Understanding and Using Dual-Trace Oscilloscopes

The basics, comparing two waveforms and a primer on probes

By TJ Byers

Modern waveform measurements are so critical that they often exceed the capabilities of the conventional oscilloscope, particularly in digital electronics. Accurate time comparisons between two waveforms is possible only when the two events can be observed simultaneously in real time. For most of us, this means using a dual-trace oscilloscope.

True dual-beam scopes exist, but the vast majority of the scopes in use employ digital switching techniques to display two traces on a conventional single-beam CRT. To obtain two or more traces from a single beam, two switching methods are used. These are identified as the alternate and chopped modes.

Switching Modes

Both the alternate and chopped modes use an electronic switch with two vertical preamplifiers and one vertical driver amplifier, as shown in Fig. 1. The electronic switch, which is sometimes called a chopper, is akin to an ultrafast relay that toggles between the outputs of the vertical preamplifiers, alternately feeding the two input signals to the vertical driver amplifier.

In the alternate mode, the electronic switch toggles between the preamplifier outputs following subsequent sweep periods. For example, the switch feeds the channel A signal to the vertical driver during the first sweep period. (The vertical driver displays the signal on the screen.) This gives the first waveform.

During retrace, the electronic switch flips position and feeds the signal on channel B through the vertical driver amplifier for the next sweep period. This gives the second waveform. Because the phosphor on the CRT screen has a persistence that is longer than the sweep time, both images appear to be on the screen simultaneously.

To keep the images separate, each preamplifier has an offset voltage that forces the trace above or below the center line of the screen. Individual panel adjustments control the

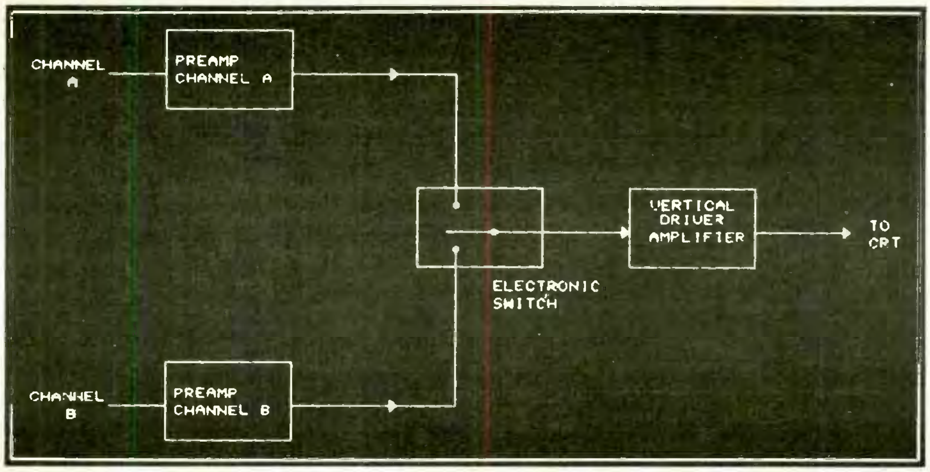


Fig. 1. Most dual-trace oscilloscopes use digital switches to display two traces on a single-beam CRT. An electronic switch alternates between outputs of vertical preamplifiers and feeds signals to a vertical driver amplifier for display.

offset voltage and subsequent screen positions of the traces.

In the chopped mode, the electronic switch alternates between channels A and B at a rate considerably faster than the sweep frequency (generally 100 kHz or better). This technique is known as sampling.

As the sweep begins, the switch first takes a sample from channel A and passes it through the vertical driver amplifier. Quickly, the electronic switch toggles to take a sample of the signal on channel B, passing this along, with a corresponding offset voltage, to the vertical driver for display. Another sample is then taken from channel A, another from channel B, etc. A typical display looks like that shown in Fig. 2.

When the samples are displayed on the screen, though, the human eye is tricked into believing that two solid traces exist—one above the other. The missing portions of each trace, which actually amount to 50% of the total information, are so small that the brain's integration system fills in the blanks so that the waveform appears to be solid and continuous. This same filling is what makes viewing a television picture a success.

The disadvantage of the chopped display is that short-lived transients may be cut out of the picture entirely during the switching period, which can lead to a false impression of the waveform. This problem does not occur in the alternate mode because each sweep is carried to the finish before transfer between channels.

