Oscilloscope Measurements Guide

Part 1

How to use an oscilloscope to accurately obtain quantitative and qualitative information about a circuit's or a device's performance

By Robert Witte

The oscilloscope is undoubtedly the most versatile electronic instrument in use today. Unlike meters, which allow the user to measure only amplitude information, the oscilloscope (or "scope") allows one to view instantaneous voltage over time. This reveals the shape of a waveform, while parameters such as frequency and phase can also be measured. The oscilloscope can also be used to compare two different waveforms and measure their time and phase relationships.

This discussion of oscilloscopes and measurement techniques will be centered around the typical two-channel analog scope, which has largely eclipsed single-channel ones. Four-channel scopes are also prevalent in the marketplace and are particularly useful for measuring signals in digital systems. (Digital systems usually have multiple data and address lines on one bus that may need to be viewed simultaneously.) Four-channel scopes operate similarly to two-channel scopes, of course, with the exception of having twice as many inputs and vertical amplifiers.

For general-purpose use, analog scopes are still more economical than digital scopes (for equivalent frequency range). As analog-to-digital conversion technology improves, this will undoubtedly change. In concept, analog and digital oscilloscopes perform the same types of measurements, but with different techniques internal to the instruments.

Let's examine the working elements of an oscilloscope as a prelude to exploring how to use it for measurement purposes that range from frequency to identifying values of components.

Typical Oscilloscope

When a sine wave is displayed on an oscilloscope, the vertical axis represents voltage and the horizontal axis represents time. The oscilloscope display has a set of horizontal and vertical lines called a graticule to aid a user in estimating the value of the waveform at any particular point.

Figure 1 highlights a block diagram incorporating scope features that will be discussed. The various switches allow the scope to be configured in a way that allows a wide variety of measurement functions to be performed. Both input channels can be configured for dc or ac coupling; the electronic switch allows both alternate and chop modes for two-channel operation and the display can be set up for either time-base or X-Y operation.

The display of an oscilloscope (usually a cathode ray tube, or CRT) requires two pieces of information: the vertical position to be plotted and the horizontal position to be plotted. The vertical axis represents the waveform to be plotted, so the input of the oscilloscope is connected to an amplifier that drives the vertical position of the display. On the horizontal axis, time is plotted. Driving the horizontal position of the display is an internally generated waveform that represents time. The section of the circuitry that produces the time waveform is called the time base.

We know what the vertical signal looks like—it's just whatever the input waveform is, perhaps a sine wave or square wave. What we want the time base to do is constantly increase the horizontal position as the input voltage goes through a cycle. This results in the input waveform being swept or painted across the display at some rate, depending on the time base. The time base waveform required to do this is a constantly increasing voltage called a ramp. Since the display is usually updated repetitively, the ramp starts over when it reaches its maximum value, resulting

