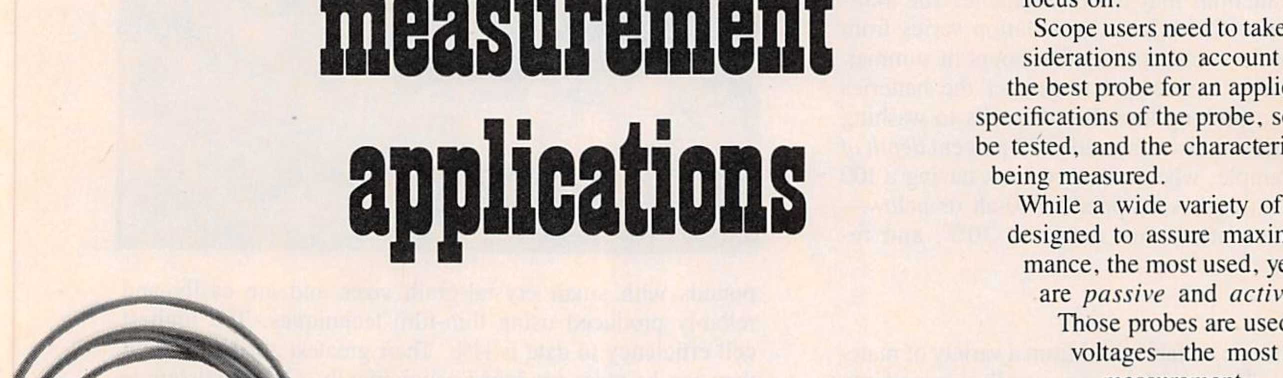
Selecting the best VOLTAGE PROBE for your measurement applications



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THE OSCILLOSCOPE (SCOPE) PROBE may be the most critical component in the scope-measurement system because it interacts *intimately* with the signal source. The probe's characteristics should be matched to both the scope and the circuit under test. Probes are to oscilloscopes very much as interchangeable lenses are to 35-mm camera bodies. The lens must mount exactly on the camera body and be suitable for the subject it must view. Any failing will produce a distorted, partial, or out-of-focus image that will be useless. Similarly, it is necessary to choose the correct probe-scope system to be able to get the best view of the signal we want to focus on.

Scope users need to take several major considerations into account when determining the best probe for an application based on the specifications of the probe, scope, the circuit to be tested, and the characteristics of the signal being measured.

While a wide variety of probes have been designed to assure maximum scope performance, the most used, yet least understood are *passive* and *active* voltage probes. Those probes are used to measure signal voltages—the most often made scope measurement.

Passive Probes

Passive voltage probes are the most common, because they are inexpensive and easy to use. Those probes use an RLC network to present a high impedance to the circuit under test, which minimizes probe loading. Passive probes are rugged and can stand more mechanical and electrical abuse than other probes. Because of their simplicity, passive probes are easy to calibrate.

Passive probes have some disadvantages. Because of the internal capacitance, the input impedance of passive probes decreases as the signal frequency increases. To obtain a high enough input impedance, the

The voltage probe is only one part of a testing system that includes the oscilloscope and the system under test. Understanding the test conditions and the characteristics of the voltage probe is of importance to the hobbyist.

attenuation of the probe must be increased; but that may make the signal amplitude too small to be seen on the scope display.

Active Probes

Active probes typically incorporate a FET input-buffer with a 50-ohm output-driver to provide the best-obtainable combination of high input-resistance and low input-capacitance, without signal attenuation. Therefore, active probes can be generally considered one of the best for general-purpose measurement.

The advantages of active probes include:

1–Full bandwidth with no signal attenuation using the 1X (no attenuation) configuration.

2–High input-resistance and low input-capacitance while working into 50-ohm scope input terminals. Those features yield fast risetime and minimum pulse-amplitude error.

3–Output impedance selection for use into 1-Megohm or 50-ohm scope input terminals.

4—The capability of extending the probe length through the use of 50-ohm cable without increasing probe loading.