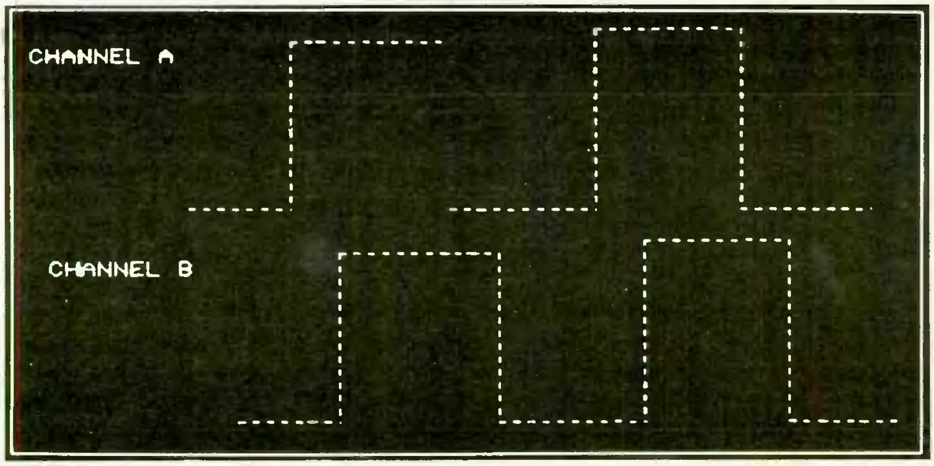
The only limitations to the number of traces that can be simultaneously displayed in the alternate mode are the persistence of the phosphor and screen area. Many oscilloscopes boast eight traces, and some digital scopes offer as many as 16 traces.

Chopped displays, on the other hand, are limited in number. As more and more time is devoted to sampling alternate inputs, less time is available for each input. In a dual-trace system, a full 50% of the waveform is lost on each trace. Displaying four traces causes 75% of the information to be lost, leaving only 25% of the waveform to be sampled and displayed per input. Hence, a lot of the waveform is unaccounted for. As input frequency increases, fewer samples are taken per cycle, and the image becomes coarser and more difficult to distinguish. The trick is to run the sampling oscillator much faster than the input signal frequency so that samplings are closer together and the display is more representative of the waveform.

There is a limit to how fast the switch can sweep the input preamplifiers and still return a true display of the input. Factors like slew rate and settling time place an upper frequency limit on the sample rate, which limits the number of traces the chopped mode can faithfully display. At the present time, four seems to be the practical limit.

Which display mode is best for an application? The answer depends on the complexity of the waveforms involved and the accuracy of the measurement required. Chopped images

Fig. 2. In chopped mode, electronic switch alternates between channels A and B at a rate considerably faster than sweep frequency, producing a broken waveform. the eye is tricked into seeing solid traces.



are less faithful because portions of the waveforms are missing. Alternate displays, on the other hand, produce objectionable flicker when the sweep rate is too slow.

Generally, it is a good idea to use the chopped mode for sweep rates of 1 millisecond or more and the alternate mode for anything faster than that. In some instruments, you make the choice. By and large, though, selection is made automatically by the oscilloscope as sweep rate is adjusted.

Sweep Triggering

As with any display, the sweep must begin at a precisely defined time for a stable waveform to appear on the screen. When working with more than one trace, this can get tricky.

Sweep triggering is handled by a trigger generator that is responsive to several trigger input sources. Typical trigger sources include internal, external and line, each designed to suit its own range of applications.

On internal triggering, the trigger generator obtains its drive from the vertical input amplifier. On external, the trigger pulse comes from an external source. Line sync triggering is unique in that it receives its trigger from the 60-Hz ac line, a source that is used when the waveform conforms to ac line timing.

Most scopes offer automatic (auto) and normal synchronization modes. Automatic triggering is the most frequently used. In this mode, a trigger signal is generated whenever the vertical input passes through an imaginary baseline reference, usually zero volt, set by the horizontal sweep. With this arrangement, a trace is displayed whether or not a vertical input is present. It is most useful when the signal amplitude is too low for triggering.

In normal triggering, the trigger pulse is generated after the input signal passes through a preset voltage. Because this mode does not have the imaginary baseline reference of the auto mode, it is important that the vertical waveform does cross this preset level or the circuit will not trigger. Most scopes have a level control that shifts the voltage of the triggering point above or below zero volt so that even negatively-biased waveforms can enable the sweep.

