If you think that only analog engineers take differential measurements, you're wrong. Every signal is differential to some extent, so digital engineers should know how to take differential measurements, too. Such measurements can let you see the signal in the presence of ground noise and voltages caused by imperfect ground runs.

You may think that it's always OK to take measurements that are all referenced to ground. Not so. Ground is a convention (some would say a fantasy) that simplifies engineers' lives. Have you ever made these assumptions about ground?

- Ground is a set of nodes that is always at the same potential.
- All paths to ground have zero impedance at all frequencies.

If you have made these assumptions, it's time to change your thinking. Real grounds have noise caused by large switching currents or by capacitive coupling between signal paths at high frequencies.

Differential measurements let you view the signals that your digital circuits receive. You make differential measurements right at the circuit's input and ground connections, which takes the noise and signal losses out of the measurement loop.

A simple way to take a differential measurement is to use two probes and subtract one channel from the other in your scope. You could also use a differential probe or a differential plug-in for your scope, but using two probes and subtracting the two channels has one significant advantage: You most likely already have all the equipment you need—an oscilloscope and a set of probes. Figure 1 shows how to connect two probes to the DUT.

There may be some time skew (differential time delay) between the probes and the scope channels. If there is, the difference signal that the scope displays will be invalid during any transitions. Only when you have equal time skew do you get a clean low-to-high transition (Fig. 2).

Some digital scopes let you adjust the time skew through software. Be sure to include the probe compensation in the diagnosis so you can account for any difference in their delays, too. You can always tell if the probes and the scope channels are properly deskewed. Just put both probe tips on the same point, and look at a signal with a risetime that is approximately the same as the time skews will be measuring. The two signals should overlap.

With analog scopes, you're generally stuck with the inherent skew between the two probes and scope channels. You can, however, measure the skew by observing the overlap between the two signals. If the skew between the two signals is a small portion of the signal's risetime or

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**Figure 1** Connect the ground leads to a common point and set your scope to subtract the signals at points A and B.
falltime, the differential measurement will still be better than a single-ended measurement.

Some scope manufacturers offer matched pairs of probes for differential measurements. These probes have their electrical length matched to minimize time skew.

Assess CMRR
You can also assess the high-frequency common-mode rejection ratio (CMRR) by switching to the scope's A-B (or channel 1-channel 2) mode and observing the difference signal. If that signal is small compared to the original signal amplitude, the differential measurement will be reliable. If the high-frequency CMRR is unacceptable, try switching the probes. If that doesn't help, borrow a few probes from your fellow engineers and sort through them until you find a pair that is better matched.

Many scopes have a vertical sensitivity vernier; some digital scopes have a probe attenuation ratio adjustment. You can use either of these adjustments to match the gains of the two probes and scope channels. Observe the difference signal with the two probes attached to the same signal. Adjust the sensitivity vernier or the probe attenuation ratio on one channel to minimize the difference signal. Pay attention to the “flat” regions of the signal, not the region near the transition, when making this adjustment.

When using two probes and subtracting channels, don't increase the sensitivities of the two channels to expand the small difference between them. Increasing the sensitivities can cause the signal to exceed the dynamic range of the scope's input amplifiers (analog or digital scope) and the analog-to-digital converters.

You can also improve the CMRR across all frequencies on most analog and digital scopes by matching the gains of the two probes and channels.

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(digital scope). Set the sensitivities of both channels so you can see the full signal.

**Using a Differential Probe**

Instead of using two probes to measure differential signals, you could attach a differential probe to your scope. Unlike when you use two probes and subtract the channels, the differential probe lets you set the sensitivity as desired for the measurement, because the two signals are subtracted right at the front end of the probe. Unfortunately, the spacing between the two probe tips may be too small to let you reach the two points you wish to measure. Adding wires to reach the measurement points will add inductance, capacitance, and skew. If you have to add wires, keep them as short as possible.

You can measure the CMRR of a differential probe and any wires you may have added by using the same technique outlined above. Attach the two inputs of the differential probe to the same signal and observe the residual signal on the scope screen.

**Bandwidth Counts**

The same general rules apply to taking differential measurements that apply to taking any waveform measurement on high-speed digital signals:

- Make sure the scope and the probe have sufficient bandwidth to faithfully reproduce the signal.

Assess the probe's capacitive loading before measuring the signals. The loading of the probe affects the operation of the circuit. Capacitive loading can dominate at high frequencies. To estimate the effect of the probe's capacitive loading, assume approximately a 50-Ω source impedance. The time constant introduced by the probe (in seconds) is thus approximately 50 times the probe's tip capacitance. If this time constant is greater than 10 percent of the signal's inherent risetime, select a probe with less capacitive loading.

**FOR FURTHER READING**


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