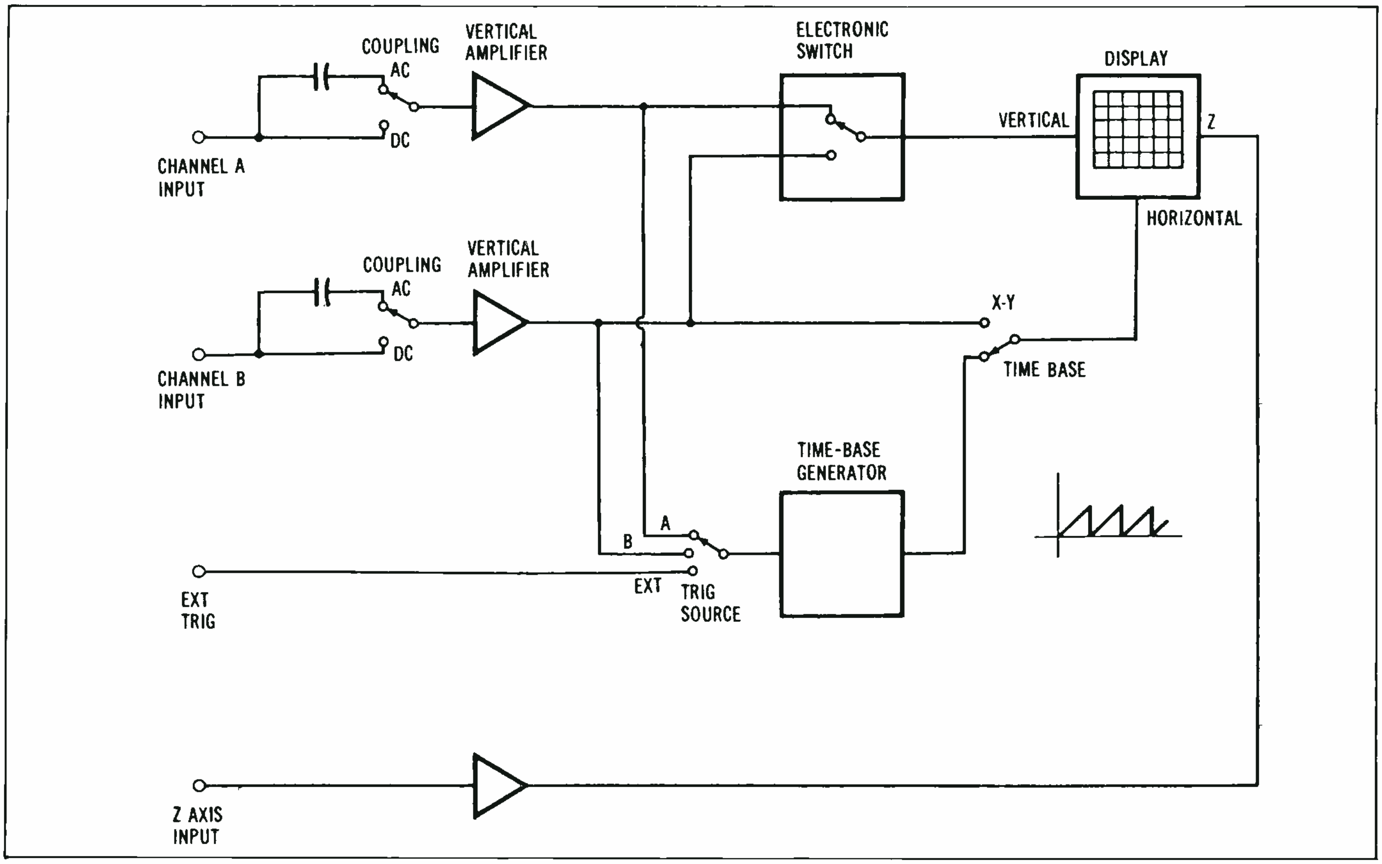

Fig. 1. Block diagram of typical two-channel oscilloscope.

in a sawtooth waveform. Each cycle of the sawtooth waveform corresponds to one sweep across the display. A small delay (called the retrace time) occurs between each ramp of the sawtooth as the horizontal position is reset to the left side of the display.

A time base alone is not sufficient to produce a usable display, however. The time base must know when to start a sweep. Without this information, the display will attempt to show the correct waveform, but with a random start time. At best, this results in an unstable waveform wandering across the display. At worst, the display is a jumbled collection of waveforms smeared together filling the entire display area (Fig. 2a). A properly triggered waveform, having a predictable and repeatable starting point, will be stationary from sweep to sweep (Fig. 2b).

The trigger point on a waveform is usually defined using both a voltage level and a slope (positive or negative). The trigger level control determines the voltage level at which the trigger will occur. The trigger slope control, in turn, determines whether the trigger will occur on rising (positive-slope) or falling (negative-slope) portions of the waveform.

When the waveform being measured is used as the trigger source, the oscilloscope is using internal trigger. Scopes that have more than one channel usually allow the user to select which of the channels is to be used. Internal trigger is used the most, but it is possible to trigger off other waveforms. An external trigger input is provided to allow the user to connect an external signal to the oscilloscope to be used for triggering purposes. This signal is usually not viewed one the scope display, but some scopes do have this capability to help the user in setting up the triggering. The line trigger selection uses the ac power-line frequency as the trigger signal (usually 60 Hz). Line trigger is useful for observing waveforms that are either directly related to the power-line frequency (including its harmonics) or have power-line related voltages superimposed on the original waveform.

The trigger can be ac coupled or dc coupled. Dc coupling presents the trigger circuit with a waveform containing both ac and dc voltages, while ac coupling removes any dc level that might be present. Ac coupling is useful when the desired trigger signal is riding on a dc voltage that must be removed. Many oscilloscopes include additional filters that can be switched into the trigger circuit to condition the trigger signal. A low-frequency reject filter, for example, removes low frequencies such as the 60-Hz line frequency (and its harmonics) that may be present in the trigger signal, causing triggering problems. A high-frequency reject filter will similarly remove high-frequency noise.

The trigger holdoff control disables the triggering circuit for a period of time after the end of the sweep. This is useful when the waveform has several places in its cycle that are the same as the trigger condition. The oscilloscope would normally trigger on all of them, but with trigger holdoff, the scope ignores all but the first one.

For a better understanding, suppose we want to display the first cycle of a pulsed sine wave. The trigger could be set to zero volt and positive slope, which will trigger off the beginning of the sine wave. Unfortunately, this trigger condition exists at the start of every one of the sine-wave periods, causing the oscilloscope to display every cycle. However, if the trigger holdoff is properly adjusted, subsequent triggers can be ignored and only the first cycle of each sine pulse will be displayed.

Triggering is probably the most troublesome part of using an oscilloscope. Most scopes provide a variety of ways to trigger on a signal so that the user can customize the triggering to a particular measurement problem. Of course, this also means that the user must understand and make decisions about what type of triggering to use.