Generally, the trigger is taken from the channel A input. Just where on the signal the sweep is to begin is determined by the trigger control settings and the triggering mode selected. Alternatively, the trigger can be taken from channel B. Since the trigger input is independent of the electronic sampling switch, trigger selection is simply a matter of monitoring one channel or the other.

Finally, the trigger can be taken alternately from channels A and B. In this mode, the trigger is derived from the output of the electronic switch. This mode is most often used when two unrelated waveforms are simultaneously displayed.

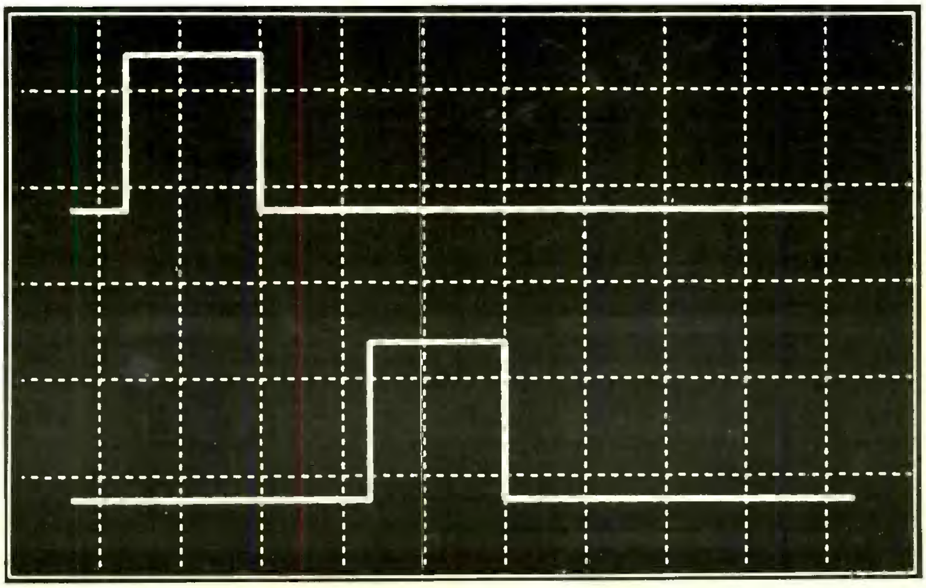
As an example of alternate channel A/B triggering, say you wish to view the ac line voltage going into a TV receiver and the receiver's vertical sweep on the two channels. Since these frequencies are similar but unrelated, there is no common denominator. Therefore, one or the other signal will appear to drift on the screen. To eliminate this drift, place the oscilloscope in the alternate-trace mode and initiate alternate triggering. Here the trigger is first taken from channel A, then channel B. Each trace is synchronized with its representative input, so both images appear stable even though they are unrelated.

Time/Phase Measurements

Dual-trace scopes are at their best when comparing two waveforms in real time. In many applications, it is important to know either the time or phase relationship between two signals, especially in digital circuits where clock pulses must fall within specific timing slots with reference to other events.

Time relationships between two waveforms can be viewed directly on a dual-trace oscilloscope simply by adjusting the vertical and sweep controls to obtain a stable display on the CRT screen. Best results are obtained when the sweep is triggered from the leading edge of the signal on channel A.

Fig. 3. With a scale factor of 1 microsecond per division, events depicted here are 3 microseconds apart.



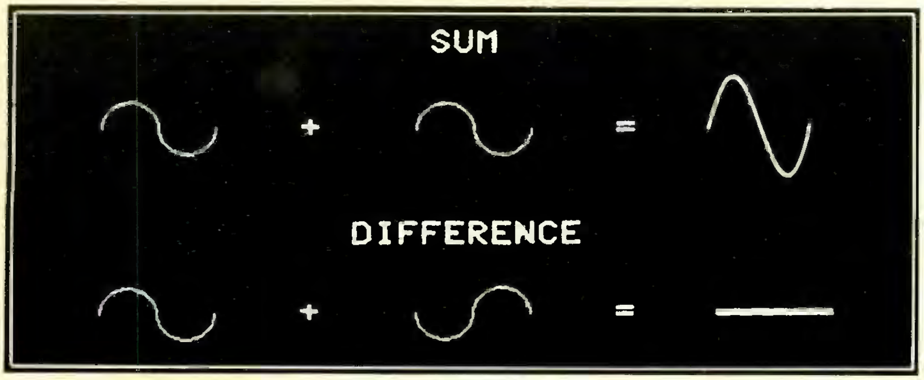


Fig. 4. Outputs of preamps can be combined to produce unique results. In sum mode, inputs are mixed in-phase and complement each other. In difference mode, inputs are 180° out-of-phase and cancel. This can be used to emphasize differences between apparently identical signals.

