Choosing the Right Probe

Because of the wide range of oscilloscope measurement applications and needs, there’s also a broad selection of oscilloscope probes on the market. This can make probe selection a confusing process.

To cut through much of the confusion and narrow the selection process, always follow the oscilloscope manufacturer’s recommendations for probes. This is important because different oscilloscopes are designed for different bandwidth, rise time, sensitivity, and input impedance considerations. Taking full advantage of the oscilloscope’s measurement capabilities requires a probe that matches the oscilloscope’s design considerations.

Additionally, the probe selection process should include consideration of your measurement needs. What are you trying to measure? Voltages? Current? An optical signal? By selecting a probe that is appropriate to your signal type, you can get direct measurement results faster.

Also, consider the amplitudes of the signals you are measuring. Are they within the dynamic range of your oscilloscope? If not, you’ll need to select a probe that can adjust dynamic range. Generally, this will be through attenuation with a 10X or higher probe.

Make sure that the bandwidth, or rise time, at the probe tip exceeds the signal frequencies or rise times that you plan to measure. Always keep in mind that non-sinusoidal signals have important frequency components or harmonics that extend well above the fundamental frequency of the signal. For example, to fully include the 5th harmonic of a 100 MHz square wave, you need a measurement system with a bandwidth of 500 MHz at the probe tip. Similarly, your oscilloscope system’s rise time should be three to five times faster than the signal rise times that you plan to measure.

And always take into account possible signal loading by the probe. Look for high-resistance, low-capacitance probes. For most applications, a 10 MΩ probe with 20 pF or less capacitance should provide ample insurance against signal source loading. However, for some high-speed digital circuits you may need to move to the lower tip capacitance offered by active probes.

And finally, keep in mind that you must be able to attach the probe to the circuit before you can make a measurement. This may require special selection considerations about probe head size and probe tip adaptors to allow easy and convenient circuit attachment.

Understanding the Signal Source

There are four fundamental signal source issues to be considered in selecting a probe. These are the signal

Figure 1 - Various probe categories based on the signal type to be measured.
type, the signal frequency content, the source impedance, and the physical attributes of the test point. Each of these issues is covered in the following discussion.

Signal Type

The first step in probe selection is to assess the type of signal to be probed. For this purpose, signals can be categorized as being:

- Voltage Signals
- Current Signals
- Logic Signals
- Other Signals

Voltage signals are the most commonly encountered signal type in electronic measurements. That accounts for the voltage-sensing probe as being the most common type of oscilloscope probe. Also, it should be noted that, since oscilloscopes require a voltage signal at their input, other types of oscilloscope probes are, in essence, transducers that convert the sensed phenomenon to a corresponding voltage signal. A common example of this is the current probe, which transforms a current signal into a voltage signal for viewing on an oscilloscope.

Logic signals are actually a special category of voltage signals. While a logic signal can be viewed with a standard voltage probe, it's more often the case that a specific logic event needs to be viewed. This can be done by setting a logic probe to provide a trigger signal to the oscilloscope when a specified logic combination occurs. This allows specific logic events to be viewed on the oscilloscope display.

In addition to voltage, current, and logic signals, there are numerous other types of signals that may be of interest. These can include signals from optical, mechanical, thermal, acoustic, and other sources. Various transducers can be used to convert such signals to corresponding voltage signals for oscilloscope display and measurement. When this is done, the transducer becomes the signal source for the purposes of selecting a probe to convey the transducer signal to the oscilloscope.

Figure 1 provides a graphical categorization of probes based on the type of signal to be measured. Notice that under each category there are various probe subcategories that are further determined by additional signal attributes as well as oscilloscope requirements.

Signal Frequency Content

All signals, regardless of their type, have frequency content. DC signals have a frequency of 0 Hz, and pure sinusoids have a single frequency that is the reciprocal of the sinusoid’s period. All other signals contain multiple frequencies whose values depend upon the signals waveshape. For example, a symmetrical square wave has a fundamental frequency (f₀) that’s the reciprocal of the square wave’s period and additional harmonic frequencies that are odd multiples of the fundamental (3f₀, 5f₀, 7f₀, ...). The fundamental is the foundation of the waveshape, and the harmonics combine with the fundamental to add structural detail such as the waveshape’s transitions and corners.