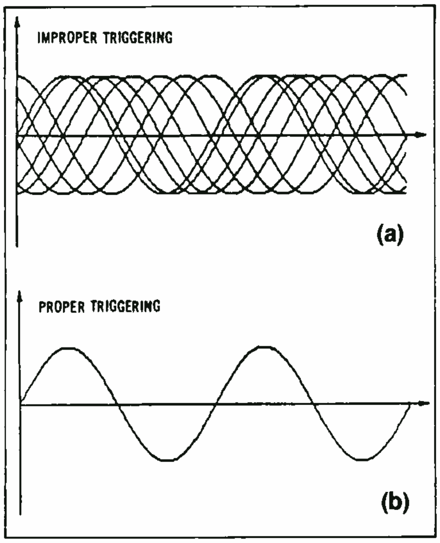

Fig. 2. Examples of oscilloscope triggering: (a) improperly triggered waveform results in unstable display; (b) properly triggered waveform has stable display.

Sweep Control

In single-sweep mode, the oscilloscope displays only one sweep and then waits until the user resets the scope for another sweep. This allows one to capture a particular one-shot, or transient event, rather than continuously updating the display with unwanted information. Although this feature is supplied on almost all oscilloscopes, it is most useful when the scope also provides a method of storing the waveform, at least temporarily, on the screen. Otherwise, the single-sweep tends to be a brilliant, but brief, flash across the display.

Most oscilloscopes supply two types of continuous sweeps: automatic and normal. The difference between the two is rather subtle but important. With normal sweep, the oscilloscope is not swept until a valid trigger occurs. This is fine for most ac waveforms, but it is inconvenient if the input is a dc voltage. In this case, no trigger will occur, since the dc input is constant and will not be passing through whatever trigger level happens to be selected. The result is a blank display.

Automatic sweep operates just like normal sweep except that if no trigger occurs for a period of time (like in the case of a dc input or an incorrectly adjusted trigger level), the scope generates a sweep anyway. This is convenient because it gives the user a look at the waveform, even if it isn't triggered properly. The user can then determine whether the waveform is on-screen and what action is necessary to correct triggering. In the case of a pure dc voltage, triggering is rather meaningless—the user just wants to view the constant voltage. If a trigger starts occurring at a fast rate (typically anything greater than 40 Hz), the scope triggers just as in the normal sweep mode.

Automatic sweep should be the default choice, since it will give good results on most waveforms. The exception is when the desired trigger condition occurs so infrequently (a very-low-frequency sine wave, for example) that the automatic mode will begin triggering before the appropriate time. In that case, normal sweep should be used.

Most oscilloscopes have at least two channels, both of which can be displayed at the same time. One way to do this is to have a display that can plot two waveforms simultaneously. Analog scopes that have true simultaneous dual-trace capability are sometimes called dual-beam oscilloscopes. This term is used when a CRT display has two electron beams active at the same time. Another, more cost-effective, method is to use a single display but electronically switch between two possible input signals. If this is done quickly enough, it will not be noticeable to the user nor will it affect most measurements. This consideration does not apply to digital scopes, which are not limited by the type of display, but by the analog-to-digital conversion circuitry.

There are two different ways of deciding when to throw the electronic switch. Chop mode switches between the two inputs as fast as possible while the waveforms are being

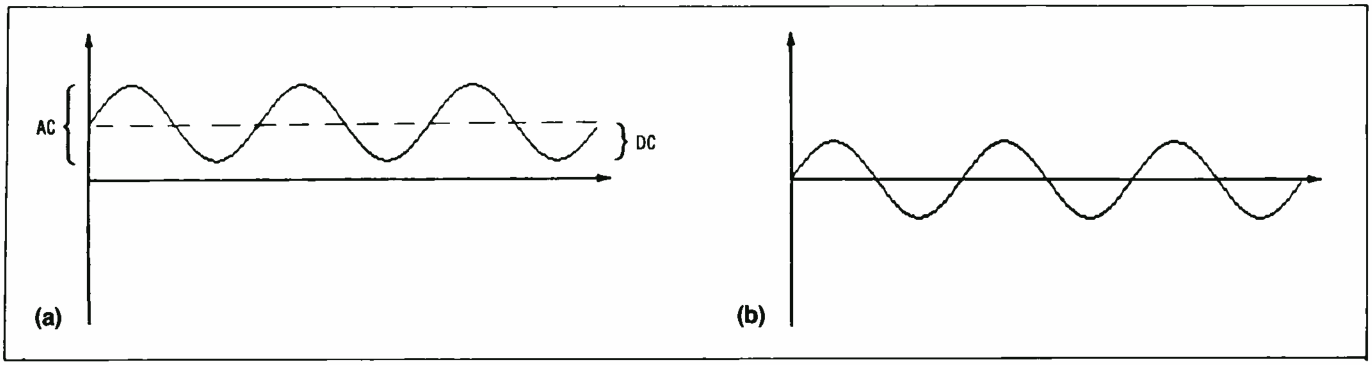

Fig. 3. Effect of dc and ac coupling: (a) dc coupling causes entire waveform to be displayed, including dc portion; (b) ac coupling removes dc portion of signal.

plotted on the display. The display trace switches back and forth ("chops") between the two waveforms during the sweep, resulting in both traces appearing on the screen. The two channels can be switched at such a high rate that the chopping cannot be seen. This works well for sweeps that are much slower than the rate at which the two channels chop. So chop is best for low-frequency signals. If chop mode is used on high-frequency waveforms (and with very fast sweeps), the chopping effect is noticeable in the display.