Once the display has been stabilized, you count the number of graticule lines between identical points on the waveforms and multiply by the scale factor. In Fig. 3, for example, the leading edge of input B begins three divisions after channel A has started. If the scale factor is 1 microsecond per division, the two events are separated by 3 microseconds.

Phase angle, on the other hand, is a calculated value determined by the duration of the clock cycle as it relates to time displacement. For example, if a shift of 250 nanoseconds is noted between two 1-MHz signals, the displacement is 0.25 times the whole, or 90 degrees, 360 degrees being the whole. A shift of 0.5 (expressed as 1:2) is 180 degrees; 3:4 is 270 degrees; and so forth.

Digital phase measurements are not as confusing as they may at first appear. A simple way to relate two waveforms is to look for phase inversions in which signals are 180 degrees out-of-phase and leading or lagging clock pulses in which the signals are generally 90 degrees out-of-phase. These are the most prominent. It is seldom that digital clocks use oddball phase angles.

Sum and Difference

Another interesting aspect of dual inputs occurs when the two signals are mixed together rather than viewed separately. In this mode, the outputs of the preamplifiers are combined in a mixer circuit. The phase shift of the two signals is precisely controlled so that predictable results are obtained.

In the sum or add mode, for instance, the inputs are in-phase and complement each other (upper portion of Fig. 4). Two sine waves of the exact same frequency, for example, reinforce to produce an output that has twice as much voltage swing as either does individually. The sum mode can be used to produce suitable displays of signals otherwise too low in amplitude for regular viewing.

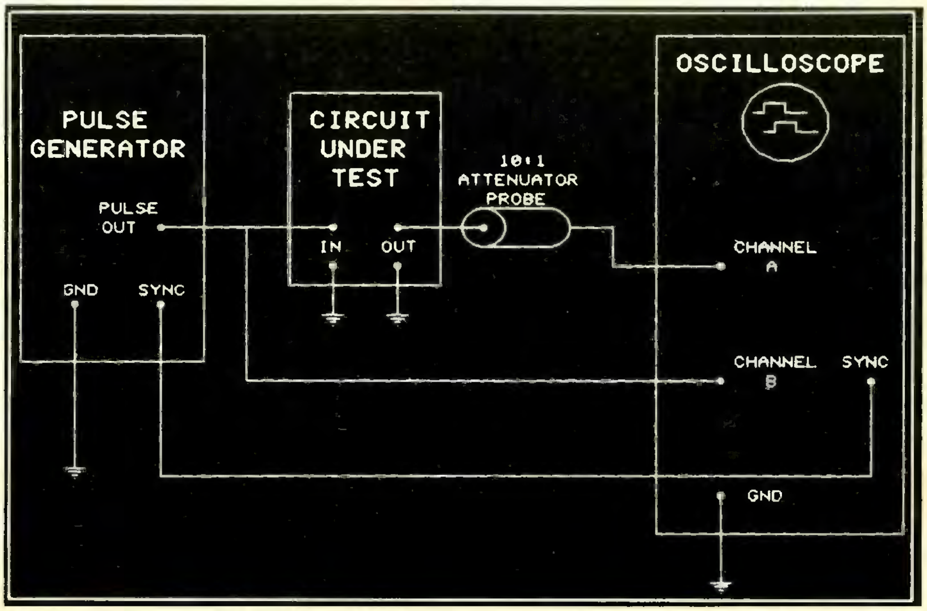
The difference (or sub) mode places the two inputs 180 degrees out-of-phase with each other (lower portion of Fig. 4). This is done inside the preamplifier by sending the signal through an inverter before routing it to the mixer. In this mode, like voltages cancel. If identical sine waves are applied to the inputs, the voltages oppose each other, causing a straight line to be displayed on the oscilloscope's screen.