For a probe to convey a signal to an oscilloscope while maintaining adequate signal fidelity, the probe must have enough bandwidth to pass the signal’s major frequency components with minimum disturbance. In the case of square waves and other periodic signals, this generally means that the probe bandwidth needs to be three to five times higher than the signal’s fundamental frequency. This allows the fundamental and the first few harmonics to be passed without undue attenuation of their relative amplitudes. The higher harmonics will also be passed, but with increasing amounts of attenuation since these higher harmonics are beyond the probe’s 3-dB bandwidth point. However, since the higher harmonics are still present at least to some degree, they’re still able to contribute somewhat to the waveform’s structure.
the 3-dB point, amplitude is down 30%. Also, those harmonics or other frequency components of a signal that extend beyond the probe’s bandwidth will experience a higher degree of attenuation because of the bandwidth roll-off. The result of higher attenuation on higher frequency components may be seen as a rounding of sharp corners and a slowing of fast waveform transitions (see Figure 2).

It should also be noted that probe tip capacitance can also limit signal transition rise times. However, this has to do with signal source impedance and signal source loading, which are the next topics of discussion.

**Signal Source Impedance**

The discussion of source impedance can be distilled down to the following key points:

1. The probe’s impedance combines with the signal source impedance to create a new signal load impedance that has some effect on signal amplitude and signal rise times.

2. When the probe impedance is substantially greater than the signal source impedance, the effect of the probe on signal amplitude is negligible.

3. Probe tip capacitance, also referred to as input capacitance, has the effect of stretching a signal’s rise time. This is due to the time required to charge the input capacitance of the probe from the 10% to 90% level, which is given by:

   \[ tr = 2.2 \times R_{\text{source}} \times C_{\text{probe}} \]

From the above points, it’s clear that high-impedance, low-capacitance probes are the best choice for minimizing probe loading of the signal source. Also, probe loading effects can be further minimized by selecting low-impedance signal test points whenever possible. Refer to the section titled “Different Probes for Different Needs” for more detail regarding signal source impedance and the effects of its interaction with probe impedance.

**Physical Connection Considerations**

The location and geometry of signal test points can also be a key consideration in probe selection. Is it enough to just touch the probe to the test point and observe the signal on the oscilloscope, or will it be necessary to leave the probe attached to the test point for signal monitoring while making various circuit adjustments? For the former situation, a needle-style probe tip is appropriate, while the latter situation requires some kind of retractable hook tip.

The size of the test point can also impact probe selection. Standard size probes and accessories are fine for probing connector pins, resistor leads, and back planes. However, for probing surface mount circuitry, smaller probes with accessories designed for surface mount applications are recommended.

The goal is to select probe sizes, geometries, and accessories that best fit your particular application. This allows quick, easy, and solid connection of probes to test points for reliable measurements.

**Understanding the Oscilloscope**

Oscilloscope issues have as much bearing on probe selection as signal source issues. If the probe doesn’t match the oscilloscope, signal fidelity will be impaired at the oscilloscope end of the probe.

**Bandwidth and Rise Time**

It’s important to realize that the oscilloscope and its probes act together as a measurement system. Thus, the oscilloscope used should have bandwidth and rise time specifications that equal or exceed those of the probe used and that are adequate for the signals to be examined.

In general, the bandwidth and rise time interactions between probes and oscilloscopes are complex. Because of this complexity, most oscilloscope manufacturers specify oscilloscope bandwidth and rise time to the probe tip for specific probe models designed for use with specific oscilloscopes. To ensure adequate oscilloscope system bandwidth and rise time for the signals that you plan to examine, it’s best to follow the oscilloscope manufacturer’s probe recommendations.

**Input Resistance and Capacitance**

All oscilloscopes have input resistance and input capacitance. For maximum signal transfer the input R and C of the oscilloscope must match the R and C presented by the probe’s output as follows:

\[ R_{\text{scope}}C_{\text{scope}} = R_{\text{probe}}C_{\text{probe}} = \text{Optimum Signal Transfer} \]

More specifically, 50Ω oscilloscope inputs require 50Ω probes, and 1 MΩ oscilloscope inputs require 1 MΩ probes. A 1 MΩ oscilloscope can also be used with a 50Ω probe when the appropriate 50 Ω adapter is used.

