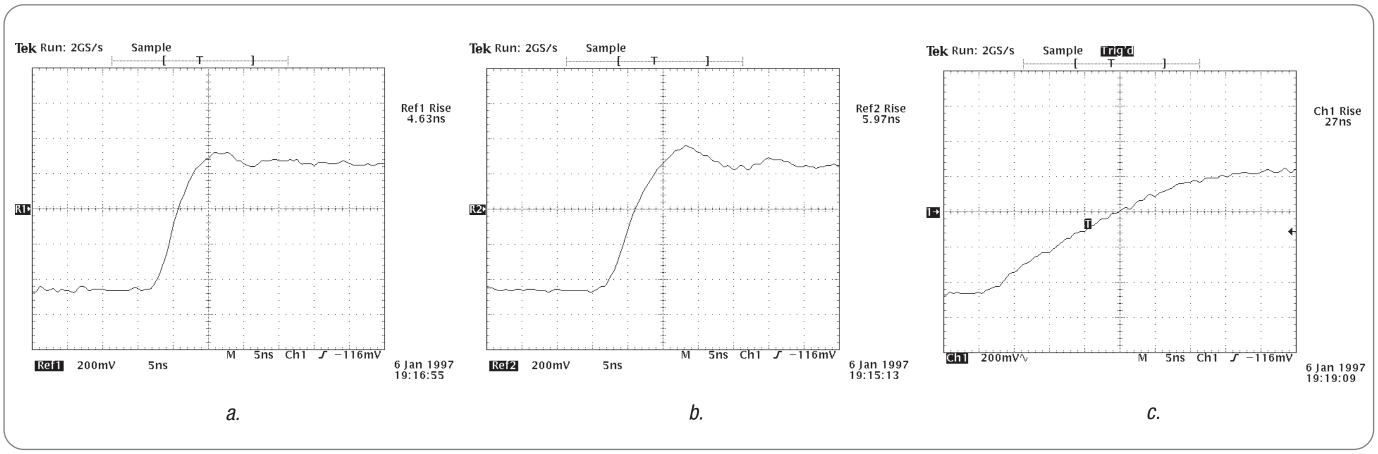


▶ ***Figure 3-9.*** *Effects on rise time of three different probes: (a) 400 MHz, 10X probe, (b) 100 MHz, 10X probe, and (c) 10 MHz, 1X probe. All measurements were made with the same 400 MHz oscilloscope.*

The key point made by Figure 3-9 is:

Just any probe will not do!

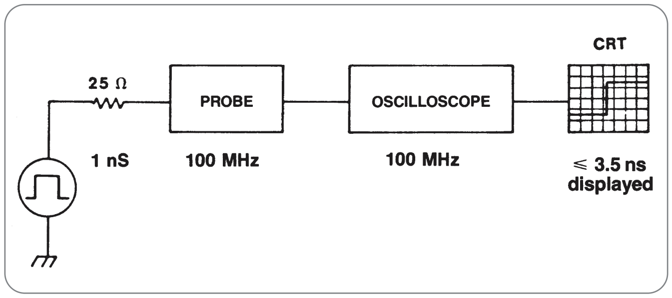
To get maximum performance from any oscilloscope – the performance that you paid for – be sure to use the manufacturer's recommended probes.

Bandwidth to the probe tip. In general, the issues of probe bandwidth and resulting probe/oscilloscope system bandwidth should be resolved by following manufacturer's specifications and recommendations. Tektronix, for example, specifies the bandwidth over which a probe will perform within specified limits. These limits include total aberrations, rise time, and swept bandwidth.

Also, when used with a compatible oscilloscope, a Tektronix probe extends the oscilloscope's bandwidth to the probe tip. For example, a Tektronix 100 MHz probe provides 100 MHz performance (–3 dB) at the probe tip when used with a compatible 100 MHz oscilloscope.