Probes Are Not Created Equal

The purpose of a probe is to deliver the selected test signal to the oscilloscope input terminals without affecting the signal or the source in any way. While that may be ideal, it is difficult to design a single probe to meet the requirements for all circuit applications. It is necessary to know how to select the best type of probe for use in a particular application. Proper probe selection will assure maximum measurement system performance while minimizing the probe's loading effects.

Circuit Loading

A typical scope input can be represented by a 1-Megohm resistance shunted by 20 pF of capacitance (Fig. 1). When that input impedance is applied to the circuit under test, it loads the circuit, causing the signal to be altered. In the worse case, the operation of the circuit itself is affected. By using an attenuating probe, the loading effects can be reduced since the combined impedance of the probe and scope input is higher than the scope alone (Fig. 2). The resulting probe-scope equivalent circuit applied to the circuit under test is shown in Fig. 3. Notice that the probe specification indicates the resulting impedance of the probe-scope input combination (10 Megohm, 9.5 pF, at 10× attenuation).

The source impedance of the circuit under test is an important consideration. That can vary from a fraction of an ohm to more than 10 Megohms and from 1 pF to greater than 100 µF. In order to minimize probe loading effects, the lowest impedance point available for a particular signal should be selected.

Bandwidth

The frequency bandwidth specification of a probe is closely related to risetime response. Bandwidth (BW) can be approximated by:

$$BW = 0.35/t_r$$

where t_r is risetime in seconds. The bandwidth of a probe is affected by the resistance and capacitance of the probe head

Based on an article that appeared in *Electronic Products Magazine.*

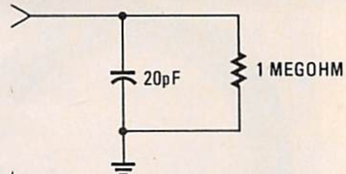


Fig. 1—Simplified oscilloscope input circuit.

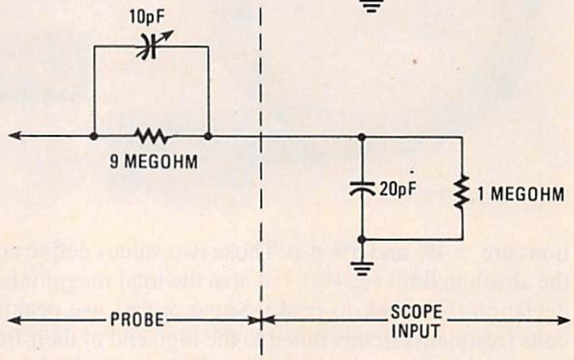


Fig. 2—Simplified oscilloscope input circuit with matching voltage probe connected.

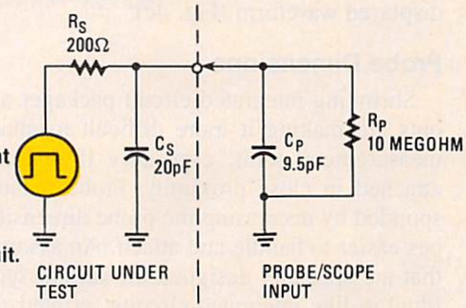


Fig. 3—Equivalent circuit for the circuit under test and the probe/scope input circuit.