The difference mode is most useful for detecting small differences in a processed signal, as would be the case if you were comparing the input of an amplifier to its output. Since the original waveform cancels itself out, small amounts of distortion and phase shift are readily visible—and are, in fact, the only images seen on the screen.

Pulse Measurements

A digital pulse contains five important parameters: pulse rate, duty cycle, pulse width, rise time and fall time. The test setup for measuring digital pulses is shown in Fig. 5. Rise

Fig. 5. Test setup for measuring digital pulses.



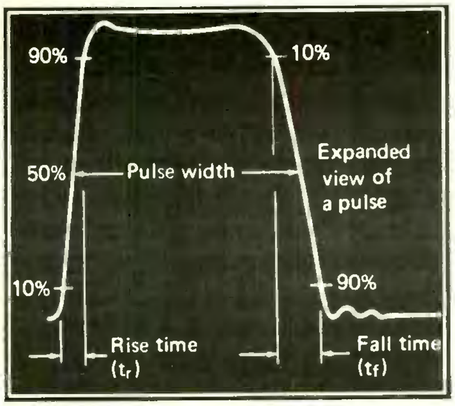


Fig. 6. Rise and fall times are measured between 10% and 90% points on vertical axis; pulse width is measured between the 50% marks.

and fall times are measured between the 10% and 90% points along the vertical axis, as shown in Fig. 6. Pulse width is measured between the 50% marks, and duty cycle is calculated as pulse width divided by the time required to complete a cycle.

In most digital and computer circuits, rise and fall times are the most important pulse parameters. When measuring rise and fall times with an oscilloscope, it is desirable to adjust sweep rate and triggering controls so that the leading (or trailing) edge fills a large part of the screen.

For rise time measurements, the trigger is set to begin on the rising edge of the waveform. Sweep rate is then adjusted so that the slope of the leading edge fills as much of the screen from left to right as possible without overscanning. The 10% and 90% points are identified on the vertical axis and a time measurement is made along the horizontal axis between these two points.

A similar method is used to measure fall time. Fall times are generally longer than are rise times by a factor of about three and vary considerably, depending on the load placed on the output of the device under test. Hence, fall times are measured using a slower sweep rate.

Unfortunately, waveform aberrations make it difficult to trigger the sweep on the falling edge, which is a critical requirement for displaying the parameter. The delayed sweep feature found on most dual-trace oscilloscopes offers a simple method for measuring fall time with very good results. You simply stabilize the image by triggering on the leading edge and activate the delay function. Using the horizontal positioning control, you then position the waveform on the screen so that the trailing edge of the pulse is visible.

In some cases, though, the width of the pulse may be too large for the time delay. When this occurs, it is possible to trigger the sweep from another source. This is where the dual-trace oscilloscope has an advantage over the single-trace scope.

Single-trace scopes require an external trigger source when operating in this mode—which includes additional external circuitry. A dual-trace oscilloscope, though, can take its cue from an alternate input. To do this, you simply search through the various waveforms available in the circuit and select one that allows you to trigger your sweep from channel B at the time desired.

Probes

Probes are critical to the proper measurement of pulses with an oscilloscope. In fact, the probe can very well be the most critical component in the system because it interacts with both the scope and the signal source. Choosing the wrong test probe can lead to false readings, and may even damage the circuit under test.

The need for a probe arises from the need to combat the electromagnetic noise pollution that is constantly with us. Unless the vertical input is insulated from this external "interference," whatever noise that may be in the vicinity, including stray 60-Hz ac-line hum, will be fed into the scope's input along with the signal. The obvious result is inaccuracies in the displayed waveform's shape, amplitude, etc.

One effective solution to the pollution problem is to shield the scope's input from external radiation by encasing its input wire in a metal shroud. Common coaxial cable offers the simplest approach. Coaxial cable consists of a single conductor surrounded by a wire braid or metal foil shield. Grounding the shield, which intercepts any electrical noise in the vicinity, routes to ground the noise before it can reach the signal-carrying inner conductor.

Several types of coaxial cable are used for scope probes, the most popular being RG58/U, RG59/U, and RG188A/U. Unfortunately, coax suffers from noticeable attenuation that is both frequency and length sensitive. As the frequency of the input signal increases, so too does the cable's attenuation characteristic. Similarly, the longer the cable, regardless of frequency, the greater the attenuation. Figure 7 shows the relationship between attenuation, length and frequency for three types of coaxial cable.

