BUYING ELECTRONIC EQUIPMENT:

1. Oscilloscopes

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1. **Versatile 150 MHz oscilloscope, having 4 plug-ins and digital readout of CRT signal parameters.**

Which oscilloscope should you buy? This article, specially written for *Electrical and Electronics Technician Engineer,* is the first of a series designed to assist those who, perhaps not necessarily qualified in electronics, have to make a decision concerning the purchase of electronic equipment. Tektronix U.K. Limited market oscilloscopes under the Telequipment and Tektronix labels.

WHICH OSCILLOSCOPE?

For years past an oscilloscope has constituted one of the main items in any laboratory's battery of measuring instruments. In numerous, varied fields of activity it has become an invaluable tool for the examination and analysis of electrical signals of all kinds.

There are probably two major reasons for the universal acceptance of the oscilloscope: one is the psychological attraction of its visual display; and the other is the diversity of its applications. By charting a graph on a CRT it is possible to immediately present information regarding the duration and amplitude of a signal, together with its waveshape. This ability to 'picture the whole situation' is unique among measuring instruments, and is an important factor in the oscilloscope's favour.

For most people engaged on the technical side of the electronics industry, and for researchers in many spheres besides, use of an oscilloscope has become a routine part of their working lives. The growing popularity of the instrument is evidenced by the steadily-increasing range of models being offered for sale by an ever-widening circle of manufacturers. This proliferation of hardware certainly gives to the prospective oscilloscope purchaser freedom of choice; but at the same time, it turns the choosing process into a formidable task. How does he go about sorting out the competing claims of the various suppliers? How is it possible to establish the best way to meet his needs? It is hoped that the following discussion will answer such questions, and provide a useful guide to those responsible for either buying, or recommending, oscilloscopes.

THE DECISION PROCESS

It may be stating the obvious to say that choosing a new oscilloscope, such as that shown in Fig. 1, is an example of making a decision; but it is, nevertheless, and we can gain some insight into the best approach to adopt by examining the decision process.

Decision theory is a subject which in recent years has been studied in some depth and developed to a considerable degree of sophistication. Advanced mathematics can figure prominently in such theory, and operation of models by means of computers is in practice commonplace—in fact, the whole field of Operations Research can be looked upon as a scientific aid to decision making. For our purposes, such refined techniques are inappropriate; but the fundamentals underlying them can be of benefit in showing what is needed for a sensible decision to be made.

The scientific method of decision making, as described in the textbooks, involves five stages, which can be stated as follows:

1. Define the problem (application).
2. Collect all relevant data (or as much as can be found) pertaining to the problem.
3. Examine and weigh the data to determine its value and application to the problem.
4. Frame some alternative solutions based on the data.
5. Select the solution that appears best and most logical.

Stated baldly in this way, the decision process would seem to be a straight-forward affair, unlikely to present any difficulty. In real life of course, things are seldom so simple, and problems can arise at each step. Very often the particular application concerned is not sufficiently clearly defined, thus making nonsense of any attempt to complete the rest of the procedure. Another frequent error is that of neglecting to obtain all the information pertinent to the situation—although there is usually no lack of information (sometimes the reverse), it can be a puzzle to know where to look for it. Probably the major difficulty, however, arises at stage 5, at which the real decision takes place. No matter how methodical, logical and careful one has been in the preceding work (except in a very few, uncomplicated cases), it is at this point that judgement will have to be exercised in order that the best course of action shall be chosen.

Looking more closely at the above procedure, consider first the definition of the problem. It is important to get this step right, and it is worthwhile giving a little more time and thought to the topic than would at first sight seem to be necessary. It happens that the applications for an oscilloscope tend to fall into a number of broad classifications, e.g. the high-speed single event (such as is encountered in pulsed laser work); switchgear development; high-voltage testing; etc. It is also usually true that there are some essential requirements, such as a need for portability or versatility; maybe a genuine dual-beam instrument is necessary; or perhaps there is only a need to monitor a signal, and not to measure it—whatever the particular situation, there are bound to be some such constraints. An obvious, and quite frequently met, constraint is the amount of money available to spend on the new oscilloscope. Consideration of these points shows that if the problem is really well defined, the range of interest is narrowed automatically, and the rest of the job made more manageable.

The next step is to gather together all the information which is required for a good decision to be made. Clearly, a lot of this information will be of a technical nature, consisting of manufacturers' specification sheets and catalogues and other published material, such as application notes, etc. This is by no means the only data required, however, since the decision to buy a specific instrument should be influenced by other factors apart from technical adequacy (as expressed by the written specification). The purchase does represent an investment of capital funds: consequently, as in all such cases, an attempt should be made to optimise the investment. This means that account must be taken of such matters as the useful life and reliability to be expected from the equipment; the availability of spare parts; the provision of efficient calibration and maintenance facilities; and the quality of field engineering services. All these items deserve considerable attention, since they have a direct bearing on instrument value and, unfortunately, cannot be specified satisfactorily. Direct experience is by far the best guide in this matter; but this begs the question as to how to judge an instrument, or supplier, not previously encountered. Third party opinions can sometimes be of help, but are heavily dependent upon the third party in question. In general, the most satisfactory solution is to arrange for demonstrations of those oscilloscopes which come closest to the desired specification. This will afford an opportunity to check that the performance characteristics are as stated, to assess the 'feel' of the instruments and how convenient they are to operate, to judge the quality of the components and workmanship which have gone into them, and to test the standard of technical representation and assistance provided.

The third step is to evaluate all the data gathered and to assign levels of importance to the various aspects of the situation. A convenient way of doing this is to group the information under four headings: technical performance, versatility, reliability and service. Technical performance is the criterion which is usually dominant, and the specification must be right if the oscilloscope is to do the work for which it is intended. This is not always the case: sometimes, maximum versatility or reliability becomes the over-riding factor. It can be seen that we are returning to our original definition, which serves to stress again its importance—for it is necessary to refer back continually to the defined requirement in order to ensure that the correct decision is reached.

The fourth and fifth steps which follow consist of setting-up a range of alternatives, assessing their individual merits and demerits, and then selecting the best one. At this stage, any of the alternatives should be capable of solving the problem in hand; the main task is normally to choose that one which offers the most overall advantages. Occasionally, however, it is found that none of the alternatives meets all the requirements. In this event, an attempt must be made to obtain more information so that new alternatives may be proposed. If this fails, a compromise solution will have to be accepted: this means selecting that alternative which has the least number of disadvantages.

Throughout the foregoing, emphasis has been placed on the necessity to fully define what is required of the oscilloscope, to obtain as much information as possible on the instruments which are available, and to evaluate that information carefully against the defined requirements. In order to facilitate a more specific analysis, we will consider in greater detail the four previously mentioned headings of technical performance, versatility, reliability and service.

TECHNICAL PERFORMANCE

As previously stated, technical performance is usually regarded as the most important characteristic in an appraisal of an oscilloscope's worth. The instrument consists of a number of functional blocks, each having its own features which contribute to the overall performance, and each needing to be compatible in operation with the rest.