On the other hand, alternate mode makes a complete sweep of one waveform and then switches to the other input and takes another sweep. The first sweep displays channel A, the second channel B, the third channel A again, and so on. This works well during fast sweeps because if the update rate in the display is fast, the user perceives that both inputs are being plotted simultaneously. Therefore, alternate mode works best with high-frequency signals. If alternate mode is used on low-frequency waveforms (and with slow sweeps), however, individual sweeps of each channel become apparent and the effect of simultaneously displayed channels is lost.

One potentially misleading problem with alternate mode is that even though the two waveforms appear to be displayed simultaneously, they are really measured at two distinctly different points in time. For most measurements, this is not a problem, since the waveform repeats the same cycle every time. There are cases, however, where the user must measure both channels simultaneously. Oscilloscopes that do not have true dual-trace capability will almost always supply chop and alternating modes (for maximum flexibility).

Vertical Amplifier

Gain of the vertical amplifier will determine how large the waveform appears on the display. In an analog scope, vertical sensitivity will determine vertical amplifier gain and will be calibrated in volts/division so that the user can determine signal amplitude by counting the number of vertical divisions on the display. For example, let us assume a sine wave that has four vertical divisions peak-to-peak. If the vertical sensitivity control is set to 0.2 volt/division, the sine wave would be $4 \times 0.2 = 0.8$ volt peak-to-peak.

Oscilloscopes have a vertical amplifier for each input channel. The channels may be labeled in a variety of ways—channels A and B, channels 1 and 2, etc. In the usual time-base mode of the scope, both A and B are displayed as a function of time.

In addition to displaying channel A and/or B, many scopes provide the capability of displaying A + B or A − B. Also, one or both channels may be capable of being displayed inverted, in reverse polarity. (A − B might not be provided, but A + B with channel B inverted can achieve the same result.)

Coupling

Each input can be selectively ac or dc coupled. Figure 2 shows a waveform containing both ac and dc. If the scope is dc coupled, the waveform is displayed as in Fig. 3a. If it is ac coupled, the dc portion of the waveform is blocked and only the ac portion is displayed, as in Fig. 3b.

The previous example seems straightforward, but the issue of ac coupling may show up in other unexpected ways. Consider the pulse waveform in Fig. 4a, shown as a dc-coupled scope would display it. Thus, one might think that it would be unaffected by coupling. However, when the scope is ac coupled, the display changes! The waveform shifts down by about one-third of its original zero-to-peak value (Fig. 4b). The original waveform did have some dc present in it (remember, dc is just the average value of the waveform). Ac coupling removed the dc, leaving a waveform whose average value is zero. Notice that the waveform is not centered exactly around zero volt, since its duty cycle is 1/3. Ac coupling may also cause voltage "droop" or "sag" in the waveform (Fig. 4c) resulting from the loss of low frequencies.

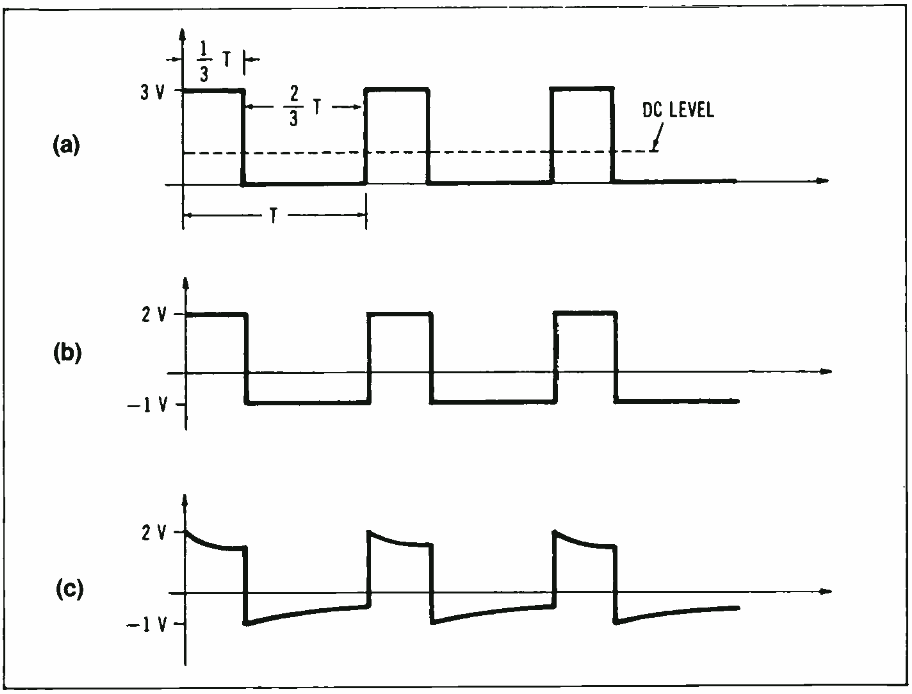

Fig. 4. Effect of ac coupling on a pulse train: (a) original waveform displayed with dc coupling; (b) pulse train with dc component removed by ac coupling; (c) ac coupling may cause voltage drop due to loss of low frequencies.