Part of the coaxial cable's attenuation is due to dielectric absorption, the remainder to capacitive loading. Capacitive loading gives the oscilloscope the most problems. Dielectric absorption can be compensated for

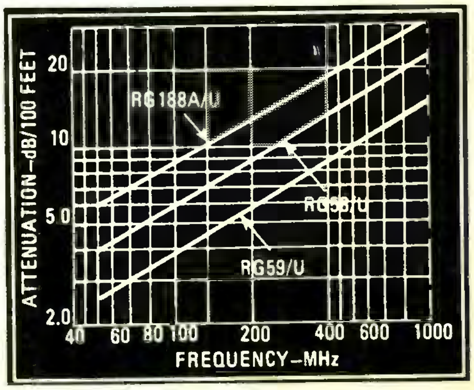


Fig. 7. Coaxial cable suffers from noticeable attenuation of signal as input frequency increases. Cable length is also a cable-loss factor.

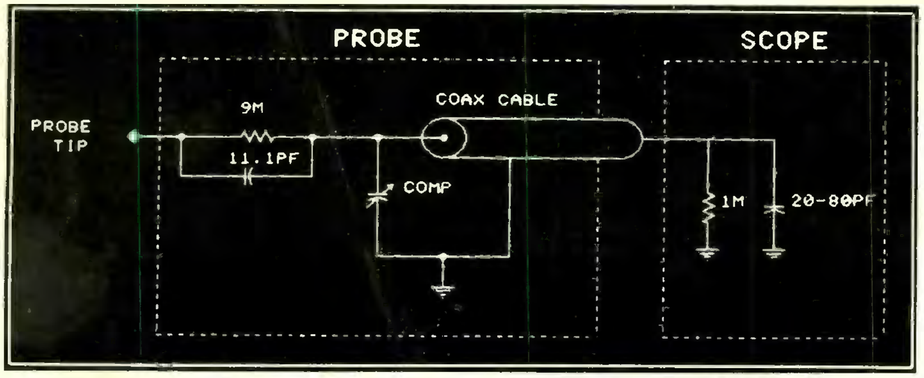


Fig. 8. Attenuator probe has series resistor that isolates cable capacitance from device under test. Series capacitor compensates for frequency attenuation.

The Bandwidth Issue

The quality of a digital pulse measurement depends heavily on the bandwidth of the oscilloscope and the probe(s) used with it. The frequency response of the vertical amplifier determines the bandwidth.

Oscilloscopes fall into two general categories: low frequency and high frequency. Low-frequency scopes have a frequency response from dc up to 10 MHz and are generally used in service applications, such as TV repair. Generally, these scopes are low-budget instruments with few features.

High-frequency scopes, on the other hand, have bandwidths as wide as 350 MHz and are used primarily in laboratory environments. These instruments normally include many features that enhance the performance, including delayed sweep and sweep magnification.

Every increase in bandwidth and added frill adds to the cost of the instrument. Even so, high-frequency scopes are being increasingly used in digital testing because of their quick rise-time response.

with standard calibration measures. The effect of capacitance loading, which affects the shape of the waveform, however, is a bit more difficult to deal with.

A good example of the problems encountered in dealing with digital measurements can be found in a square wave. The square wave, by definition, consists of the summation of an infinite number of odd-harmonic frequencies. The lowest frequency determines the oscillation period, the highest the sharpness of the corners of the waveform.

As a signal passes through a length of coax, the cable attenuates the higher frequencies more than it does the lower frequencies. If a perfectly square waveform were fed into the input end of the cable, it would have rounded corners when it exited the output end. This is obviously unacceptable for critical scope work. The problem is compounded by the cable capacitance, which loads the circuit under test and causes further distortion the waveform.

Isolating the Load

To solve the distortion problem, a two-fold approach is used. Firstly, the circuit must be isolated from the capacitive loads imposed by the coaxial cable and the oscilloscope. This is done by inserting a resistor in series with the cable's center conductor, as shown in Fig. 8. The resistor is placed at the very tip of the probe, where it has the most effect. The load now appears to the oscilloscope to be resistive rather than capacitive.