The Vertical Deflection System

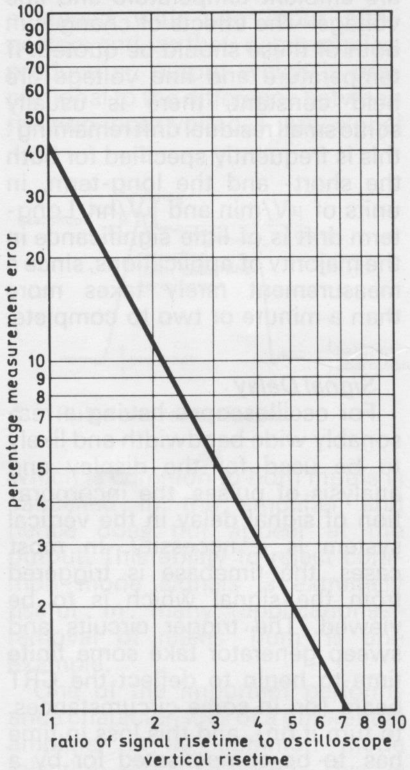
Risetime and Bandwidth

In general, the first requirement sought is an adequately short risetime, or an adequately wide bandwidth. Risetime is the more important for pulse work, and bandwidth for sine waves. Both these parameters describe essentially the same attribute, the specification of risetime being more important in a 'fast' (wideband) oscilloscope, that of bandwidth being more appropriate to a 'slow' oscilloscope. In practice, the two should be closely related if the oscilloscope has a good transient response. Most modern oscilloscope vertical systems are adjusted for a 'Gaussian' response: if this is the case, the product of risetime and bandwidth should have a value very close to 0.35. For instance, an oscilloscope with 100 MHz bandwidth should have a risetime of 3.5 ns.

Ideally, the vertical system should have a risetime at least five times faster than that of the fastest signal to be examined. This will produce an error of about 2% in the displayed risetime, on the assumption of perfect calibration and linearity in the timebase. Quite often, an oscilloscope risetime which is only equal to the fastest signal is considered to be adequate, since it is possible to predict actual risetime, provided that transient response is optimum. Under these conditions, a close approximation to the signal risetime can be obtained from the equation:

$$T_s=\sqrt{T_1^2-T_2^2},$$

where T_s=signal risetime, T_1= indicated risetime, and T_2=vertical system risetime. Because of the increased effect of measurement errors, when the signal risetime is faster than the oscilloscope risetime, the accuracy of this calculation rapidly deteriorates, and it becomes of little use. Fig. 2 is a graph of measurement error against the ratio of signal risetime to oscilloscope vertical risetime.



2. Graph of measurement error against the ratio of signal risetime to oscilloscope vertical risetime.

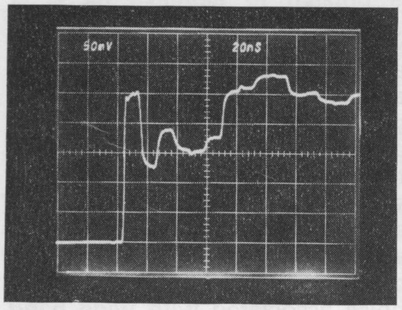
Transient Response

Apart from the need to measure risetime, adequate vertical system bandwidth is required in order that any rapidly-changing signal may be faithfully displayed. This point is clarified in Fig. 3, which shows the same wave-form displayed at three different bandwidths. (The characters displayed on the screen refer to the oscilloscope scale factors which have been selected, i.e. 50 mV per vertical division and 20 ns per horizontal division.) The transient response is also important in this context, and distortions introduced by the amplifier should be as low as possible. Pulse response fidelity is sometimes specified in terms of permissible overshoot, but there are a number of other aberrations which are just as significant—see Fig. 4. As a rule, the only way to find out if such aberrations exist in an oscilloscope is to apply a clean square wave signal of known characteristics—this is one of the checks that can usefully be carried out during a demonstration.

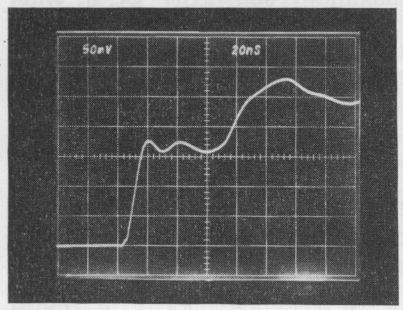
Sensitivity and Noise

Deflection factor (or sensitivity), like bandwidth and transient response, is one of the prime factors which determine the suitability of an oscilloscope for a particular application. Due to the inherent gain—bandwidth limitations of amplifiers, when extreme sensitivity is required it is necessary to sacrifice bandwidth. Even without such a fundamental restriction, some reduction is desirable because of the greater background noise associated with wide band amplifiers. A reasonable figure for maximum sensitivity of a wide band vertical amplifier would be in the region of 1 mV to 5 mV per division of deflection on the CRT screen. Displayed noise should not be a problem in this area and should not impose any restraints upon the making of a measurement. In the case of an amplifier whose design has been optimised for high sensitivity, the deflection factor may be as high as 10 μV per division; at this setting, displayed noise will have some effect upon measurement ability. When this is so, the amount of noise must be specified, in order that any performance impairment can be assessed.

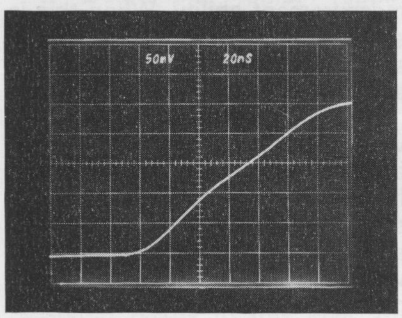
There are a number of different ways of quoting noise as related to an oscilloscope display; any specification of this parameter should state which method has been used, and at what bandwidth and with what source impedance the measurement was made. The method should be one which relates to the way in which noise limits resolution in the CRT display, since this is the aspect of most importance when the usefulness of an amplifier is being determined. The two fundamental ways of expressing noise are to state either its r.m.s. or its peak-to-peak value. In both cases, a misleading impression is given, as r.m.s. noise is much less than that apparent in the display, and the peak-to-peak figure seems to be much more. For the normal noise distribution, the peak-to-peak value is about six times the r.m.s. value, so it is usual to quote a figure somewhere between these extremes (i.e. two to three times the r.m.s. value), based upon a tangential measurement which relates very well to what is visually observed. With all other factors remaining the same, noise voltage is proportional to the square root of bandwidth. For this reason, it is not uncommon to find high-gain amplifiers which have some means of selecting a range of bandwidths, a feature which can be very useful in many applications.



150 MHz.



20 MHz.



5 MHz.

3. Display of the same waveform at three different bandwidths.

Deflection factor is adjustable in fixed calibrated steps, usually to a 1-2-5 sequence, together with a continuously-variable control which allows setting of any factor between the fixed steps. The normal way of providing this arrangement is by means of fixed attenuators switched into the input circuit. The accuracy with which a voltage measurement can be made is dependent upon the accuracy of the attenuation ratio. A figure of 3%, or less, is usually considered to be necessary when the oscilloscope is to be used for the making of measurements, as opposed to just the monitoring of a waveform.