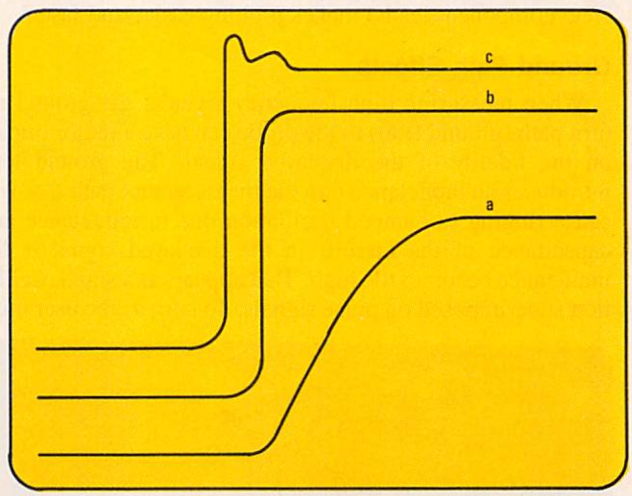
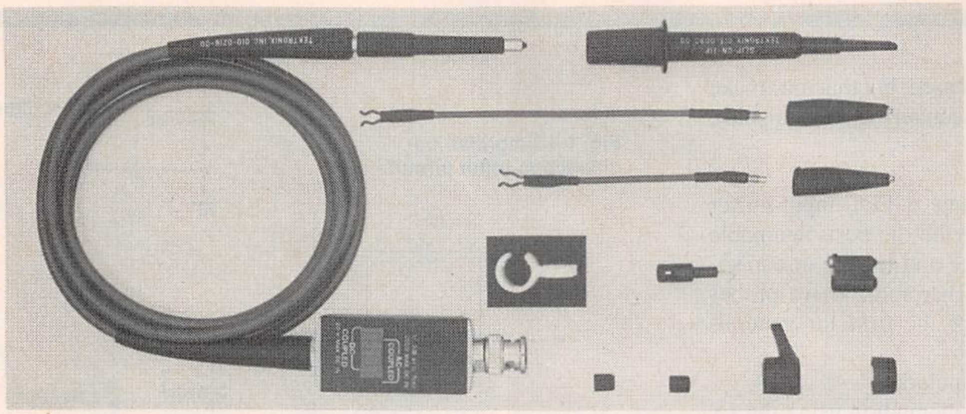


Fig. 4—Views of the leading edge of a squarewave where: a–there is insufficient bandwidth pulse response, b–optimum pulse response, and c–poorly matched probe that causes ringing.

as well as the transmission characteristics of the probe cable and connector. Insufficient bandwidth will cause attenuation of higher-frequency sinewaves and rounded edges when measuring squarewaves and other pulses (Fig. 4a). That leads to an inaccurate representation of the waveform of the circuit under test.

Aberrations

Aberrations are the percentages of allowable deviations from optimum pulse response (Fig. 4b). Typical specifica-



Probes come in all sizes and shapes. Shown here is the Tektronix P6048 DC-to-200-MHz, 10X probe with a minimum loading of 1 pF to 1000 ohms. The probe comes complete with accessories to make measurement taking easier.

tions are ±4% and 5% p-p. Those two values define not only the absolute limit (±4%), but also the total magnitude of the deviation (5% peak-to-peak). Some probes use peaking circuits (resonant circuits tuned to the high end of their frequency range) to extend bandwidth. However, without careful design practices that may cause aberrations (ringing) in the displayed waveform (Fig. 4c).

Probe Dimensions

Shrinking integrated-circuit packages and increasing pinouts are making it more difficult to attach a probe to the measurement point, especially if several probes must be attached in close proximity. Probe manufacturers have responded by decreasing the probe dimensions that make probes easier to handle and attach. An assortment of probe tips that are specially designed for various types of attachments (dual in-line integrated circuits, printed-circuit boards, discrete component leads) makes probing easier and faster.

Ground Path Effects

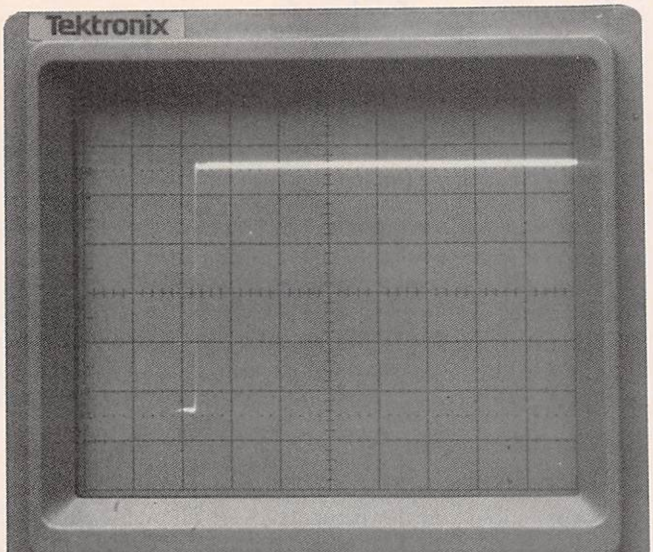
When measuring high-frequency signals, the ground return path (ground lead) to the probe can have a major impact on the fidelity of the displayed signal. The ground lead introduces an inductance into the measurement path that will cause ringing (a damped oscillation due to inductance and capacitance of the circuit) in the displayed signal if the inductance becomes too high. That appears as a small oscillation superimposed on pulse signals: To cure it, the user must ensure that the return-wire length (ground lead) is as short as possible to prevent ringing at the LC resonant frequency. Therefore, it is important to have an assortment of different-length ground leads and special fittings on hand when making measurements at very high frequencies.

