scan rate as high as is reasonably feasible to ensure that measurements are made as quickly as possible. Normally the scan rate, span and the filter bandwidths are linked within the instrument to ensure the optimum combination is chosen.
- **Filter bandwidths:** The other controls concern the filter bandwidths within the instrument. There are generally two types: IF filte and Video filter
  The IF filter basic provides the resolution of the spectrum analyzer in terms of the frequency. Choosing a narrow filter bandwidth will enable signals to be seen that are close together. However by the very fact that they are narrow band these filters do not respond to changes as quickly as wider band ones. Accordingly a slower scan rate must be chosen when using them. The video filters enable a form of averaging to be applied to the signal. This has the effect of reducing the variations caused by noise and this can help average the signal and thereby reveal signals that may not otherwise be seen. Using video filtering also limits the speed at which the spectrum analyzer can scan. When having to use narrow bandwidths and slow scan rates, the time that a measurement can be made by reducing the span that needs to be scanned. Even though a slow scan rate must be used, the range over which the scan must be made can be reduced, thereby reducing the scan time for the analyzer.

Although most spectrum analyzers will have further controls, the ones mentioned are the main ones that are used and will enable a good understanding of how to use a spectrum analyzer. Spectrum analyzers are very useful items of test equipment and they are invaluable for RF design, development and test.

7 Spectrum analyzer tracking generator

A tracking generator provides spectrum analyzers with additional measurement capability beyond that of the basic spectrum analyzer.

The tracking generator enables some basic network measurements to be made, thereby providing additional capability beyond basic spectrum analysis.

In view of this a tracking generator considerably extends the applications for which a spectrum analyzer can be used, making them more flexible and versatile.

7.1 Tracking generator basics

Normally spectrum analyzers are what may be termed passive instruments, making measurements of signals applied to them. Typically they may be used for measuring the spectra of oscillators, transmitters or other signals in RF systems. They measure signals in the frequency domain rather than the time, and this makes them ideal for looking at many RF signals.

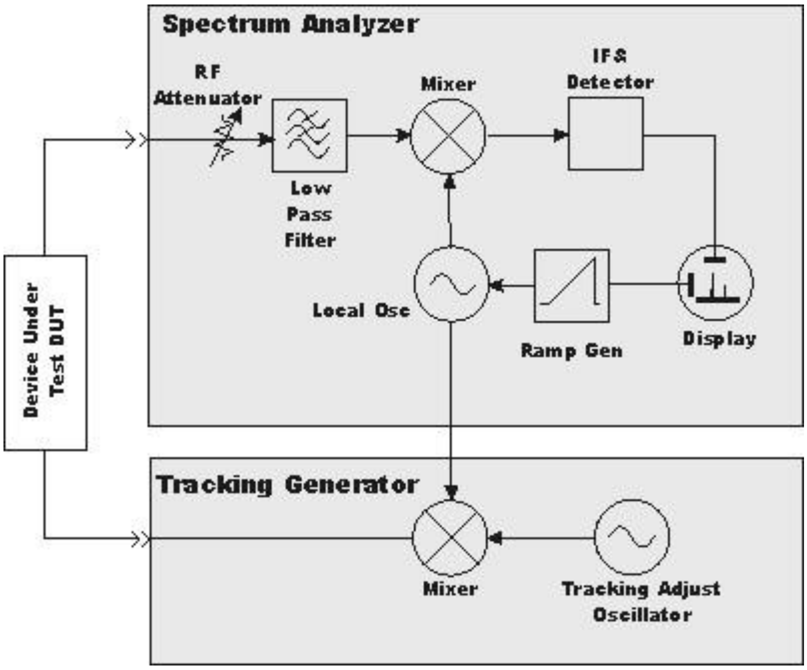
In their basic form, analyzers are not able to make response or network measurements. These types of measurements require signals to be applied to a particular device or network under test, and then measuring the response or output.