Drift

Another characteristic of importance in high-gain, d.c.-coupled amplifiers is positional trace stability, or 'drift'. An appreciable time may be required for such an amplifier to stabilise after switch-on: hence, the 'warm-up' period required should be stated. The warm-up having been completed, the factors most influencing drift are ambient temperature and line voltage—the effects of changes in both of these should be quoted. If temperature and line voltage are held constant, there is usually some small residual drift remaining: this is frequently specified for both the short- and the long-term, in units of μV/min and μV/hr. Long-term drift is of little significance in the majority of applications, since a measurement rarely takes more than a minute or two to complete.

Signal Delay

For oscilloscopes having a reasonably wide bandwidth and likely to be used for the display and analysis of pulses, the incorporation of signal delay in the vertical system is a necessity. In most cases, the timebase is triggered from the signal which is to be viewed. The trigger circuits and sweep generator take some finite time to begin to deflect the CRT beam (or, in some circumstances, to turn it on), and this loss in time has to be compensated for by a slightly greater delay time in the signal path between the trigger pick-off and the deflection plates. Without this delay, some part of the leading edge of the signal would be lost. A typical figure for triggering delay might be 100 ns, while the amount of signal delay could be 120 ns—thus giving some 20 ns of lead time in the display. It is clear that the need for signal delay is greatest in the faster oscilloscopes, in which a significant portion of the time scale can be lost at the maximum sweep speeds. The method of producing the required amount of delay can be either a lumped constant delay line, or a special-purpose delay cable. The former is little used in present day instruments, due to the complexities of its construction and calibration; however, whichever technique is used, it must be carried out with great care, since it can be a major source of waveform distortion. It is probably true to say that the quality of the transient response is dependent more upon the delay system than upon any other part of the vertical amplifier.

Input Impedance

The input impedance of an oscilloscope is usually described as a parallel resistance and capacitance combination. The input resistance is generally of the order of 1 MΩ, and the capacitance typically between 15 pF and 50 pF. In order to minimise the loading effect of the input upon the signal source, it is important to make the input impedance as high as possible. At the higher frequencies, or for fast-rising signals, the resistive component becomes insignificant: the input can then be regarded as a capacitive load. For example, at 1 MHz the reactance of a 15 pF capacitor is only 10.6 kΩ—obviously, this will have a much greater loading effect than the 1 MΩ resistance, and for practical purposes the latter can be ignored. Input resistance does become important, however, when one is considering the d.c. or low-frequency loading of the oscilloscope; thus, it is still desirable that it should have a high value. In the case of oscilloscopes which have very wide bandwidths, the input resistance is sometimes arranged to match the characteristic impedance of co-axial cable, 50 Ω being a popular value to use. This is the best arrangement for very high frequencies, since signals of this sort usually exist only at the very low impedance levels which are encountered in co-axial cables. The main disadvantage is that the static input resistance to the oscilloscope is also very low—thus it becomes of limited use in low-frequency, or other, more general, applications. A way of overcoming this drawback is to use an impedance-matching device, such as an active probe, to raise the input resistance to a more appropriate level. Such devices generally afford very high input impedance at the probe tip but, due to their restricted dynamic range, require the use of plug-on attenuators for signals of even a few volts' amplitude. Because of these limitations, the use of low input impedance oscilloscopes is usually restricted to those applications which demand the extra wide bandwidths, or fast risetimes, which they can offer. In practice, a co-axial cable can be used quite effectively with a conventional high input impedance by placing a termination at the input connector of the oscilloscope. This is not as satisfactory as a correctly-matched input, because of the effect of the input capacity in parallel with the termination; but in many cases the technique is perfectly adequate, particularly when the bandwidth of the oscilloscope is taken into account. For instance, for a 15 pF input capacity and a correctly-terminated 50 Ω system, the bandwidth will be limited to 425 MHz. This is clearly not of much concern when the oscilloscope bandwidth is about 100 MHz to 200 MHz, since the additional signal loss due to the input circuit is small in comparison with that due to the rest of the vertical system.

D.C.-Coupling and Input Rating

Most modern oscilloscopes have vertical amplifiers which are d.c.-coupled throughout, a feature which is necessary if low-frequency signals are to be measured. It is also useful for dealing with signals derived from d.c.-powered sources such as the collectors of transistors, since it permits the determination of the level to which the point moves when complex waveforms are being generated. Removal of the d.c. is desirable when it is large in relation to the a.c. component, in order that the display may be prevented from being driven off the screen—the simplest way of accomplishing this is with a.c.-coupling at the input. When a.c.-coupling is available, the specification should state the lower frequency limit which it imposes.

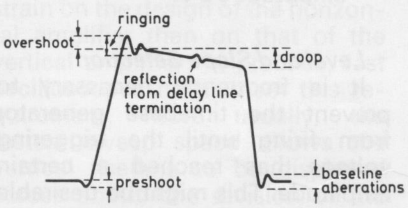
A further aspect of interest is the input voltage rating. This should be sufficiently high to withstand any signal which is likely to be applied; in general, the higher the rating, the better. At the same time, it is unrealistic to expect a very sensitive amplifier to accommodate very high input voltages, and there remains some responsibility on the part of the user to prevent overloading of the input, with possible consequent damage.

Offset

Another technique which is used to counteract a high d.c. level at the input is called 'offset'. This involves the injection of an internally generated voltage into the input circuit in such a manner as to bring the trace back on to the screen. It has the advantage of retaining the d.c. response, and also allows detailed examination of a signal in the vertical axis by effectively providing a long scale length. In some amplifiers the amount of offset is uncalibrated, the control acting as a wide-range positioning control. In others, designated 'differential comparators', the input signal is compared with a precise, calibrated voltage: this method affords a means of measuring large signals very accurately.

Differential Amplifiers

Push-pull signals may be directly displayed by means of a differential amplifier. Such amplifiers are equipped with two input connectors and, as their name implies, produce an output which is proportional to the difference between the two input voltages. Any signal



4. Pulse characteristics.

which is common to both inputs is cancelled in the amplifier and hence does not appear at the output. This ability to reject common mode signals is extremely useful in many applications—removal of mains 'hum' is one example.

One of the important performance characteristics of a differential amplifier is its 'common mode rejection ratio' (CMRR). This is the ratio of the amplitude of the in-phase signals presented at the inputs to the amplitude of the display. For example, if a 1V common mode signal is applied to the amplifier and produces a display of 1 mV, the CMRR is 1,000:1.

The rejection ratio is not necessarily the same for all deflection factors—the mis-matching of input attenuators is a common cause of degradation—and there is a limit to the dynamic range, i.e. there is a maximum common mode peak voltage allowable before the amplifier's linearity is affected. The rejection ratio is usually highest at low frequencies, and falls off appreciably at high frequencies. The quality of a differential amplifier is largely determined by the magnitude of its CMRR (and the manner in which this varies with frequency), and the dynamic range provided.

Multi-trace Amplifiers

A common arrangement with present-day oscilloscopes is to have either two or four inputs to an amplifier, any one of which can be switched for display on the CRT. The switching can be effected in three ways: manually, by means of front panel channel selectors; by control of the time-base generator (which changes from one channel to the next during each sweep retrace interval); or by control of an internal oscillator (which switches channels at a rapid, free-running rate). The last two methods are called 'Alternate' and 'Chopped' displays, respectively. The principal uses of such dual- or four-trace units are for comparison of the relative amplitudes and time relationships of a number of signals.