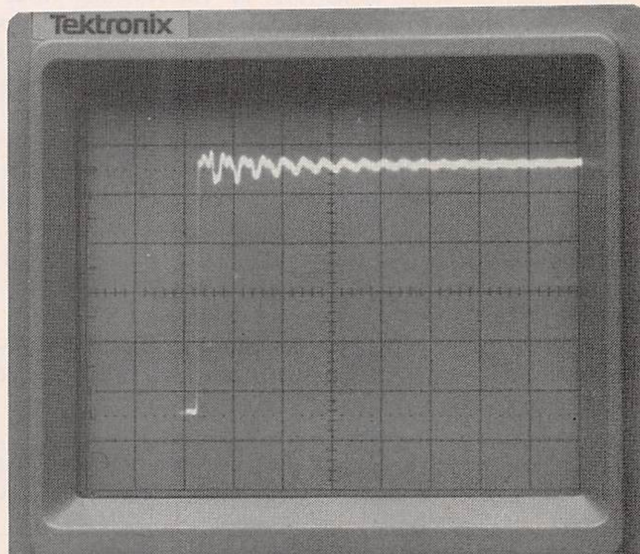
For example, Figs. 5a and 5b show the improvement that the proper grounding arrangement can make. In Fig. 5a, a 100-MHz signal is measured with a 25-cm long ground lead. Fig. 5b shows the same signal measured with a similar setup except that the ground lead has been replaced by an in-circuit probe tip connector. In that case the ringing due to the ground lead has been completely eliminated.

Amplitude Measurements

In making amplitude measurements we must consider two types of signals: sinewave (CW) and pulse. For CW signals, the accuracy of an amplitude measurement is a function of the probe-loading impedance.

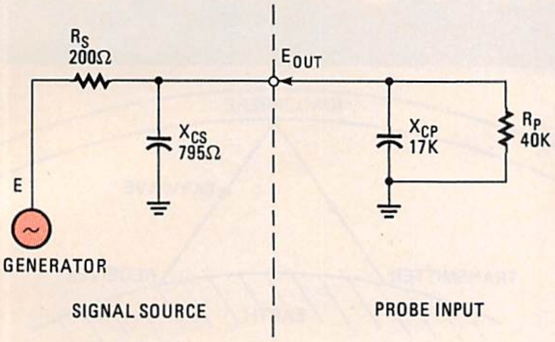
That would imply that the highest division-ratio probe (highest resistance) available would be the best choice. However, as the signal frequency increases, the probe impedance is affected more by the probe's input capacitance, until the capacitance is the dominant parameter. Then the probe impedance may be drastically less than the division ratio would imply. In that case, it might be better to opt for a lower resistance, lower capacitance probe to reduce loading (such as a 500-ohm divider probe whose input capacitance may be only 1-2 pF).





Estimating Amplitude Error

Amplitude errors for sinewave signals can be calculated by considering the equivalent circuit of the signal source and probe input (Fig. 6). Using the values in Fig. 3 at a signal frequency of 10 MHz, R_P is 40,000 ohms and X_{Cp} is 1700 ohms. The output voltage, E_{OUT}, of the source without probe loading is about 97% of the generator voltage. However, when the circuit is loaded by the probe, the output voltage drops to 94% of the generator voltage, a change of 3%.



WITHOUT PROBE

$Z = \sqrt{R_S^2 + X_{CS}^2} = 820\Omega$

$\% E_{OUT} = \frac{1}{Z} X_{CS} 100$

$\% E_{OUT} = 97\%$

WITH PROBE

$X_{CEQ} = \frac{X_{CS}\,X_{CP}}{X_{CS} + X_{CP}} = 542\Omega$

$Z = \sqrt{R_S^2 + X_{CEQ}^2} = 577\Omega$

$\% E_{OUT} = \frac{1}{Z} X_{CEQ}\,(100) = 94\%$

Fig. 6—This illustration presents the circuits and equations that are used to determine the loading affect between the probe-input circuit and the circuit under test. Refer to the text.