The industry recognized test setup for verifying bandwidth to the probe tip is illustrated by the equivalent circuit in Figure 3-10. The test signal source is specified to be a 50 Ω source terminated in 50 Ω, resulting in an equivalent 25 Ω source termination. Additionally, the probe must be connected to the source by a probe-tip-to-BNC adaptor or its equivalent. This latter requirement for probe connection ensures the shortest possible ground path.

Using the above described test setup, a 100 MHz oscilloscope/probe combination should result in an observed rise time of ≤3.5 ns. This 3.5 ns rise time corresponds to a 100 MHz bandwidth according to the previously discussed bandwidth/rise time relationship ($T_r \approx 0.35/BW$).



▶ ***Figure 3-10.*** *Equivalent circuit for testing bandwidth to the probe tip. For a 100 MHz system, the displayed rise time should be 3.5 ns or faster.*

Most manufacturers of general-purpose oscilloscopes that include standard accessory probes promise and deliver the advertised oscilloscope bandwidth at the probe tip.

However, it's important to remember that bandwidth at the probe tip is determined by the test method of Figure 3-10. Since real-world signals rarely originate from 25 Ω sources, somewhat less than optimum response and bandwidth should be expected in real-world use — especially when measuring higher impedance circuits.

Ground lead effects. When making ground-referenced measurements, two connections to the circuit or device under test are necessary. One connection is made via the probe which senses the voltage or other parameter being measured. The other necessary connection is a ground return through the oscilloscope and back to the circuit under test. This ground return is necessary to complete the measurement current path.

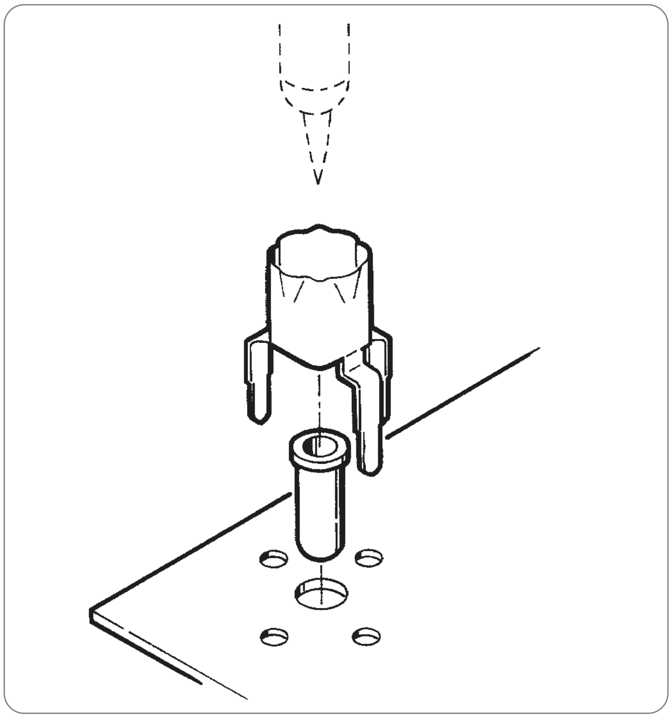


Figure 3-11. An ECB to probe-tip adaptor.

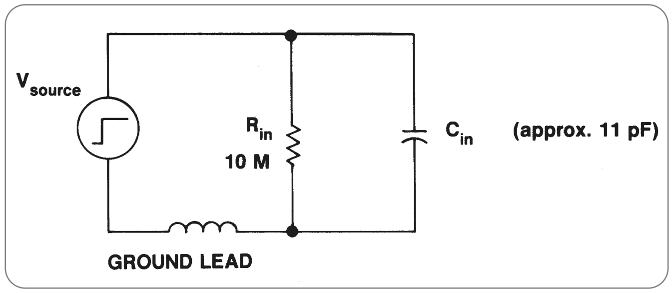


Figure 3-12. Equivalent circuit of a typical passive probe connected to a signal source.