The characteristics of most interest in multi-trace amplifiers are the types of display mode provided and the chopping rate. The Alternate and Chopped displays have already been mentioned; however, a further type of display is produced by adding of the signals. Since this process is essentially opposite in action to that of the differential amplifier, it is commonly referred to as 'Added Algebraically'. The term implies that if the polarity of one of the signals were inverted, a difference signal would result—this is so in practice: it is possible to use a dual-trace system as a differential amplifier.

The Chopped mode is most often used for the simultaneous display of waveforms of relatively low frequency and of a non-repetitive nature, thus simulating the characteristics of a true dual-beam instrument with its two sets of CRT vertical deflection plates, driven by two separate vertical amplifiers. In general, the higher the chopping rate the better, since this means that higher input frequencies can be displayed without excessive loss of resolution due to the segmented nature of the display.

The Triggering System

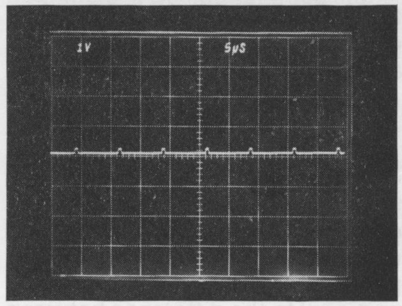
Owing to the general-purpose nature of an oscilloscope, it is required to work with signals of numerous different shapes, amplitudes and frequencies. Many of these waveforms are not suitable for use in starting the sweep generator, and some means is thus required for producing a standardised pulse to serve this purpose. The circuit of the oscilloscope which performs this function, together with its associated controls and selectors, is called the 'triggering system'.

Of all an oscilloscope's characteristics, it is the triggering performance that is of greatest importance from an operator's point of view. An oscilloscope may have all sorts of other fine features and excellent characteristics, but if it is difficult to maintain a stable display on the instrument under a wide variety of conditions, most users will reject it—many otherwise good oscilloscopes have been pushed into a corner to decay because of poor triggering. Unfortunately, it is impossible to define in a truly adequate way just how well an instrument performs in this respect. The assessment of triggering capability can be highly subjective, even emotional in some cases; this is one of the areas that should be carefully checked during demonstration.

Sensitivity and Frequency Range

The sensitivity and operating frequency range of the trigger are the characteristics which are of most concern. A reasonably high sensitivity is required for use with externally-applied trigger signals, since these can sometimes be quite small. When internal triggering is provided (as it is in virtually all cases), the sensitivity needs to be a careful compromise. With wideband oscilloscopes, there is bound to be a certain amount of noise present in the trigger pick-off system: it is thus desirable that the sensitivity should be such that this noise does not produce erratic operation. In practice, this does not impose any limitations in use, since there is little point in being able to trigger internally on signals which are too small to view comfortably. At the same time, the sensitivity needs to be adequate for the display of slowly-rising waveforms, since it determines the amount of the leading edge which will be displayed. For instance, if the internal triggering sensitivity is 0.2 divisions, then with a signal of 1 division height only 0.8 divisions of the rising edge will be shown. An internal sensitivity of about 0.2 or 0.3 divisions is usually adequate in most general-purpose oscilloscopes—see Fig. 5.

The triggering frequency range clearly needs to be compatible with the bandwidth of the vertical system. In practice, it should be possible to obtain satisfactory operation well beyond the upper 3 dB frequency limit of the oscilloscope. The sensitivity naturally falls off at the higher frequencies; therefore, either a higher external voltage or a greater deflection is needed. Fig. 6 shows a 250 MHz sine wave displayed on a 150 MHz oscilloscope which has internal triggering.



5. Timebase internally triggered by a pulse of width 0.5μs and amplitude 0·2 V.

Level and Slope Selection

It is frequently necessary to prevent the timebase generator from firing until the triggering voltage has reached a certain amplitude. This might be desirable if the signal is noisy, or if it is required to start the timebase with reference to a particular point on the waveform of interest. The trigger circuits are voltage-sensitive, and can respond to timing information only when this is related to amplitude. The 'Triggering Level' control selects the voltage level through which the trigger signal must pass in order that a sweep may be initiated. Since the signal can pass through this level with either a positive or a negative slope, a 'Slope Selector' is also provided, which allows the trigger to take place at almost any point on the waveform. Fig. 7 shows how the Level and Slope controls can be used to start the timebase at points which vary both in amplitude and time with respect to a sine wave.

The main characteristics required of the Level control are a smooth and positive action and a sufficient range, in order either that the full vertical scale may be covered when internal triggering is used, or that a reasonably large external trigger voltage may be accommodated. An additional selector is frequently incorporated so that the range of the Level control may be extended for external signals only.

Source, Coupling and Mode Selection

It is usual to include various other facilities in the trigger circuit, principally for the purpose of improving its versatility and ease of use.

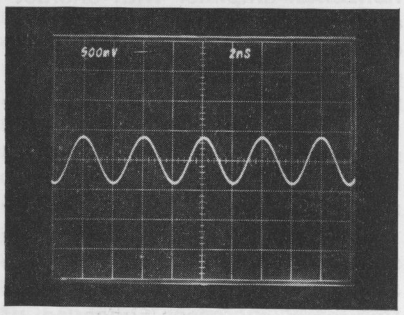
Source selection allows the triggering signal to be obtained from a variety of sources. Internal and external triggering have already been mentioned; additionally, a line (50 Hz) trigger signal is common. Some oscilloscopes are equipped with sync separators, which facilitate internal selection of field and line rate triggers when a television video signal is being examined. A form of internal trigger which is extremely useful is the 'single channel' trigger. When a dual- or four-trace amplifier is used, it is necessary to be able to trigger from one channel only if true time relationships are to be depicted.

Coupling selection permits the signal to be coupled into the trigger circuit in a number of ways, so as to allow for differing circumstances; a.c.-coupling is the mode most commonly used, e.g. for removal of the influence of any steady voltage on the trigger. Other forms of a.c.-coupling reject either high or low frequencies and filter out undesirable components, such as noise or hum, which might otherwise interfere with stable triggering; d.c.-coupling passes all the information in the signal into the trigger circuit. It is used for very low-frequency work and whenever shifts in level occur due to changes in repetition rate and pulse width, etc., with a.c.-coupling.

There are normally three modes in which the timebase may be triggered: these are typically labelled 'Automatic', 'Normal' and 'Single Sweep'. In the Automatic mode, the sweep generator will free-run in the absence of a triggering signal, thus producing a bright baseline on the CRTscreen. The application of trigger signals is sensed by special circuits within the timebase system, the sweep generator being automatically returned to its triggered condition. The Auto mode requires minimum manual operation of the triggering controls, and is suitable for the majority of regularly-repetitive signals. A particular type of automatic operation, known as 'Peak-to-Peak Auto', sets the range of the Level control to the same value as the peak-to-peak excursion of the trigger signal. For all practical purposes, this method is foolproof, the only condition which causes mal-triggering being too small a signal amplitude.

The Normal mode is identical to the Auto mode in all respects save one—when trigger signals are not present, the sweep generator becomes inoperative and remains at rest. This mode requires manual setting of the Level control to suit the circumstances, and is most useful for events of a random nature or whenever the repetition rate of the signal is low.