In order to make a network measurement like this, it is necessary to have a source to stimulate the device under test, and then a receiver is needed to measure the response. In this way it is possible to make a variety of network measurements including frequency response, conversion loss, return loss, and other measurements such as gain versus frequency, etc..

There are two items of test equipment that can be made to make these stimulus-response measurements. Possibly the most obvious type of test equipment is an RF network analyzer and the other is a spectrum analyzer with a tracking generator. If phase information is required, then it is necessary to use a vector network analyzer, but it possible to use a spectrum analyzer tracking generator arrangement for many other measurements. As many laboratories will already use a spectrum analyzer, the tracking generator approach is particularly attractive. In addition to this, tracking generators are incorporated into many spectrum analyzers as standard. This means that it is possible to use these test instruments to make many network measurements at no additional cost.

7.2 What is a tracking generator?

A spectrum analyzer tracking generator operates by providing a sinusoidal output to the input of the spectrum analyzer. The by linking the sweep of the tracking generator to the spectrum analyzer, the output of the tracking generator is on the same frequency as the spectrum analyzer, and the two units track the same frequency.



If the output of the tracking generator was connected directly to the input of the spectrum analyzer, a single flat line would be seen with the level reflecting the output level of the tracking generator. If a device under test, such as a filter is placed between the output of the tracking generator and the input of the spectrum analyzer, then the response of the device under test will alter the level of the tracking generator signal seen by the spectrum analyzer, and the level indicated on the analyzer screen. In this way the response of the device under test will be seen on the analyzer screen.

7.3 Using a tracking generator

Using tracking generators is normally very easy. As a tracking generator is either built into the spectrum analyzer, or is manufactured as an external option for a test instrument, then there are few issues with their use. However there are a few standard precautions to remember when using one:

- Adjust tracking generator to centre of analyse passband: There is often an adjustment for the tracking oscillator to trim its frequency. Before using the tracking generator, it is wise to adjust the frequency trim adjustment to ensure that it is on exactly the same frequency as the spectrum analyzer. This is achieved by maximising the reading on the spectrum analyzer display.
- Calibrate system using direct connection: To ensure that any cable losses are known, it is always wise to replace the device under test with a back-to-back connector, or other short connecting line. In this way, the system will reveal any losses which it may be possible to "calibrate out".

When using a spectrum analyzer tracking generator it is possible to make many measurements very easily. A few precautions, when making the measurements will enable inaccuracies to be counteracted, and reliable measurements made.

8 Logic probe

A logic probe is a low cost item of test equipment. As the name indicates, a logic probe tester is used for probing and analyzing logic circuits.

A logic probe tester is normally a small item of test equipment, typically handheld in the form of what could be thought of as a large oscilloscope probe, but without the lead.

This makes logic probes very portable and easy to use for troubleshooting and general simple maintenance work on low complexity logic circuitry.

For most applications, a logic probe would not be used within a laboratory test environment - here more sophisticated test equipment would be used because much closer investigation of problems is required.

8.1 Logic probe basics

A logic probe is able to give an indication of the logic state of a line carrying a digital signal The logic probe indicates whether there is a logic state "1" or "0", normally using an LED as the indicator. Often the LED on the logic probe will use different colors to indicate different states.

A logic probe normally may be capable of indicating up to four different states:

- **Logic high:** If the logic circuit is at a logic or digital high voltage, the logic probe will indicate this on its interface - typically this will be a color red.
- **Logic low**: Again the logic probe will indicate a logic or digital low. The most common colour for this is green.
- **Pulses:** The logic probe is likely to incorporate a pulse detection circuit. When the line is active a third colour, possibly amber will be indicated. The logic probe may well incorporate circuitry to detect very short pulses and in this way indicate when the line is active. Sometimes the length of the pulses may be indicated by the brightness of the LED.
- **Line tri-stated:** Often it is possible for lines to be tri-stated, i.e. the output device has its output turned off and no real state is defined. Many logic probes are able to indicate this state by having all indicators turned off.

Some logic probes may have a control to select the logic family being tested - different logic families have slightly different high and low voltage levels.