For pulse amplitude measurements, the probe resistance is the overriding factor and should be large relative to the source impedance. An accurate amplitude measurement can be made with no concern for the input capacitance, if the RC time-constant of the probe-scope input is greater than 1/5 of the pulse width.

Risetime Measurements

When measuring the risetime of pulses, the input probe and scope capacitance becomes much more important. Since the risetime of the signal is affected by the probe resistance and capacitance, it is desirable to minimize both, giving the shortest probe time-constant. But the resistance can not be decreased too much, because the loading effects will be too great. It becomes very important to make C_{IN} as small as possible.

The probe/scope input system adds resistance and capacitance to the circuit under test, affecting the measured risetime. If the resistance of the probe is high compared to the circuit-source resistance, then the measured risetime will be:

$$T_R = 2.2\,R_S\,(C_S + C_P)$$

Fig. 5—Failing to provide a proper ground return for the probe can introduce unknown inductances, resistances and capacitances into the input circuit. In most instances, the added inductance will cause ringing in high-frequency waveforms. In (a) we see the effect of an improperly grounded probe, and in (b) we see the resulting waveform when the ground return is proper. The photos shown were taken from the screen of a Tektronix 2235 100-MHz oscilloscope.

where R_S is the source resistance, C_S is the source capacitance and C_P is the probe capacitance. From that formula you can see that minimizing the probe capacitance reduces the risetime error.

For example, consider a typical signal source loaded by a 10X probe (Fig. 7). Since R_P is much larger than R_S, it may be disregarded. The change in risetime caused by the capacitive loading of the probe is given by:

$$C_P/C_S \times 100 = 9.5\text{ pF}/20\text{ pF} = 48\%.$$

From that example, you can see that minimizing the probe capacitance reduces the risetime error.

Summary

No probe is perfect for all measurement applications; scope users need to consider their probe, scope, and circuit as a system before making a measurement. Knowing the characteristics of the signal source, and choosing the proper probe for the application, will assure accurate scope voltage measurements.

Here are some general rules that give a starting place for selecting the right probe for a particular measurement situation:

1. Always check probe compensation on the scope being used before making measurements. Compensation matches the capacitance of the probe to that of the scope input to ensure accurate attenuation at all signal frequencies. If you change scopes, or even channels on the scope, you should recheck the probe compensation.

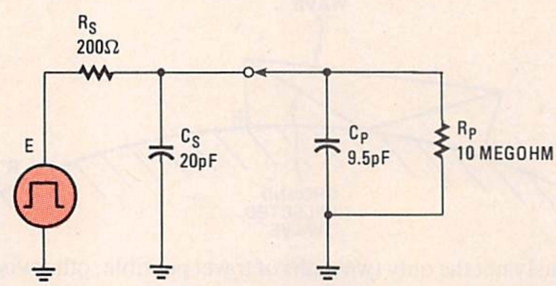
2. Choose the lowest-impedance test point possible to view the signal.

3. Always use the shortest ground-return path (ground lead) possible to minimize ringing.

4. When making amplitude measurements:

a. For sinewave measurements, choose a probe with the highest input impedance at the frequency of interest. Remember, loading error changes with frequency.

b. For pulse measurements, choose a probe with a large input resistance relative to the source impedance. Input C is of little concern if pulse duration is about five times longer than the input RC time constant.



$\Delta t_R = \frac{C_P}{C_S}\,(100) = 48\%$

Fig. 7—Effect of capacitor loading on rise-time measurements.

5. When making risetime measurements:

a. Choose a probe with R and C as low as possible.

b. Scope and probe risetime should be short relative to the signal risetime.

c. The observed risetime should be approximately equal to the square root of the sum of the squares of all risetimes in the system. Those risetimes include the risetime of the signal source, and the specified probe/scope system risetime. ■