Selection of a value for the resistor is based on a compromise between isolation characteristics, signal attenuation, and bandwidth. The larger the value, the greater the isolation. On the other hand, signal attenuation, increases as resistance increases, while bandwidth decreases. Obviously, then, the value selected must provide a compromise that will provide acceptable overall performance results.

Probe bandwidth is closely related to rise time response. It is calculated using the formula: $BW = 0.35/(t_r)$, where BW is bandwidth in Hz and (t_r) is rise time in seconds.

Rise time response is a factor of isolation resistance and cable capacitance and is defined as the amount of time it takes to charge the RC (resistive and capacitive) components of the test probe to the nominal voltage value. The resistive component consists largely of the series resistor, while the capacitive component consists of the combination of distributed cable capacitance and oscilloscope input impedance.

As input resistance increases, the RC time constant also increases. This reduces bandwidth, evidenced by rounding of the corners of square waves, and attenuates high-frequency sine waves. Both situations lead to an inaccurate representation of the waveform under test.

A compromise value of 9 megohms is typical for the series resistance. An input impedance of 10 megohms effectively reduces the shunt capacitance to a low 10 pF while maintaining a respectable 10:1 attenuation ratio.

Equalizing the Bandwidth

Effects of frequency-selective signal attenuation within the coaxial cable must be dealt with next. In essence, you want to accentuate the highs while maintaining the lows. This is accomplished with a high-frequency boost to overcome the losses caused by the coaxial cable. Ideally, the boost should increase with frequency to offset the frequency-sensitive attenuation characteristic of the cable.

A series capacitor offers a virtually ideal solution. Capacitive reac-

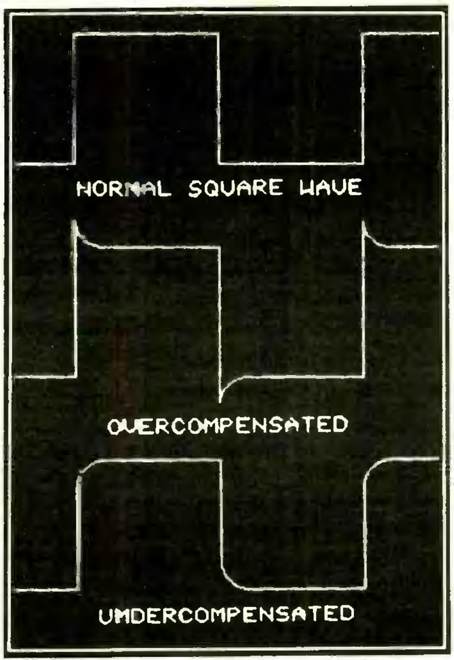


Fig. 9. Probe compensation is done using square waves. At top is example of perfect compensation, center and bottom show distortion that results with too much and too little compensation, respectively.

tance (the amount of effective resistance a capacitor exhibits to the passage of an ac current) is an inverse function of frequency. That is, the higher the frequency, the less resistance a capacitor represents. By providing a capacitive path for the signal, the high frequencies can be proportionally boosted.

Compensation is most effective when the capacitor is placed across the isolation resistor, as shown in Fig. 8. Because the compensating capacitor is typically very low in value (on the order of 10 pF), it has little effect on the lower frequencies that must make their way through the isolating resistor. Higher frequencies, however, find the capacitive path easier going and bypass the isolation resistor altogether. The higher the frequency, the less the resistance encountered. By the time both components reach the input of the scope, though, the high-frequencies have been attenuated to the level of the low frequencies and the waveform appears in its original form.

Cable length complicates the picture. For the compensating capacitor to put all frequencies back in balance, the exact distributed capacitance of the scope probe must remain constant from unit to unit. Standard manufacturing practices, however, prohibit such precision. A variable capacitor is placed across the line to allow the user to compensate for differences in cable capacitance.

Before the probe can be used, therefore, the trimmer capacitor must be adjusted. Not surprisingly, adjustment is done using a square wave. Most quality oscilloscopes provide an internal square-wave calibrator for such purposes. With the probe attached to the voltage calibrator output, you adjust the capacitor until the waveform is as square in appearance as you can get it. What you are actually looking for is a very square corner at the leading edge of the waveform.

If a probe is undercompensated, the leading-edge corner will appear rounded; while too much compensation causes the signal to overshoot and result in leading-edge ringing. Figure 9 shows typical waveforms for a properly compensated probe, along with those for an over- and an undercompensated probe.