Single Sweep mode operates in the same way as the Normal trigger mode, but locks out the timebase generator after one sweep has occurred. The generator requires resetting manually or, in some cases, remotely before another sweep can be initiated. This mode is used when a single event is being recorded, either by means of a camera, or by use of a storage CRT.



6. Timebase internally triggered at 250 MHz.

The Timebase System

With few exceptions, oscilloscopes are equipped with internal sawtooth sweep generators which are designed to produce a constant speed deflection of the beam in the horizontal axis. The slope of the sawtooth is so arranged as to provide a defined amount of deflection in a defined time period, —hence the term 'timebase'. The characteristics of most importance in the timebase system are the range of sweep speeds; the accuracy and linearity of the sweeps; and the provision of such features as sweep magnification, sweep delay and sweep switching.

Sweep Range

Some oscilloscope applications require fast timebase sweeps, and others slow sweeps. An instrument which offers the widest range of sweep speeds is clearly the most versatile; speeds of from as low as 5 s per division to as high as 2 ns per division are to be found in general-purpose oscilloscopes. However, the major use of an oscilloscope is as a high-speed tool: therefore, the performance of the timebase at the faster sweeps is generally of most importance. Compatibility with the high-frequency response of the vertical system is normally regarded as adequate if it is possible to display one cycle of the upper 3 dB frequency limit across the full horizontal scale. In the case of high-frequency oscilloscopes, it is rare to find sweep speeds which are as high as this.

For risetime measurement to be as accurate as possible, the step signal should cover the full vertical scale and the sweep rate should be sufficiently fast for the leading edge to be displayed at about a 45-degree slope. This means that the fastest sweep should be able to move the beam a horizontal distance equal to the full vertical scale in a time equal to the vertical risetime. Because of the relative insensitivity of the CRT horizontal deflection plates, such a requirement would impose a greater strain on the design of the horizontal amplifier than on that of the vertical amplifier; in practice, fast oscilloscopes never meet this requirement. More usually, the fastest sweep speed allows the vertical risetime to be displayed across about one division of the horizontal scale.

Sweep Accuracy and Linearity

If satisfactory time measurements are to be made with an oscilloscope, its timebase system must be capable of producing sweeps which are both accurate and linear (as viewed on the CRT screen). The best method of verifying these properties is to apply accurate time marks in such a manner that, if the sweep is perfect, each pulse will coincide with its appropriate graticule mark.

The accuracy of the timebase is expressed in terms of rate error (e_r) as a percentage of full scale deflection. (Because of anomalies at sweep start and finish, it is common to find that the first and last portions of the sweep are excluded from the specification—'full scale', in this context, is usually defined as the centre 8 divisions of a 10-division display). This means that, with an accuracy of 3%, the actual full scale duration of the sweep should be within 3% of that indicated. In Fig. 8, V_r/T represents an accurate reference timebase ramp, while V_o/T represents the observed ramp. Sweep accuracy is

$$\frac{V_r - V_o}{V_r}\ (100)\%,$$

or, measured from the oscilloscope display,

$$\frac{e_r}{T}\ (100)\%.$$

In the case of magnified sweeps, the accuracy may be poorer than normal, since magnification is typically obtained by reducing feedback in order to increase amplifier gain.

Now consider Fig. 9: according to the above definition, the sweep shown has no error, since it passes through both the defined end points of the full scale. At the same time it is clear that something is wrong with the sweep, since the time marks on the display do not coincide with every graticule mark. The discrepancy is due to the sweep's non-linearity (shown greatly exaggerated). Although the concept of sweep linearity is a simple one, there are a number of ways in which it may be stated numerically. Fig. 9 illustrates one of these ways, which uses displacement error (e_d), the maximum displacement of a time mark from its correct position: non-linearity is

$$\frac{e_d}{T}\ (100)\%.$$

Other methods of describing this characteristic are the 'deviation from average' and 'difference measurement' methods.

A fairly recent trend is to combine sweep rate and linearity into one statement, by specifying accuracy as a function of defined increments of the display. For example, timebase accuracy may be 2% over the centre 8 divisions—if a 2 division interval is used for measurement, the accuracy may be no better than 5%.

Non-linearity in oscilloscope timebases can take various forms; several of these may be present at the same time in the same sweep. For this reason, linearity is seldom specified as such for fear of giving the impression that the sweep characteristics are worse than they really are. Once again, the demonstration affords the best opportunity to assess this aspect of an oscilloscope's performance.

Sweep Magnification

It is quite often necessary to examine a portion of a waveform which occurs considerably later than a suitable triggering event. Such waveforms can be displayed, provided that a sufficiently slow sweep is used; but then it may not be possible to obtain adequate resolution of that part of the signal which is of interest. One way of overcoming this problem is by means of sweep magnification, or expansion. This is achieved by increasing the gain of the horizontal amplifier in such a manner that the sweep overscans the screen, the range of the positioning control allowing any portion of the sweep to be displayed.

Apart from its use for selecting out a part of a waveform for more detailed analysis, another purpose of the sweep magnifier is to provide very fast sweep speeds. The maximum sweep rate available in a given oscilloscope is a function of both its fastest timebase setting and its highest magnification ratio. As mentioned before, sweep rate accuracy normally deteriorates when magnification is used—an uncertainty of about 1% in the magnification ratio is typical, this adding directly to the discrepancies which exist in the basic unmagnified sweep rate.

Sweep Delay

An alternative way of providing an expanded display of a waveform (or part of a waveform) is to use the delayed sweep technique. This involves holding the sweep generator in an inoperable condition until just before the arrival of the signal to be examined. At this point, the sweep can either be fired at once or else put into a triggerable state. In the first case, the delay between the initial trigger and the sweep start is continuously variable and can be directly calibrated; but any uncertainty in the time of arrival of the signal will show up as horizontal jitter. In the second case, the delay to the sweep start will be dependent upon the timing of the second trigger event (usually the same signal as that being examined), and thus cannot be calibrated; however, this mode has the advantage of removing any jitter in the display. It can be appreciated that there are circumstances in which one of these methods would be preferable to the other; indeed, both modes of operation are desirable in a delayed sweep system.

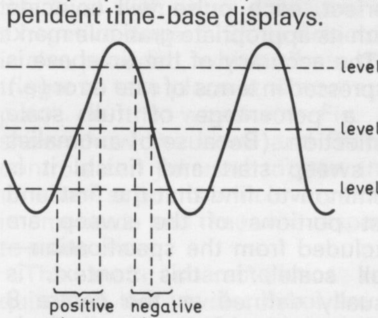
In general, much the same remarks can be made about the sweep delay generator as were made about the main timebase; in fact, in many oscilloscopes, the function is performed by a second imebase which has many, if not all, of the features of the main one. Considerations of sweep (delay) range, accuracy, linearity and triggering facilities are of concern, as are also the resolution and the inherent delay jitter.

The calibrated delay control usually consists of a multi-turn potentiometer whose dial is divided into 500 or 1,000 parts. The time discrimination obtainable is therefore dependent upon the delay time covered by the control: the smaller the increments between the fixed steps, the better able is the system to provide good resolution over a wide delay range. Some oscilloscopes have decade switching of delay time steps, which is adequate when there is a need to obtain a magnified view of a signal. When it is intended to use the technique for making accurate time interval measurements, a 1-2-5 switching sequence is more suitable: this usually calls for two complete and separate sweep generators in the oscilloscope.