Most oscilloscopes have a convenient means of grounding the input (usually a switch near the connector). This is symptomatic of one of the most confusing things in using a scope—where is zero volt on the display? The ground switch allows the user to quickly ground the input and observe the flat trace on the display, which is now at zero volt. The line can then be set anywhere on the display that is convenient, using the display's position controls. Knowing where zero is defined along with the volts/division selection determines the scale on the display. Fortunately, more-recent digital scopes have eliminated the confusion by always displaying data on-screen in a known calibrated manner.

Many scopes provide a bandwidth limit control that activates a fixed-frequency low-pass filter in the vertical amplifier. This has the effect of limiting bandwidth of the scope (typically to about 20 MHz). Since bandwidth is such a desirable characteristic, it may seem strange to intentionally limit it. An example of where this comes in handy is when there is a noticeable amount of high-frequency noise riding on the waveform. When the bandwidth limit control is switched on, the high-frequency noise is eliminated, but the original sine wave remains uncorrupted. Of course, this works only when the interfering noise is outside the bandwidth of the filter and the desired signal is inside the filter's bandwidth.

X-Y Display

Most two-channel scopes have the ability to plot the voltage of one channel on the vertical (Y) axis and the voltage of the other channel on the horizontal (X) axis. This results in a voltage-vs.-voltage display, usually called A vs. B, Y vs. X, or simply X-Y. The time-base triggering circuits are not used when operating in this manner.

This feature greatly enhances an oscilloscope's usefulness. Now the horizontal axis is no longer limited to only time. Another parameter that can be represented as a voltage can now be used as the X axis. More precisely, both vertical and horizontal axes can be used to display any two parameters represented by a voltage. For instance, if a current-sensing resistor were used to convert a current into a voltage, a current could be

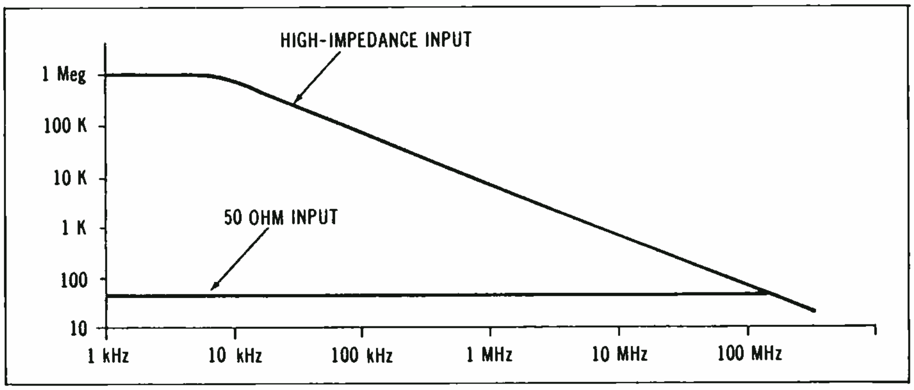

Fig. 5. Plot of magnitude of input impedance for high-impedance and 50-ohm inputs.

plotted on the vertical axis while another voltage is plotted along the horizontal axis.

Z-Axis Input

The Z-axis input (also known as the intensity-modulation input) provides a means for controlling a display's intensity while in the X-Y mode. The name "Z axis" comes from the fact that, in addition to the X-axis and Y-axis information, display intensity can be varied to provide an additional "axis" of information—the Z axis. If a positive voltage (typically several volts) is applied to the Z-axis input, the trace is blanked (has no intensity). If a negative voltage is applied to the Z-axis input, the trace has full intensity. Voltages between the two extremes produce less than full intensity (but is not blanked).

The actual voltages, and even the Z-axis input polarity, vary depending on the model of instrument. Given the proper Z-axis control signals, different sections of the trace can have different intensities. This is useful for highlighting a particular point on a display or for turning off the trace to start a plot over at a particular point (without having a trace drawn to that point).

Oscilloscope Inputs

The typical oscilloscope has a high-impedance input so that the circuit under test is not loaded significantly. The input can be modeled by a 1-megohm resistor in parallel with a capacitance. The value of the capacitance depends on the particular model of scope, but is generally in the range of 10 to 30 pF.