After a probe has been adjusted, it is ready to use. Just keep in mind that the probe's internal network is in series with the input and, thus, attenuates the signal by a factor of 10. Hence, always remember to make the appropriate mental adjustment.

Special-Purpose Probes

In addition to the low-capacitance probe, the oscilloscope has a rather large family of special-purpose test probes. These are designed to enhance the versatility of the oscilloscope. The most popular is the demodulator probe, which is used to convert an r-f signal into dc voltage.

Inside the demodulator probe is a small-signal diode that converts the r-f input to a voltage that is proportional to the peak r-f signal. An RC network inside the probe, shown in

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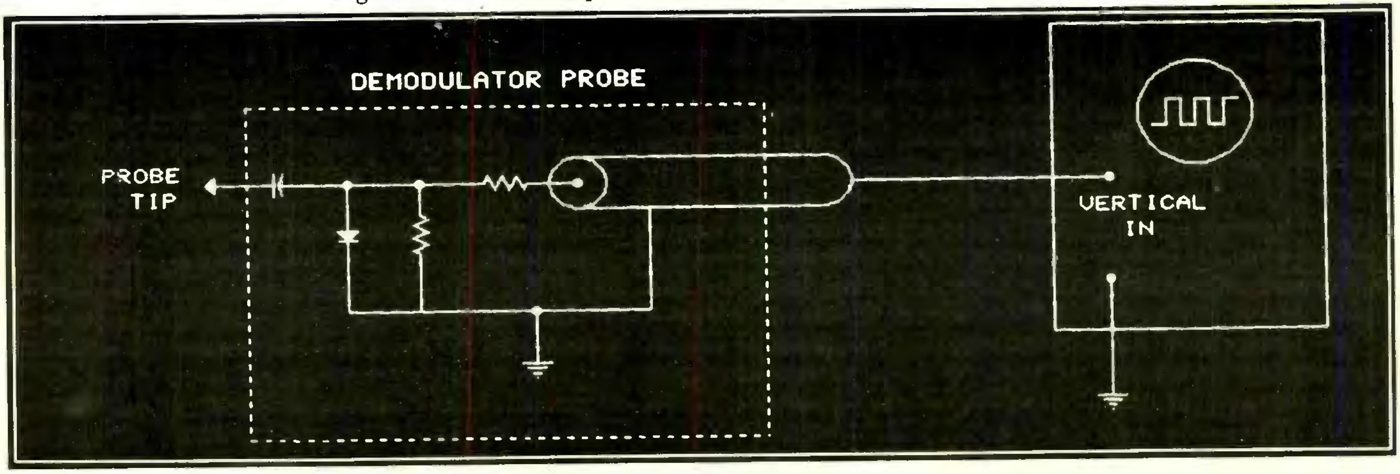

Fig. 10. Demodulator probe converts r-f signal into dc voltage.

Fig. 10, lowers the input capacitance and prevents loading of the r-f circuit under test.

Demodulator probes are most often used when servicing sensitive r-f circuits, such as those used in i-f amplifiers and r-f tuners. Demodulator probes can also be used as a detector to extract modulated information from an r-f carrier.

Another popular special-purpose probe has an internal FET amplifier. The output impedance of the amplifier in this "active probe" is typically 50 ohms, which matches the impedance of the coax used with it.

Using an active probe, the amplifier isolates the signal from line disturbances. Thus, the length of the coax has little effect on the waveform at the scope input.

One of the advantages of the active probe is that it gives full bandwidth response with no signal attenuation. This makes the probe ideal for measuring low-level pulse signals in high-frequency circuits.

A third popular probe, the current probe, is used for measuring current and displaying it on the screen. Because the oscilloscope is basically a voltage measuring device, the current probe is needed to convert the current in a circuit under test into a voltage that can be displayed. Most current probes are of the split-core type in which the core slides back to allow the current-carrying lead in the circuit under test to be inserted into its center without breaking the lead.

In Conclusion

Knowing how to use an oscilloscope is as important as the quality of the scope itself. We have presented here the important fundamentals and talked about using the scope to make measurements in various types of circuits. We also touched upon the types of probes commonly used for different applications. We hope this information will lead you to studying in more detail oscilloscope operation and use.