Although a little complex and somewhat costly, a calibrated delay facility with two sweep generators can considerably enhance an oscilloscope's usefulness. As well as offering improved accuracy and high effective magnification ratios, dual-beam measuring capabilities become possible when it is allied to sweep switching.

Sweep Switching

The term 'sweep switching' refers to a method of time-sharing of a common horizontal deflection system between two sweep generators. The switching is accomplished in the same basic way as that described for the vertical system under 'Multi-Trace Amplifiers' (above). When used in conjunction with a dual-trace vertical amplifier, this arrangement provides in one package all the features of two separate oscilloscopes. A variety of novel display modes are made possible, such as sequential delaying and delayed sweep presentation, and independent time-base displays.



7. Control of triggering point by use of Slope and Level controls.

The Horizontal Amplifier

The main function of the horizontal amplifier is to process the sweep sawtooth waveform in such a manner that a satisfactory timebase is presented on the CRT screen. From this point of view, most of the characteristics of interest are included in the description of time base performance, such factors as sweep range, accuracy and linearity being determined as much by the quality of the horizontal amplifier as by that of the sweep generator itself. However, it is usual to find that facilities for accepting an external signal are provided, so that the plotting of one variable against another may be undertaken (XY operation). Amongst the uses for this type of presentation are the plotting of hysterisis curves and measurement of phase shift. The properties of most importance in these applications are bandwidth, sensitivity and phase response.

There are usually few problems encountered in XY operation when the signals being dealt with are of low frequency. Low-frequency oscilloscopes often incorporate a horizontal amplifier with characteristics virtually identical to those of the vertical amplifier. With fast, general-purpose oscilloscopes, though, the bandwidth of the horizontal system will seldom be more than a fraction of the vertical bandwidth: this limits the usefulness of XY techniques at the higher frequencies. In addition, phase shift differences between the two amplifiers become much greater as frequency increases, because of the effect of the signal delay line in the vertical channel (100 ns delay is equivalent to 90° phase shift at 2.5 MHz, 180° at 5 MHz, and so on). Sometimes a compensating network, which is included in the external input circuit to the horizontal amplifier, helps to balance out the extra delay and reduce the phase shift.

When high-frequency XY operation is to be a major use area, serious consideration should be given to the sampling oscilloscope. Most dual-channel samplers are equipped with a mode which permits one channel to control the vertical deflection, and the other the horizontal deflection. By this means, a wide-band system with excellent sensitivity and phase response properties is obtained, which is useful for frequencies of the GHz order.

The Display

It is true to say that the heart of any oscilloscope is its display device, the CRT. CRT's, like most other active components, are manufactured in a wide variety of types, each of which has its own set of performance features and characteristics to suit it to a particular application area. Some parameters are of interest whatever the application may be, while others have specific relevance to the sort of measurements for which the oscilloscope is mainly intended.

Display Size and Trace Width

In most cases, an oscilloscope is used directly, the operator setting the controls by hand and making direct visual observation of the screen. In these circumstances, display size is not one of the critical factors which affect measurement ability, but is more a subjective matter of taste. In recent years, there has been a trend towards larger screen sizes; today, a display of 8 cm × 10 cm is normal for a laboratory oscilloscope.

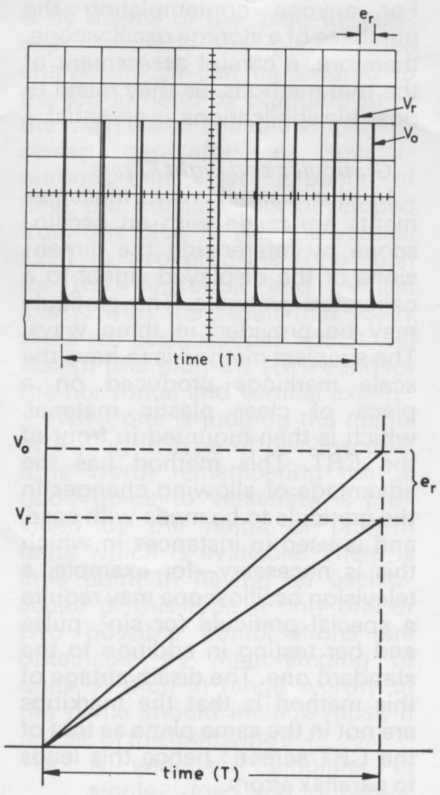
A more important aspect of the display is the spot diameter, or trace width, since this determines, in an absolute sense, the ability of the oscilloscope to resolve fine detail in a waveform. Because trace width varies with the position and intensity of the display, it is very rarely specified as such—yet another point to be carefully checked during the demonstration. Display size and trace width are to a certain extent inter-dependent, since a small display can be perfectly usable so long as the spot diameter is sufficiently small. Conversely, a large display can the more readily accommodate a fairly large spot diameter.

Phosphors

Cathode ray tubes may be fitted with any one of a wide range of phosphors. For oscilloscope work, however, a range of four or five phosphors is sufficient to cover the majority of applications. The characteristics of most interest are the brightness and spectral range of the light emitted, the time taken for the emission to decay to some low level, and the phosphor's relative resistance to burning.

Brightness is affected, to a significant degree by the spectral response of the viewing medium. For example, the human eye is most responsive to yellow or green light: consequently, phosphors having these colours (e.g. P31, P1 and P2) appear brighter than would ones having red or blue emissions. Photographic film, on the other hand, is usually most sensitive in the blue region: a phosphor such as P11 is thus the most suitable to use.

The decay time of the phosphor, sometimes termed its 'persistence', is of importance when an oscilloscope is to be used for low-frequency work. If the decay time is too short, the viewing of such signals will be uncomfortable and tiresome; a phosphor having a reasonably long persistence is a better choice, since the 'after-glow' will provide a visual image after the sweep has finished. This effect can be an embarassment when waveforms are being photographed: in these circumstances a medium or medium-short decay time produces the best results.



8. Sweep rate accuracy.

When the electron beam strikes the phosphor on the face of the CRT, heat is produced as well as light. In fact, with most phosphors only about 10% of the energy in the beam is converted into light, the remaining 90% being dissipated as heat. Should the energy applied to the phosphor become excessive, the heat will not be conducted away quickly enough: the phosphor will burn, leaving a permanent mark on the screen. The two factors most affecting burning, from an operator's point of view, are beam current density (controlled by the Intensity and Focus controls), and the time for which the beam excites a particular region of the phosphor (controlled by the Sweep Speed control). In practice, if the intensity of the display is kept to reasonable levels when slow sweeps are being used, the risk of burning will be minimised. Some phosphors are more resistant to burning than are others; broadly, three groups can be distinguished: those having low, moderate and high resistance to burns. Examples are: P12, P19 and P26 (all of low burn resistance); P1, P2, P7 and P11 (all of moderate burn resistance); and P31 and P15 (both of high burn resistance).

It can be seen that the choice of a phosphor can be quite difficult in those cases in which a number of conflicting requirements exist. For photographic purposes, P11 has the best performance; however, due to its purplish-blue colour and relatively short decay time, it is uncomfortable to look at, especially with signals of low and medium frequency. At the other end of the scale, P1 has a pleasant yellowish-green colour and reasonably long decay time but is poor from a photographic point of view. In most general purpose oscilloscopes, the best compromise is P31: this is the brightest phosphor visually, has a moderate persistence, a high resistance to burning and is good photographically.