The magnitude of a typical input impedance is plotted in Fig. 5. At low frequencies, the capacitance acts like an open circuit and the impedance consists of only the 1-megohm resistor. At about 8 kHz, the capacitor's impedance becomes significant as it just equals the 1-megohm resistor's impedance. Impedance of the parallel combination continues to gradually increase for higher frequencies. Although the input impedance is very high at low frequencies, keep in mind that it will tend to load the circuit being measured as the frequency increases.

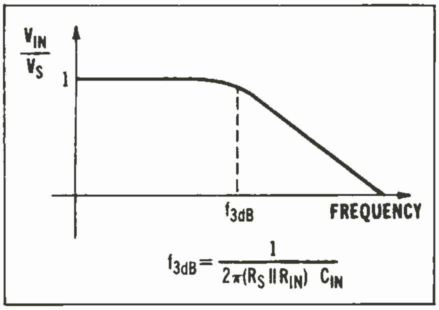

Fig. 6. Response of 1× probe rolls off at higher frequencies; 3-dB bandwidth is calculated with equation shown.

Some oscilloscopes offer a second type of input having a 50-ohm input impedance. It is often the same connector as the high-impedance input, with a switch for selecting between the two, and is frequently implemented by placing a 50-ohm resistor in parallel with the 1-megohm input. Since 1 megohm is much larger than 50 ohms, the effective parallel impedance is approximately 50 ohms.

If a scope does not have the 50-ohm input built in, an appropriate load can be placed in parallel with the high-impedance input to produce the same result. The input impedance is modeled as a single 50-ohm resistor, with the input capacitance in parallel. In a 50-ohm system, the capacitive effect is less critical, resulting in a wider-bandwidth system. Figure 5 shows that even though the 50-ohm input impedance starts out much smaller than the high-impedance input, it remains constant out to a higher frequency.

The major disadvantage of a 50-ohm input it that it is too low a load resistance for many circuits. (For these cases, very-low-capacitance active probes, which are designed to drive the 50-ohm input, are used to provide minimal circuit loading and greater overall bandwidth.) Of course, the 50-ohm input is especially convenient for systems that have an inherent 50-ohm impedance.

Most oscilloscopes have inputs that have one side directly connected to ground. This is the most practical and economical way to build the instrument. This is usually not a problem, since most measurements are made with respect to ground anyway. For some measurement situations, however, it is desirable to connect the scope input to arbitrary

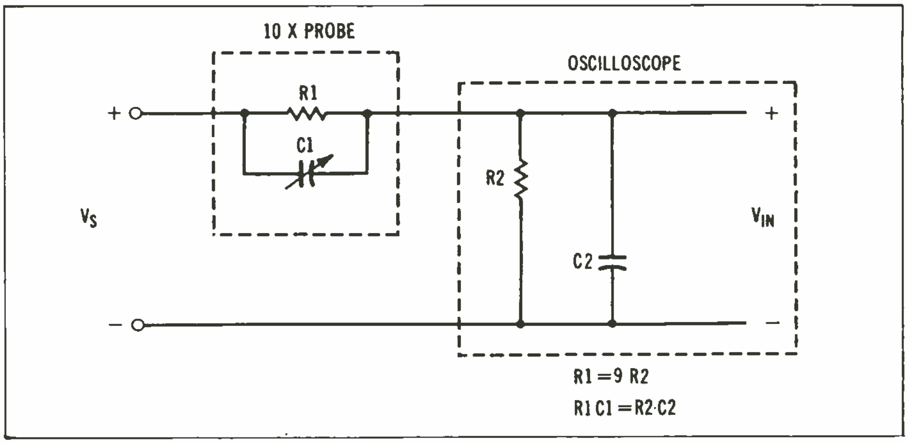

Fig. 7. A 10× probe used with high-impedance oscilloscope input. Effect of capacitors cancels when C1 is properly adjusted.

points in the circuit, including ones that are not grounded. Some scopes do have floating or differential inputs that allow both leads of the input to be connected away from ground. In this case, grounding is not a problem. A two-channel scope with the ability to display A − B (the difference between the two channels) can be used as a one-channel floating input source.

Oscilloscope Specifications

A set of typical scope specifications may appear as follows:

Bandwidth (3 dB): 40 MHz
Rise time: 8.8 ns
Input impedance: 1 megohm in parallel with 20 pF
Deflection factor: 1 mV/div to 5 V/div, ±3%; 12 steps in 1-2-5 sequence
Sweep time: 0.1 µs/div to 0.5 s/div, ±3%; 21 steps in 1-2-5 sequence

The deflection factor tells what vertical volts per division settings are available. In this example, settings between 1 mV and 5 volts per division are available in a 1-2-5 sequence (1 mV, 2 mV, 5 mV, 10 mV, 20 mV, etc.). Included with the deflection factor is a percent error (±3%) that defines the fundamental accuracy of the instrument. Similarly, the time-per-division settings on the horizontal axis are from 0.1 µs to 0.5 second per division. Again, an error specification that defines the accuracy of the time scale is included in the specs (±3%).