In cases where the circuit under test and the oscilloscope are plugged into the same power outlet circuit, the common of the power circuit provides a ground return path. This signal return path through the power grounds is typically indirect and lengthy. Consequently it should not be relied on as a clean, low-inductive ground return.

As a rule, when making any kind of oscilloscope measurement, you should use the shortest possible grounding path. The ultimate grounding system, is an in-circuit ECB (etched circuit board) to probe-tip adapter. This is shown in Figure 3-11. The ECB adaptor allows you to plug the probe tip directly into a circuit test point, and the outer barrel of the adaptor makes a direct and short ground contact to the ground ring at the probe's tip.

For critical amplitude and timing measurements, it's recommended that circuit board designs include ECB/probe-tip adaptors for established test points. Not only does this clearly indicate test point locations, but it ensures the best possible connection to the test point for the most reliable oscilloscope measurements.

Unfortunately, the ECB/probe-tip adaptor isn't practical for many general-purpose measurement situations. Instead of using an adaptor, the typical approach is to use a short ground lead that's clipped to a grounding point in the circuit under test. This is far more convenient in that it allows you to quickly move the probe from point to point in the circuit under test. Also, the short ground lead that most probe manufacturers supply with their probes provides an adequate ground return path for most measurement situations.

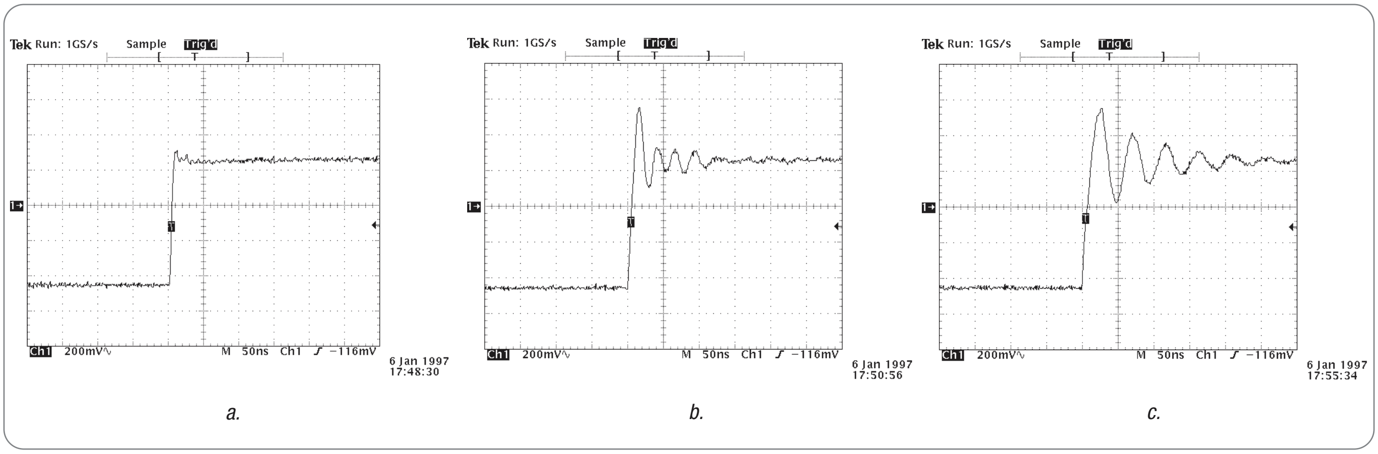
However, it's wise to be aware of the possible problems that can arise from improper grounding. To set the stage for this, notice that there's an inductance (L) associated with the ground lead in the equivalent circuit shown in Figure 3-12. This ground-lead inductance increases with increasing lead length.

Also, notice that the ground lead L and C_{in} forms a series resonant circuit with only R_{in} for damping. When this series resonant circuit is hit with a pulse, it will ring. Not only will there be ringing, but excessive ground-lead L will limit the charging circuit to C_{in} and, thus, will limit the rise time of the pulse.