Writing Rate

When considering an oscilloscope for use in the analysis of high-speed transient events, writing rate is a factor of prime importance. The term 'writing rate' refers to the maximum spot velocity (in units of cm/μs) which can be recorded as a visible trace on photographic film. It is important to realise that the expression describes the performance of not only the oscilloscope, but also the camera and film used for recording. If a faster camera or film were to be used, the writing rate figure would be increased without the oscilloscope being improved in any way. Any statement of writing rate must therefore be accompanied by a complete description of the method by which the figure was obtained. Because of the variability of the factors involved, writing rate is seldom specified directly; in the few instances in which it is given, it usually represents the worst case condition, i.e. the minimum writing rate is stated.

In order to obtain optimum results during recording of high-speed single events, it is necessary to choose the correct oscilloscope/camera combination. Among the factors affecting oscilloscope performance are: the design of the CRT and its spot diameter, the type of phosphor and the overall accelerating potential. Camera characteristics of interest are the lens *f* number and the object-to-image ratio, together with the ability to use very fast film. The only satisfactory way to determine the suitability of an oscilloscope and camera for the recording of a particular event is by direct experiment.

Storage Displays

An alternative to using a camera for recording a waveform is to employ an oscilloscope which has a storage CRT. Such oscilloscopes are able to retain a display on the screen after the spot has passed, and to allow observation of a signal long after it has ceased to exist. The main applications of a storage oscilloscope are the analysis of transient events (in which application it obviates the need for a camera), and for the examination of slowly-changing phenomena (in which application it removes the need for a long-persistence phosphor).

Storage CRT's as used in oscilloscopes are of two types, each operating on a different principle and having its own advantages and drawbacks. The direct view bistable storage tube relies on a process of secondary emission which takes place in the phosphor layer for its operating principle. The main advantages of this tube are a relatively fast writing rate, long viewing periods (up to an hour or more), good resolution in the stored display, and the possibility of independent control of the upper and lower halves of the screen (this is extremely useful for comparison purposes). The mesh (or transmission) storage tube contains a mesh of insulating material, situated just behind the screen, which is charged with the pattern of the display. This type of tube can offer a bright stored picture; furthermore, because the rate of decay of charge on the mesh can be varied, it can give the effect of a phosphor which has a variable persistence.

It is difficult to classify in any rigid way the application areas best served by these two different storage tubes. In a very general sense, however, it could be said that the bistable tube is somewhat more suited to transient analysis work, and the mesh tube to the display of slowly-changing signals. As with many aspects of oscillography, the personal inclinations and tastes of an oscilloscope user can subjectively modify the relative importance of the arious factors to be considered. For anyone contemplating the purchase of a storage oscilloscope, therefore, a careful assessment of the two methods, as they relate to possible applications, is essential.

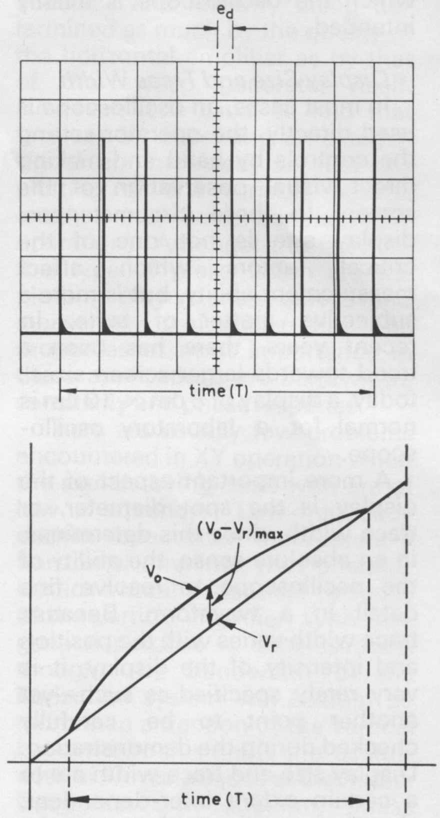
Graticules and Light Filters

In the normal way, measurements are made with an oscilloscope by referencing the dimensions of the displayed signal to a calibrated graticule. The graticule may be provided in three ways. The simplest method is to have the scale markings produced on a piece of clear plastic material, which is then mounted in front of the CRT. This method has the advantage of allowing changes in the graticule to be made with ease, and is used in instances in which this is necessary—for example, a television oscilloscope may require a special graticule for sin² pulse and bar testing in addition to the standard one. The disadvantage of this method is that the markings are not in the same plane as that of the CRT screen: hence this leads to parallax errors.

The problem of parallax can be overcome by marking of the graticule on the inside of the CRT face-plate. With such a system, (known as an 'internal graticule') it is possible to change the markings only by changing the CRT. For general-purpose instruments this is not a real drawback, an internal graticule being standard fitment to the majority of today's oscilloscopes.

A third technique for producing a graticule, and the one which is often used in conjunction with a camera, is to project the markings, via a beam-splitting mirror in front of the screen, into the same plane as the phosphor. By this means parallax is eliminated; furthermore, by changing the projected transparency, it is possible to use any type of markings.

The main use of light filters is for improving the contrast of the display, by reduction of the amount of ambient light reflected from the CRT face-plate. A simple smoke-grey plastic filter is effective in most cases, but can suffer from disturbing reflections from its shiny surface. If this happens, it is possible to use either a polarizing or a mesh filter, both of which considerably improve the contrast ratio. Another use for a light filter is for separation of the long decay component from the short decay component when a double-layer phosphor is in use. For example, if a blue filter is used with P7, the persistence will appear to be quite short; but if an amber filter is fitted, the persistence will be significantly increased.



9. Sweep linearity.

Environmental and Mechanical Characteristics

When an oscilloscope is to be used in a normal laboratory or factory environment, there is usually no need to seek any particular mechanical characteristics. For field use, however, or when an instrument is to be stored or transported under less than ideal conditions, the need for an ability to withstand a harsh environment becomes apparent.

The environmental characteristics which are of most significance are temperature, humidity, altitude, vibration and shock. Specifications for temperature and altitude are typically such that prolonged operation at the extremes will not cause serious damage in the short term. In the long term, operation at high temperatures will clearly have an adverse effect on reliability: it is thus advisable to take this into account if there is no possibility of avoiding such operation. Specifications for humidity, vibration and shock are usually conservative (from a practical point of view), and operation at these limits may lead to some slight physical deterioration.

Another aspect which may in

some circumstances be of interest is the amount of electromagnetic interference produced by the oscilloscope. This can be very important at times when the oscilloscope is to be used in close proximity to other instruments or equipments which are liable to have their operation upset by such interference. It is sometimes possible to obtain a special version of an oscilloscope which incorporates additional shielding which will reduce the level of interference.

If it will be necessary to carry an oscilloscope for any appreciable distance, consideration must be given to its size, weight and shape. Obviously, a small, light oscilloscope will be the easiest to carry; but the mechanical configuration, in particular the placing of the carrying handle, is just as important.