Digital Scopes

Conceptually, analog and digital oscilloscopes do the same thing—they display voltage waveforms. The analog scope uses traditional circuit technology to display the voltage waveform on a CRT. In contrast, a digital scope converts the original analog signal into a series of binary numbers that can be displayed or stored in memory. This means that a digital scope is inherently a storage scope because the waveform is stored in digital form. Contrast this with the analog scope, where the waveform is a short-lived voltage trace. (There are techniques for storing waveforms on an analog display, but they are generally expensive, temperamental and have finite storage time.)

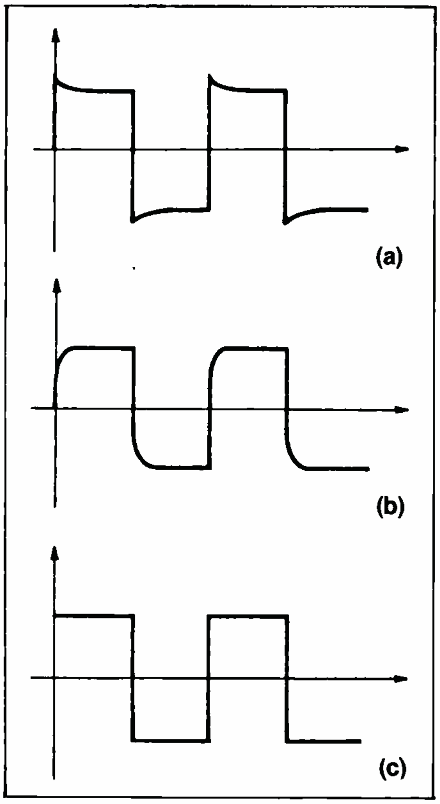

Fig. 8. Examples of 10× probe compensation: (a) undercompensated; (b) overcompensated; (c) properly compensated.

The ability to store waveforms is especially important when capturing one-time events. Without waveform storage, the waveform is plotted across the display and then abruptly disappears. With storage, the waveform remains on the screen so that the user can carefully analyze the data.

Another advantage of digital scopes is the ability to display the waveform that occurred before the trigger. This may seem impossible at first glance, but a digital scope can accomplish this by constantly storing the input signal in memory while waiting for the trigger to occur. When the trigger does activate, the waveform portion that occurred just before the trigger is already stored.

Like other digital instruments, the digital scope is well suited to applications that require transferring waveform data to a computer. Since it stores the waveform internally as digital numbers, the data is already in a form compatible with computers.

Oscilloscope Probes

The high-impedance input of an oscilloscope can be connected directly to a circuit under test using only a simple cable. It is highly recommended that any cable used should be shielded, naturally, to minimize noise pickup. For maximum performance, however, a probe matched to the input of the scope should be used.

1× probes, also known as 1:1 (one-to-one) probes, simply connect the high-impedance input of the oscilloscope to the circuit being measured. They are designed for low capacitance, minimum loss and easy connection. Otherwise, they are equivalent to using a basic cable to connect the scope.

The 1× probe and the input impedance of the oscilloscope together produce a low-pass filter. For very-low frequencies, the capacitor acts as an open circuit and has little or no effect on the measurement. For high frequencies, the capacitor's impedance becomes significant and loads down the voltage seen by the scope. If the input is a sine wave, the amplitude will tend to decrease (due to the loading effect) and the phase will be shifted. The rise and fall times of pulse inputs will be increased. Figure 6 shows this effect in the frequency domain.

10× probes (also called 10:1 probes, divider probes or attenuating probes) have a resistor and capacitor in parallel inserted into the probe. Figure 7 shows the circuit for the 10× probe connected to a high-impedance input of a scope. If $R_1C_2 = R_2C_2$, the circuit has the amazing result that the effect of both capacitors exactly cancel. In practice, this condition may not be met precisely, but it can be approximated. The capacitor is usually made adjustable and can be tweaked for near-perfect match. Under these conditions, the relationship of V_s to V_{in} is:

$$V_{in} = V_sR_2/(R_1 + R_2)$$

which should be reminiscent of the voltage-divider equation. Resistor R_2 is the input resistance of the scope's high input impedance (1 megohm) and $R_1 = 9R_2$. From the previous equation, this results in

$$V_{in} = (1/10)V_s$$

Therefore, the net result is a probe and scope input combination that has much wider bandwidth than the 1× probe due to the effective cancellation of the two capacitors. The penalty incurred is loss of voltage. The scope now sees only one-tenth of the original voltage (hence the name 10× probe). Also, the circuit being measured sees a load impedance of $R_1 + R_2 = 10$ megohms, which is much higher than with the 1× probe. Some probes are designed to be conveniently switched between 1× and 10× operation.

This factor-of-ten loss in voltage is not a problem as long as the voltage being measured is not so small that dividing it by 10 makes it unreadable by the scope. This means that the scope's sensitivity may be a factor in deciding whether to use a 10× probe. On most oscilloscopes, the user must remember that a 10× probe is being used and must multiply the resulting measurements by a factor of 10. This is sort of a nuisance and, fortunately, some scopes include two scale markings: one valid for a 1× probe and the other valid for a 10× probe. Some new digital scopes have gone one step further and automatically adjust the reading by the correct amount when an attenuating probe is used.