Another facility that some logic probes may include is an audible indication of the logic state. This feature is particularly useful when using a probe as eyes may need to be trained on the circuit and not on the logic probe itself.

8.2 Logic probe tester advantages and disadvantages

As with any item of test equipment, there are advantages and disadvantages to the use of a logic probe.

Logic probe advantages

- **Low cost:** A logic probe does not contain much circuitry, and the display is very rudimentary. Therefore the cost of manufacture is very low.
- **Ease of use:** To use a logic probe typically requires the connection of power leads and then connecting the probe to the required point on the circuit.

Logic probe disadvantages

- **Very rough measurement:** The nature of the logic probe means that only an indication of the presence of a logic signal can be detected.
- **Poor display:** A logic probe only uses a few LEDs to indicate the nature of the logic signal. As a result, little information can eb displayed about the nature of the logic signal that is detected.

A logic probe tester is a cheap and relatively simple item of test equipment. It is versatile and very transportable, and it also is able to provide a quick test for many circuits. However it is not nearly as flexible as an oscilloscope or a logic analyzer. A logic probe can be used for quick testing, whereas for more in-depth testing more sophisticated test equipment is needed.

8.3 How to Use a Logic Probe

A logic probe can be used to provide an indication about the signals on logic lines in digital circuits.

A logic probe is a simple items of electronic test equipment and as a result, using a logic probe is quite easy, however its limitations should be remembered when using it test circuits.

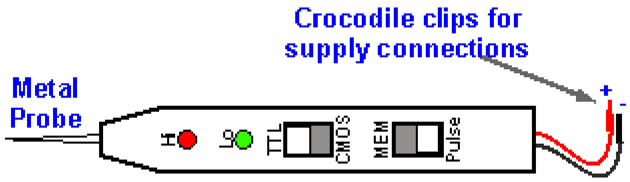
Understanding how to use a logic probe is very straightforward. There are many different logic probe products, all of which are slightly different, but they all conform to the same basic overview of their functionality and operation, for example some have audible indications as well as the visual ones whereas others may not.

Accordingly it is possible to give some basic guidelines about how to use a logic probe, but there will be slight variation in the way they are used dependent upon the particular logic probe in use.

8.4 Logic probe connections and controls

Logic probe connections Before using the logic probe, it is necessary to understand the connections. As can be seen, there are three connections to the logic probe:

1. **Black lead with crocodile clip:** There are two leads which generally come out of the opposite end of the instrument to the metal probe itself. The black lead is connected to negative ground and is also used as the return.
2. **Red lead with crocodile clip:** This lead will have red on it somewhere, possibly just on the crocodile / alligator clip and is used to connect to the supply. Be careful to connect this to the logic supply which will normally be +5 volts. Read the instructions to see over what range the probe will operate.
3. **Probe:** The probe, as shown on the diagram is a metal point used for probing the circuit.



The first requirement before using the logic probe is to connect the power connections to the circuit. Apart from ensuring they are the right voltage, the points used for connecting the crocodile clips to should be accessible and provide a reliable connection without the risk of touching any adjacent components or other connections.

Note: If possible connect the power connections to the unit under test when it is powered off. In this way risk of damage due to shorting, etc. is minimized.

8.5 Initial settings

When using the logic probe, it is necessary to select the required settings on the switches. Dependent upon the logic probe manufacturer and model, there are a number of options that may need to be set:

1. **TTL / CMOS:** It is necessary to select the logic family. Normally two options are given, namely CMOS and TTL. As the high and low states of these two logic families are slightly different, it is necessary to select the correct option.
2. **MEM / PULSE:** This is used to select he operational mode of the logic probe. The Pulse position is used for normal operation for pulse or level detection. The MEM or memory position is used to capture a pulse. For example if it is necessary to detect whether a pulse has occurred or not.

Note: Some surface mount devices these days use supply rails of 3.3 volts or less. Most logic probes will not work with these ICs as the logic levels cannot normally be accommodated. Additionally it is often difficult to probe surface mount boards as there is a real danger of shorting pins.