VERSATILITY

An oscilloscope is, by its very nature, a versatile tool, able to measure a wide variety of parameters on a diverse range of signals. This property of versatility is a highly desirable one in a measuring instrument, since the type of work that it is required to do is frequently not precisely known at the time of purchase. Even when a piece of test equipment is obtained for a particular job, it can happen that requirements change or new requirements arise—in these circumstances, an instrument with a high degree of versatility is excellently protected against obsolescence. Naturally, extra attributes inevitably have to be paid for; but there is no doubt that money spent on buying versatility can prove to be a sound investment.

Versatility in an oscilloscope generally means the ability to make most types of measurement on most types of signal. It is derived from two sources: the basic performance of the oscilloscope and the features that it incorporates, and the possibility of changing the oscilloscope's characteristics, or supplementing them, by means of accessories of various kinds. A wideband oscilloscope, for example, is necessarily more versatile than is a narrowband one, because it can display those high-frequency signals which are not observable on the low-frequency oscilloscope. Similarly, a delayed sweep feature enables more measurements to be made on those signals which can be displayed. One of the most important ways in which flexibility can be provided in an oscilloscope is by means of the 'plug-in' concept, whereby the performance characteristics can be tailored to the job in hand by plugging-in to the main frame suitable amplifiers, sweep generators or special-purpose units. Over a period of time the concept has developed from one plug-in (for the vertical axis) to two plug-ins (one each for the horizontal and vertical axes), with the result that today there are oscilloscopes which will accept four plug-ins (two each for the horizontal and vertical axes).

When one is judging the merits of a plug-in type of oscilloscope, it is worth remembering that a good guide to versatility is provided by the range of plug-in units which is available. There is little point in having an oscilloscope of this type if only one or two possible combinations are obtainable by interchanging of units. A plug-in range worthy of the name should include most, if not all, of the following:

a. A wideband amplifier in single-, dual- and four-trace versions.
b. A high-gain differential amplifier, preferably with bandwidth selection for control of display noise.
c. A wideband differential amplifier, perhaps with precision comparison voltage for slide-back measurements.
d. A current probe amplifier.
e. Delaying- and delayed-type sweep generators.
f. Sampling amplifiers which offer a range of bandwidths and input impedance characteristics.
g. Sampling timebases with real time, sequential and random sampling modes.

An oscilloscope system which has a range of units as described is capable, within individual performance limitations, of making most of the measurements on waveforms which are normally required. It has the great advantage that the system can be built up step by step as the need dictates, and expanded as improving technology allows. A good example of this philosophy is the instrument shown in Fig. 1. This is a four plug-in type of oscilloscope, equipped with a built-in alpha-numeric character generator which gives digital readout on the screen of both signal parameters and selected scale factors. In addition to having a full complement of normal oscilloscope plug-ins, this instrument will accept counter and multimeter units which permit digital measurement of frequency, temperature, resistance, voltage and current. The combination of analogue and digital display provides optimum versatility: the term 'Integrated Test System' has been used to describe this arrangement.

Another significant factor affecting versatility is the availability of suitably-designed accessories to augment the oscilloscope's basic measuring capacity. For example, few oscilloscopes are capable of displaying a pulse of amplitude 30 kV—for this requirement a special-purpose attenuating probe of high-voltage rating is required. If no such probe is available the measurement cannot be made. Signal probes are among the most useful of the accessories used with oscilloscopes, and form a convenient and high-performance interface between the signal source and the oscilloscope itself. In order that the many varied needs of signal coupling should be catered for, the available probes should include: a.c. and d.c. current, high-voltage, differential and high-speed attenuating and active (FET) probes. Other accessories in common use are: co-axial cables, terminations, attenuators and connector adaptors of various kinds; oscilloscope trolleys and carrying cases for ease of transportation; mounting frames and racks; and viewing devices such as hoods and light filters.

RELIABILITY

An important characteristic of any oscilloscope is its reliability. In some circumstances (military applications for instance) it is of paramount concern; but even for normal laboratory or factory use it must still be carefully considered, because of its effect on the instrument's value. Clearly, if an oscilloscope is frequently breaking down, then not only will heavy repair charges result but time will be lost, projects delayed and personnel and plant under-employed. The cumulative effect of such a situation can be excessively high costs which are out of all proportion to the sum initially spent on the equipment.

Although the term 'reliability' is frequently heard, it is mostly used in an ill-defined and ambiguous fashion. From the point of view of electronic equipment, it means the ability of a system to continue to carry out, in a satisfactory manner, the tasks for which it was built. In other words, the specified performance of the system must be maintained for extended periods of time without repairs, replacements or adjustments being necessary. The extent to which an oscilloscope achieves this goal is a reflection of many things, such as the soundness of design; the quality of materials and components used; the degree of care and attention to detail which is taken during construction; and the extensiveness and thoroughness of quality control and evaluation procedures.

Reliability, in common with some other desirable oscilloscope attributes, is difficult to describe and quantify. Methods have been devised to measure reliability, but it is questionable whether the resulting statistical data offers a realistic basis upon which to make decisions. One problem is concerned with defining a 'failure' —is it to be regarded only as a catastrophic breakdown, or should it also include any deviation from specified performance limits? If the latter, then the completeness and tightness of a specification would have a marked influence upon the reliability figure. Also, due to variations in the conditions in which equipment is used, it is difficult to relate the figure to practical results. Because there is, as yet, no standardised way in which oscilloscopes characteristics, or reliability numbers, are specified, the current usefulness of such numbers is limited.

Reliability depends, in the final analysis, upon company philosophy and the abilities and attitudes of the people that it employs. For this reason, the best indication of the reliability to be expected of an instrument is probably the past performance record of the manufacturer's instruments.

SERVICE

The quality of service, when added to the technical performance, versatility and reliability of the product, completes the 'package' which the instrument manufacturer is offering for sale. Before-sales service, in the form of applications analysis and the provision of demonstrations, can be a valuable aid in selection of the right instrument to suit present and future needs. Once an instrument has been purchased, the need for after-sales service arises, in order that the maximum benefit may be obtained from the instrument. After-sales service can take various forms, repair and recalibration being an obvious one. Even the most reliable of instruments will require maintenance and, eventually, replacement of parts which have worn out. When this time comes, it is important that the work be carried out both quickly and thoroughly. This, in turn, implies the existence of comprehensive servicing documentation and spare parts stocks, together with trained personnel, skilled in such work. Other types of service can include technical training programmes (carried out either on the customer's premises or at the factory), and the publication of technical periodicals and books.

Before-sales service can be judged at no cost to the customer. It is only prudent, therefore, for any potential purchaser to avail himself of the opportunity to have a demonstration of equipment in which he is interested, and to seek applications assistance from the manufacturer's field engineer. By this means he will not only obtain help in clarifying any points regarding the technical aspects of the situation, but also gain some idea of the type of after-sales service that is available. The provision of good service, like reliability, is the result of company policy and the outlook of the people responsible for providing such service—once again, the past performance of the manufacturer concerned is the most reliable guide to what may be expected in the future.

CONCLUSION

The modern oscilloscope is a sophisticated and complex system capable of measuring a wide range of electrical phenomena. The above discussion has been concerned with some of the factors which affect the choice of a general-purpose oscilloscope. It is hoped that it will prove to be of use to anyone about to buy such an instrument, by helping him to reach a better purchasing decision.

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