Scopesmanship

An oscilloscope is a fairly complex instrument, especially when compared with a voltmeter. The large number of switches and knobs on its front panel can be intimidating to a novice user. Therefore, a few comments are in order to help the first-time user to get started.

After carefully reading the scope manufacturer's operating manual, the best way to get started with a measurement is to put the oscilloscope into a known state that will get at least something on the display screen. Some digital scopes have included a key called "Autoscale," which automatically evaluates the waveform, chooses an appropriate trigger condition, and selects reasonable horizontal and vertical scales. Pushing this button can prevent a lot of user frustration. Assuming that this feature is not available, a suggested starting point for setting up an oscilloscope measurement is listed here. (This can only be a start, as each measurement is somewhat different.)

Vertical Amplifier:
  Input coupling = dc
  Volts/div = 1 volt or (Expected Vo – p)/4
Time Base:
  Time base operation
  Time/div = 1 ms or 1/(4 × expected frequency)
  Auto sweep
Trigger:
  Internal trigger
  Trigger level = 0 volt
  Trigger slope = positive
  Trigger coupling = dc

Hopefully, a trace will appear on the display after the oscilloscope is set up and the scope settings optimized for the particular measurements. If there is no trace at all, then things like the power switch (yes, the power switch) and intensity control should be checked. Perhaps the waveform is just off-screen because it is much larger than the volts/division setting will allow on the screen? Try grounding the input—a horizontal line corresponding to zero volt should appear. Some scopes have a beam-finder button, which, when pushed, gives the user some idea where an off-screen trace is hiding.

If the trace is on-screen but is not stable, adjust the trigger controls. Try tweaking the trigger level to make the waveform stable. The slope and trigger coupling may also be helpful. If the display is stable but scaled improperly, adjust the time/division or/and volts/division knobs.

Probably the best advice for operating an oscilloscope is: carefully try something! The two approaches that do not work are: (1) just sitting in front of the instrument, staring at it, and (2) twisting every knob until all controls are guaranteed to be in the wrong positions. Instead, make an educated guess as to what control might correct the problem and try it. If it does not improve the situation, it should probably be returned to the original setting. On the other hand, try not to get the oscilloscope set up so that only a seasoned technician can straighten it out. If in doubt, revert to the suggested starting point.

In order to maximize the bandwidth of the 10× probe, it is necessary to precisely adjust the probe's capacitor to cancel the input capacitance of the scope. This is accomplished by a procedure known as compensation. To do this, the scope probe is connected to a square-wave source called a calibrator, which is built into the scope. The probe is then adjusted to make the square wave as square and flat-topped as possible. Figures 8a and 8b show the oscilloscope display during compensation with an overcompensated and undercompensated probe. Figure 8c shows the display using a properly compensated probe.

Other types of attenuating or divider probes are available, including

Typical Oscilloscope Probe Specifications

Probe Type	Frequency Range	Resistive Load	Capacitive Load
1×	dc-5 MHz	1 megohm	30 pF
10×	dc-50 MHz	10 megohms	10 pF
Active	dc-500 MHz	10 megohms	2 pF

50:1 and 100:1 probes. The general principles of these probes are the same as for the 10× divider probe: voltage level and bandwidth are traded off. To obtain wider bandwidth, more loss is incurred in the probe and less voltage is supplied to the input of the scope. This may require a more-sensitive scope for low-level measurements. Some divider probes use the scope's 50-ohm input instead of the 1-megohm input.

So far, all of the probes discussed have been simple passive circuits with no active components such as transistors or integrated circuits. In instances where extremely low capacitance is required for high-frequency measurements, an active probe can be used. An active probe has a small amplifier built into it that is designed to have very little capacitance on its input. The output of the amplifier is usually matched to drive the 50-ohm input of the oscilloscope. This allows a length of 50-ohm cable to be used between the probe and scope without additional capacitive loading.

A summary of typical specifications of various types of scope probes that have been discussed is given in the table. Actual characteristics will vary according to manufacturer and model, of course.

Although oscilloscopes are designed for a voltage input, they also can be used to measure current using a current probe. Such a probe has a set of "jaws" that enclose the wire through which the measured current is flowing. No electrical connection is needed. The circuit does not have to be broken or altered in any way.

Current probes generally use one of two technologies. The simplest uses the transformer principle, with one winding of the transformer being the wire being measured. Since transformers work with only ac voltages and currents, current probes of this type do not measure direct current.

The other type of current probe works on the Hall effect. This technique requires the use of an external power supply, but it measures both ac and dc.

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Coming Next Month

In this installment, we have introduced you to the basic elements that make up the typical oscilloscope and discussed the differences that exist between the traditional analog and the more modern digital designs. Next month in the conclusion of this article, we will discuss in detail the various tests and measurements that can be made with the oscilloscope. **ME**