Without going into the mathematics, an 11 pF passive probe with 6-inch ground lead will ring at about 140 MHz when excited by a fast pulse. With a 100 MHz oscilloscope, this ringing is well above the bandwidth of the oscilloscope and may not be seen at all. But, with a faster oscilloscope, say 200 MHz, the ground lead induced ringing will be well within the oscilloscope's bandwidth and will be apparent on the display of the pulse.

If you see ringing on a pulse display, try shortening the length of your ground lead. A shorter ground lead has less inductance and will cause a higher frequency ringing. If you see the ringing frequency change on the pulse display, you'll know that it's ground-lead related. Shortening the ground lead further should move the ring frequency beyond the bandwidth of the oscilloscope, thereby minimizing its effect on your measurements. If the ringing doesn't change when you change ground-lead length, then the ringing is likely being induced in the circuit under test.

Figure 3-13 illustrates ground lead induced ringing further. In Figure 3-13a, a matched oscilloscope/probe combination was used to acquire a fast transition. The ground lead used was the standard 6.5-inch probe ground clip, and it was attached to a common near the test point.



▶ ***Figure 3-13.*** *Ground lead length and placement can dramatically affect measurements.*

In Figure 3-13b, the same pulse transition is acquired. This time, however, the probe's standard ground lead was extended with a 28-inch clip lead. This ground lead extension might be done, for example, to avoid having to move the ground clip each time different points are probed in a large system. Unfortunately, this practice lengthens the ground loop and can cause severe ringing, as shown in Figure 3-13b.

Figure 3-13c shows the results of another variation of lengthening the ground loop. In this case, the probe's ground lead wasn't connected at all. Instead, a separate, 28-inch clip lead was run from the circuit common to the oscilloscope chassis. This created a different, and apparently longer, ground loop, resulting in the lower frequency ringing seen in Figure 3-13c.

From the examples in Figure 3-13, it's clear that grounding practices have tremendous impact on measurement quality. Specifically, probe ground leads need to be kept as short and direct as possible.

What to do About Probing Effects

From the preceding examples and discussion, we've seen that the signal source impedance, the probe, and the oscilloscope form an interactive system. For optimum measurement results, you need to do everything possible to minimize the oscilloscope/probe affects on the signal source. The following general rules will help you in doing this:

— Always match your oscilloscope and probes according to the oscilloscope manufacturer's recommendations.

— Make sure that your oscilloscope/probe has adequate bandwidth or rise time capabilities for the signal you're trying to measure. Typically, you should select a oscilloscope/probe combination with a rise time specification that's three to five times faster than the fastest rise time you plan to measure.

— Always keep your probe ground leads as short and direct as possible. Excessive ground loops can cause ringing on pulses.

— Select the probes that best match your application's needs in terms of both measurement capabilities and mechanical attachment to test points.

And finally, always be aware of the possible probe loading effects on the circuit being probed. In many cases, loading can be controlled or minimized through probe selection. The following summarizes some of the probe loading considerations to be aware of:

Passive probes. 1X passive probes typically have a lower resistance and higher capacitance than 10X passive probes. As a result, 1X probes are more prone to cause loading, and whenever possible 10X probes should be used for general-purpose probing.

Voltage divider (Z_0) probes. These probes have very low tip capacitance, but at the expense of relatively high resistive loading. They're intended for use where impedance matching is required in 50 Ω environments. However, because of their very high bandwidth/rise time capabilities, voltage divider probes are often used in other environments for high-speed timing measurements. For amplitude measurements, the effect of the probe's low input R should be taken into account.

Bias-offset probes. A bias-offset probe is a special type of voltage divider probe with the capability of providing a variable offset voltage at the probe tip. These probes are useful for probing high-speed ECL circuitry, where resistive loading could upset the circuit's operating point.

Active probes. Active probes can provide the best of both worlds with very low resistive loading and very low tip capacitance. The trade-off is that active probes typically have a low dynamic range. However, if your measurements fit within the range of an active probe, this can be the best choice in many cases.