Probe-to-oscilloscope capacitances must be matched as well. This is done through selection of probes designed for use with specific oscilloscope models. Additionally, many probes have a compensation adjustment to allow precise matching by compensating for minor capacitance variations. Whenever a probe is attached to an oscilloscope, the first thing that should be done is to adjust the probe’s compensation. Failing to properly match a probe to the oscilloscope – both through proper probe selection and proper compensation adjustment – can result in significant measurement errors.

**Sensitivity**

The oscilloscope’s vertical sensitivity range determines the overall dynamic range for signal amplitude measurement. For example, an oscilloscope with a 10-division vertical display range and a sensitivity range from 1 mV/division to 10 V/division has a practical vertical dynamic range from around 0.1 mV to 100 V. If
the various signals that you intend to measure range in amplitude from 0.05 mV to 150 V, the base dynamic range of the example oscilloscope falls short at both the low and high ends. However, this shortcoming can be remedied by appropriate probe selection for the various signals that you’ll be dealing with.

For high-amplitude signals, the oscilloscope’s dynamic range can be extended upwards by using attenuator probes. For example, a 10X probe effectively shifts the oscilloscope’s sensitivity range upward by a decade, which would be 10 mV/division to 100 V/division for the example oscilloscope. Not only does this provide adequate range for your 150-volt signals, it gives you a top-end oscilloscope display range of 1000 volts. However, before connecting any probe to a signal make sure that the signal doesn’t exceed the probe’s maximum voltage capabilities.

For low-amplitude signals, it’s possible to extend the range of the oscilloscope to lower sensitivities through use of a probe amplifier system. This typically is a differential amplifier, which could provide a sensitivity of 10 \( \mu \text{V/division} \) for example. Such probe amplifier systems are highly specialized and are designed to match specific oscilloscope models. As a result, it’s important in making an oscilloscope selection to always check the manufacturer’s list of recommended accessories for available differential probe systems that meet your small-signal application requirements.

Selecting the Right Probe

From all of the preceding signal source and oscilloscope issues, it’s clear that selecting the right probe can be a daunting process without some assistance. In fact, since some key selection criteria – such as probe rise time and oscilloscope input C – are not always specified, the selection process may be reduced to guesswork in some cases.

To avoid guesswork, it’s always best to select an oscilloscope that includes a wide selection of probes in the recommended accessories list. Also, when you encounter new measurement requirements, be sure to check with the manufacturer of your oscilloscope for newly introduced probes that may extend your oscilloscope’s capabilities.

And finally, keep in mind that there really is no “right” probe selection for any given application. There are only “right” oscilloscope/probe combination selections, and they rely on first defining your signal measurement requirements in terms of:

- Type of signal (voltage, current, optical, etc.)
- Signal frequency content (bandwidth issues)
- Signal rise time
- Source impedance (R and C)
- Signal amplitudes (maximum, minimum)
- Test point geometries (leaded component, surface mount, etc.)

By considering the above issues and filling in the blanks with information specific to your applications, you’ll be able to specify the oscilloscope and various compatible probes that will meet all of your application needs.

Caution - Always observe the probe’s maximum specified voltage capabilities. Attaching the probe to a voltage in excess of those capabilities may result in personal injury as well as damage to equipment.

Caution - Differential probe systems often contain sensitive components that may be damaged by overvoltages, including static discharges. To avoid damage to the probe system, always follow the manufacturer’s recommendations and observe all precautions.

Readout Capability

Most modern oscilloscopes provide on-screen readouts of their vertical and horizontal sensitivity settings (volts/division and seconds/division). Often these oscilloscopes also provide probe sensing and readout processing so that the readout properly tracks the type of probe being used. For example, if a 10X probe is used, the oscilloscope should appropriately reflect that by adjusting the vertical readout by a 10X factor. Or if you’re using a current probe, the vertical readout is changed from volts/division to amps/division to reflect the proper units of measurement.

To take advantage of such readout capability, it’s important to use probes that are compatible with the oscilloscope’s readout system. Again, this means following the manufacturer’s recommendations regarding probe usages with specific oscilloscopes. This is especially important for newer oscilloscopes which may have advanced readout features that may not be fully supported by many generic or commodity probes.